DISEÑO Y CONSTRUCCIÓN DE UN SISTEMA DE MORDAZAS HIDRÁULICAS PARA LA MÁQUINA DE PRUEBAS UNIVERSAL INSTRON MODELO 1323

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UNIVERSIDAD INDUSTRIAL DE SANTANDER
FACULTAD DE INGENIERIAS FÍSICO-MECÁNICAS
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Trabajo de Grado para optar al título de
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DEDICATORIA

A Dios.
A mis padres Abelardo y Maria por su constante apoyo y dedicación.
A mi esposa Jenny por su comprensión y amor.
A mis hijos Nicolás y Felipe por ser mi fuente de inspiración constante.
A mis hermanos Diego y Yesid (Q.E.P.D.) por su colaboración.
A mis familiares y amigos que me ayudaron en mi formación como profesional, en especial a mi colega Jhon Alexander Suárez.

Omar Fernando.

A Dios, vida.
A mi hija María Alejandra, esperanza.
A mis padres María Teresa y Juan Bautista, amor.
A mis hermanas Ángela y Nathalie, confianza.
A mi familia, unión.
A mis amigos.
Jhon Alexander.

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Omar Fernando Gómez y Jhon Alexander Suárez

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TÍTULO:

DISEÑO Y CONSTRUCCIÓN DE UN SISTEMA DE MORDAZAS HIDRÁULICAS PARA LA MÁQUINA DE PRUEBAS UNIVERSAL INSTRON 1323. [Θ]

AUTORES:
Jhon Alexander Suárez Suárez
Omar Fernando Gómez Landazábal

PALABRAS CLAVES: Maquina de pruebas universal, sistema de agarre, SOLID EDGE, ANSYS.

DESCRIPCION:

La finalidad de este proyecto de grado es proveer a la máquina de pruebas universal INSTRON 1323; ubicada en el laboratorio de sistemas oleoneumáticos de la escuela de ingeniería mecánica; un sistema de agarre versátil que agilice el proceso de posicionamiento y retirada de la probeta (ASTM E8 y E9).

El proceso de diseño del sistema se desarrolló en cuatro etapas: **1.** Bosquejo de alternativas y selección de la alternativa definitiva, **2.** Modelado en SOLID EDGE 14, **3.** Simulación en ANSYS Workbench 8.1, **4.** Construcción y montaje del sistema; dando como resultado un sistema adecuado a las necesidades.

El bosquejo de las alternativas se realiza tomando como base el sistema de mordazas antiguo. Para la selección de la alternativa se utilizan métodos de diseño funcional y la herramienta QFD (Quality Function Deployment), posteriormente se dimensionan en base a la cinemática del conjunto. En la simulación en ANSYS se da prioridad a los factores de seguridad que a los esfuerzos resultantes. La construcción se realiza en un centro de mecanizado particular con acero 1045 para las piezas menos solicitadas a esfuerzo y acero 4340 para las mordazas puesto que son las más solicitadas a esfuerzos. Para las pruebas se utilizaron 15 probetas obteniendo resultados satisfactorios teniendo en cuenta las condiciones de funcionamiento de la maquina.

[Θ] Trabajo de Grado
Facultad de Ingenierías Físico-Mecánicas, Escuela de Ingeniería Mecánica, Director del Proyecto Ing. Abel Parada, Codirector Ing. Isnardo González

SUMMARY

TITLE:
DESIGN AND CONSTRUCTION OF A SYSTEM OF HYDRAULIC GAGS FOR THE MACHINE OF UNIVERSAL TESTS INSTRON 1323. [Θ]

AUTHORS:
Jhon Alexánder Suárez Suárez
Omar Fernando Gómez Landazábal

KEY WORDS: Universal test machine, system of grabs, SOLID EDGE, ANSYS

DESCRIPTION:

The purpose of this grade project is to provide to the machine of universal tests INSTRON 1323; located in the oleoneumatics systems laboratory of the school of mechanical engineering; a versatile system of grabs that speeds up the positioning and retreat process of the test tube (ASTM E8 and E9).

Design process of the system was developed in four stages: 1. Sketching of alternatives and selection of the definitive alternative, 2. Modeling in SOLID EDGE 14, 3. Simulation in ANSYS Workbench 8.1, 4. Construction and assembly of the system; giving as a result an appropriate system to the necessities.

The alternatives Sketches are made taking as base the old gripping system. To select the appropriate alternative functional design methods were used and the QFD (Quality Function Deployment) tool, after this, dimensions were calculated according to the kinematics of the group. In the ANSYS simulation, priority was given to the security factors over the resulting efforts. The construction was made on a machining center using 1045 steel for the low efforts parts, and 4340 steel for the jaws since these elements demand the most efforts. For testing, 15 probes were used, obtaining satisfactory results if we consider the actual condition of the machine.

[Θ] Degree Work
Physical-Mechanical Engineering Faculty, Mechanical Engineering School, Proyect Director Eng. Abel Parada, Co-director Eng. Isnardo González

INTRODUCCIÓN.

Con el transcurrir del tiempo la humanidad ha querido innovar y crear nuevos instrumentos para realizar de una manera más fácil, sencilla y rápida sus actividades.

En el presente trabajo de grado, se busca la creación de un nuevo sistema de agarre de probetas para realizar pruebas de tensión y compresión a materiales metálicos de una manera fácil y rápida sin que afecte la lectura final de los ensayos, para ello se busca el aprovechamiento de la energía hidráulica presente en la máquina (Instron 1323) de tal forma que esta última sea un conjunto mas compacto.

Para dar solución a esta necesidad se diseño y construyó un sistema hidráulico de mordazas, que reemplazará el tradicional sistema de pernos con que hoy se cuenta en esta máquina; para ser posible este trabajo se cuenta con el apoyo de las herramientas tecnológicas idóneas en cada fase del desarrollo, podemos mencionar algunas software de diseño CAD y de análisis ingeniería CAE. Los programas CAD facilitan el desarrollo de elementos o conjuntos en cuanto a la geometría y por consiguiente al aspecto físico de los mismos, nos ayudan a visualizar con anterioridad como han de ser físicamente o que semblante tendrá lo diseñado. Esto no es suficiente en diseño de ingeniería y para un óptimo producto final también se necesita conocer la respuesta del diseño a las posibles condiciones de trabajo en las que se desenvolverán los diferentes elementos diseñados. Para esto los software CAE nos permiten simular dichas condiciones, con el fin de observar y analizar entre otras la repuesta cinética a fuerzas que el diseñador impone, además de facilitar el análisis de esfuerzos y fatiga en el prototipo virtual a los que muy posiblemente se encuentre sometido el conjunto a construir y poner en funcionamiento; permitiendo así que el diseñador observe el comportamiento de la geometría y los materiales con los que finalmente se podrá fabricar.

Para la ejecución final de este trabajo, se utilizaron las herramientas CAD "Solid Edge V 18" y CAE "Ansys Workbench V 10". Su construcción se realizó en un centro de mecanizado.

1. ENSAYOS EN PROBETAS DE MATERIALES METALICOS

1.1 ENSAYOS DE TRACCION

La prueba de tracción es uno de los métodos más útiles que se emplean para determinar las propiedades mecánicas más importantes de los materiales utilizados en ingeniería. El procedimiento a seguir en cada prueba varía de acuerdo al tipo de material; sin embargo, en la prueba de tensión ordinaria, aun cuando se trate de distintos materiales, se deben cumplir una serie de normas básicas:

- Debe realizarse a una temperatura ambiente o cercana a ésta.
- La carga sobre la probeta debe ser aplicada lentamente y totalmente axial.

Hay además otras pruebas que son efectuadas a diferentes temperaturas y a niveles de carga muy elevados, pero estas no son consideradas como prueba de tensión ordinaria.

1.1.1 Probetas de ensayo. Existen varios perfiles de probetas las cuales deben ser labradas simétricamente a máquina a lo largo de su eje longitudinal con el fin de obtener una carga uniformemente distribuida en su sección transversal y cuya geometría varía de acuerdo a la operación de la máquina de ensayo encontrando entre estos:

- Placa rectangular
- Cilíndrica
- Tubular

Figura 1. Perfil de placa rectangular

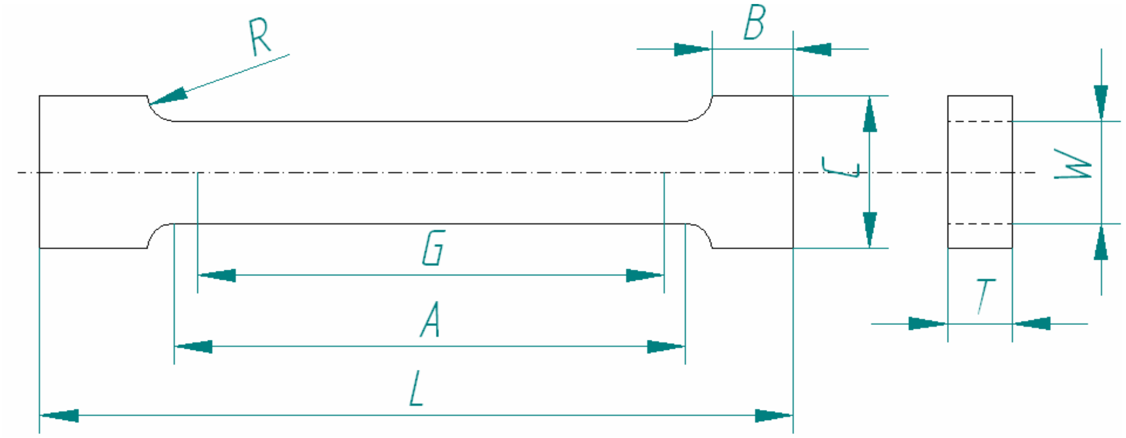


Tabla 1. Dimensiones del perfil de placa rectangular

Dimensions, mm			
Nominal Width	Standard Specimens		Subsize Specimen
	Plate Type 40	Sheet Type 12,5	6
G— Gage length	200 ± 0,2	50 ± 0,1	25 ± 0,1
W— Width	40 ± 2	12,5 ± 0,2	6 ± 0,1
T— Thickness	Thickness of material		
R— Radius of fillet, min	25	12,5	6
L— Overall length	450	200	100
A— Length of reduced section, min	225	57	32
B— Length of grip section	75	50	30
C— Width of grip section, approximate	50	20	10

Figura 2. Perfil cilíndrico

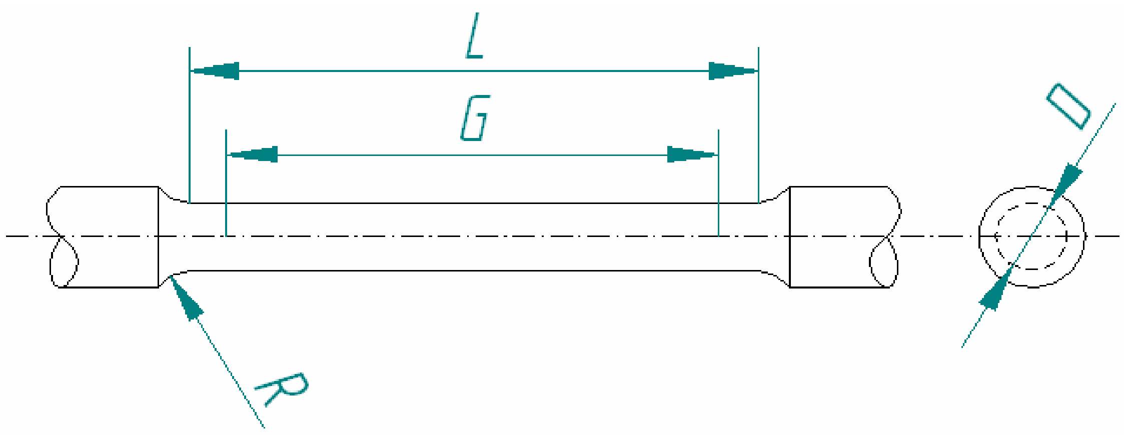


Tabla 2. Dimensiones del perfil cilíndrico

	Dimensions, mm				
	Standard Specimen	Small-Size Specimens Proportional To Standard			
	12,5	9	6	4	2,5
G—Gage length	62,5 ± 0,1	45 ± 0,1	30 ± 0,1	20 ± 0,1	12,5 ± 0,1
D—Diameter	12,5 ± 0,2	9 ± 0,1	6 ± 0,1	4 ± 0,1	2,5 ± 0,1
R—Radius of fillet, min	10	8	6	4	2
A—Length of reduced section, min	75	54	36	24	20

De estos últimos el redondo es el mas común y usado de todos. Adicionalmente estos últimos cuentan con varios tipos de extremos dependiendo del sistema de agarre de la máquina:

- De extremo liso
- De extremo bordeado
- De extremo roscado

Figura 3. Perfil cilíndrico de extremo liso

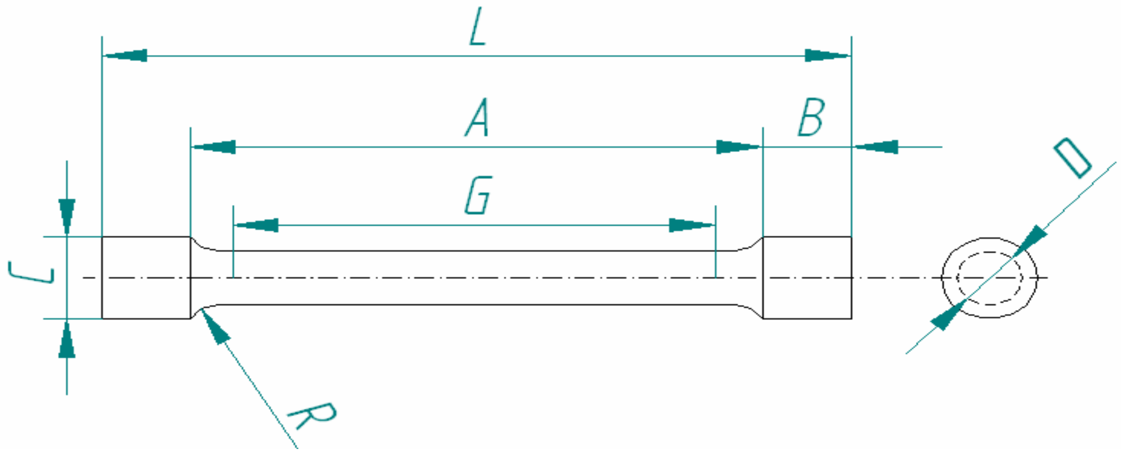


Figura 4. Perfil cilíndrico de extremo roscado

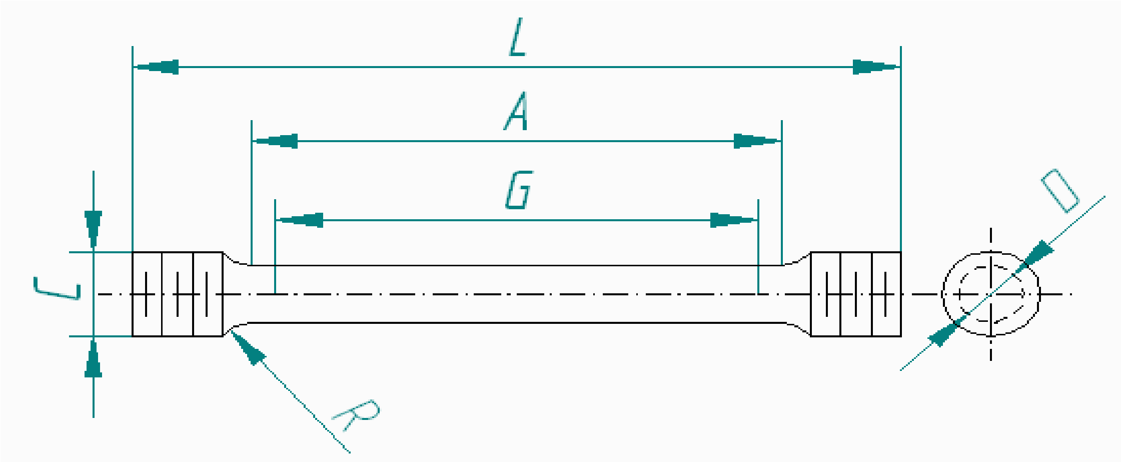


Figura 5. Perfil cilíndrico de extremo roscado

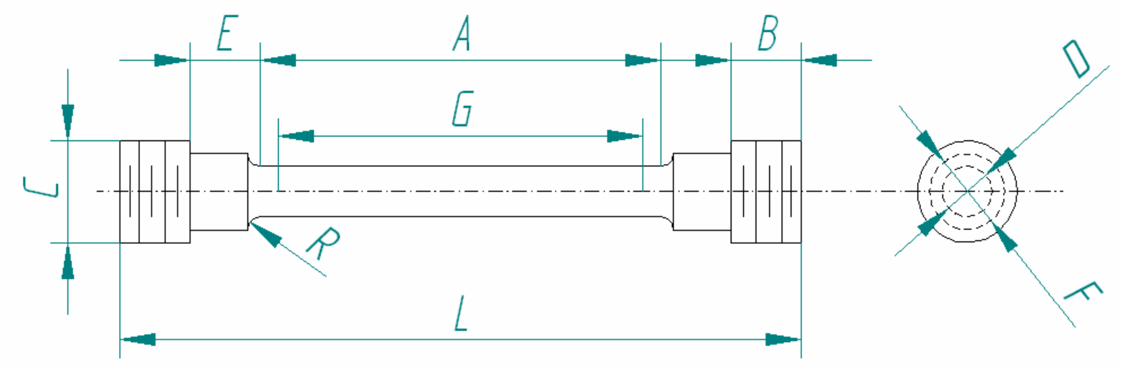


Figura 6. Perfil cilíndrico de extremo bordeado

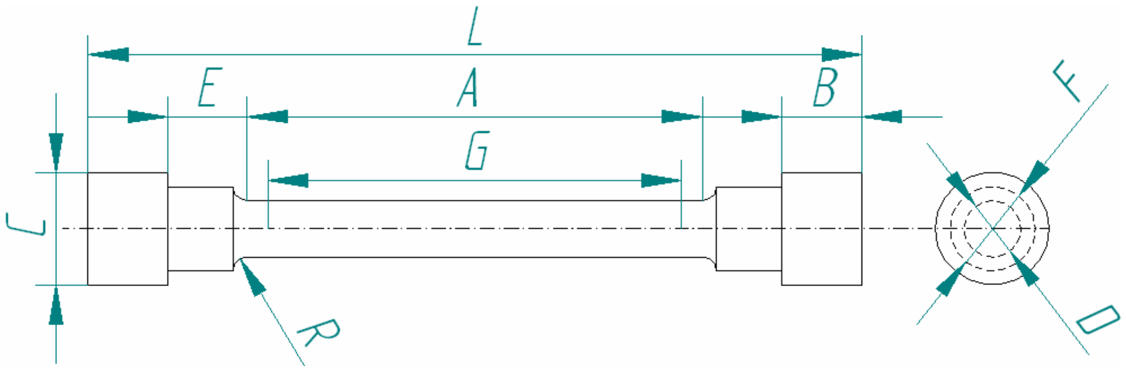


Figura 7. Perfil cilíndrico de extremo bordeado

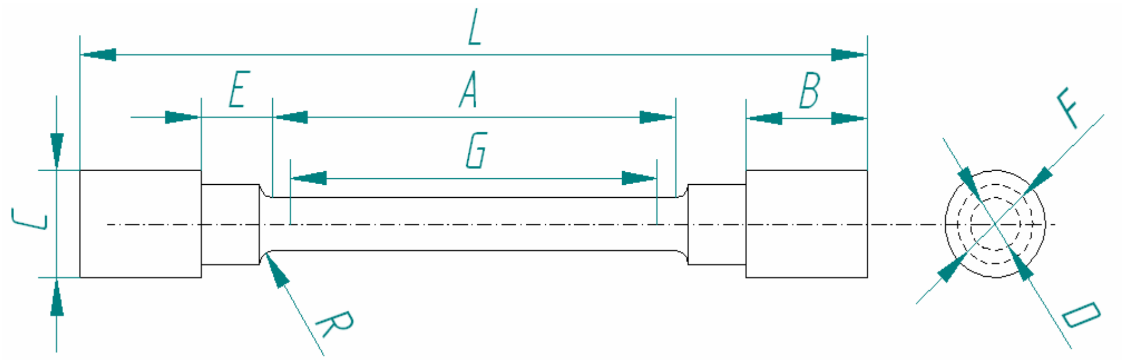


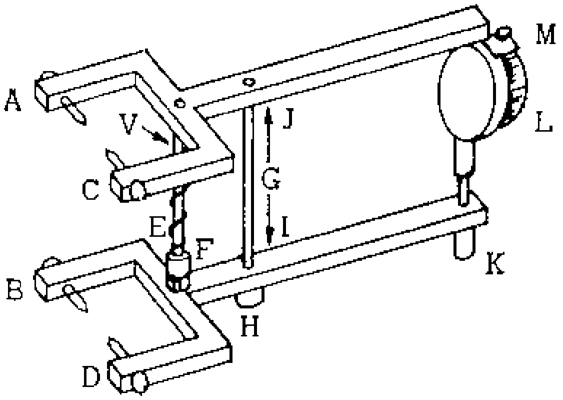
Tabla 3. Clases de extremos en probetas cilíndricas estándar

Dimensions, mm					
	Figura 3	**Figura 4**	**Figura 5**	**Figura 6**	**Figura 7**
G- gage length	62,5 ± 0,1	62,5 ± 0,1	62,5 ± 0,1	62,5 ± 0,1	62,5 ± 0,1
D- diameter	12,5 ± 0,2	12,5 ± 0,2	12,5 ± 0,2	12,5 ± 0,2	12,5 ± 0,2
R- radius of fillet, min	2	10	10	10	10
A- length of reduced section	100	75	75	75	75
L- overall length, aprox.	140	145	155	140	255
B- length of end section	20	35	25	15	75
C- diameter of end section	20	20	20	22	20
E- length of shoulder and fillet section, approx.	....	......	15	20	15
F- diameter of shoulder	....	....	15	15	15

1.1.2 Aplicación de la carga. La aplicación de la carga puede ser de tipo hidráulica o mecánica de acuerdo a cual de los dos tipos de máquinas de pruebas existentes se este utilizando para tal fin. Las cargas de tipo mecánico tienen la ventaja que proporcionan un medio conveniente para controlar la velocidad de deformación, aunque generalmente se prefiere usar las de tipo hidráulico por su bajo costo y mayor capacidad de operación.

1.1.3 Medición de la deformación. Esta puede ser medida por métodos mecánicos, eléctricos, electromecánicos u ópticos. Entre los métodos mecánicos encontramos el extensómetro H. F. Moore, el cual al trabajar con una probeta estándar de 2 pulgadas los pares de puntos con que se sujeta el extensómetro se ajustan con una separación de 2 pulgadas; los puntos del medidor se colocan a 1 pulgada del punto de apoyo y este debe estar a su vez a 5 pulgadas de la carátula del medidor. Un aumento en la longitud de escala del extensómetro de 0.0003 pulgadas hará que la aguja indicadora de la carátula registre una lectura de 0.0015 pulgadas. La deformación estará definida como $\Delta L / L$, es decir $0.0003/2 = 0.00015$.

Figura 8. Extensómetro H. F. Moore



1.1.4 Interpretación de resultados. La lectura de datos consta de las longitudes inicial y final L_0 y L_f, los diámetros inicial y final D_0 y D_f, además de las lecturas del extensómetro (en pulgadas) y las de carga (en libras). Las lecturas del extensómetro se transforman en datos de deformación al ser divididas por 10 y las lecturas de carga se transforman en esfuerzos al ser divididas por el área de la sección transversal de corte original.

Con estos datos se realiza la gráfica de esfuerzo-deformación en la cual se aprecian dos tipos de comportamiento definidos por cambios drásticos en la continuidad de la línea de tendencia los cuales identifican conceptos tales como:

- Limite proporcional: esfuerzo máximo hasta el cual el esfuerzo y la deformación son directamente proporcionales.
- Limite elástico: esfuerzo máximo que puede soportar el material sin sufrir deformación plástica o permanente, para su determinación se requiere un aumento sucesivo de la carga anterior a sus respectivas descarga y medición para detectar la más mínima deformación permanente.
- Esfuerzo de fluencia: esfuerzo que produce en un material una deformación especifica, permanente y limitadora. Debido a que para valores inferiores al limite elástico la relación esfuerzo-deformación puede considerarse idéntica, no se requiere descargar sucesivamente una probeta para determinarlo; para esto se construye una línea paralela a la sección recta de la curva desplazada del origen en una cantidad igual a la deformación permanente especificada. La intersección entre esta y la curva esfuerzo-deformación nos da la resistencia del punto de fluencia. El desplazamiento mas común es un 0.2 % de la resistencia en el punto de fluencia, es decir, 0.002 pulg. def./pulg.

- Punto de fluencia: propiedad que tienen los aceros blandos no endurecidos y algunas otras aleaciones; es también un indicador del limite de comportamiento elástico del material.
- Resistencia a la tracción: conocida también como esfuerzo último, se calcula dividiendo la carga máxima soportada por la muestra entre el área de la sección transversal original de la misma.
- Resistencia a la ruptura: se determina dividiendo la carga soportada entre el área de la sección transversal original de la muestra en el momento de la ruptura.

1.2 ENSAYOS DE COMPRESION

Algunos materiales tienen comportamientos dramáticamente diferentes bajo esfuerzos de compresión que de tensión y en algunos casos estos materiales son usados principalmente para soportar esfuerzos compresivos. Los ensayos de compresión son muy similares a los de tensión en la forma de conducir la prueba así como de analizar e interpretar los resultados de la misma. Las ratas de desplazamiento uniforme en las pruebas de compresión son similares a las de tensión excepto por supuesto por la dirección de la carga.

1.2.1 Procedimientos en ensayos de compresión. Las probetas son comúnmente un cilindro con una relación L/d (longitud-diámetro) dentro de un rango de 1 a 3 sin embargo valores de L/d mayores a 10 son usados en ocasiones cuando el principal objetivo es determinar con exactitud el modulo elástico. También son usadas probetas de sección rectangular o cuadrada.

La elección de la longitud adecuada de la probeta es critica puesto que si la relación L/d es relativamente alta puede presentarse pandeo y si esto sucede el resultado de la prueba no tendría significado como una medida fundamental del comportamiento compresivo del material. El pandeo es afectado por pequeñas imperfecciones inevitables en la geometría de la probeta y por la alineación de esta con respecto a la máquina de pruebas.

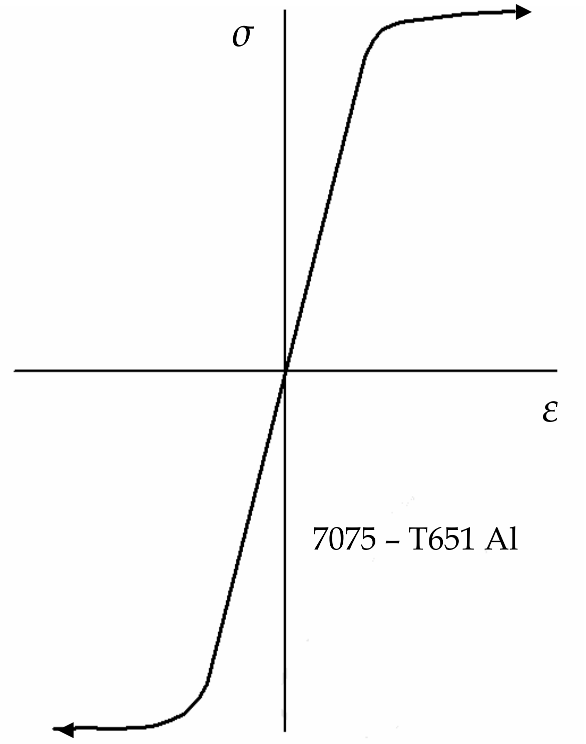
Por el contrario si L/d es bajo el resultado de la prueba se verá afectado por los detalles de las condiciones en los extremos de la probeta.

Como la probeta es comprimida el diámetro se incrementa debido al efecto POISSON pero la fricción retarda este movimiento en los extremos resultando una deformación en forma de barril. Aunque este efecto puede ser minimizado con una apropiada lubricación de los extremos, es difícil eludirlo por completo. Como resultado en materiales con capacidad de grandes cantidades de deformación bajo esfuerzos de compresión, la elección de un L/d bajo puede traer como consecuencia un comportamiento de la probeta dominado por los efectos de los extremos.

Considerando las dos alternativas; L/d bajo para evitar pandeo y L/d alto para evitar los efectos de los extremos; una determinación razonable a la hora de realizar el test es escoger un L/d = 3 para materiales dúctiles. Valores de L/d = 1,5 o 2 son apropiados para materiales frágiles debido a que las bajas deformaciones que sufren se ven menos afectadas por los efectos de los extremos.

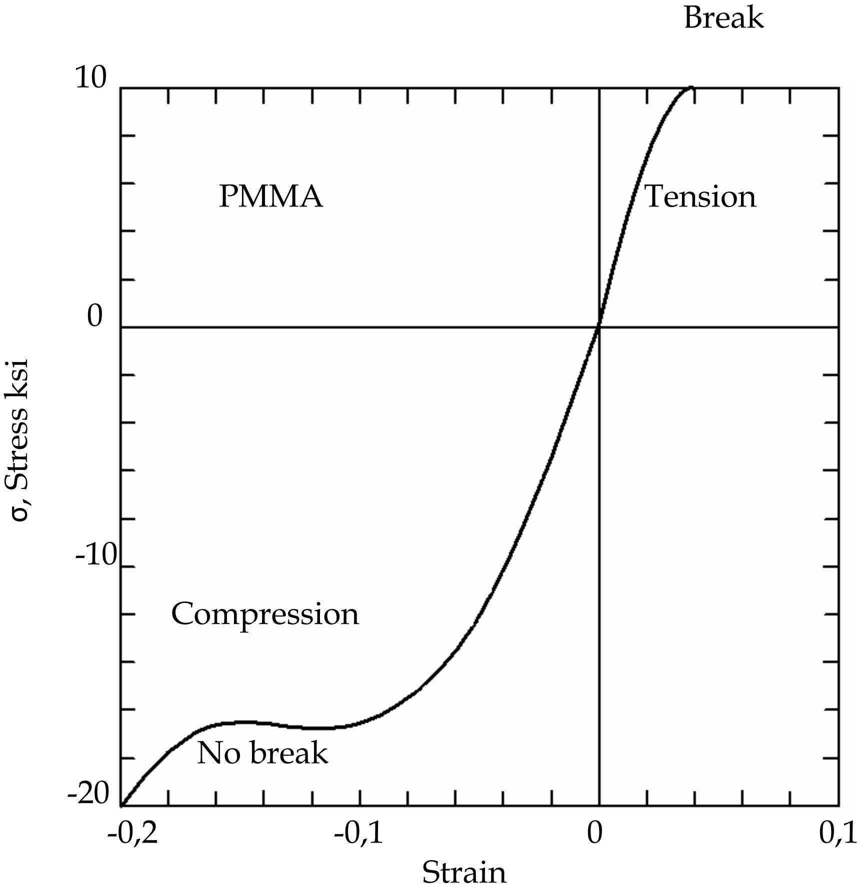
1.2.2 Tendencias del comportamiento compresivo. La ingeniería de los metales dúctiles tiene una afinidad en cuanto a comportamiento esfuerzo-deformación en los tramos iniciales de las curvas de tensión y compresión (ver figura 9). Luego de cantidades relativamente grandes de deformación, las curvas pueden coincidir si estos son graficados.

Figura 9. Tramos iniciales de curva esfuerzo-deformación para aluminio 7075 – T651



Muchos materiales que son frágiles bajo tensión tienen este comportamiento debido a que contienen grietas o poros que crecen y combinan las causas de falla a lo largo de los planos de máxima tensión, o sea perpendicular al eje de la probeta. Estos defectos tienen un efecto menor bajo esfuerzos de compresión, de modo que materiales que llegan a comportarse de forma frágil bajo tensión usualmente tienen una resistencia considerablemente alta a esfuerzos de compresión. Un comportamiento completamente dúctil puede presentarse a menudo en materiales que son frágiles en tensión como polímeros (ver figura 10).

Figura 10. Curva de esfuerzo deformación para plexiglás bajo tensión y compresión



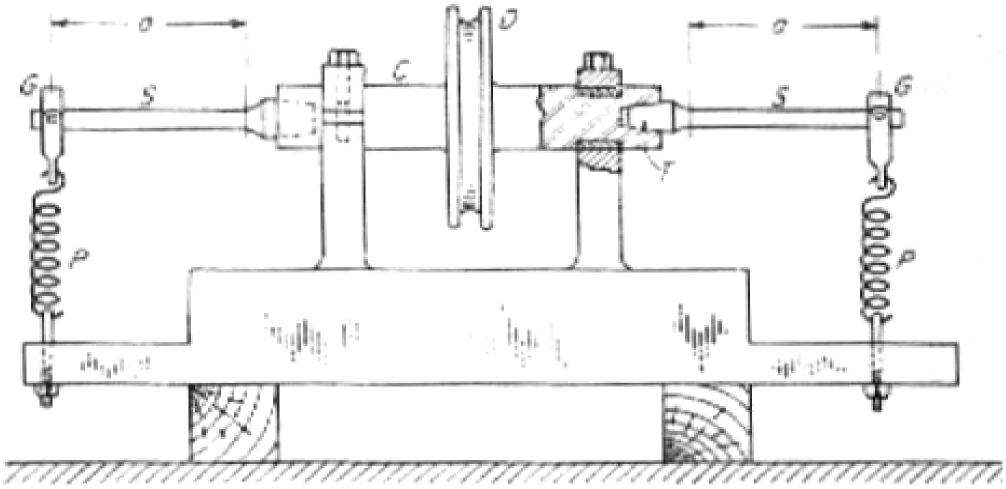
Al ocurrir una falla por compresión generalmente se asocia con un esfuerzo cortante, de modo que la fractura se observa relativamente inclinada con respecto al eje de la probeta. Este tipo de fractura es evidente para fundiciones de hierro gris, aleaciones de aluminio y concreto.

1.3 ENSAYOS DE FATIGA

Los ensayos sobre materiales para obtener curvas S-N (Esfuerzo-Vida) se han convertido en una práctica muy generalizada. Varios artículos de la ASTM direccionan tales pruebas para metales; como el No. E466; y para plásticos (polímeros); como la D671. Un entendimiento de las bases de estas pruebas es muy útil para un efectivo uso de sus resultados con propósitos ingenieriles.

Maquinas de prueba. Una de las máquinas empleadas por Wöhler utilizaba un par de especímenes rotatorios, sujetos como una viga en voladizo (ver figura 11). Los resortes suministran una fuerza constante a través de un rodamiento, el cual permite la rotación del espécimen de tal modo que el momento flector varia linealmente con la distancia desde el resorte. En este tipo de prueba cualquier punto sobre el espécimen es sometido a un esfuerzo sinusoidal que varía de tensión a compresión en cada extremo del espécimen (superior e inferior) a medida que rota durante un ciclo completo de 360º.

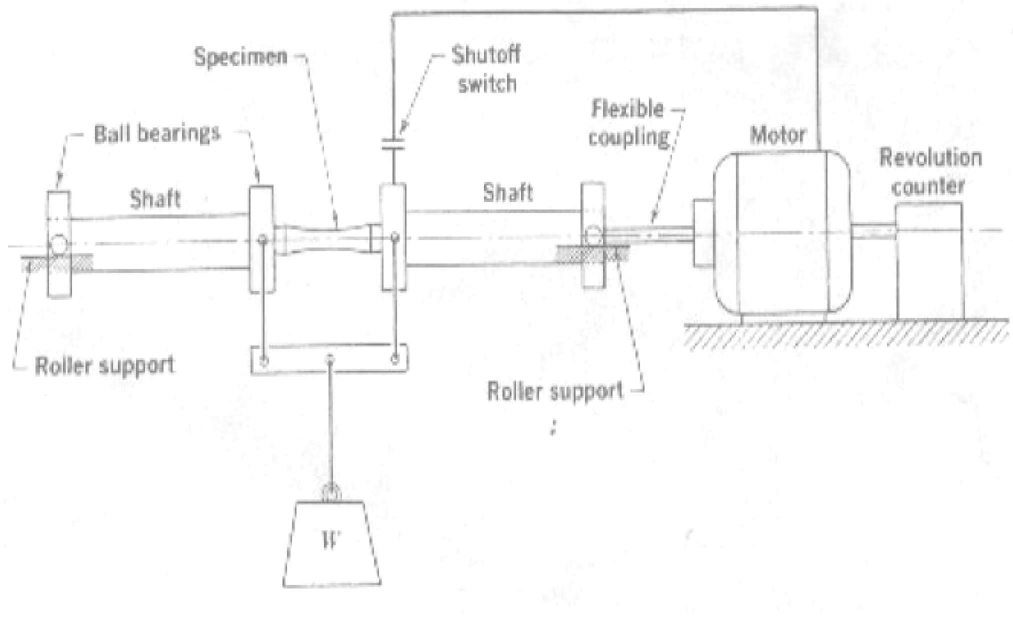
Figura 11. Máquina para prueba de fatiga con viga en voladizo rotativa



Equipos para pruebas sobre vigas rotativas que operan sobre principios similares con pocas variaciones son usados aun hoy en día.

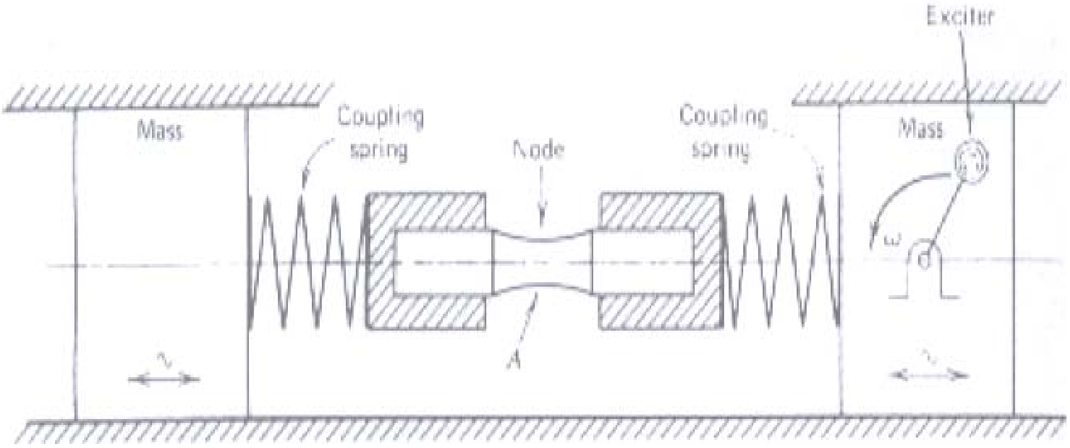
Una de las más usadas incluye una variación que consiste en 4 puntos de apoyo (ver figura 12); los 2 cojinetes próximos a los extremos de la probeta permiten que la carga sea aplicada mientras la probeta rota y los 2 cojinetes externos a la probeta proveen soporte. Una masa colgante provee una fuerza constante. Esta variación tiene la ventaja que suministra un momento flector constante y cero cortante a lo largo de la probeta.

Figura 12. Máquina para prueba de fatiga con viga rotativa de Moore



Otra variación que garantiza un esfuerzo cíclico con niveles cortantes nulos se puede conseguir por excitación de una vibración resonante en un sistema elástico tal como la máquina de prueba axial (ver figura 13).

Figura 13. Máquina para prueba de fatiga axial basada en vibración resonante causada por masa excéntrica rotativa



En la mayoría de las máquinas de prueba la frecuencia se mantiene constante por la velocidad de un motor eléctrico o por la frecuencia natural de un mecanismo resonante vibratorio. Esta frecuencia fija esta generalmente en un rango de 10 a 100 Hz. A este ultimo valor una prueba de 10^7 ciclos tomaría 28 horas, una de 10^8 tomaría 12 días y una de 10^9 ciclos casi 4 meses. Estos largos tiempos de prueba limitan en forma práctica el rango de vida que puede ser estudiado.

Si se está interesado en estudiar elementos de larga vida una posibilidad es usar mecanismos resonantes vibratorios con una alta frecuencia; sin embargo esto puede afectar los resultados de la prueba por lo que no es seguro decir que una curva obtenida a una frecuencia de 20 kHz pueda ser aplicada para análisis ingenieriles.

2. DESCRIPCIÓN DE LA MÁQUINA DE PRUEBAS UNIVERSAL INSTRON 1323

La máquina de pruebas universal INSTRON 1323 es una máquina hidráulica cuya máxima presión de trabajo es de 4000 [psi]. Esta máquina es utilizada para realizar pruebas de ensayo de materiales a tracción, compresión y fatiga. Esta formada por cuatro módulos principales:

- Modulo de suministro de potencia hidráulica
- Manifold de control de fluido
- Marco de carga
- Consolas de control y lectura

Figura 14. Maquina de pruebas universal Instron 1323

2.1 MODULO DE POTENCIA

Este módulo ha sido diseñado para el uso con un alto grado de funcionamiento, utilizando un servo-sistema electro-hidráulico. Esta unidad ofrece un alto grado de versatilidad y exactitud así como también una fácil operación. Además el módulo cuenta con la instrumentación necesaria para su operación. Sus dimensiones son 135[cm.] de altura, 154[cm.] de largo y 105[cm.] de ancho y su peso aproximado es de 955[Kg.] .Se encuentra compuesto básicamente por los siguientes elementos (ver figura 8):

- **Bomba**: unidad de desplazamiento positivo con capacidad de 10 [g.p.m.] a 3000 [p.s.i.] con alimentación por gravedad para máxima eficiencia. Es accionada por un motor eléctrico trifásico de 20[hp], 230-460[V], 55[Amp], y que gira a 1200[r.p.m.]; el cual es activado directamente desde la consola de control y lectura.

Figura 15. Módulo de Suministro de Potencia Hidráulica.

- **Manifold de control**: unidad que lleva internamente una válvula de seguridad y un filtro; externamente presenta los puertos de presión y retorno cuyas conexiones son de diferente tamaño para evitar un intercambio accidental de las líneas respectivas además puertos para la conexión de dos presostatos.
- **Acumuladores**: su función es amortiguar las pulsaciones de la bomba en los diversos modos de operación.
- **Sistema de enfriamiento:** consiste en un intercambiador de calor que toma el aceite caliente de retorno y le extrae calor por medio de agua de enfriamiento, antes de su llegada al depósito.
- **Conector eléctrico:** es usado para unir todos los componentes de control eléctrico de la unidad.
- **Interruptor de control de temperatura:** controla la temperatura del aceite del tanque, trabajando en un rango de temperaturas de 80[°F] a 240[°F]. Se encuentra normalmente abierto y se cierra si la temperatura de ajuste es alcanzada apagando la maquina.
- **Interruptor de control de presión máxima:** controla la presión máxima que se puede desarrollar en la maquina. Puede ser ajustado en un rango de presión entre 190 [psi.] y 3200 [psi.], se activa apagando la maquina cuando se alcanza la presión de ajuste.
- **Interruptor de presión diferencial:** controla la caída de presión que se presenta en el filtro que se encuentra internamente en el manifold. Puede ser ajustada dentro de un rango de caída de presión de 20[psi.] a 140[psi.]. La máquina se apaga si la caída de presión sobrepasa el valor ajustado.

- **Interruptor de control de nivel:** verifica el nivel mínimo de aceite en el depósito; en caso de estar por debajo del valor ajustado la máquina se apagará.

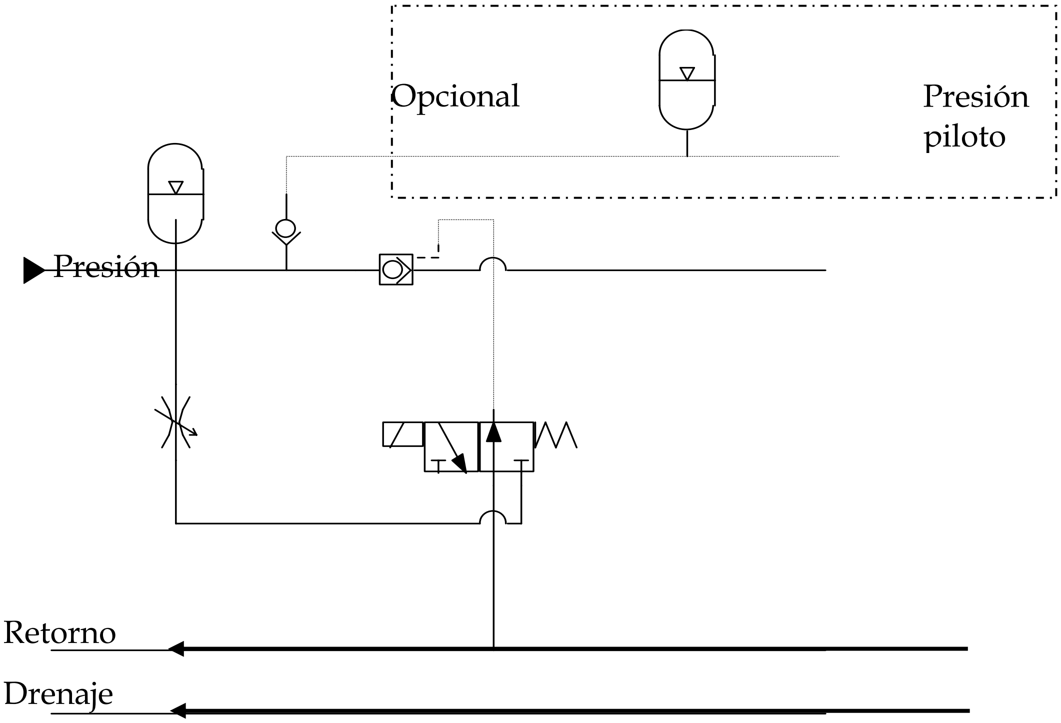
2.2 MANIFOLD DE CONTROL

Tiene como función controlar el paso del fluido desde el módulo de suministro de potencia hacia el actuador hidráulico que se encuentra ubicado en el marco de carga, mediante una electroválvula direccional 3/2 reposicionada por resorte que se activa desde la consola de control. Tiene además dos acumuladores cuya función es amortiguar las pulsaciones y una reguladora de caudal a la entrada de la válvula direccional.

En su entrada identificamos tres puertos; presiona, retorno y drenaje. A su salida además de los anteriores encontramos un cuarto puerto de presión piloto (ver figuras 10 y 11). Sus dimensiones son 41[cm.] de altura, 27[cm.] de largo y 31[cm.] de ancho y un peso de 34[kg.] aproximado.

Figura 16. Manifold de Control de Fluido.

Figura 17. Circuito Hidráulico del Manifold de Control de Fluido



2.3 MARCO ESTRUCTURAL

Es un conjunto rígido conformado por dos columnas principales con sus bases sobre las cuales descansan las vigas superior e inferior, siendo esta última la que sirve de apoyo al actuador hidráulico de trabajo (ver figura 12). La viga superior se desplaza a lo largo de las columnas principales por medio de dos actuadores hidráulicos de simple efecto para permitir una longitud variable de probetas a utilizar y posicionar las mismas.

En la viga superior se encuentra una celda o transductor de carga, mientras que a la viga inferior se encuentra fijo el actuador hidráulico de precisión de doble efecto. Sobre este se encuentra montada una servoválvula, la cual es un amplificador de potencia que regula el flujo de aceite al actuador, en proporción a la señal de comando del servoamplificador. Tiene la capacidad de llevar aceite dentro o fuera de los dos lados del actuador o permanecer en posición de no flujo o cierre total.

Es el elemento en donde se lleva a cabo el ensayo, para lo cual dispone de un actuador de doble efecto cuya área efectiva es de 40.5 [in^2] y un sistema de sujeción, formado por unos platos compactos para la prueba de compresión.

Los utilizados en la prueba de tracción tienen una superficie cónica interna en donde se introducen las mordazas correspondientes a su medida que sostendrán la probeta durante el transcurso del ensayo.

Las dimensiones de la estructura compacta son 366[cm.] de alto, 122[cm.] de largo y 129[cm.] de ancho; su peso total es de 160[kg.] aproximadamente.

2.4 CONSOLA DE CONTROL DE LECTURA

En ella se encuentran ensamblados los dispositivos necesarios para un sistema de control servohidráulico. Los controladores son unidades que trabajan básicamente con corriente directa con excepción de una excitación de corriente alterna para los transductores.

Las consolas cuentan con una unidad de alta ganancia para controlar la velocidad y carga del actuador, la cual esta diseñada para una gran exactitud; es muy sensible y posee un control de circuito cerrado para posición y carga de un actuador hidráulico. Además, posee un control de deformación.

El panel de control indica las funciones de bloqueo, las cuales interrumpen la acción de la unidad de potencia hidráulica. Los indicadores de falla indican bajo nivel en el tanque de aceite, alta temperatura del aceite, y baja presión a la salida de la bomba.

2.5 SISTEMA DE MORDAZAS ACTUAL

Los diámetros del orificio de las mordazas actuales fueron determinados a partir de las dimensiones de las probetas a ensayar (ver figura 12 y tabla 4)

Figura 18. Dimensiones de probetas actuales

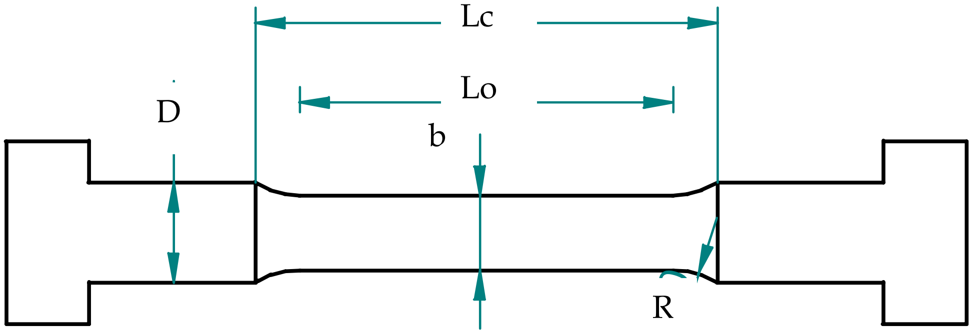


Tabla 4. Dimensiones de probetas actuales

PROBETA	B	Lo	Lc	D	R
1	9±0,3	35±0,2	45	12	10
2	12±0,4	50±0,2	57	20	10
3	20±0,8	50±0,2	57	25	10
4	20±0,8	100±0,2	115	25	10

La prensa dispone de dos platos de diferente sección que se acoplan perfectamente y en medio de los cuales se alojan las mordazas de agarre (ver figuras 19 y 20). Las dimensiones aparecen en las tablas 5 y 6.

Figura 19. Dimensiones del Plato Inferior

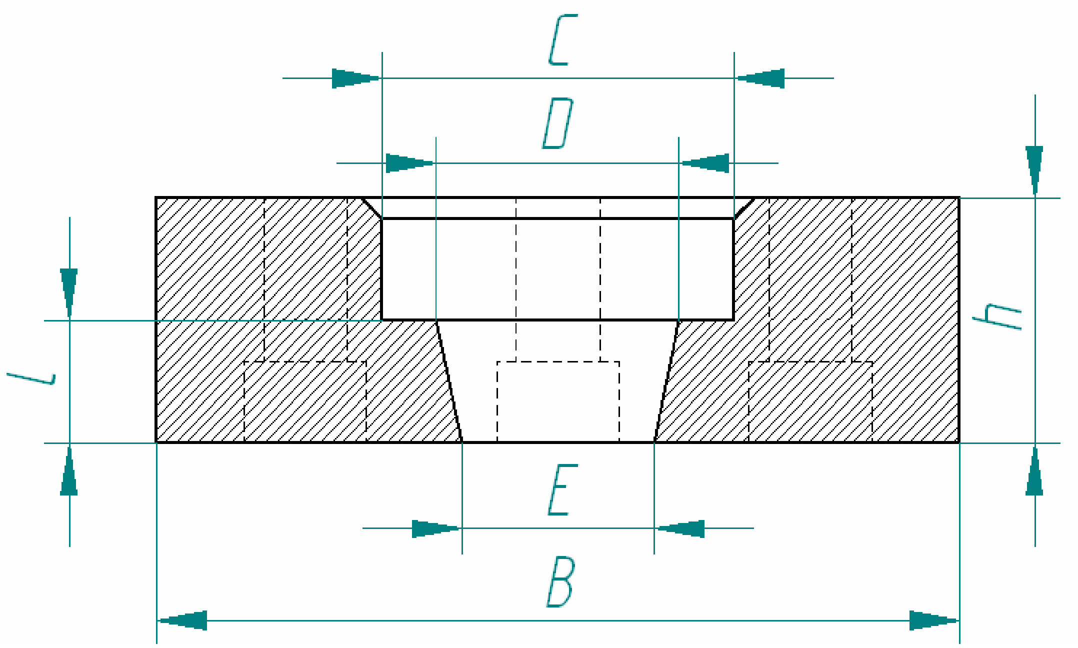


Tabla 5. Dimensiones de platos

PLATO No	B	C	D	E	h	L
1	95	41	30	20	38	19
2	130	57	41	31	38	19

Figura 20. Dimensiones de las mordazas

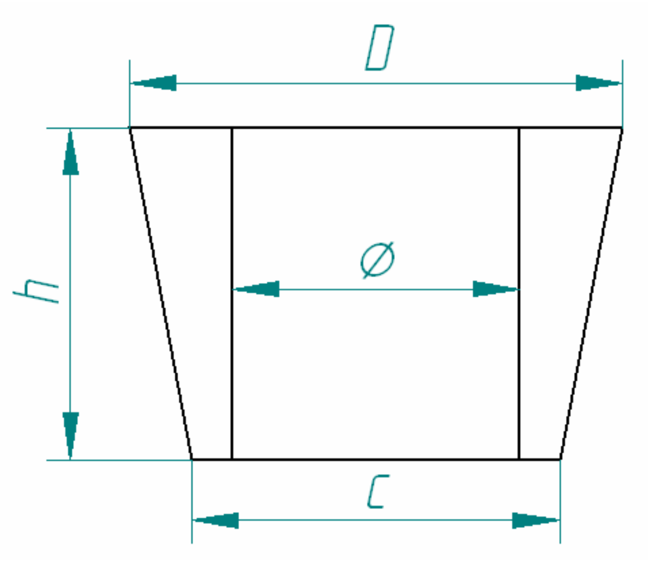


Tabla 6. Dimensiones de mordazas

No	D	C	∅	H
1	33	22	12	25
2	33	22	20	25
3	43	32	20	25
4	43	32	25	25

Análisis de resistencia. Para el análisis de resistencia es necesario tener en cuenta que el numero de mordazas es de tres cubriendo cada una un ángulo de 120° y que cuentan con un ranurado interno para mejorar la fuerza de fricción y por lo tanto el agarre de la probeta.

Tomando como base para los cálculos una carga crítica que es la máxima que esta en capacidad de efectuar la prensa y conociendo los diámetros del actuador hidráulico:

Diámetro del pistón : 8.75 pulgadas

Diámetro del vástago: 5 pulgadas

Área efectiva : 40.5 pulgadas

$$F = P * Ae = 3000[{}^{lb}/_{pu\,lg^2}] * 40.5[pu\,lg^2] = 121500[lb]$$

$$F = 55.2[ton]$$

En donde

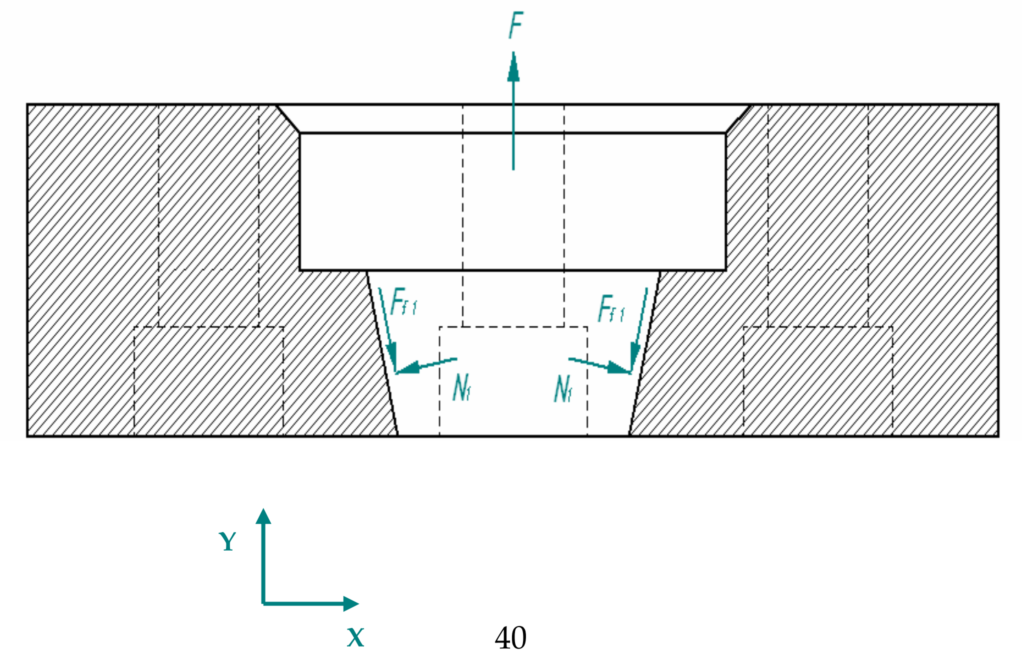
F : Fuerza máxima ejercida por el actuador

P : Presión máxima de trabajo

Ae : Área efectiva

A partir de F se obtienen las cargas a las cuales se encuentra sometido el sistema de agarre, tomando como caso critico cuando se trabaja con el sistema de agarre Nº 2, del diagrama de cuerpo libre del plato inferior(ver figura 21):

Figura 21. Diagrama de Cuerpo Libre del Plato Inferior



$$\sum Fy = 0$$

$$\mathrm{N}_1 \cos * \phi + F_{f1} * sen\phi = F \qquad \text{Ecuación 1}$$

$$F_{f1} = \mu * N_1 \qquad \text{Ecuación 2}$$

Reemplazando Ecuación 2 en Ecuación 1:

$$\mathrm{N}_1 \cos * \phi + \mu * N_1 * sen\phi = F \qquad \text{Ecuación 3}$$

En donde

N₁: Fuerza normal entre el plato y la mordaza de agarre

Ff1: Fuerza de fricción entre el plato y la mordaza de agarre

Φ : Angulo de inclinación del plato

μ : Coeficiente de fricción entre el plato y la mordaza

F : Fuerza ejercida por los tornillos

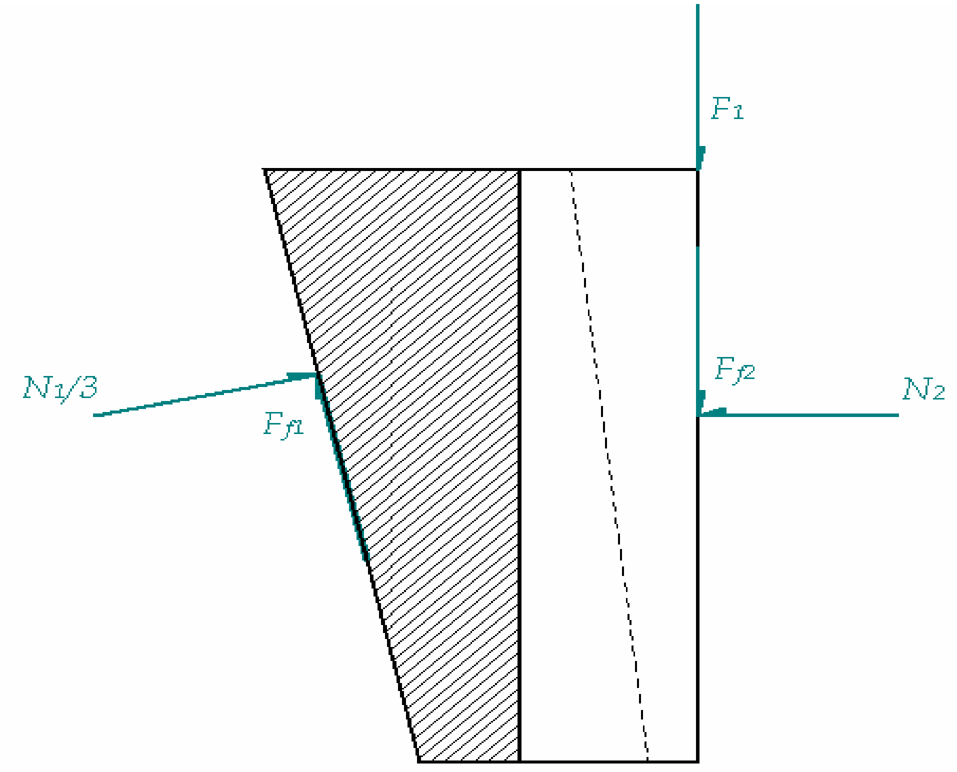
Despejando N_1 de Ecuación 3:

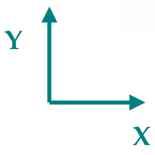
$$\mathrm{N}_1 = \frac{\mathrm{F}}{\cos\varphi + \mu * \mathrm{sen}\varphi} = \frac{55200}{\cos 75 + 0.5 * \mathrm{sen} 75}$$

$$\mathrm{N}_1 = 74415.4[\mathrm{kg}]$$

Haciendo el DCL para una de las tres mordazas teniendo en cuenta que son simétricas axialmente (ver figura 22):

Figura 22. Diagrama de Cuerpo libre de la Mordaza





$$\sum Fx = 0$$

$$N_2 + F_{f1} * \cos\phi = N_1 * {}^{sen\phi}\!/_{3}$$ Ecuación 4

Despejando N_2 :

$$N_2 = N_1 * {}^{sen\phi}\!/_{3} - {}^{\mu * N_1 * \cos\phi}\!/_{3}$$

$$N_2 = {}^{N_1(sen\phi - \mu\cos\phi)}\!/_{3} = {}^{74295.4 * (sen75 - 0.5 * \cos 75)}\!/_{3}$$

$$N_2 = 20716.4[kg]$$

$$\sum Fy = 0$$

$$\mathrm{F}_1 + F_{f2} - F_{f1} * sen\phi = {N_1 * \cos\phi}/{3}$$

$$F_{f2} = \mu * N_2 \qquad \text{Ecuación 5}$$

entonces reemplazando se tiene :

$$F_1 + \mu * N_2 = {N_1 \cos\phi}/{3} + {\mu * N_1 sen\phi}/{3}$$

despejando F_1 se obtiene :

$$\mathrm{F}_1 = {N_1 * \cos\phi}/{3} + {N_1 * \mu * sen\phi}/{3} - \mu * N_2$$

$$F_1 = {74295.4 * \cos 75}/{3} + {74295 * 0.5 * sen 75}/{3} - 0.5 * 20716.4$$

$$F_1 = 8012.1[kg]$$

En donde

F_{f2}: Fuerza de fricción entre mordaza de agarre y probeta.

N_2: Fuerza normal entre mordazas de agarre y probeta.

F_1 : Fuerza ejercida por la probeta.

Despejando Ecuación 2 se tiene:

$$F_{f1} = {0.5 * 74295.4}/{3}$$

$$F_{f1} = 12382.6[kg]$$

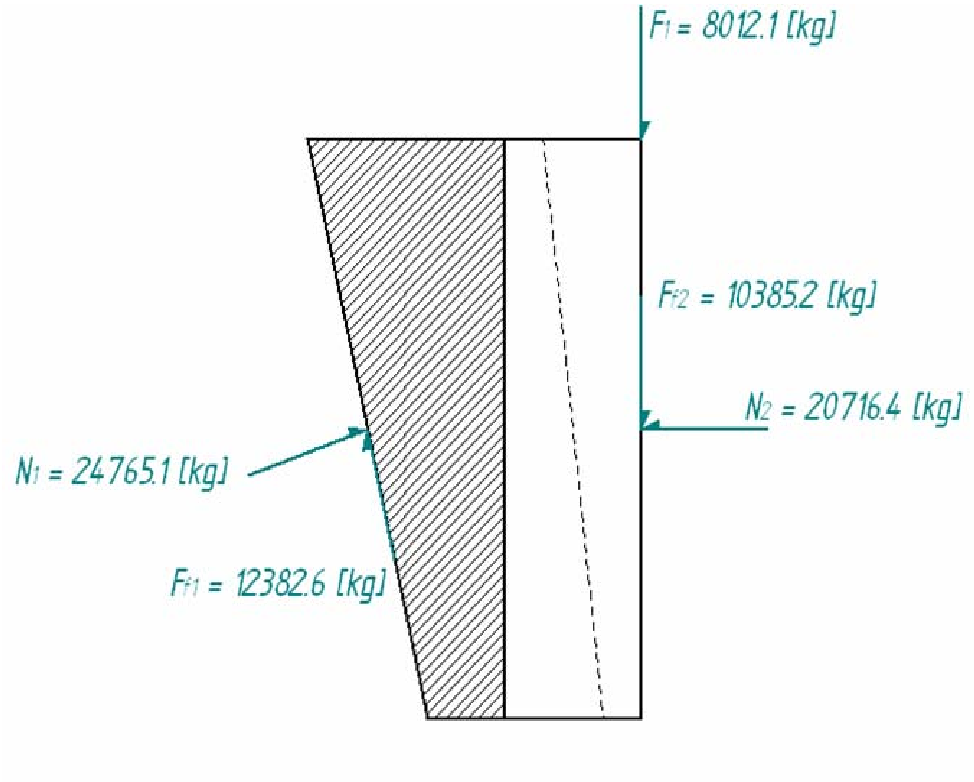
Despejando F_{f2} de Ecuación 5 tenemos :

$$\mathrm{F}_{f2} = 0.5 * 20716.4$$

$$\mathrm{F}_{f2} = 10358.2[kg]$$

En conclusión la mordaza se encuentra sometida a las fuerzas anteriores (ver figura 23).

Figura 23. Fuerzas Aplicadas a las Mordaza



3. ANALISIS QFD PARA EL SISTEMA DE MORDAZAS HIDRÁULICAS

3.1 PLANTEAMIENTO DEL SISTEMA DE MORDAZAS REDISEÑADO

Con el transcurrir del tiempo, nuestro mundo se ha visto afectado por la competitividad y por el deseo de realizar las actividades de una manera más rápida y confiable. Para poder entrar en este mundo debemos de innovar y mejorar nuestros equipos, de tal forma que se comporten como sistemas rápidos y de pronta respuesta, aprovechando todas las variables que nos puedan facilitar este comportamiento.

En miras de mejorar el procedimiento de anclaje de probetas realizado en la máquina de pruebas universales Instron 1323 ubicada en el laboratorio de sistemas oleoneumáticos; procedimiento que se realiza actualmente con pernos y platos de acuerdo al tamaño de las probetas que se utilicen en donde para cada prueba se deben soltar los seis tornillos con que cuenta cada conjunto, haciendo de este un procedimiento largo, tedioso y con respuestas lentas; se planteó la posibilidad de mejorar el sistema de anclaje .

Para subsanar este trabajo se requiere un diseño ingenieril que haga de esta labor un procedimiento más acorde a nuestra necesidad.

Requerimientos para desarrollo del nuevo sistema de anclaje:

- Fácil de operar.
- Sirva para las pruebas de tensión y compresión.
- Permita cambios rápidos de probetas.

- Fácil de armar.
- Fácil de desarmar.
- Fácil montaje.
- Sus repuestos sean fácil de conseguir.
- Limpia.
- Segura.
- Peso moderado.

A continuación se realiza una asociación de los requerimientos en subgrupos de criterios de evaluación.

- Operación y uso
  - Fácil de operar
  - Para las dos pruebas
  - Cambios rápidos de probetas
- Mantenimiento
  - Fácil de armar
  - Fácil de desarmar
  - Fácil montaje
  - Repuestos fácil conseguir
  - Limpia
- Seguridad
  - Seguro
  - Peso

Estos requerimientos se introducen en la matriz de la calidad en las celdas verticales y son las necesidades del cliente; a estas se les asigna un valor de importancia para el consumidor. En posición horizontal se asignan los requisitos del proyecto, paso que se realiza anteriormente con el método de tormenta de ideas (ver tabla 7).

El relacionamiento se efectúa basado en los siguientes valores:

- 9 (para un relacionamiento fuerte)
- 3 (para un relacionamiento medio)
- 1 (para un relacionamiento débil)

Luego de ubicados los valores en cada recuadro, se procede a realizar la sumatoria de cada una de las columnas con el fin de identificar los de mayor valor en la matriz de la calidad, estos constituyen los indicadores más fuertes que mas adelante se ponderarán y que deberán influir en la proposición de las alternativas.

Tabla 7. Matriz de la calidad

			Acero	Mecanismo Sencillo	Pocas Piezas	Económico	Solo conjunto	Hermético	Fácil de construir (Local	Unida a máquina	Fácil de abrir y cerrar	Ocupe poco espacio
	Importancia		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Operación y uso	**Fácil de operar**	**8**		**9**	**9**		**9**			**9**	**9**	**9**
	Para las dos pruebas	**8**	**9**	**9**	**9**		**9**		**3**	**9**	**9**	**9**
	Cambios rápidos	**7**		**9**	**9**		**9**			**3**	**9**	**9**
Mantenimiento	**Fácil de armar**	**7**		**9**	**9**		**9**	**3**	**3**	**3**		**3**
	Fácil de desarmar	**7**		**9**	**9**		**9**	**3**	**3**	**3**		**3**
	Fácil montaje	**7**	**3**	**3**	**9**		**9**	**3**	**3**	**3**		**3**
	Repuestos fácil conseguir	**6**		**9**	**9**	**9**	**3**		**9**	**9**		
	Limpia	**4**	**3**		**3**			**9**		**3**		
Seguridad	**Segura**	**8**		**3**	**3**		**9**	**3**		**9**	**9**	**9**
	Peso	**3**	**9**	**3**	**9**		**3**			**3**		
Totales			**120**	**441**	**513**	**54**	**495**	**123**	**141**	**375**	**279**	**342**

Luego de llenado la matriz de la calidad se procede a la selección de los requisitos del proyecto con mayor puntuación, estos requisitos serán el pilar para la selección final de la alternativa.

Para nuestro efecto se ha seleccionado los 5 con puntuación más alta y se mostrarán a continuación en %. Para efectuar este cálculo se toma el valor del requisito y se divide en la sumatoria total de todas las columnas (ver tabla 8).

Tabla 8. Selección de requisitos

	Acero	Mecanismo Sencillo	Pocas Piezas	Económico	Solo conjunto	Hermético	Fácil de construir (Local	Unida a máquina	Fácil de abrir y cerrar	Ocupe poco espacio	
Totales	120	441	513	54	495	123	141	375	279	342	2883
%	**4**	**15**	**18**	**2**	**16**	**4**	**5**	**13**	**10**	**12**	

Los requisitos que predominan de acuerdo a sus porcentajes son:

- Pocas Piezas
- Un solo conjunto
- Mecanismo Sencillo
- Unida a la máquina
- Ocupe poco espacio

3.2 ALTERNATIVAS PROPUESTAS

Las alternativas presentadas a continuación son el resultado de un estudio basado en el funcionamiento de elementos hidráulicos tradicionales.

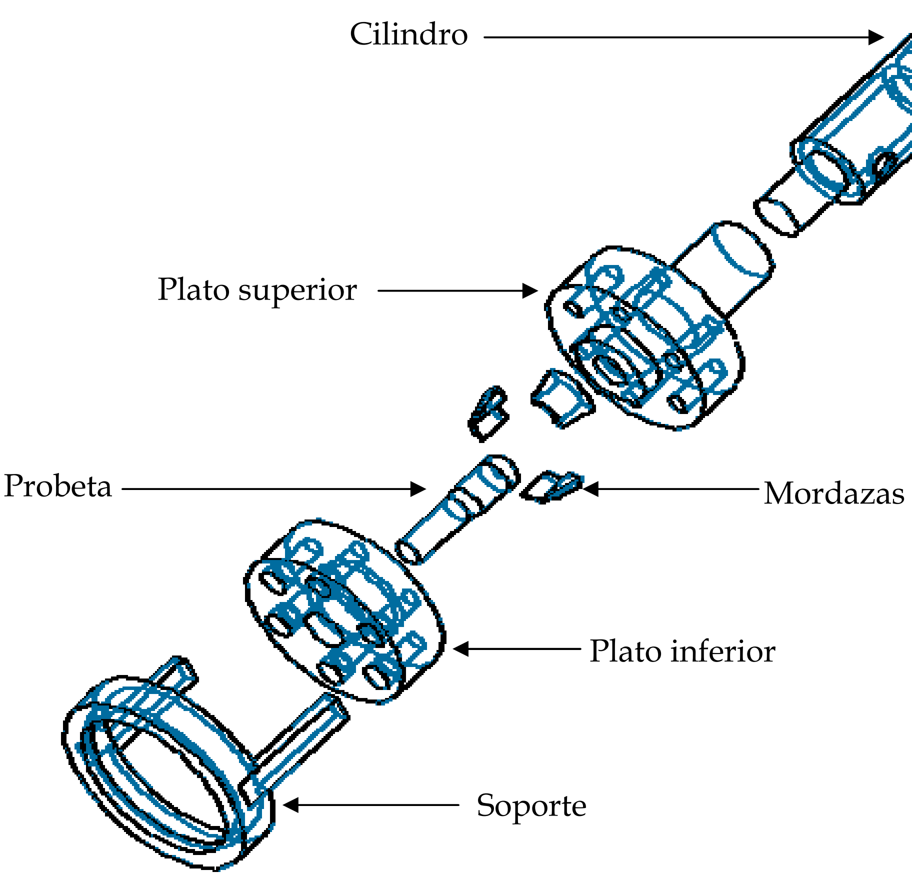
3.2.1 Sistema hidráulico con cilindros. Lo propuesta consiste en utilizar los elementos existentes actualmente, adaptándoles un cilindro hidráulico que ejecute la acción de agarre y unos resortes que permitan la reposición de las mordazas y la extracción de la probeta.

- **Montaje:** Se adaptara un cilindro hidráulico previamente seleccionado al marco de la prensa y se acondicionara al vástago del cilindro el plato superior del sistema de agarre, el plato inferior (plato con la perforación cónica) estará apoyado fijamente a una estructura que se diseñará e irá soportada en el marco de la prensa. En su posición inicial el cilindro se encontrará retraído, y utilizando una válvula direccional 4/3 con centro cerrado se darán las respectivas órdenes para la dirección del flujo. Adicional a esto las mordazas irán sujetadas lateralmente al plato superior por medio de resortes (ver figura 18).

- **Procedimiento para el agarre:** Como el plato inferior se encuentra independiente del conjunto vástago-plato superior, podemos colocar la probeta de una manera fácil; luego de colocada la probeta en el plato inferior, se dará la orden a la válvula direccional para que el cilindro se empiece a extender, lo que quiere decir que el plato superior empieza a descender lentamente hasta alcanzar la cabeza de la probeta, ajustando de manera adecuada la probeta entre los dos platos mencionados(este procedimiento se realizara de igual manera en la parte inferior).

Luego de realizada la prueba respectiva, se dará la contraorden a la válvula direccional, reposicionando el cilindro a su estado actual y liberando la probeta para realizar la siguiente prueba. Con el sistema de resortes adaptado a cada una de las mordazas, garantizamos siempre que estas suban de igual manera como lo hace el plato superior, evitando que las mordazas no liberen la probeta estudiada.

Figura 24. Sistema hidráulico con cilindros



3.2.2 Sistema hidráulico con placa móvil. Lo que proponemos en esta solución es el diseño y construcción de una camisa de doble sección, con sus agujeros laterales para realizar la respectiva conexión de las mangueras que transportarán el fluido hidráulico. Adicional a esto se diseñará y construirá un disco de doble sección que se acople perfectamente en la camisa nombrada anteriormente (ver figura 19).

- **Montaje:** Dentro de la camisa se alojará el disco de doble sección; cada sección del disco irá con sus respectivos sellos para evitar que el fluido pase de una cámara a otra y así crear dos cámaras independientes con diferente área efectiva.

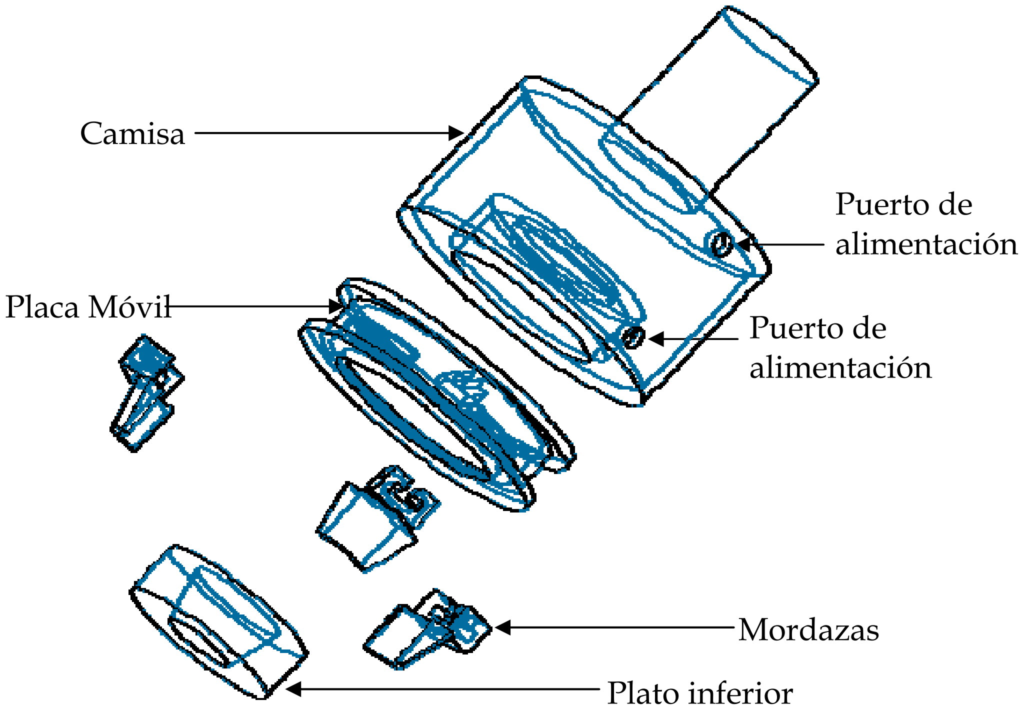
Además en la parte interna de la camisa irá alojado el plato inferior (plato con la perforación cónica) que podrá ser desmontado fácilmente para cualquier cambio de las dimensiones de la probeta a estudiar (para cada dimensión de probeta habrá un plato inferior con sus respectivas mordazas).

El disco móvil llevará consigo un sistema de guía para las mordazas que irán montadas en éste, esto para garantizar que las mordazas se desplacen verticalmente, adicional a esto las mordazas irán agarradas lateralmente a la camisa por medio de resortes previamente seleccionados, garantizando su desplazamiento radial.

- **Procedimiento para el agarre:** Inicialmente el disco móvil se encontrará en su posición mas elevada, lo que quiere decir que la cámara superior aloja el mínimo volumen de fluido hidráulico, luego se montan las mordazas en las guías del disco móvil y se aseguran lateralmente con resortes a la parte interna de la camisa; siguiente a esta operación se montara el plato inferior, asegurando que quede el espacio suficiente para introducir la probeta.

  Por medio de una válvula direccional 4/3 con centro cerrado se darán las respectivas órdenes para la dirección del flujo, de modo que se llene de fluido hidráulico la cámara superior (cámara de sección mayor) desplazando el disco móvil, el cuál transmite el movimiento a las mordazas que se deslizan libremente en la superficie cónica del plato inferior hasta permitir el agarre de la probeta (este procedimiento se realizará de igual manera en la parte inferior). Luego de realizada la prueba respectiva se dará la contraorden a la válvula para el llenado de la cámara inferior (cámara de menor sección), produciéndose un desplazamiento del disco móvil y de las mordazas, que volverán a su posición inicial por medio de la fuerza de los resortes, liberando la probeta previamente estudiada.

Figura 25. Sistema Hidráulico con placa móvil

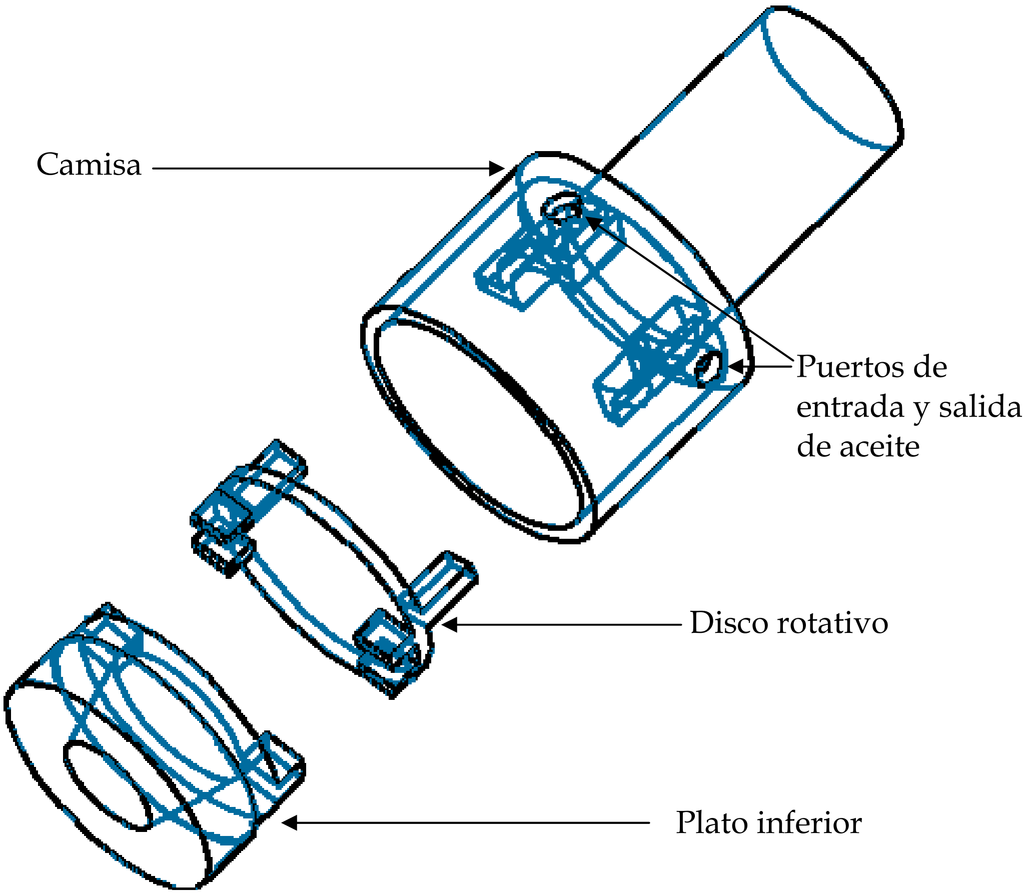


3.2.3 Sistema hidráulico con rotación del plato inferior. Lo que proponemos con esta solución es el diseño y construcción de una camisa con perforaciones laterales para la conexión de las mangueras que transportan el fluido hidráulico; dentro de la camisa se alojara un disco que crea dos cámaras independientes de igual sección que al llenarse de fluido hidráulico permitirán su rotación en un sentido u otro transmitiendo este movimiento al plato inferior para proporcionar el agarre o soltura de la probeta (ver figura 20).

- **Montaje:** Dentro de la camisa construida se acondicionara un disco que proporcionara dos cámaras independientes de igual sección que proporcionan movimiento en los dos sentidos dependiendo del direccionamiento del fluido. Solidario a este disco se acoplara el plato inferior por medio de unas guías para garantizar que el movimiento rotacional del disco se transmita al plato inferior (plato con perforación cónica). En el plato inferior irán alojadas las mordazas que serán conectadas al disco por medio de resortes.

- **Procedimiento para el agarre:** Luego de realizar el montaje previamente explicado direccionamos el fluido hidráulico por medio de una válvula direccional 4/3 con centro cerrado de tal manera que con una sola orden gire el conjunto convirtiendo el movimiento rotacional del plato inferior en lineal de las mordazas para el ajuste de la probeta.

Figura 26. Sistema Hidráulico con Rotación del Plato Inferior.



Luego de realizada la prueba se dará la contraorden a la válvula para que el conjunto gire en sentido contrario liberando de este modo la probeta. La función de los resortes es reposicionar las mordazas a su posición inicial.

3.3 SELECCIÓN DE ALTERNATIVA

De acuerdo al análisis realizado en el QFD y a las propuestas hechas anteriormente, se llego a la conclusión de que el sistema que se va a desarrollar y que cumple con las condiciones descritas es la opción número 2, sistema hidráulico con placa móvil, basado en el principio de embolo de los cilindros convencionales; además este es un mecanismo sencillo que de deslizamiento que cumple con las condiciones descritas anteriormente (ver tabla 9).

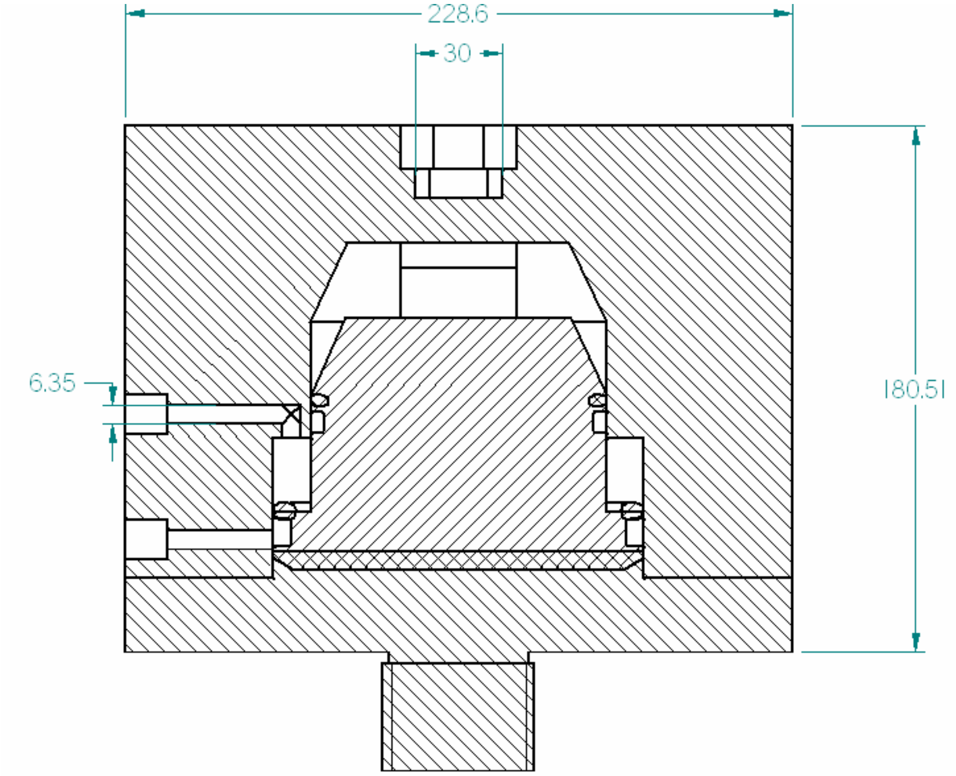
Tabla 9. Selección de alternativa

				Alternativa 1. Sistema hidráulico con cilindros.		Alternativa 2. Sistema hidráulico con placa móvil.		Alternativa 3. Sistema hidráulico con rotación del plato inferior.	
pocas piezas 0,18	Sistema mecánico	50%	0,09	2	0,18	5	0,45	5	0,45
	Sistema hidráulico	30%	0,054	2	0,108	5	0,27	4	0,216
	Sistema eléctrico	20%	0,036	5	0,18	5	0,18	5	0,18
Un solo conjunto 0,16	Fácil de armar	40%	0,064	2	0,128	5	0,32	3	0,192
	Fácil de desarmar	40%	0,064	2	0,128	5	0,32	3	0,192
	Peso moderado	20%	0,032	3	0,096	3	0,096	3	0,096
Mecanismo Sencillo 0,15	Económico	40%	0,06	2	0,12	3	0,18	3	0,18
	Fácil de construir	40%	0,06	3	0,18	4	0,24	1	0,06
	Seguro	20%	0,03	5	0,15	5	0,15	5	0,15
Unido a máquina 0,13	Fácil montaje	40%	0,052	2	0,104	5	0,26	5	0,26
	Fácil desmontaje	40%	0,052	2	0,104	5	0,26	5	0,26
	Presión máquina	20%	0,026	5	0,13	5	0,13	5	0,13
Ocupe poco espacio 0,12	Compacto	40%	0,048	1	0,048	5	0,24	4	0,192
	Estético	30%	0,036	1	0,036	5	0,18	5	0,18
	Probeta Standard	30%	0,036	4	0,144	5	0,18	5	0,18
Totales				1,836		**3,456**		2,918	

4. DISEÑO CAD-CAE

4.1. GEOMETRIA

Figura 27. Geometría de conjunto



El diseño de la geometría se basó en la selección de la propuesta realizada en el capitulo anterior (ver figura 27).

4.2. ESTATICA

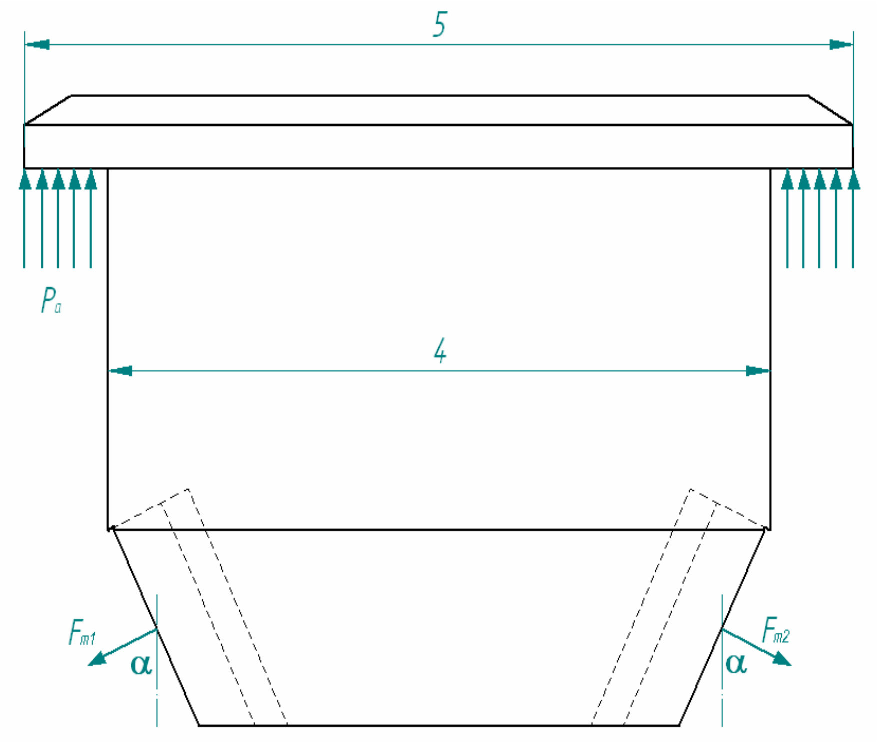
Los diagramas de cuerpo libre se realizan teniendo en cuenta: las operaciones a realizar por el sistema de mordazas que en este caso son tensión y compresión de probetas; y una presión de servicio para su operación de 900 psi.

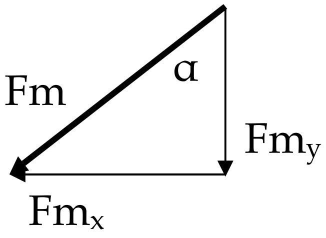
4.2.1 Tensión.

DCL placa móvil (Ver figura 28).
P_a: Presión de aceite = 900 psi.
F_{m1} y F_{m2}: Fuerza ejercida por las mordazas sobre la placa móvil.

A ef: Área efectiva de Presión de aceite.
α : 25º

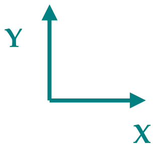
Figura 28. DCL placa móvil





$$Fm_1 = Fm_2 = Fm$$

$$\mathrm{Fm}_x = \mathrm{Fm} * \mathrm{sen}25$$
$$\mathrm{Fm}_y = \mathrm{Fm} * \cos 25$$



$$\sum fy \approx 0$$
$$Pa * Aef - 2Fm_y = 0$$
$$900 * {}^{\pi}\!/_{4}(5^2 - 4^2) - 2Fm\cos 25 = 0$$
$$Fm = 3510lb$$

Ecuación 6.

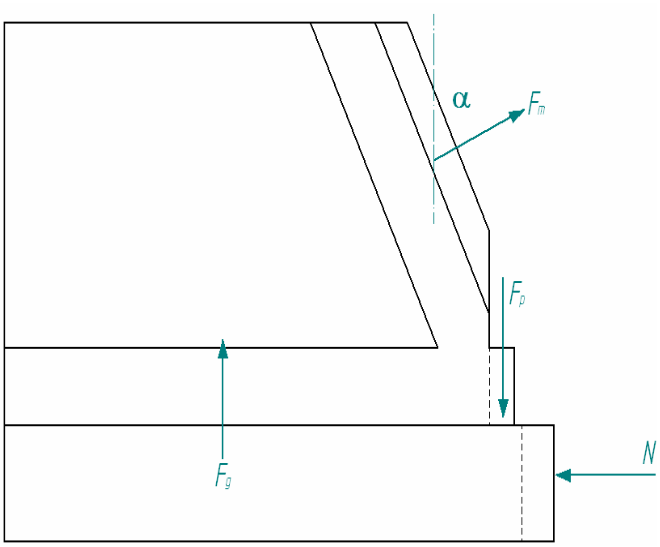
$$Fm_x = 3510 * sen25 = 1483lb$$
$$Fm_y = 3510 * \cos 25 = 3181lb$$

DCL Mordazas (Ver figura 29):

Fg: Fuerza ejercida por guías de sección inferior.
Fp: fuerza ejercida por la probeta.= 56770 lb

N: Normal entre mordazas y probeta.
α : 25º

Figura 29. DCL Mordazas.



$$\sum Fx = 0$$

$$Fm_x - N = 0$$

$$N = Fm * sen25 = 3510 * sen25$$

$$N = 1483lb$$

Ecuación 7.

$$\sum Fy = 0$$

$$Fm_y + 2Fg - Fp = 0$$

$$Fm * \cos 25 - 2Fg - 56770 = 0$$

$$Fg = \frac{56770 - 3510 * \cos 25}{2}$$

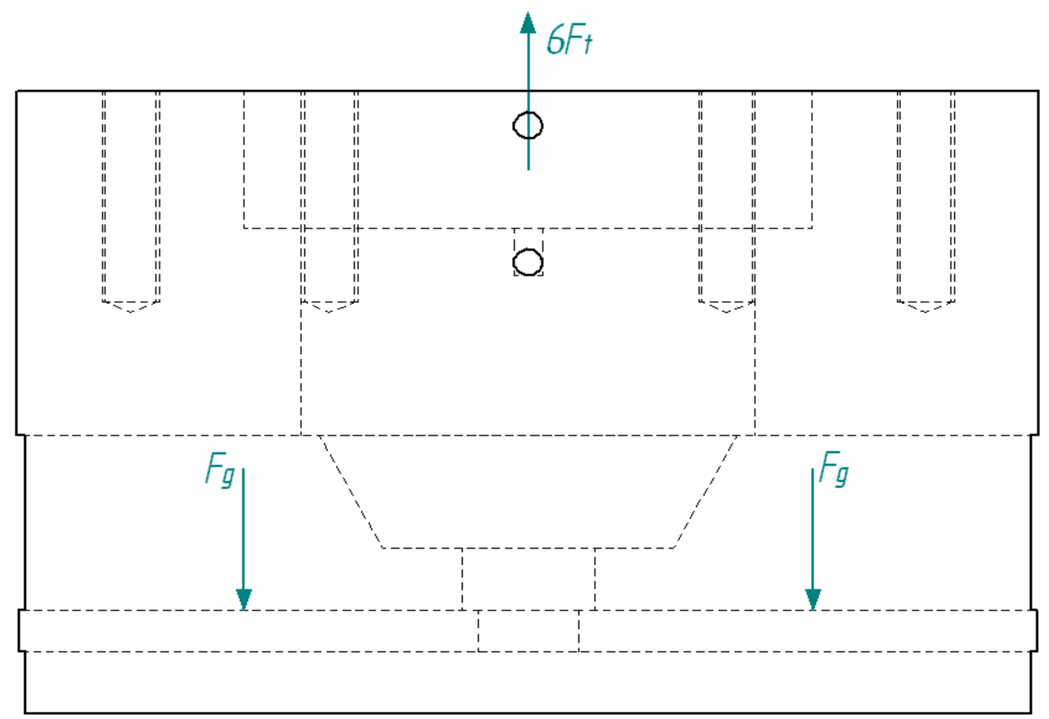
$$Fg = 26794lb$$

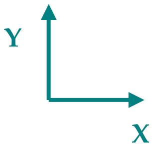
Ecuación 8.

DCL Sección inferior (Ver figura 30):

Fg: Fuerza de las guías. = 26794 lb.
Ft: Fuerza ejercida por cada tornillo.

Figura 30. DCL Sección inferior



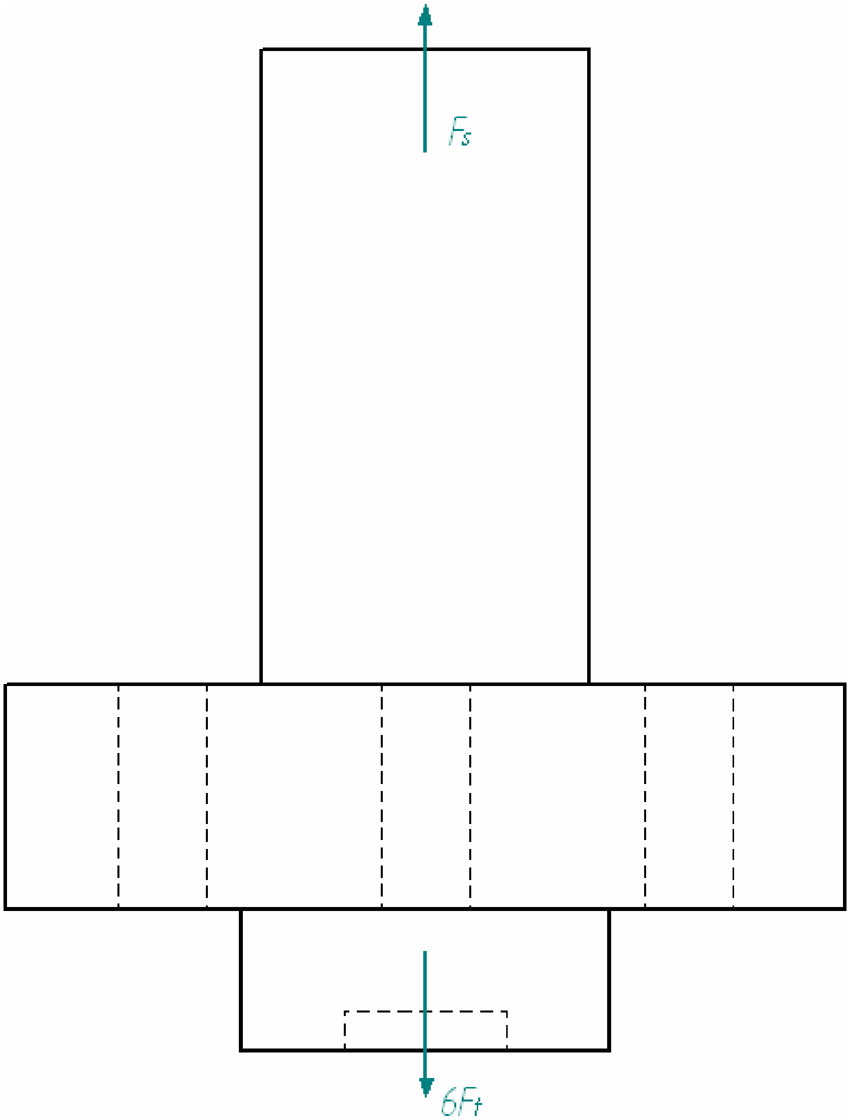


$$
\begin{aligned}
&\sum Fy = 0 \\
&6Ft - 4Fg = 0 \\
&Ft = \frac{4 * 26794}{6} \\
&Ft = 17863 lb
\end{aligned}
$$

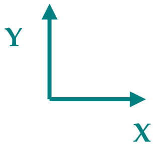
Ecuación 9.

DCL Tapa (Ver figura 31):

Figura 31. DCL Tapa.



Fs: fuerza ejercida por el soporte.



$$\sum Fy = 0$$

$$Fs - 6Ft = 0$$

Ecuación 10.

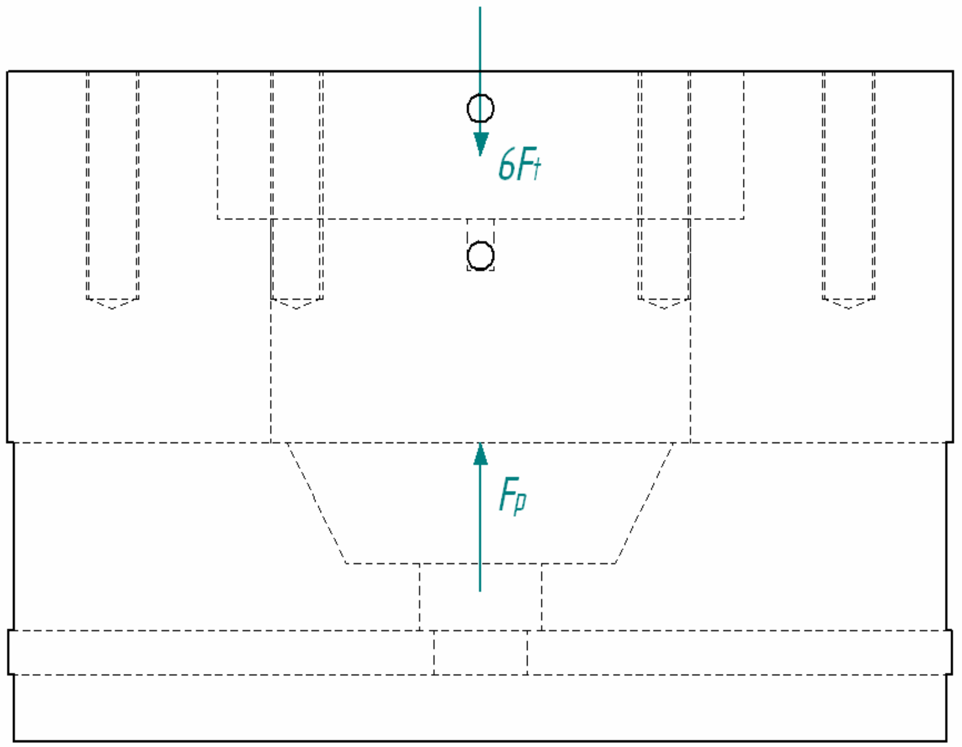
$$Fs = 107178lb$$

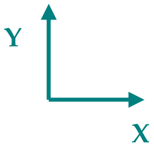
4.2.2. Compresión. En compresión solo actúan los cuerpos sección inferior y tapa por lo tanto los otros dos no se tendrán en cuenta para esta operación.

DCL sección inferior (Ver figura 32):

Fp: Fuerza de la probeta. 113538 lb.
Ft: Fuerza ejercida por la tapa.

Figura 32. DCL sección inferior.





$$\sum Fy = 0$$

$$Fp - Ft = 0$$

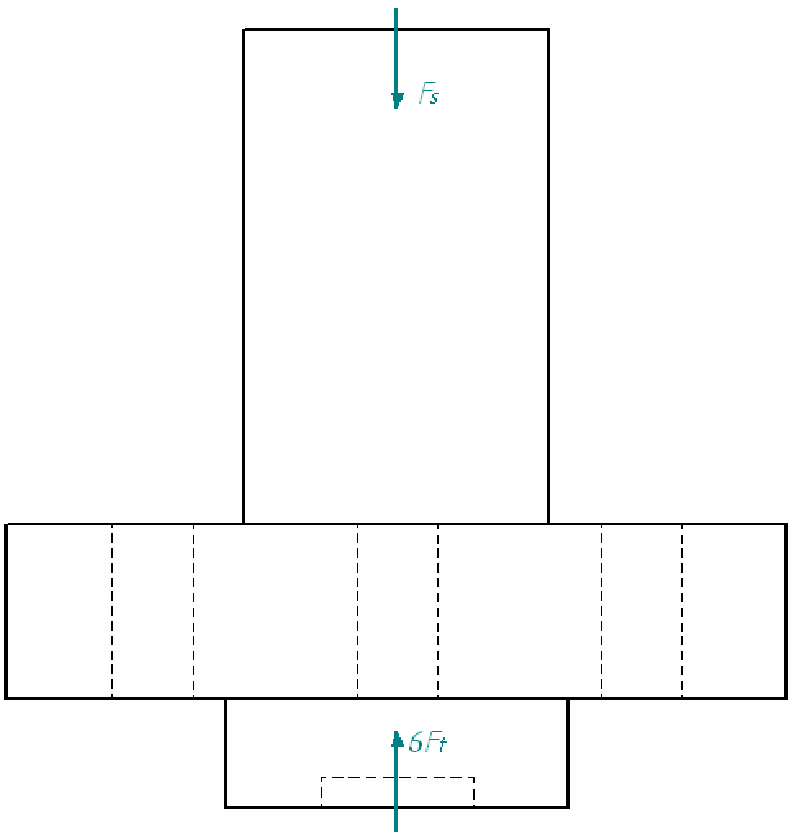
$$Ft = 113538 lb$$

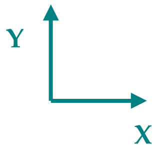
Ecuación 11.

DCL tapa (Ver figura 33):

Fs: Fuerza del soporte.
Ft: Fuerza soportada por la tapa. = 113538 lb

Figura 33. DCL Tapa.





$$\sum Fy = 0$$

$$Ft - Fs = 0$$

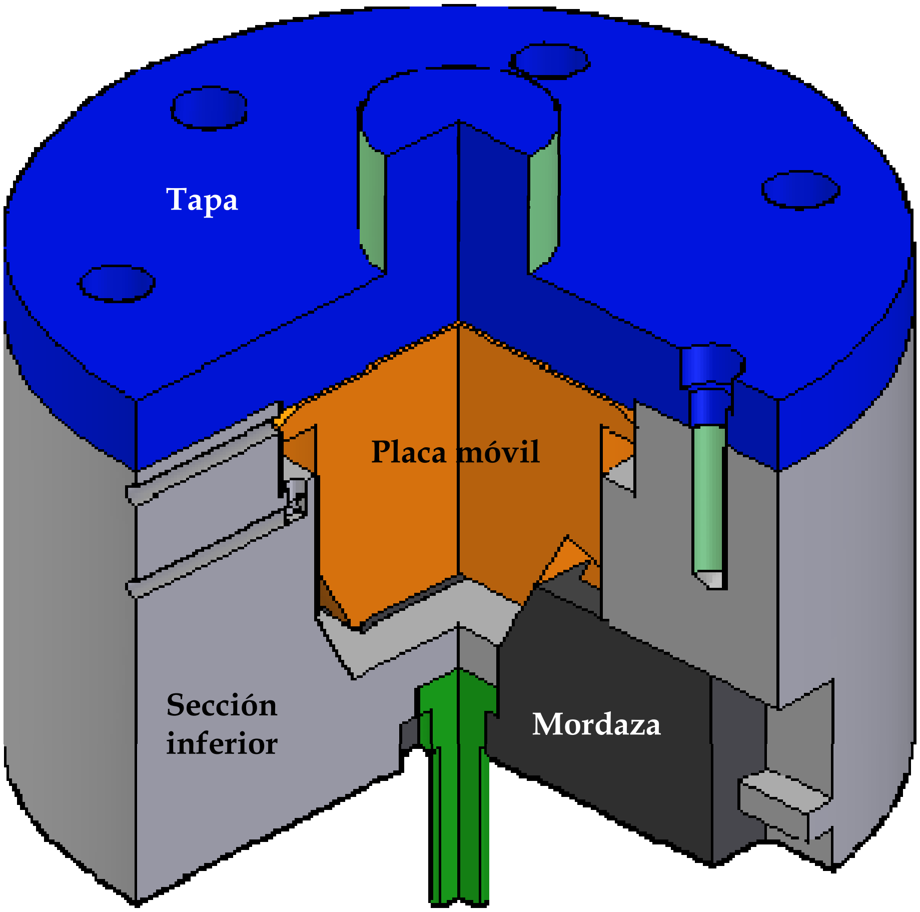
$$Fs = 113538 lb$$

Ecuación 12.

4.3 PARTES DEL SISTEMA MECÁNICO.

El sistema diseñado y descrito a continuación (Ver figura 34) se realizo con la ayuda de los paquetes CAD/CAE con los que cuenta la escuela de ingeniería mecánica: Solid-Edge V-14 y Ansys V- 8.1.

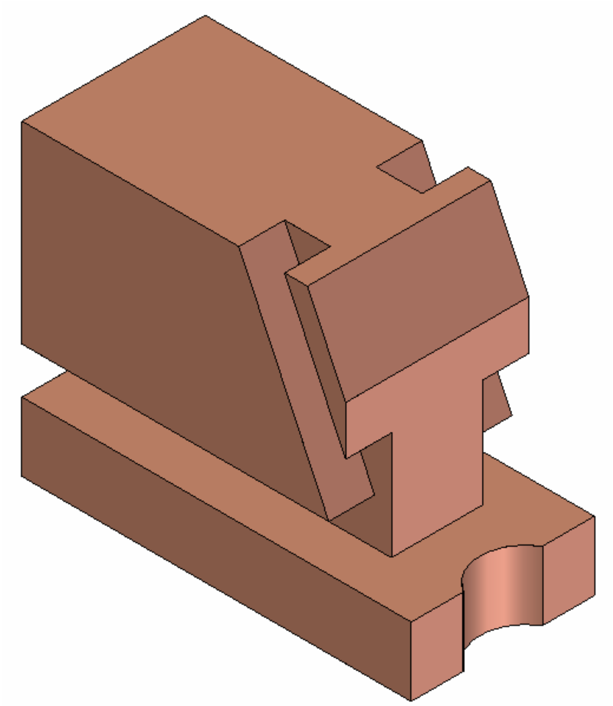
Figura 34. Conjunto de sistema de mordazas.



4.3.1 Juego de mordazas. Constituido por dos piezas de acero AISI SAE 4340 y permitirá agarrar o soltar la probeta a la que se va a realizar la prueba.

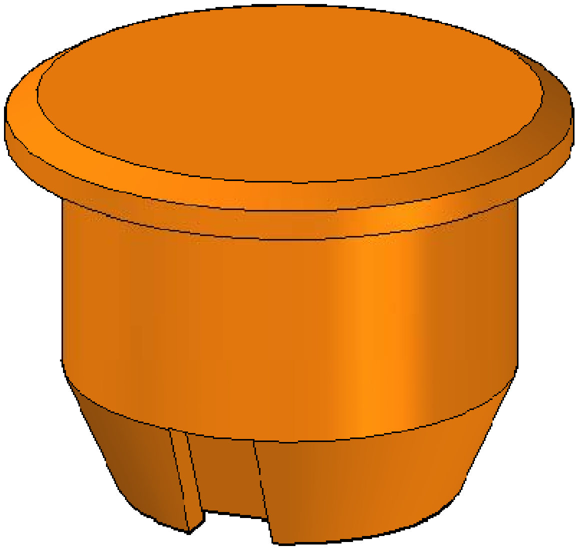
En ellas se apoyará la cabeza de la probeta (Ver figura 35), cuando se realicen pruebas a tensión.

Figura 35. Mordazas.



4.3.2 Placa móvil. Es la pieza motora del conjunto, y es sobre donde recae todo el éxito del sistema (Ver figura 36). Construida de acero AISI SAE 1045 y su movimiento es debido a que el fluido proveniente de la presión piloto del sistema pega a las dos (2) áreas (dependiendo de la orden dada a la válvula), permitiendo el desplazamiento vertical de la placa, a su vez este transmitirá el movimiento a las mordazas por medio de un sistema de guías espaciadas cada una a 180° y mecanizadas al interior del cono.

Figura 36. Placa móvil.



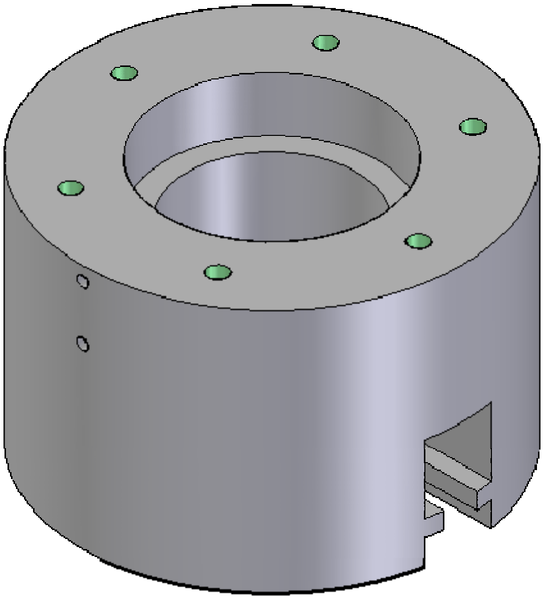
4.3.3 Sección inferior.

Es la base del sistema , y es por donde se desliza tanto la placa móvil como el juego de mordazas, lleva internamente un apoyo fijo para que allí descanse la probeta cuando se estén realizando las pruebas de compresión; con esta base se garantiza siempre la misma ubicación de la probeta dentro del sistema (Ver figura 37).

Esta parte del sistema es la encargada de direccionar el movimiento de las mordazas, debido a que radialmente se mecanizaron dos guías cada una a 180°, que es donde están descansando las mordazas antes mencionadas.

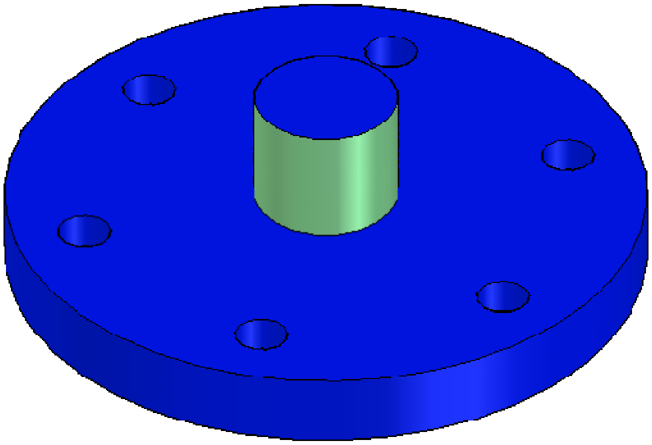
En la periferia se mecanizaron dos puertos para la entrada y salida del fluido. Su construcción es de acero AISI SAE 1045.

Figura 37. Sección inferior.



4.3.4 Tapa. Parte que permite dar el hermetismo buscado para el sistema, lleva consigo un tornillo roscado que va unido al marco de la máquina de pruebas, se une a la sección inferior por medio de 6 pernos de ½″ grado 8 (Ver figura 38). Su construcción es de acero AISI SAE 1045.

Figura 38. Tapa.



4.4 SIMULACION CINEMATICA

Funcionamiento. La operación del sistema esta regida por cuatro fases o tiempos:

- Posicionamiento de la probeta

La orden para el inicio de la primer fase se da por medio de un accionamiento de la válvula direccional conduciendo el fluido hidráulico al puerto No. 1 localizado en la sección inferior, ocasionando el desplazamiento de la placa móvil que a su vez induce la apertura de las mordazas proporcionando el espacio necesario para introducir la probeta en la sección inferior.

- Agarre de la probeta

Una vez colocada la probeta en posición de prueba se dará la contraorden a la válvula para direccionar el fluido hidráulico hacia el puerto No. 2 induciendo el cierre de las mordazas y por tanto la acción de agarre de la probeta.

- Prueba

En esta fase la válvula direccional permanece en la posición central mientras que el actuador de la maquina aplica la fuerza de tracción o compresión según sea el caso, hasta producir la fractura de la probeta.

- Retirada de la probeta

La última fase se ejecuta de forma similar a la primera con la diferencia de que la apertura de las mordazas permite la extracción de las partes falladas.

4.5 SIMULACION GENERAL Y ANALISIS DE ESFUERZOS

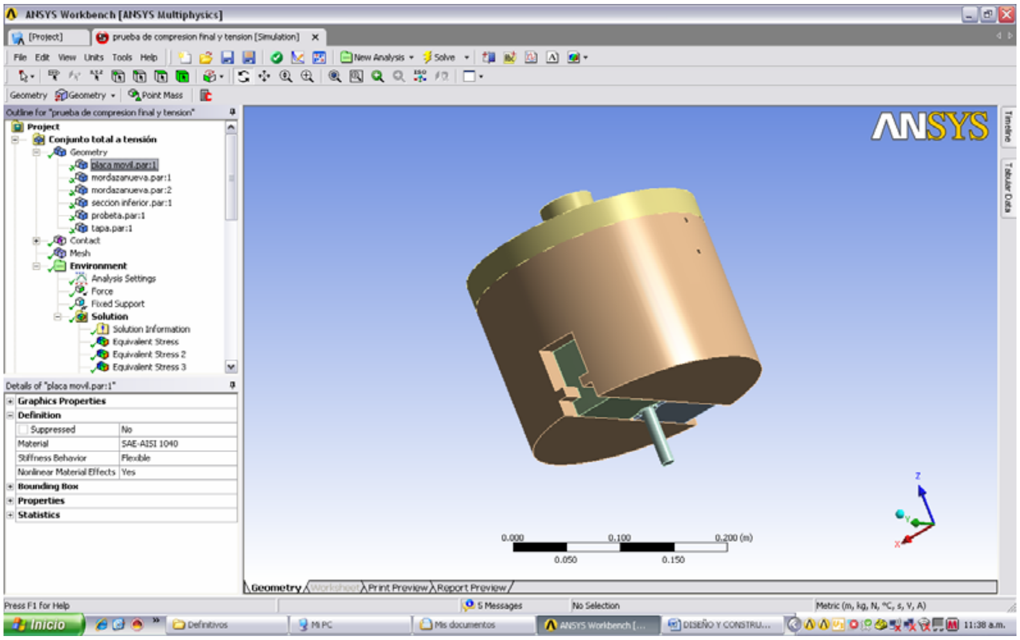
Después de haber modelado previamente las ideas que se tenían sobre el conjunto de mordazas se procede a analizar el sistema con el programa de CAE ANSYS Workbench V8.1.

El proceso de realización del análisis de ingeniería al modelo es el siguiente.
Luego de elaborar el conjunto en Solid Edge V18; el programa captura el parasólido y lo deja disponible para agregar las cargas a las que se verá sometido, estas cargas son externas y el mediante análisis de elementos finitos realizara el cálculo de el comportamiento interno de los materiales a esos factores externos ya mencionados. Es importante recalcar que el análisis (FEA acrónimo de Finite Element Analysis) del conjunto solo se le hace a los elementos que están comprometidos y afectados por las cargas externas dentro del conjunto
Para cada una de las pruebas realizadas se ha construido un análisis diferente con el fin de poder desarrollar nuestro prototipo. El análisis de esfuerzos se ha realizado utilizando el software ANSYS workbench V 8.1.

4.5.1 Prueba a tensión. Para realizar el modelo de esta prueba se ha tomado como base la posición donde se debe estar sujetando la probeta, en este punto los elementos que soportan directamente los esfuerzos generados por la probeta son las mordazas.

- **Geometría**

Figura 39. Selección de materiales



Details of "placa movil.par:1"

Graphics Properties	
Definition	
☐ Suppressed	No
Material	SAE-AISI 1040
Stiffness Behavior	Flexible
Nonlinear Material Effects	Yes
Bounding Box	
Properties	
Statistics	

El material seleccionado (ver figura 39) es un acero 1045 para todas las partes del conjunto, excepto las mordazas para las que se utiliza acero 4340. Estos materiales aplican de igual forma para la prueba a compresión.

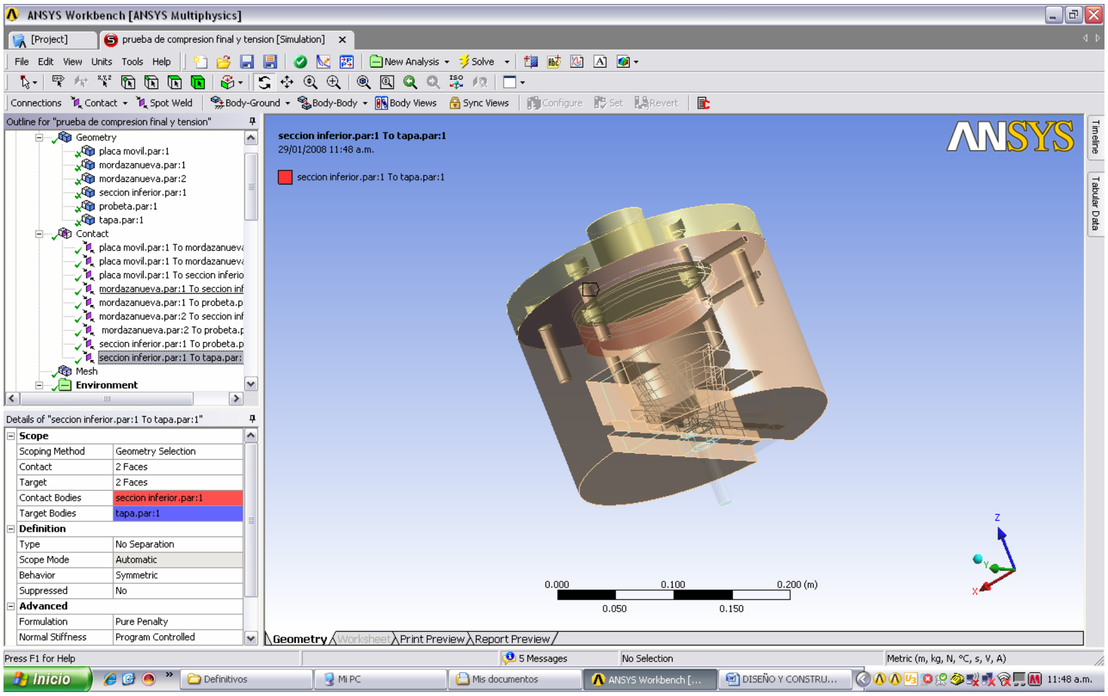
- **Tipos de contacto**

Los diversos tipos de contacto son seleccionados para cada pieza en particular de acuerdo a las condiciones de trabajo existentes entre ellas (ver figura 40).

- **Enmallado**

Se selecciona con relevancia de 0, con el fin de lograr un punto de equilibrio con la solución (ver figura 41).

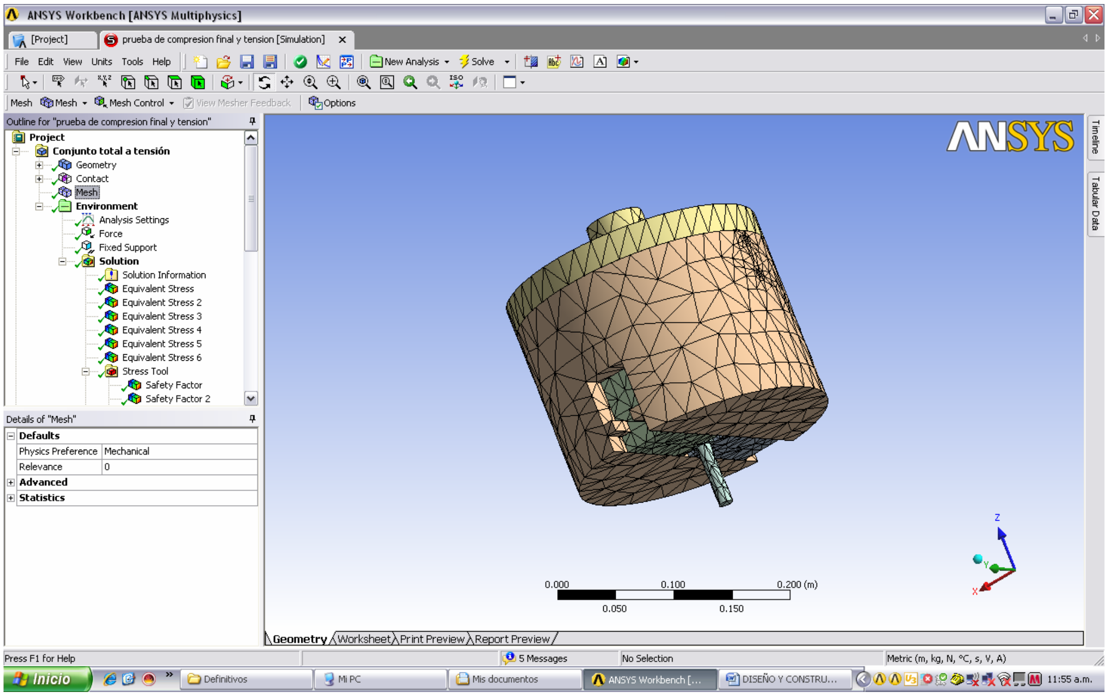
Figura 40. Tipos de contacto



Details of "seccion inferior.par:1 To tapa.par:1"

Scope	
Scoping Method	Geometry Selection
Contact	2 Faces
Target	2 Faces
Contact Bodies	seccion inferior.par:1
Target Bodies	tapa.par:1
Definition	
Type	No Separation
Scope Mode	Automatic
Behavior	Symmetric
Suppressed	No
Advanced	
Formulation	Pure Penalty
Normal Stiffness	Program Controlled

Figura 41. Enmallado



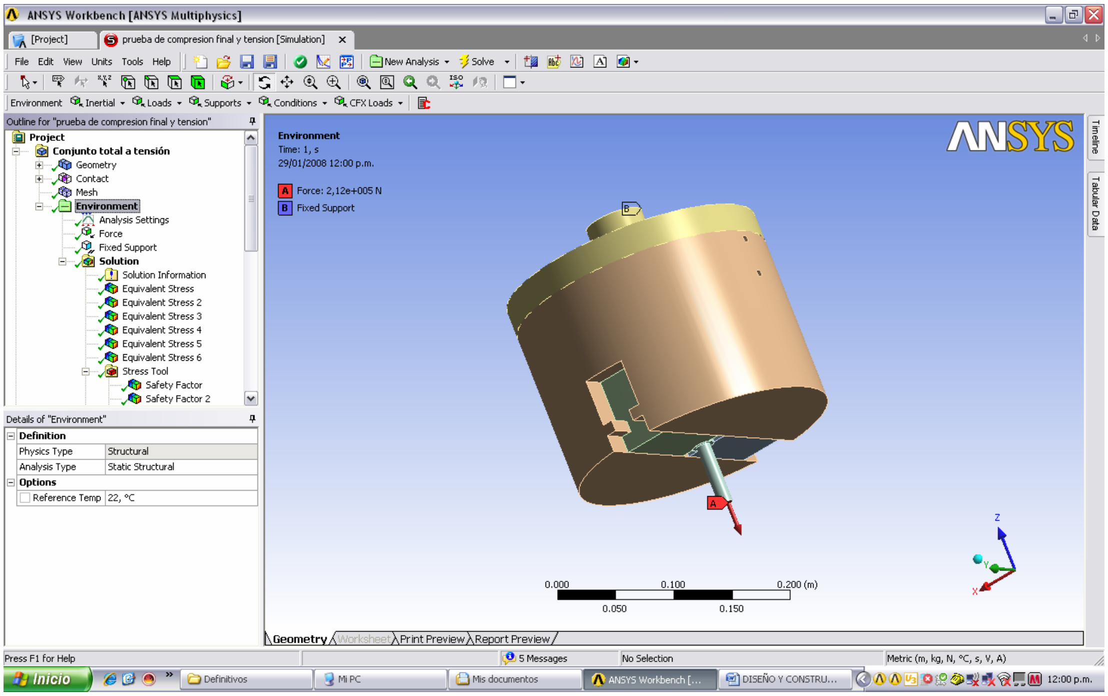
Details of "Mesh"

Defaults	
Physics Preference	Mechanical
Relevance	0
Advanced	
Statistics	

- ## Enviroment

Entorno en el cual se establecen las condiciones en que opera el conjunto (ver figura 42). Para ello se define un soporte fijo representado sobre la tapa, haciendo similitud con el marco de la máquina; la fuerza de diseño aplicada es basada en la resistencia última (acero 4340) del material de las probetas a ensayar teniendo en cuenta las dimensiones dadas en la norma ASTM E 8.

Figura 42. Enviroment tensión



Details of "Environment"

Definition	
Physics Type	Structural
Analysis Type	Static Structural
Options	
☐ Reference Temp	22, °C

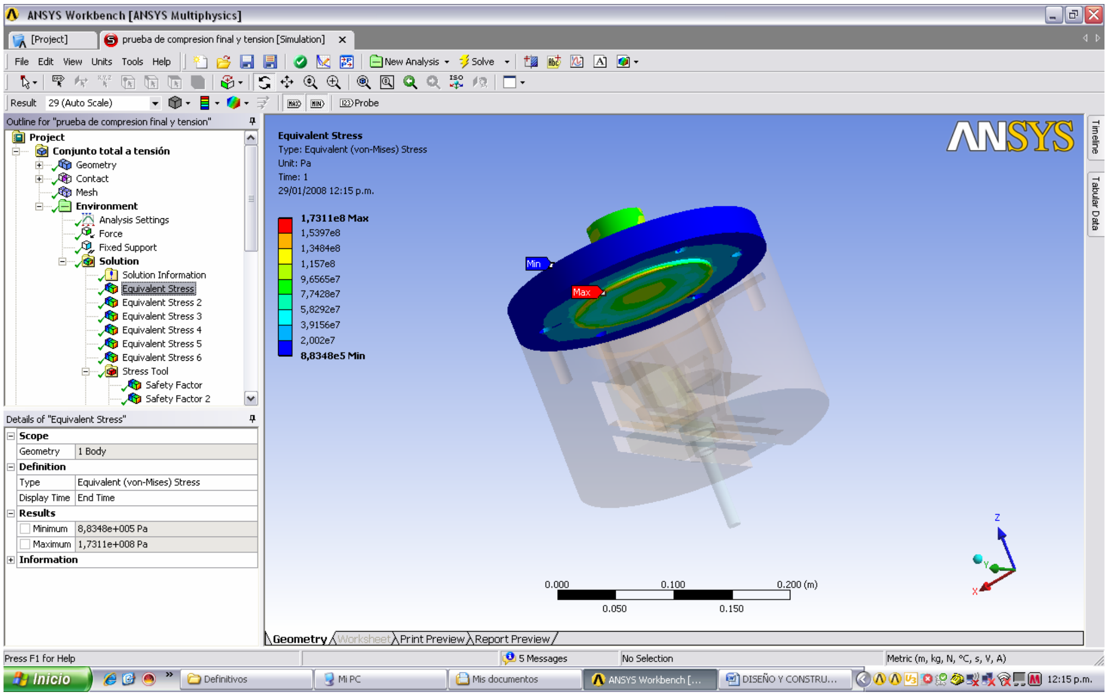
Environment
Time: 1, s
29/01/2008 12:00 p.m.

A Force: 2,12e+005 N
B Fixed Support

- ## Esfuerzos resultantes

La imagen muestra en gama de colores los esfuerzos resultantes a que están sometidos cada uno de los elementos que componen el sistema diseñado resaltando igualmente los puntos en los cuales se presentan los valores máximo y mínimo (ver figuras 43, 44, 45, 46).

Figura 43. Esfuerzos en la tapa



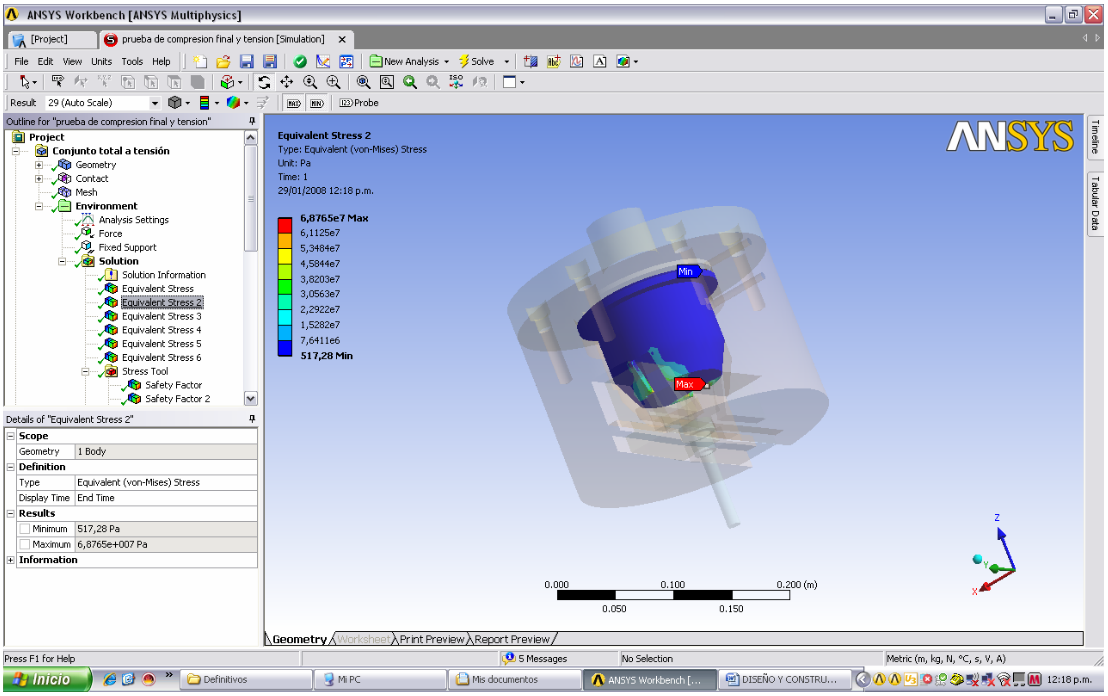
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: Pa
Time: 1
29/01/2008 12:15 p.m.

Details of "Equivalent Stress"

Scope
Geometry: 1 Body
Definition
Type: Equivalent (von-Mises) Stress
Display Time: End Time
Results
Minimum: 8,8348e+005 Pa
Maximum: 1,7311e+008 Pa
Information

Press F1 for Help
5 Messages
No Selection
Metric (m, kg, N, °C, s, V, A)

Figura 44. Esfuerzos en la placa móvil



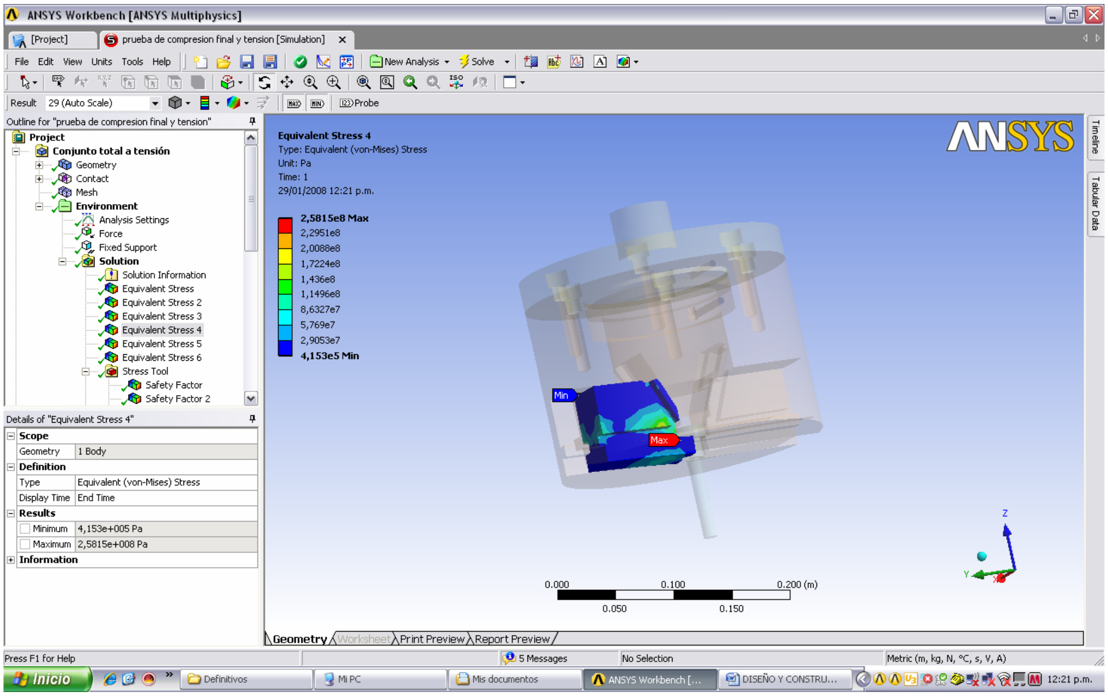
Equivalent Stress 2
Type: Equivalent (von-Mises) Stress
Unit: Pa
Time: 1
29/01/2008 12:18 p.m.

Details of "Equivalent Stress 2"

Scope
Geometry: 1 Body
Definition
Type: Equivalent (von-Mises) Stress
Display Time: End Time
Results
Minimum: 517,28 Pa
Maximum: 6,8765e+007 Pa
Information

Press F1 for Help
5 Messages
No Selection
Metric (m, kg, N, °C, s, V, A)

Figura 45. Esfuerzos en mordazas.

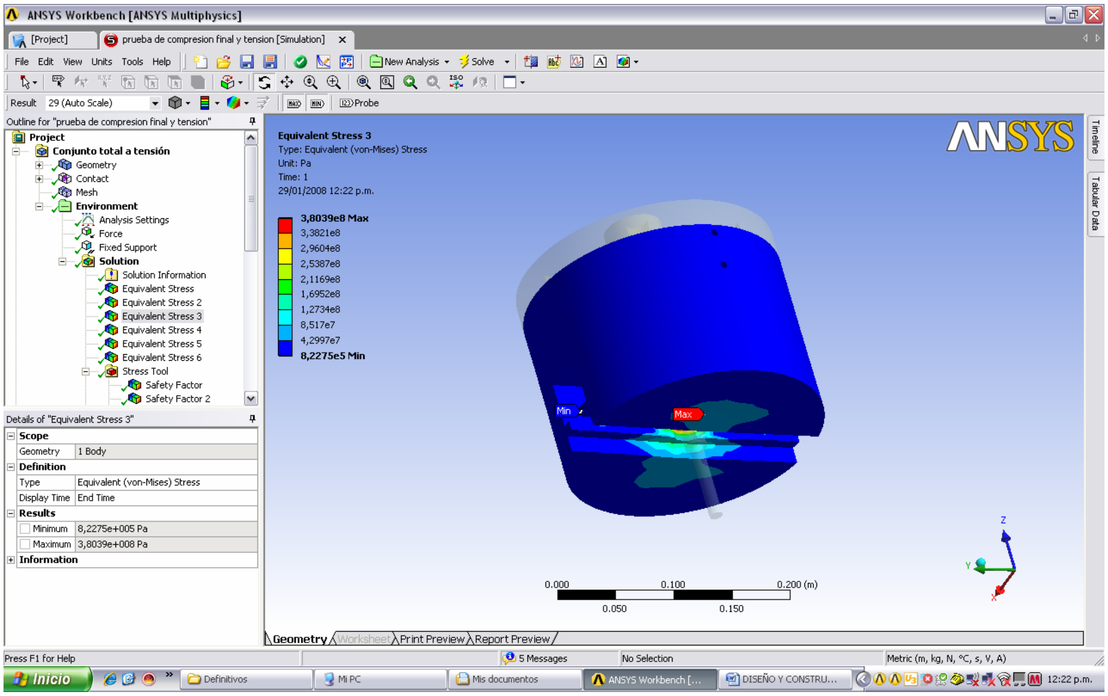


Equivalent Stress 4
Type: Equivalent (von-Mises) Stress
Unit: Pa
Time: 1
29/01/2008 12:21 p.m.

Details of "Equivalent Stress 4"

Scope	
Geometry	1 Body
Definition	
Type	Equivalent (von-Mises) Stress
Display Time	End Time
Results	
Minimum	4,153e+005 Pa
Maximum	2,5815e+008 Pa
Information	

Figura 46. Esfuerzos en sección inferior



Equivalent Stress 3
Type: Equivalent (von-Mises) Stress
Unit: Pa
Time: 1
29/01/2008 12:22 p.m.

Details of "Equivalent Stress 3"

Scope	
Geometry	1 Body
Definition	
Type	Equivalent (von-Mises) Stress
Display Time	End Time
Results	
Minimum	8,2275e+005 Pa
Maximum	3,8039e+008 Pa
Information	

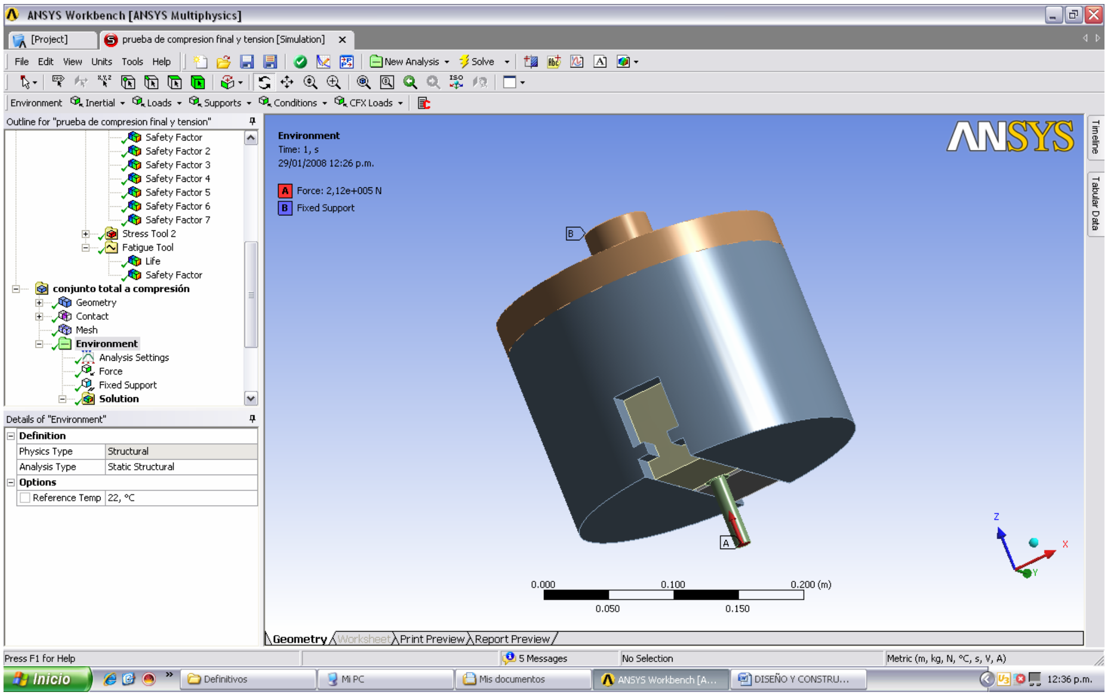
4.5.2 Prueba a compresión. Para realizar el modelo de esta prueba se ha tomado como base la posición donde se debe estar sujetando la probeta, en esta posición el elemento que soporta directamente los esfuerzos generados por la probeta es la sección inferior.

Para efectos de la simulación los puntos mencionados anteriormente en tensión como geometría, tipos de contacto y enmallado, permanecen iguales.

- **Enviroment**

  La fuerza de diseño es igual a la colocada en la prueba a tensión, solo que con sentido contrario; el apoyo sigue siendo el mismo (ver figura 47).

Figura 47. Enviroment compresión



Environment
Time: 1, s
29/01/2008 12:26 p.m.

A Force: 2,12e+005 N
B Fixed Support

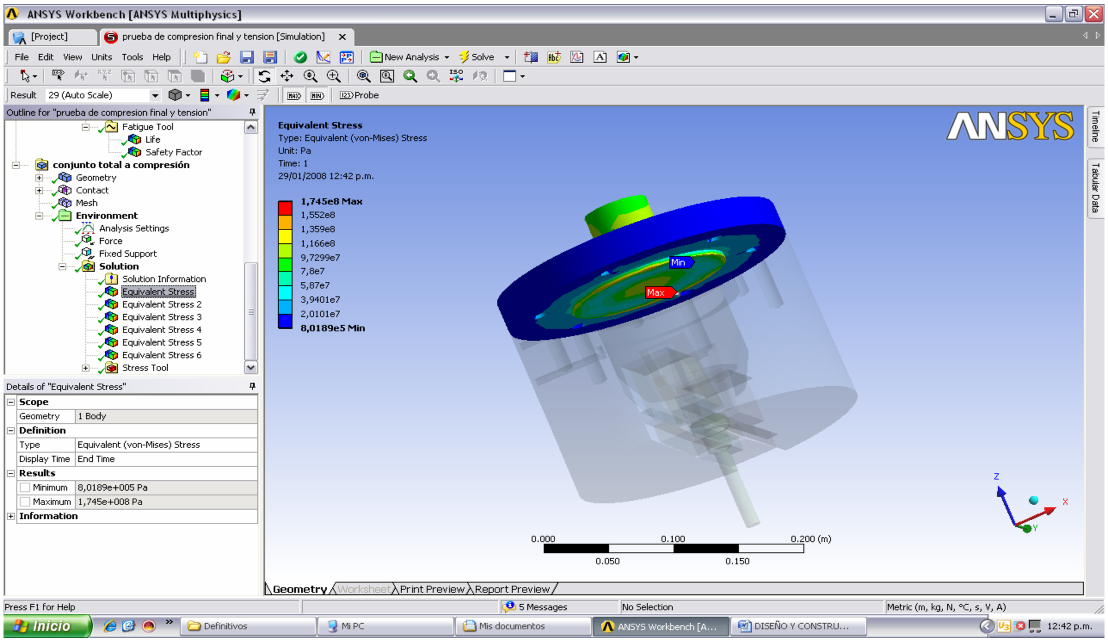
Details of "Environment"

Definition	
Physics Type	Structural
Analysis Type	Static Structural
Options	
Reference Temp	22, °C

- **Esfuerzos resultantes**

  Debido a que el contacto de la probeta es directamente sobre la sección inferior, se ha decidido mostrar en detalle la antes mencionada junto con la tapa, puesto que hay transmisión de fuerzas solo entre ellas (ver figuras 48, 49).

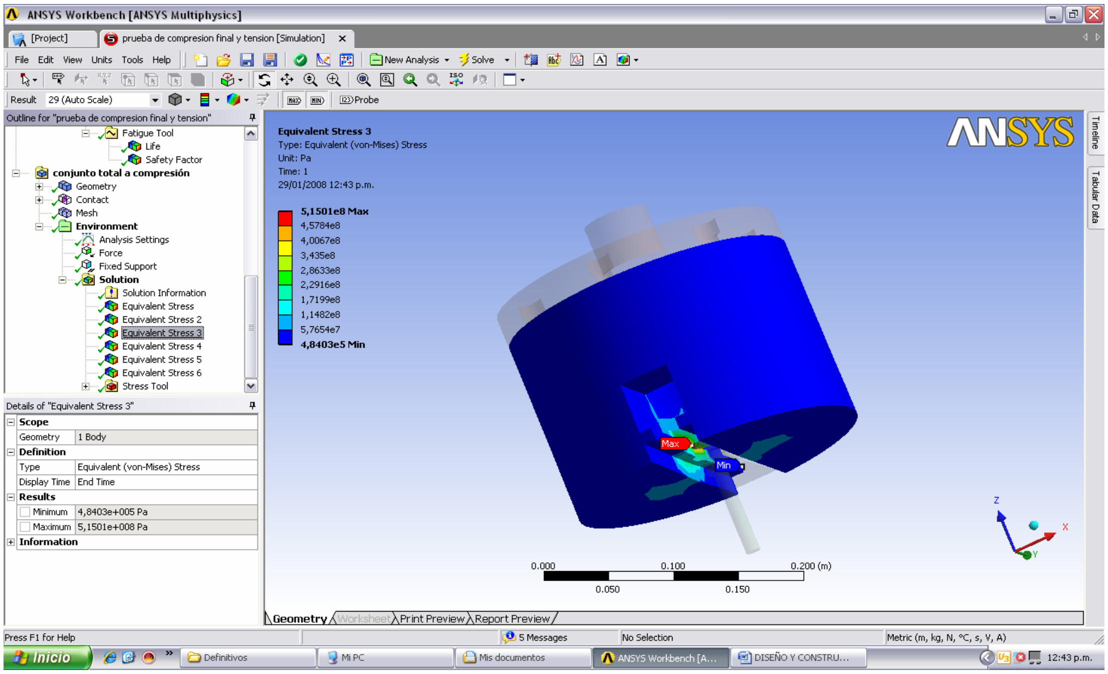
Figura 48. Esfuerzos en la tapa



Details of "Equivalent Stress"

Scope	
Geometry	1 Body
Definition	
Type	Equivalent (von-Mises) Stress
Display Time	End Time
Results	
Minimum	8,0189e+005 Pa
Maximum	1,745e+008 Pa
Information	

Figura 49. Esfuerzos en sección inferior



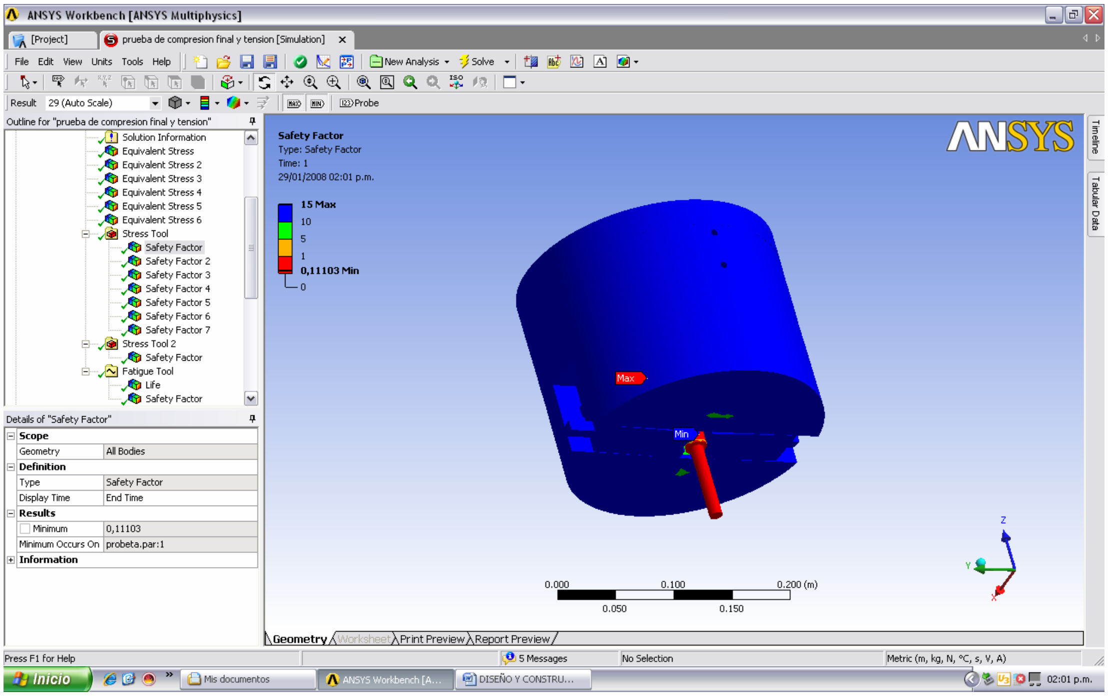
Details of "Equivalent Stress 3"

Scope	
Geometry	1 Body
Definition	
Type	Equivalent (von-Mises) Stress
Display Time	End Time
Results	
Minimum	4,8403e+005 Pa
Maximum	5,1501e+008 Pa
Information	

4.6 RESULTADO DE LA SIMULACION

4.6.1 Tensión. Luego de realizado el análisis se evidencia que la probeta falla primero. Presentando un factor de seguridad de 0,11103; el resto de componentes se comportan de manera satisfactoria (ver figura 50).

Figura 50. Factor de seguridad a tensión



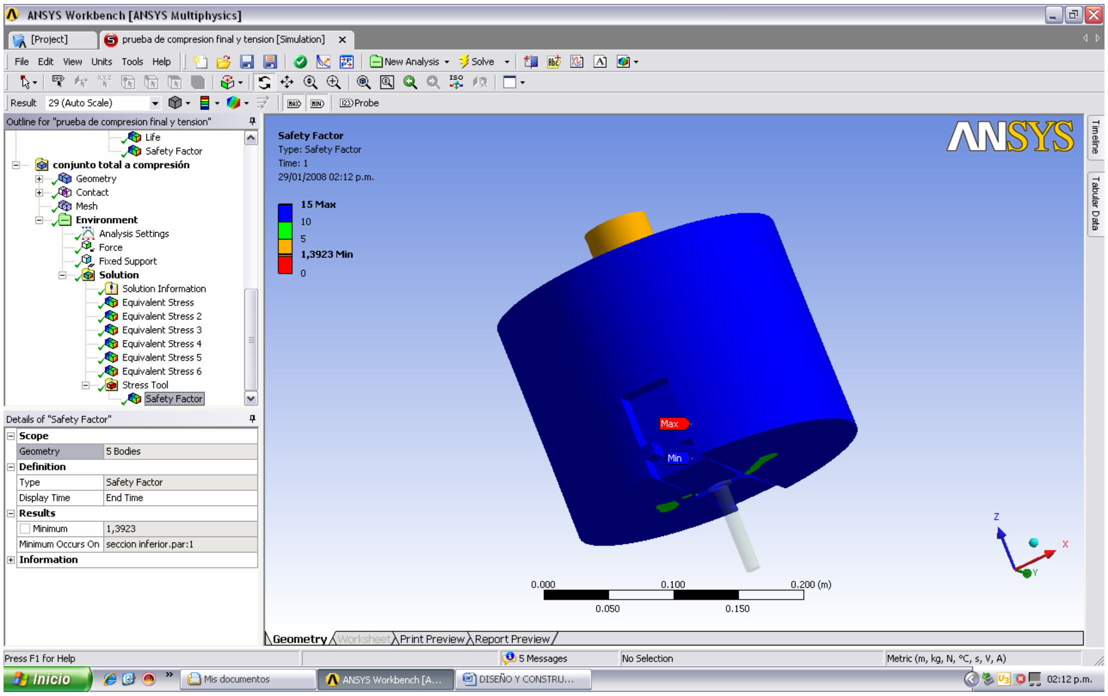
Details of "Safety Factor"

Scope	
Geometry	All Bodies
Definition	
Type	Safety Factor
Display Time	End Time
Results	
☐ Minimum	0,11103
Minimum Occurs On	probeta.par:1
Information	

Safety Factor
Type: Safety Factor
Time: 1
29/01/2008 02:01 p.m.

4.6.2 Compresión. En el comportamiento a compresión se evidencia que la rotura de la probeta ocurre primero, antes de que cualquier otra parte del conjunto falle (ver figura 51).

Figura 51. Factor de seguridad a compresión



Safety Factor
Type: Safety Factor
Time: 1
29/01/2008 02:12 p.m.

Scope	
Geometry	5 Bodies
Definition	
Type	Safety Factor
Display Time	End Time
Results	
Minimum	1,3923
Minimum Occurs On	seccion inferior.par:1
Information	

Para efectos de cualquier otro análisis, referirse a Anexo 3 Reporte Ansys.

5. CIRCUITO ELECTROHIDRAULICO DEL SISTEMA DE MORDAZAS DISEÑADO

El circuito hidráulico del sistema diseñado se alimenta de la línea de presión piloto del manifold de control la cual maneja un rango de presiones de 750 psi a 900 psi cuando la presión máxima del sistema está dentro de un rango de 1600 a 2000 psi respectivamente (ver figura 16**)**.

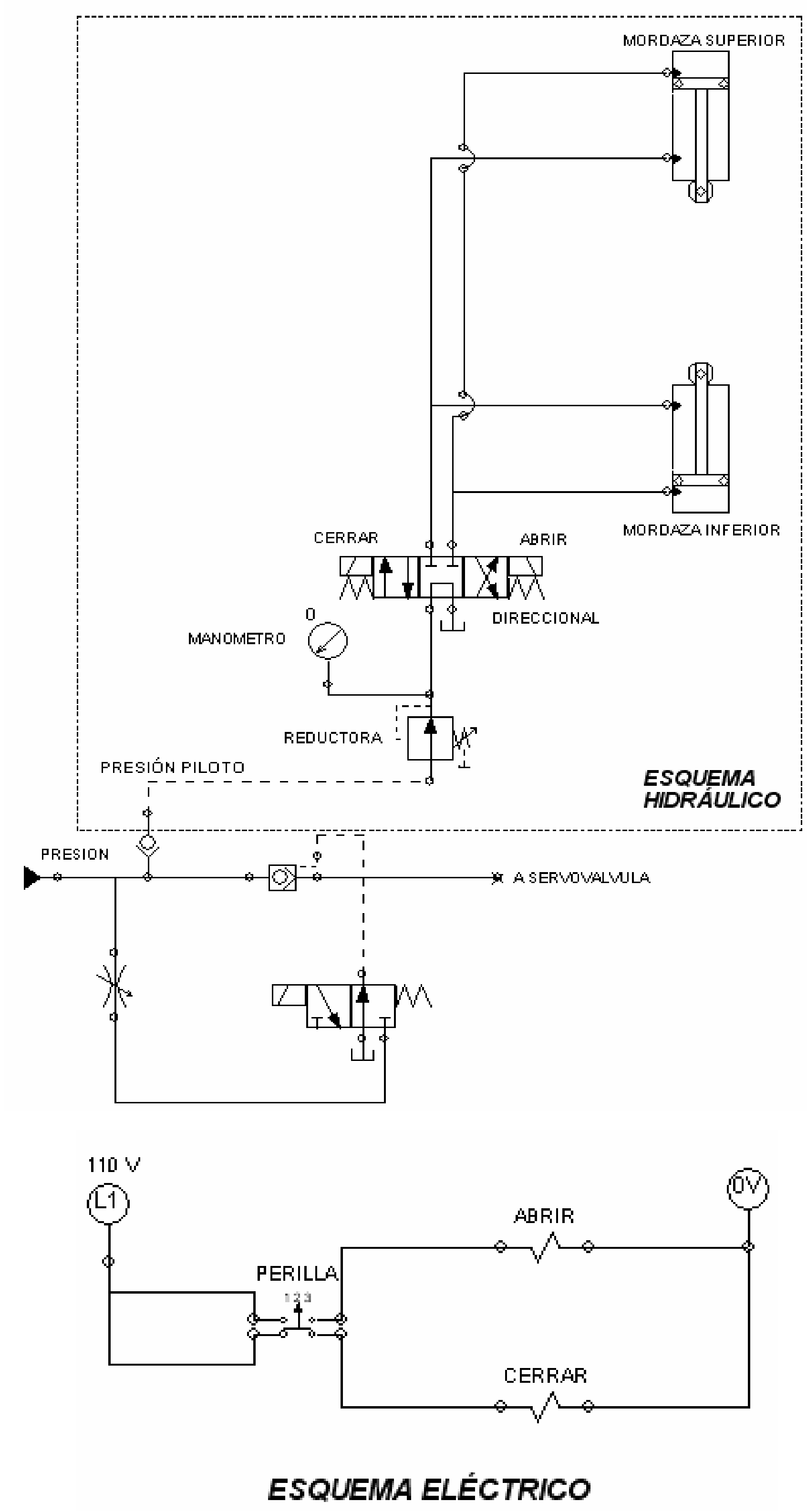
Consta de una válvula reductora de presión que proporciona una presión acorde a la necesidad del diseño (500 psi), una válvula direccional 4/3 centro tándem accionada por solenoides a 110 Voltios; los cuales se energizan por medio de una perilla de 3 posiciones con dos contactos normalmente abiertos; para dirigir el fluido al conjunto de mordazas diseñado (representado por los cilindros en este esquema) los cuales se encuentran conectados entre sí por medio mangueras R1 (ver figura 52).

Para la alimentación a partir del puerto de presión piloto del manifold se uso una "T" de ¼ rosca NPT conectada al manifold por medio de un adaptador de ¼ a 9/16. De las dos salidas restantes una va conectada a la válvula reductora y da la otra sale una manguera hacia la servo válvula de la prensa.

El drenaje de la válvula reductora y el puerto de tanque de la válvula direccional se conectan al drenaje del manifold principal.

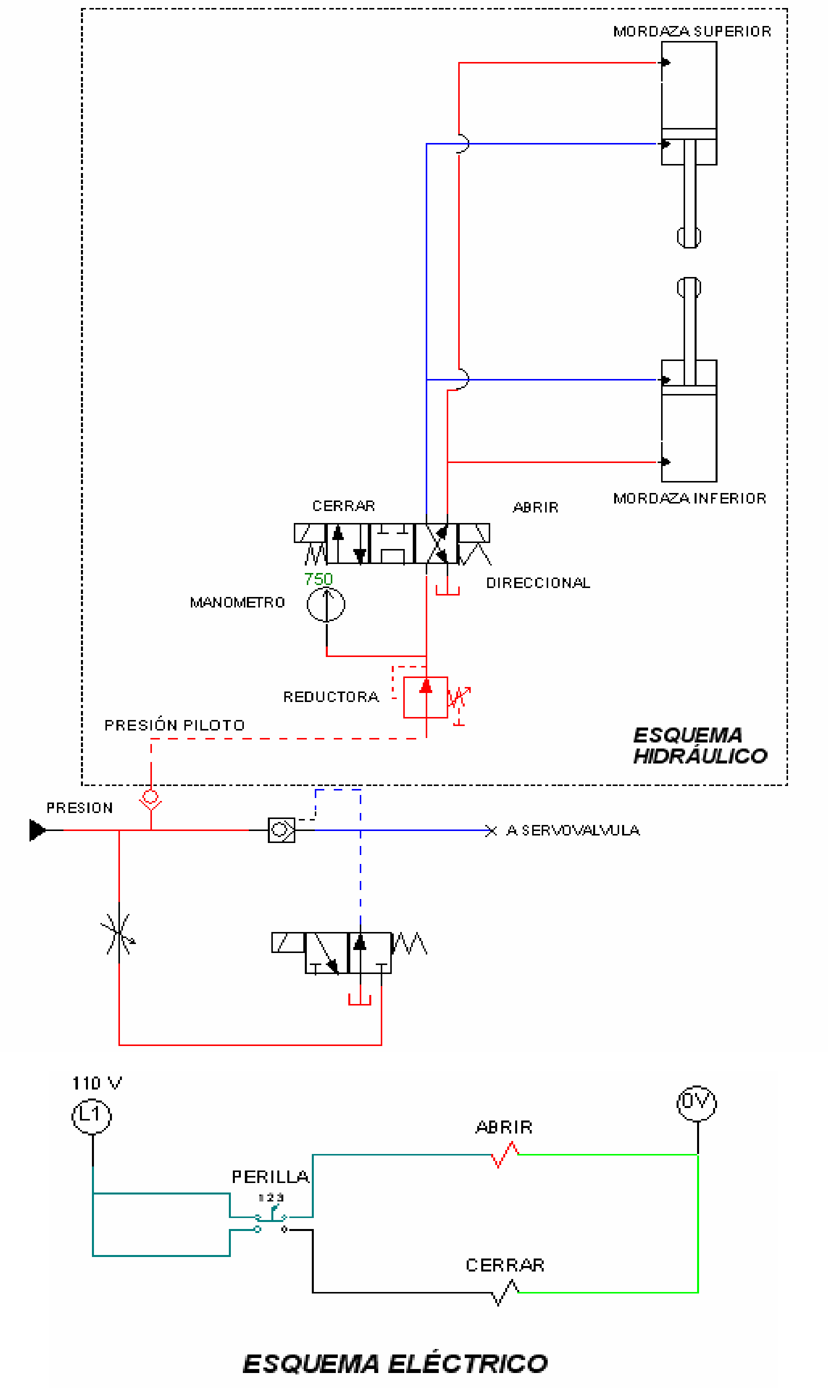
Los puertos A y B de la válvula direccional se conectan a los puertos de entrada y salida de cada una de las mordazas.

Figura 52. Esquema hidráulico



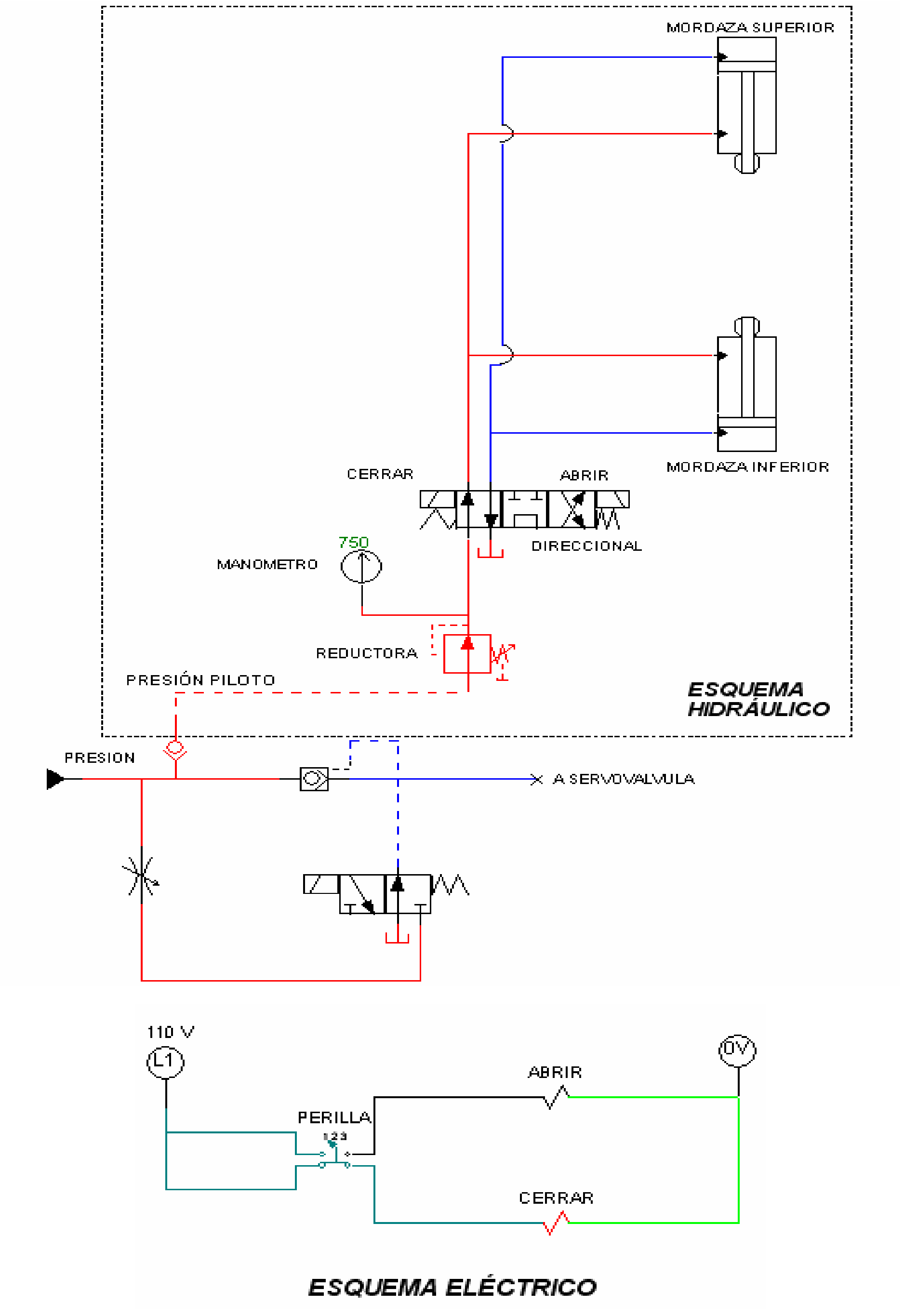
Para la apertura del sistema de mordazas se gira la perilla de control a la posición 3 (ver figura 53).

Figura 53. Esquema hidráulico de apertura de mordazas



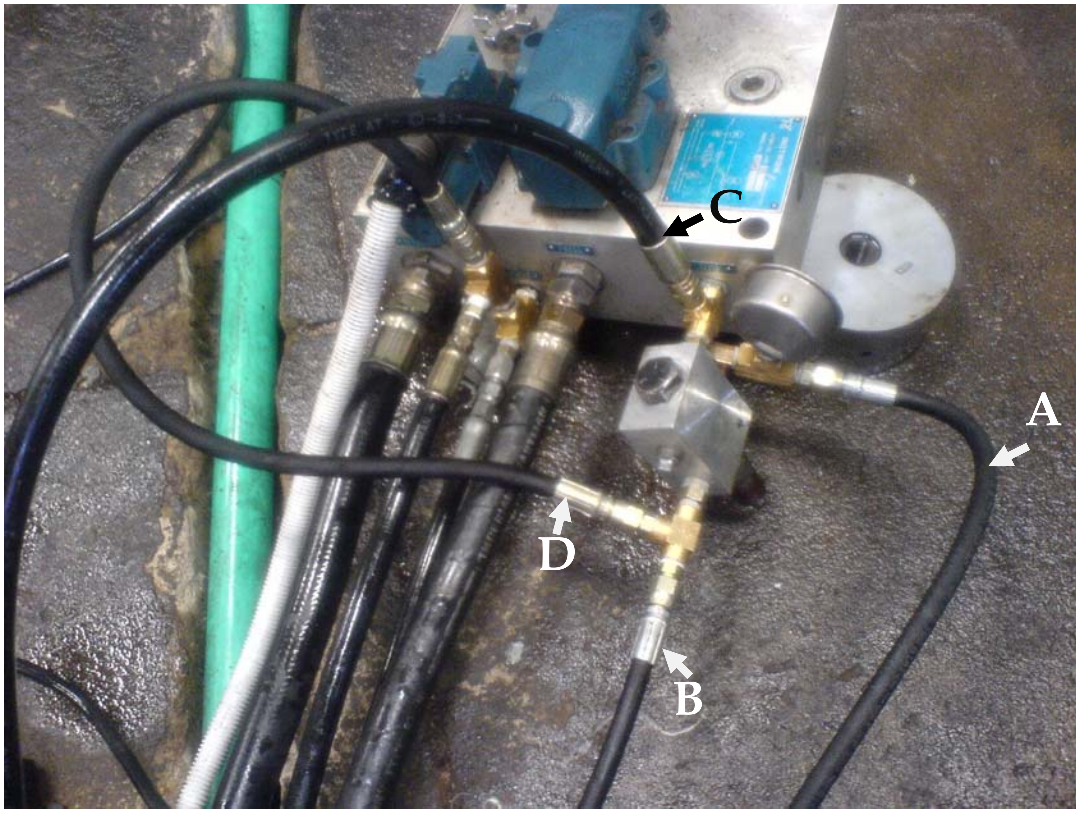
Para el cierre del sistema de mordazas se gira la perilla de control a la posición 1 (ver figura 54).

Figura 54. Esquema hidráulico de cierre de mordazas



A continuación se muestra el montaje de las conexiones hidráulicas y eléctricas para el funcionamiento del sistema de mordazas diseñado (ver figuras 55, 56, 57 y 58).

Figura 55. Conexión de válvula reductora a manifold



A: Manguera de presión para válvula direccional

B: Manguera de tanque de la válvula direccional

C: Manguera de presión piloto a servo válvula

D: Drenaje de válvula reductora a manifold

Figura 56. Conexión de electro válvula direccional

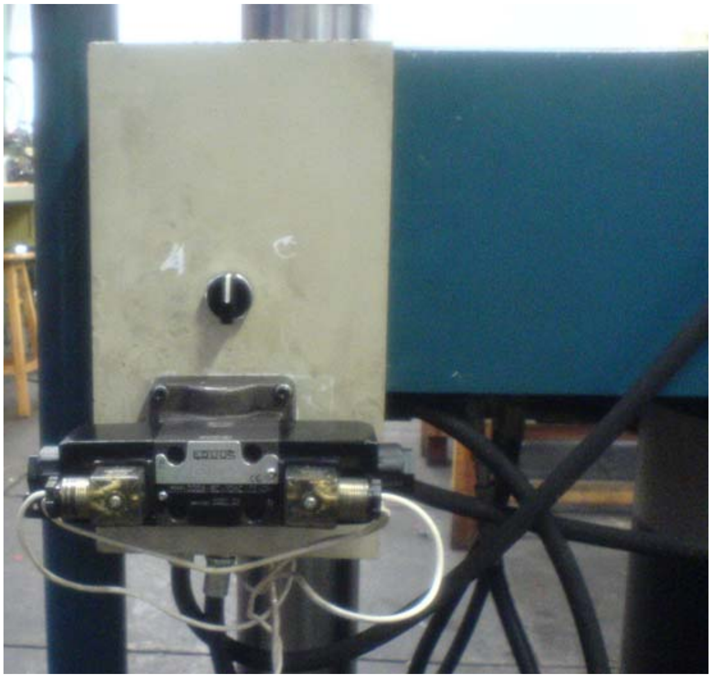


Figura 57. Conexión de válvula direccional a sistemas de mordazas

Figura 58. Conexión a puertos de mordazas

6. MANTENIMIENTO Y MONTAJE

El mantenimiento requerido por el sistema diseñado consta de principios básicos que hacen de su ejecución un procedimiento fácil de llevar a cabo. Debido a que los únicos elementos que sufren un deterioro considerable son los sellos ubicados en la placa móvil y la tapa, se requiere una revisión periódica de los mismos en intervalos semestrales, considerando su reemplazo dependiendo del desgaste sufrido por cada uno de ellos el cual se evidencia con fugas o deformación.

Se debe considerar adicionalmente el desgaste sufrido por las piezas en contacto directo metal-metal (guías de las mordazas) para lo cual se recomienda el uso periódico de grasa que facilite su deslizamiento.

Cabe resaltar el chequeo constante del estado de las mangueras, puntos de acople y válvulas para detectar posibles fugas de aceite hidráulico.

El montaje de las piezas que componen el sistema diseñado consta de los siguientes pasos:

- Deslice las mordazas sobre las guías de la sección inferior hasta que hagan contacto.
- Verifique visualmente por la cara superior de la sección inferior que las guías inclinadas de las mordazas se encuentren centradas.
- Introduzca la placa móvil; con sus respectivos sellos instalados; por la cara superior de la sección inferior rotándola si es necesario hasta que coincidan las guías inclinadas de las mordazas con las guías de la placa móvil.

- Presione hacia abajo la placa móvil de modo que las guías de las mordazas entren en las guías de la placa móvil hasta encontrar la restricción de la sección inferior; esto ocasionara un desplazamiento radial de las mordazas sobre la sección inferior.
- Ubique la tapa sobre la sección inferior con su sello previamente instalado y haga coincidir las perforaciones de los tornillos.
- Coloque los tornillos ajustándolos en cruz hasta lograr hermeticidad.
- Tome el conjunto e instálelo en el marco de la maquina de pruebas.
- Repita los pasos anteriores para ensamblar el siguiente conjunto.
- Luego de ubicar los conjuntos en la maquina, conecte las mangueras correspondientes al puerto 2.
- Con la maquina en funcionamiento y verificando las conexiones de las válvulas reductora y direccional, accione la válvula direccional de tal forma que el fluido se dirija al puerto 2 de cada conjunto.
- Conecte la manguera correspondiente al puerto 1 de cada conjunto.
- Accione la contraorden de la válvula direccional y verifique el correcto funcionamiento de los conjuntos (apertura y cierre de mordazas).

7. PRUEBAS

La realización de las pruebas se llevo a cabo teniendo en cuenta las disposiciones de la norma vigente y las condiciones de la maquina al momento del montaje, ya que esta no cuenta con la totalidad de los dispositivos que se requieren para tener un control preciso de la misma.

7.1 EVALUACIÓN DEL ESTADO ACTUAL DE LA MÁQUINA PARA EFECTOS DE LAS PRUEBAS

7.1.1 Control y lecturas. Para tener un optimo control de la maquina se requiere de dispositivos que evalúen constantemente y con precisión diferentes aspectos tales como posición del actuador, velocidad de avance del actuador, deformación de las probetas y esfuerzos.

Como sabemos la máquina cuenta con una consola de control de lecturas (ver figura 59) en la cual se encuentran montados los controladores que junto con los transductores controlan de forma precisa los aspectos mencionados anteriormente; desafortunadamente estos no están en capacidad de operación debido a que la tarjeta de control de posición de la consola se encuentra averiada motivo por el cual los demás dispositivos no funcionan correctamente.

7.1.2 Alineación de los ejes. Inicialmente se procedió a verificar la alineación de los ejes de los dos conjuntos encontrando que había un desfase de aproximadamente 5 mm. Al realizar un análisis más exhaustivo se encontró que la causa de este desfase es una deformación de la camisa del eje que sostiene al conjunto superior producida tiempo atrás por una manipulación inadecuada de la máquina.

Para corregir este problema se procedió a dar un ajuste diferente a los pernos que se encuentran ubicados en la parte superior de la viga del marco de carga logrando reducir este desfase a 1mm.

Figura 59. Consola de control

7.2 ELABORACIÓN DE PRUEBAS

Para los ensayos finales fue necesario coordinar las acciones entre 3 personas; entre las cuales se encuentra el profesor Abel Parada, Director del proyecto. Debido a que el movimiento del actuador se controla por medio de una perilla ubicada en la consola de control (por las razones expuestas en la sección anterior), se requería de alguien que posicionara la probeta mientras el actuador avanzaba, al tiempo que otra persona debía accionar en el momento preciso la electroválvula direccional que controla la apertura y cierre de las mordazas hidráulicas.

Como primera medida se procedió a mover el actuador de manera tal que se pudiera posicionar la probeta en medio de los dos conjuntos verticalmente, posteriormente se accionó la electroválvula hidráulica para abrir las mordazas y permitir la libre entrada de los extremos de la probeta en cada conjunto. En ese momento con la perilla se ponía el actuador de nuevo en movimiento tratando de detenerlo en el preciso instante en que los extremos de las probetas encajaban en los espacios correspondientes de cada conjunto para en ese mismo instante dar la orden de cerrado de las mordazas por medio de la electroválvula.

La dificultad de sincronizar todas estas acciones hizo que en varias ocasiones no se alcanzara a detener el avance del actuador sometiendo la probeta a esfuerzos de compresión y produciendo en ella la consecuente deformación (ver figura 60).

Figura 60. Probetas averiadas

Las probetas utilizadas fueron fabricadas de acuerdo a la tabla de dimensiones que se encuentra en la norma, utilizando solo las que se muestran en la tabla. Se realizaron pruebas con probetas de 6 mm, 9mm y 12.5 mm de diámetro según Norma ASTM E8 (ver figuras 61, 62 y tabla 10), sección 3.

Figura 61. Probetas utilizadas para pruebas

Figura 62. Probetas recomendadas

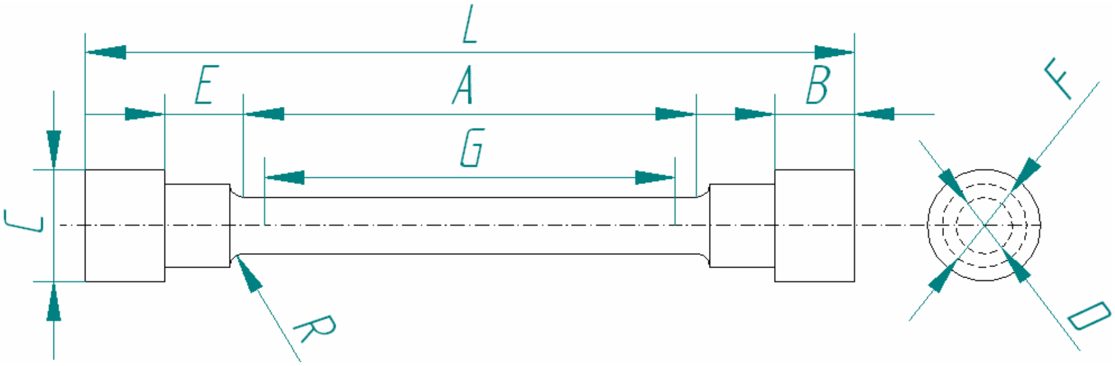


Tabla 10. Dimensiones de probetas a utilizar

Dimensions, mm					
	Standard Specimen	**Small-Size Specimen Proporcional to Standard**			
	12.5	**9**	**6**	**4**	**2.5**
G- gage length	62,5 ± 0,1	45 ± 0,1	30 ± 0,1	20 ± 0,1	12,5 ± 0,1
D- diameter	12,5 ± 0,2	9±0,1	6±0,1	4±0,1	2,5±0,1
R- radius of fillet, min	10	8	6	4	2
A- length of reduced section	75	54	35	24	20
L- overall length, aprox.	150	150	150	150	150
B- length of end section	10	10	10	10	10
C- diameter of end section	22,5	22,5	22,5	22,5	22,5
E- length of shoulder and fillet section, approx.	30	30	30	30	30
F- diameter of shoulder	20	20	20	20	20

Para poder observar el comportamiento de las mordazas se realizaron pruebas con 3 tipos de probetas de diferente sección escogiendo para ello diámetros de 6mm, 9mm y 12.5mm (ver tabla 11).

Tabla 11. Tabla de pruebas

PRUEBA N°	**DIAMETRO(mm)**	**ROTURA**	
		OK	**NO OK**
1	**6**	♦	
2	**6**	♦	
3	**6**		♦
4	**6**		♦
5	**6**	♦	
6	**9**		♦
7	**9**		♦
8	**9**		♦
9	**9**		♦

10	**9**		♦
11	**12.5**		♦
12	**12.5**		♦
13	**12.5**		♦
14	**12.5**		♦
15	**12.5**		♦

- **Análisis de pruebas 1 a 5(6 mm).** Se efectuaron 5 pruebas de las cuales 3 probetas presentaron falla satisfactoria con las características propias de fractura por esfuerzos de tensión (ver figuras 63 y 64), las 2 probetas restantes presentan la avería típica por falta de coordinación entre las ordenes mostrada en la figura 60. Se observo un correcto funcionamiento del sistema de mordazas realizando un agarre adecuado sin presencia de fugas de aceite hidráulico en ninguna de las conexiones realizadas.

Figura 63. Prueba con probeta 6 mm

Figura 64. Rotura de probeta 6 mm

- **Análisis de pruebas 10 a 16(9 mm).** Se efectuaron 5 pruebas de las cuales presentan la avería típica por falta de coordinación entre las ordenes mostrada en la figura 60. Se observa un incorrecto funcionamiento del sistema de mordazas realizando un agarre inadecuado, puesto que no se aloja la cabeza de la probeta perfectamente en la sección inferior, en la prueba ahí ausencia de fugas de aceite hidráulico en las conexiones realizadas.

Figura 65. Prueba con probeta 9 mm

Figura 66. Falla de probeta 9 mm

- **Análisis de pruebas 11 a 15(12.5 mm).** Se efectuaron 5 pruebas de las cuales ninguna presentaron falla satisfactoria debido a que sufre un desgarramiento de material en la cabeza de la probeta (ver figuras 67). Esto debido a que por la robustez de su geometría no permite el pequeño pandeo generado por el desalineamiento, que si aceptaron las dos geometrías anteriores; este desalineamiento impide un correcto agarre del cuello de la probeta puesto que a medida que se cierran las mordazas la probeta se inclina.

Figura 67. Prueba con probeta de 12.5 mm

8. CONCLUSIONES Y RECOMENDACIONES

- Se logra construir un conjunto de mordazas, reemplazando el tradicional de pernos por uno hidráulico como se propuso (ver figura 66).

Figura 68. Conjunto de mordazas

- La vida útil de la sección inferior está limitada a un número de ciclos o pruebas a realizar cuyo valor corresponde a 12752 según los resultados del análisis realizado en ANSYS.

- La presión de diseño para la apertura y cierre de las mordazas es de 750 psi la cual se obtiene por medio de una válvula reductora ubicada en la salida de presión piloto del manifold principal, sin embargo un análisis posterior demostró que el sistema de mordazas funciona de la misma forma si se trabaja con la totalidad de la presión piloto por lo cual se obvio el uso de la válvula reductora.

- La prueba de compresión se efectúa con probetas cuya relación L/d = 3, siendo el diámetro mayor de 22 mm, teniendo cuidado de alojar perfectamente la probeta en la sección inferior para evitar resultados erróneos.

- El montaje de cada uno de los conjuntos se realiza de acuerdo a los lineamientos mencionados en el capitulo de mantenimiento y montaje, cabe resaltar que el ensamble de la placa móvil se debe realizar con los tornillos extractores que se enroscan en los orificios que se encuentran en la parte superior de la misma.

- La apertura y cierre de las mordazas dependen única y exclusivamente de las órdenes dadas a la válvula.

- No se deben usar probetas que excedan el límite de fluencia del material de las mordazas (Acero AISI SAE 4340), utilizando las tres dimensiones menores para probetas de acuerdo a la norma ASTM sección 3.

- Se debe verificar siempre que los pernos de unión de tapa y sección inferior, sean 6 para evitar posibles fugas de aceite hidráulico por cada uno de ellos.

- Se debe verificar después de cada montaje la no existencia de fugas de aceite hidráulico, para garantizar el buen funcionamiento de los conjuntos.

- Se deben llevar registros de pruebas realizadas con el fin de no exceder el número máximo de ciclos permitidos para el elemento crítico sección inferior.

- Asegúrese que las conexiones de las mangueras estén a los mismos puertos de cada conjunto.

- Se debe de garantizar la linealidad de los dos conjuntos para evitar posibles aplastamientos de la sección inferior.

- Se recomienda el montaje de válvulas reguladoras de caudal a la salida de los puertos A y B de la electro válvula, esto con el fin de poder controlar la velocidad de apertura y cierre de las mordazas.

- Por seguridad se recomienda conectar a la salida de los puerto A y B de la electro válvula, anti retornos pilotados para evitar la apertura de mordazas.

- Se recomienda alinear la estructura de la máquina, esto para garantizar la exactitud de la prueba (ver anexo E).

- Se recomienda realizar un cambio en el diámetro de alojamiento, pasando de 22 mm actual, a 25 mm de diámetro (ver figuras 69 y 70), con el fin de poder sostener la probeta de manera adecuada.

Figura 69. Diámetro actual alojamiento de probeta en sección inferior

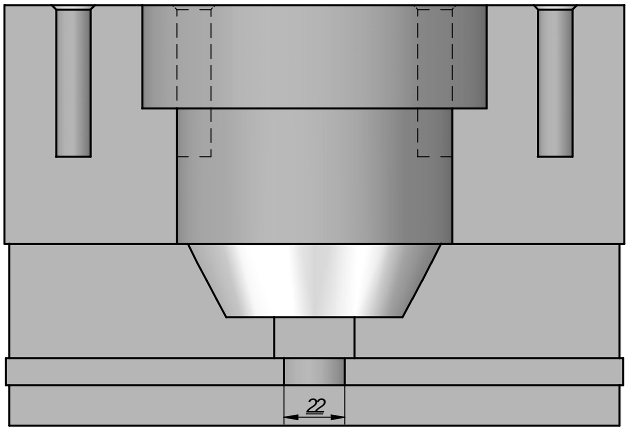
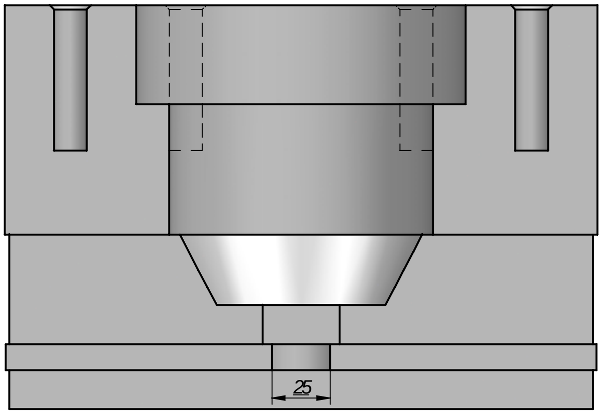


Figura70. Diámetro recomendado alojamiento de probeta en sección inferior



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Section 3: Standard Test Methods for Tension Testing of Metallic Materials, 2004

Disponible en Internet: www.matweb.com/ search/ SpecificMaterial.asp?bassnum

ANEXO A. Norma ASTM E8 Pruebas a tensión

Designation: E 8M – 04

METRIC

Standard Test Methods for Tension Testing of Metallic Materials [Metric][1]

This standard is issued under the fixed designation E 8M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 These test methods cover the tension testing of metallic materials in any form at room temperature, specifically, the methods of determination of yield strength, yield point elongation, tensile strength, elongation, and reduction of area.

NOTE 1—These test methods are the metric companion of Test Methods E 8. Committee E-28 was granted an exception in 1997 by the Committee on Standards to maintain E8 and E8M as separate companion standards rather than combining standards as recommended by the Form and Style manual.

NOTE 2—These metric test methods are essentially the same as those in Test Methods E 8, and are compatible in technical content except that gage lengths are required to be 5D for most round specimens rather than 4D as specified in Test Methods E 8. Test specimens made from powder metallurgy (P/M) materials are exempt from this requirement by industry-wide agreement to keep the pressing of the material to a specific projected area and density.

NOTE 3—Exceptions to the provisions of these test methods may need to be made in individual specifications or test methods for a particular material. For examples, see Test Methods and Definitions A 370 and Test Methods B 557M.

NOTE 4—Room temperature shall be considered to be 10 to 38°C unless otherwise specified.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:* [2]

A 356/A356M Specification for Steel Castings, Carbon, Low Alloy, and Stainless Steel, Heavy-Walled for Steam Turbines
A 370 Test Methods and Definitions for Mechanical Testing of Steel Products
B 557M Test Methods of Tension Testing Wrought and Cast Aluminum- and Magnesium-Alloy Products [Metric]
E 4 Practices for Force Verification of Testing Machines
E 6 Terminology Relating to Methods of Mechanical Testing
E 8 Test Methods for Tension Testing of Metallic Materials
E 29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
E 83 Practice for Verification and Classification of Extensometers
E 345 Test Methods of Tension Testing of Metallic Foil
E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method
E 1012 Practice for Verification of Specimen Alignment Under Tensile Loading

3. Terminology

3.1 *Definitions*—The definitions of terms relating to tension testing appearing in Terminology E 6 shall be considered as applying to the terms used in these test methods of tension testing. Additional terms being defined are as follows:

3.1.1 *discontinuous yielding*—in a uniaxial test, a hesitation or fluctuation of force observed at the onset of plastic deformation, due to localized yielding. (The stress-strain curve need not appear to be discontinuous.)

3.1.2 *lower yield strength, LYS* $[FL^{-2}]$—in a uniaxial test, the minimum stress recorded during discontinuous yielding, ignoring transient effects.

3.1.3 *upper yield strength, UYS* $[FL^{-2}]$—in a uniaxial test, the first stress maximum (stress at first zero slope) associated with discontinuous yielding.

3.1.4 *yield point elongation, YPE*—in a uniaxial test, the strain (expressed in percent) separating the stress-strain curve's first point of zero slope from the point of transition from

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[1] These test methods are under the jurisdiction of ASTM Committee E28 on Mechanical Testing and are the direct responsibility of Subcommittee E28.04 on Uniaxial Testing.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

***A Summary of Changes section appears at the end of this standard.**

discontinuous yielding to uniform strain hardening. If the transition occurs over a range of strain, the YPE end point is the intersection between (*a*) a horizontal line drawn tangent to the curve at the last zero slope and (*b*) a line drawn tangent to the strain hardening portion of the stress-strain curve at the point of inflection. If there is no point at or near the onset of yielding at which the slope reaches zero, the material has 0 % YPE.

3.1.5 *uniform elongation, El_u*, [%]—the elongation determined at the maximum force sustained by the test piece just prior to necking or fracture, or both.

3.1.5.1 *Discussion*—Uniform elongation includes both elastic and plastic elongation.

4. Significance and Use

4.1 Tension tests provide information on the strength and ductility of materials under uniaxial tensile stresses. This information may be useful in comparisons of materials, alloy development, quality control, and design under certain circumstances.

4.2 The results of tension tests of specimens machined to standardized dimensions from selected portions of a part or material may not totally represent the strength and ductility properties of the entire end product or its in-service behavior in different environments.

4.3 These test methods are considered satisfactory for acceptance testing of commercial shipments. The test methods have been used extensively in the trade for this purpose.

5. Apparatus

5.1 *Testing Machines*—Machines used for tension testing shall conform to the requirements of Practices E 4. The forces used in determining tensile strength and yield strength shall be within the verified force application range of the testing machine as defined in Practices E 4.

5.2 *Gripping Devices*:

5.2.1 *General*—Various types of gripping devices may be used to transmit the measured force applied by the testing machine to the test specimens. To ensure axial tensile stress within the gage length, the axis of the test specimen should coincide with the center line of the heads of the testing machine. Any departure from this requirement may introduce bending stresses that are not included in the usual stress computation (force divided by cross-sectional area).

NOTE 5—The effect of this eccentric force application may be illustrated by calculating the bending moment and stress thus added. For a standard 12.5-mm diameter specimen, the stress increase is 1.5 % for each 0.025 mm of eccentricity. This error increases to about 2.5 %/0.025 mm for a 9-mm diameter specimen and to about 3.2 %/0.025 mm for a 6-mm diameter specimen.

NOTE 6—Alignment methods are given in Practice E 1012.

5.2.2 *Wedge Grips*—Testing machines usually are equipped with wedge grips. These wedge grips generally furnish a satisfactory means of gripping long specimens of ductile metal and flat plate test specimens such as those shown in Fig. 1. If, however, for any reason, one grip of a pair advances farther than the other as the grips tighten, an undesirable bending stress may be introduced. When liners are used behind the wedges, they must be of the same thickness and their faces must be flat and parallel. For best results, the wedges should be supported over their entire lengths by the heads of the testing machine. This requires that liners of several thicknesses be available to cover the range of specimen thickness. For proper gripping, it is desirable that the entire length of the serrated face of each wedge be in contact with the specimen. Proper alignment of wedge grips and liners is illustrated in Fig. 2. For short specimens and for specimens of many materials, it is generally necessary to use machined test specimens and to use a special means of gripping to ensure that the specimens, when under load, shall be as nearly as possible in uniformly distributed pure axial tension (see 5.2.3, 5.2.4, and 5.2.5).

5.2.3 *Grips for Threaded and Shouldered Specimens and Brittle Materials*—A schematic diagram of a gripping device for threaded-end specimens is shown in Fig. 3, while Fig. 4 shows a device for gripping specimens with shouldered ends. Both of these gripping devices should be attached to the heads of the testing machine through properly lubricated spherical-seated bearings. The distance between spherical bearings should be as great as feasible.

5.2.4 *Grips for Sheet Materials*—The self-adjusting grips shown in Fig. 5 have proved satisfactory for testing sheet materials that cannot be tested satisfactorily in the usual type of wedge grips.

5.2.5 *Grips for Wire*—Grips of either the wedge or snubbing types as shown in Fig. 5 and Fig. 6 or flat wedge grips may be used.

5.3 *Dimension-Measuring Devices*—Micrometers and other devices used for measuring linear dimensions shall be accurate and precise to at least one half the smallest unit to which the individual dimension is required to be measured.

5.4 *Extensometers*—Extensometers used in tension testing shall conform to the requirements of Practice E 83 for the classifications specified by the procedure section of this test method. Extensometers shall be used and verified to include strains corresponding to the yield strength and elongation at fracture (if determined).

5.4.1 Extensometers with gage lengths equal to or shorter than the nominal gage length of the specimen (dimensions shown as "G-Gage Length" in the accompanying figures) may be used to determine the yield behavior. For specimens without a reduced section (for example, full cross sectional area specimens of wire, rod, or bar), the extensometer gage length for the determination of yield behavior shall not exceed 80 % of the distance between grips. For measuring elongation at fracture with an appropriate extensometer the gage length of the extensometer shall be equal to the nominal gage length required for the specimen being tested.

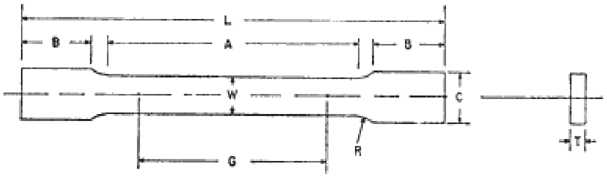
6. Test Specimens

6.1 *General*:

6.1.1 *Specimen Size*—Test specimens shall be either substantially full size or machined, as prescribed in the product specifications for the material being tested.

6.1.2 *Location*—Unless otherwise specified, the axis of the test specimen shall be located within the parent material as follows:

6.1.2.1 At the center for products 40 mm or less in thickness, diameter, or distance between flats.



Dimensions, mm			
Nominal Width	Standard Specimens		Subsize Specimen
	Plate-Type 40 mm	Sheet-Type 12.5 mm	6 mm
G— Gage length (Note 1 and Note 2)	200.0 ± 0.2	50.0 ± 0.1	25.0 ± 0.1
W— Width (Note 3 and Note 4)	40.0 ± 2.0	12.5 ± 0.2	6.0 ± 0.1
T— Thickness (Note 5)		thickness of material	
R— Radius of fillet, min (Note 6)	25	12.5	6
L— Overall length, (Note 2, Note 7 and Note 8)	450	200	100
A— Length of reduced section, min	225	57	32
B— Length of grip section, (Note 8)	75	50	30
C— Width of grip section, approximate (Note 4 and Note 9)	50	20	10

NOTE 1—For the 40-mm wide specimen, punch marks for measuring elongation after fracture shall be made on the flat or on the edge of the specimen and within the reduced section. Either a set of nine or more punch marks 25 mm apart, or one or more pairs of punch marks 200 mm apart, may be used.

NOTE 2—When elongation measurements of 40-mm wide specimens are not required, a minimum length of reduced section (*A*) of 75 mm may be used with all other dimensions similar to the plate-type specimen.

NOTE 3—For the three sizes of specimens, the ends of the reduced section shall not differ in width by more than 0.10, 0.05 or 0.02 mm, respectively. Also, there may be a gradual decrease in width from the ends to the center, but the width at each end shall not be more than 1 % larger than the width at the center.

NOTE 4—For each of the three sizes of specimens, narrower widths (*W* and *C*) may be used when necessary. In such cases the width of the reduced section should be as large as the width of the material being tested permits; however, unless stated specifically, the requirements for elongation in a product specification shall not apply when these narrower specimens are used.

NOTE 5—The dimension *T* is the thickness of the test specimen as provided for in the applicable material specifications. Minimum thickness of 40-mm wide specimens shall be 5 mm. Maximum thickness of 12.5-mm and 6-mm wide specimens shall be 19 mm and 6 mm, respectively.

NOTE 6—For the 40-mm wide specimen, a 13-mm minimum radius at the ends of the reduced section is permitted for steel specimens under 690 MPa in tensile strength when a profile cutter is used to machine the reduced section.

NOTE 7—The dimension shown is suggested as a minimum. In determining the minimum length, the grips must not extend in to the transition section between Dimensions A and B, see Note 9.

NOTE 8—To aid in obtaining axial force application during testing of 6-mm wide specimens, the overall length should be as large as the material will permit, up to 200 mm.

NOTE 9—It is desirable, if possible, to make the length of the grip section large enough to allow the specimen to extend into the grips a distance equal to two thirds or more of the length of the grips. If the thickness of 12.5-mm wide specimens is over 10 mm, longer grips and correspondingly longer grip sections of the specimen may be necessary to prevent failure in the grip section.

NOTE 10—For the three sizes of specimens, the ends of the specimen shall be symmetrical in width with the center line of the reduced section within 2.5, 0.25, and 0.13 mm, respectively. However, for referee testing and when required by product specifications, the ends of the 12.5-mm wide specimen shall be symmetrical within 0.2 mm.

NOTE 11—For each specimen type, the radii of all fillets shall be equal to each other within a tolerance of 1.25 mm, and the centers of curvature of the two fillets at a particular end shall be located across from each other (on a line perpendicular to the centerline) within a tolerance of 2.5 mm.

NOTE 12—Specimens with sides parallel throughout their length are permitted, except for referee testing, provided: (*a*) the above tolerances are used; (*b*) an adequate number of marks are provided for determination of elongation; and (*c*) when yield strength is determined, a suitable extensometer is used. If the fracture occurs at a distance of less than 2*W* from the edge of the gripping device, the tensile properties determined may not be representative of the material. In acceptance testing, if the properties meet the minimum requirements specified, no further testing is required, but if they are less than the minimum requirements, discard the test and retest.

FIG. 1 Rectangular Tension Test Specimens

6.1.2.2 Midway from the center to the surface for products over 40 mm in thickness, diameter, or distance between flats.

6.1.3 *Specimen Machining*—Improperly prepared test specimens often are the reason for unsatisfactory and incorrect test results. It is important, therefore, that care be exercised in the preparation of specimens, particularly in the machining, to maximize precision and minimize bias in test results.

6.1.3.1 The reduced sections of prepared specimens should be free of cold work, notches, chatter marks, grooves, gouges,

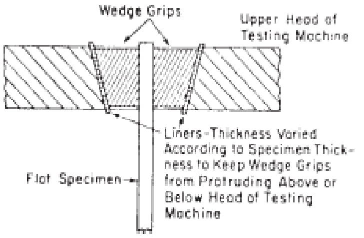


FIG. 2 Wedge Grips with Liners for Flat Specimens

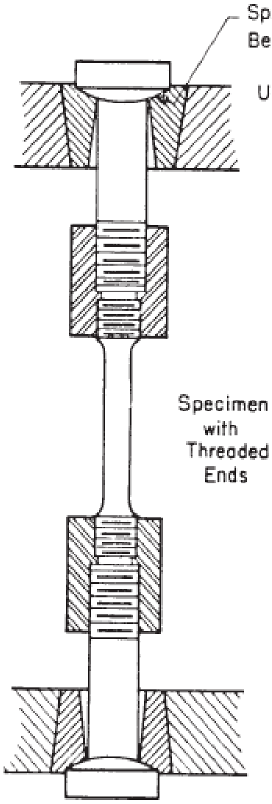


FIG. 3 Gripping Device for Threaded-End Specimens

burrs, rough surfaces or edges, overheating, or any other condition which may deteriously affect the properties to be measured.

NOTE 7—Punching or blanking of reduced section may produce significant cold work or shear burrs, or both, along the edges which should be removed by machining.

6.1.3.2 Within the reduced section of rectangular specimens, edges or corners should not be ground or abraded in a manner which could cause the actual cross-sectional area of the specimen to be significantly different from the calculated area.

6.1.3.3 For brittle materials, large radius fillets at the ends of the gage length should be used.

6.1.3.4 The cross-sectional area of the specimen should be smallest at the center of the reduced section to ensure fracture within the gage length. For this reason, a small taper is permitted in the reduced section of each of the specimens described in the following sections.

6.1.4 *Specimen Surface Finish*—When materials are tested with surface conditions other than as manufactured, the surface finish of the test specimens shall be as provided in the applicable product specifications.

NOTE 8—Particular attention should be given to the uniformity and quality of surface finish of specimens for high strength and very low ductility materials, since this has been shown to be a factor in the variability of test results.

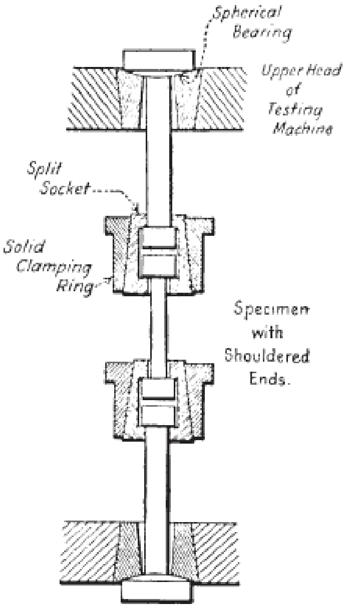


FIG. 4 Gripping Device for Shouldered-End Specimens

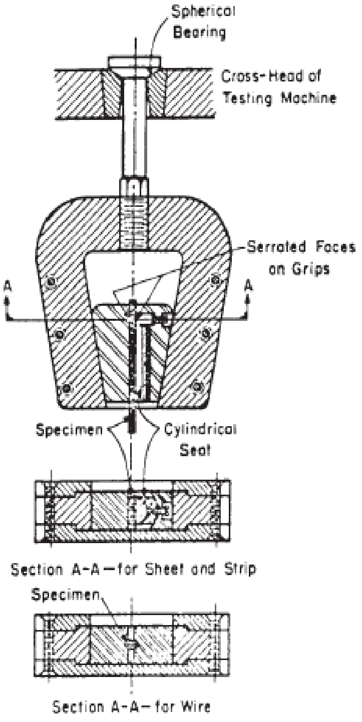


FIG. 5 Gripping Devices for Sheet and Wire Specimens

6.2 *Plate-Type Specimens*—The standard plate-type specimen is shown in Fig. 1. This specimen is used for testing

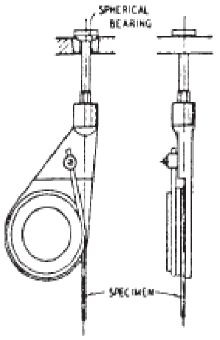


FIG. 6 Snubbing Device for Testing Wire

metallic materials in the form of plate, shapes, and flat material having a nominal thickness of 5 mm or over. When product specifications so permit, other types of specimens may be used, as provided in 6.3, 6.4, and 6.5.

6.3 *Sheet-Type Specimens*:

6.3.1 The standard sheet-type test specimen is shown in Fig. 1. This specimen is used for testing metallic materials in the form of sheet, plate, flat wire, strip, band, hoop, rectangles, and shapes ranging in nominal thickness from 0.13 to 19 mm. When product specifications so permit, other types of specimens may be used as provided in 6.2, 6.4, and 6.5.

NOTE 9—Test Methods E 345 may be used for tension testing of materials in thicknesses up to 0.150 mm.

6.3.2 Pin ends as shown in Fig. 7 may be used. In order to avoid buckling in tests of thin- and high-strength materials, it may be necessary to use stiffening plates at the grip ends.

6.4 *Round Specimens*:

6.4.1 The standard 12.5-mm diameter round test specimen shown in Fig. 8 is used quite generally for testing metallic materials, both cast and wrought.

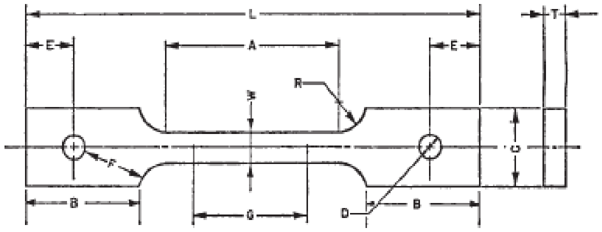
6.4.2 Fig. 8 also shows small-size specimens proportional to the standard specimen. These may be used when it is necessary to test material from which the standard specimen or specimens shown in Fig. 1 cannot be prepared. Other sizes of small, round specimens may be used. In any such small-size specimen, it is important that the gage length for measurement of elongation be five times the diameter of the specimen.

6.4.3 The shape of the ends of the specimen outside of the gage length shall be suitable to the material and of a shape to fit the holders or grips of the testing machine so that the forces may be applied axially. Fig. 9 shows specimens with various types of ends that have given satisfactory results.

6.5 *Specimens for Sheet, Strip, Flat Wire, and Plate*—In testing sheet, strip, flat wire, and plate, use a specimen type appropriate for the nominal thickness of the material, as described in the following:

6.5.1 For material with a nominal thickness of 0.13 - 5 mm, use the sheet-type specimen described in 6.3.

6.5.2 For material with a nominal thickness of 5 - 12.5 mm, use either the sheet-type specimen of 6.3 or the plate-type specimen of 6.2.



Dimensions, mm	
G— Gage length	50.0 ± 0.1
W— Width (Note 1)	12.5 ± 0.2
T— Thickness, max (Note 2)	12.5
R— Radius of fillet, min (Note 3)	13
L— Overall length, min	200
A— Length of reduced section, min	57
B— Length of grip section, min	50
C— Width of grip section, approximate	50
D— Diameter of hole for pin, min (Note 4)	13
E— Edge distance from pin, approximate	40
F— Distance from hole to fillet, min	15

NOTE 1—The ends of the reduced section shall differ in width by not more than 0.1 mm. There may be a gradual taper in width from the ends to the center, but the width at each end shall be not more than 1 % greater than the width at the center.

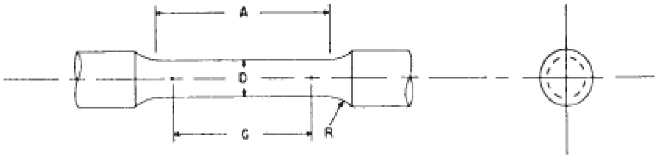
NOTE 2—The dimension *T* is the thickness of the test specimen as stated in the applicable product specifications.

NOTE 3—For some materials, a fillet radius *R* larger than 13 mm may be needed.

NOTE 4—Holes must be on center line of reduced section, within ± 0.1 mm.

NOTE 5—Variations of dimensions *C, D, E, F,* and *L* may be used that will permit failure within the gage length.

FIG. 7 Pin-Loaded Tension Test Specimen with 50-mm Gage Length



	Dimensions, mm				
	Standard Specimen	Small-Size Specimens Proportional To Standard			
	12.5	9	6	4	2.5
G—Gage length	62.5 ± 0.1	45.0± 0.1	30.0 ± 0.1	20.0± 0.1	12.5 ± 0.1
D—Diameter (Note 1)	12.5 ± 0.2	9.0 ± 0.1	6.0 ± 0.1	4.0 ± 0.1	2.5 ± 0.1
R—Radius of fillet, min	10	8	6	4	2
A—Length of reduced section, min (Note 2)	75	54	36	24	20

NOTE 1—The reduced section may have a gradual taper from the ends toward the center, with the ends not more than 1 % larger in diameter than the center (controlling dimension).

NOTE 2—If desired, the length of the reduced section may be increased to accommodate an extensometer of any convenient gage length. Reference marks for the measurement of elongation should, nevertheless, be spaced at the indicated gage length.

NOTE 3—The gage length and fillets shall be as shown, but the ends may be of any form to fit the holders of the testing machine in such a way that the load may be axial (see Fig. 9). If the ends are to be held in wedge grips it is desirable, if possible, to make the length of the grip section great enough to allow the specimen to extend into the grips a distance equal to two thirds or more of the length of the grips.

NOTE 4—On the round specimens in Figs. 8 and 9, the gage lengths are equal to five times the nominal diameter. In some product specifications other specimens may be provided for, but the 5-to-1 ratio is maintained within dimensional tolerances, the elongation values may not be comparable with those obtained from the standard test specimen.

NOTE 5—The use of specimens smaller than 6 mm in diameter shall be restricted to cases when the material to be tested is of insufficient size to obtain larger specimens or when all parties agree to their use for acceptance testing. Smaller specimens require suitable equipment and greater skill in both machining and testing.

FIG. 8 Standard 12.5-mm Round Tension Test Specimen with Gage Lengths Five Times the Diameters (5D), and Examples of Small-Size Specimens Proportional to the Standard Specimen

6.5.3 For material with a nominal thickness of 12.5 - 19 mm, use either the sheet-type specimen of 6.3, the plate-type specimen of 6.2, or the largest practical size of round specimen described in 6.4.

6.5.4 For material with a nominal thickness of 19 mm, or greater, use the plate-type specimen of paragraph 6.2 or the largest practical size of round specimen described in 6.4.

6.5.4.1 If the product specifications permit, material of a thickness of 19 mm or greater may be tested using a modified sheet-type specimen conforming to the configuration shown by Fig. 1. The thickness of this modified specimen must be machined to 10 +/- 0.50 mm and must be uniform within 0.1 mm throughout the reduced section. In the event of disagreement, a round specimen shall be used as the referee specimen.

6.6 *Specimens for Wire, Rod, and Bar*:

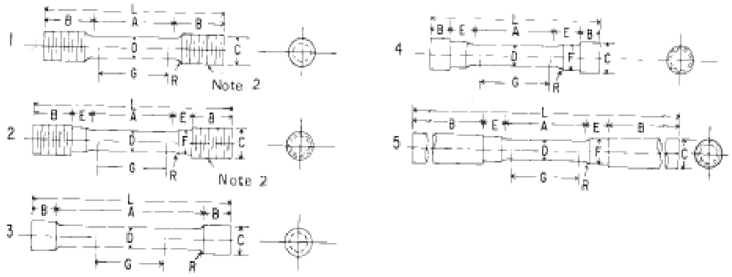
6.6.1 For round wire, rod, and bar, test specimens having the full cross-sectional area of the wire, rod, or bar shall be used wherever practicable. The gage length for the measurement of elongation of wire less than 4 mm in diameter shall be as prescribed in product specifications. In testing wire, rod, or bar that has a 4 mm or larger diameter, unless otherwise specified, a gage length equal to five times the diameter shall be used. The total length of the specimens shall be at least equal to the gage length plus the length of material required for the full use of the grips employed.

6.6.2 For wire of octagonal, hexagonal, or square cross section, for rod or bar of round cross section where the specimen required in 6.6.1 is not practicable, and for rod or bar of octagonal, hexagonal, or square cross section, one of the following types of specimens shall be used:

6.6.2.1 *Full Cross Section* (Note 10)—It is permissible to reduce the test section slightly with abrasive cloth or paper, or machine it sufficiently to ensure fracture within the gage marks. For material not exceeding 5 mm in diameter or distance between flats, the cross-sectional area may be reduced to not less than 90 % of the original area without changing the shape of the cross section. For material over 5 mm in diameter or distance between flats, the diameter or distance between flats may be reduced by not more than 0.25 mm without changing the shape of the cross section. Square, hexagonal, or octagonal wire or rod not exceeding 5 mm between flats may be turned to a round having a cross-sectional area not smaller than 90 % of the area of the maximum inscribed circle. Fillets, preferably with a radius of 10 mm, but not less than 3 mm, shall be used at the ends of the reduced sections. Square, hexagonal, or octagonal rod over 5 mm between flats may be turned to a round having a diameter no smaller than 0.25 mm less than the original distance between flats.

NOTE 10—The ends of copper or copper alloy specimens may be flattened 10 to 50 % from the original dimension in a jig similar to that shown in Fig. 10, to facilitate fracture within the gage marks. In flattening the opposite ends of the test specimen, care shall be taken to ensure that the four flattened surfaces are parallel and that the two parallel surfaces on the same side of the axis of the test specimen lie in the same plane.

6.6.2.2 For rod and bar, the largest practical size of round specimen as described in 6.4 may be used in place of a test specimen of full cross section. Unless otherwise specified in the product specification, specimens shall be parallel to the direction of rolling or extrusion.



Dimensions, mm					
	Specimen 1	Specimen 2	Specimen 3	Specimen 4	Specimen 5
G—Gage length	62.5 ± 0.1	62.5± 0.1	62.5 ± 0.1	62.5 ± 0.1	62.5 ± 0.1
D—Diameter (Note 1)	12.5 ± 0.2	12.5 ± 0.2	12.5 ± 0.2	12.5± 0.2	12.5 ± 0.2
R—Radius of fillet, min	10	10	2	10	10
A—Length of reduced section	75, min	75, min	100, approximately	75, min	75, min
L—Overall length, approximate	145	155	140	140	255
B—Length of end section (Note 3)	35, approximately	25, approximately	20, approximately	15, approximately	75, min
C—Diameter of end section	20	20	20	22	20
E—Length of shoulder and fillet section, approximate	....	15	....	20	15
F—Diameter of shoulder	....	15	....	15	15

NOTE 1—The reduced section may have a gradual taper from the ends toward the center with the ends not more than 1 % larger in diameter than the center.

NOTE 2—On Specimens 1 and 2, any standard thread is permissible that provides for proper alignment and aids in assuring that the specimen will break within the reduced section.

NOTE 3—On Specimen 5 it is desirable, if possible, to make the length of the grip section great enough to allow the specimen to extend into the grips a distance equal to two thirds or more of the length of the grips.

FIG. 9 Various Types of Ends for Standard Round Tension Test Specimens

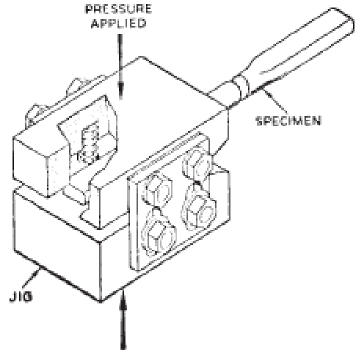


FIG. 10 Squeezing Jig for Flattening Ends of Full-Size Tension Test Specimens

6.7 *Specimens for Rectangular Bar*— In testing rectangular bar one of the following types of specimens shall be used:

6.7.1 *Full Cross Section*—It is permissible to reduce the width of the specimen throughout the test section with abrasive cloth or paper, or by machining sufficiently to facilitate fracture within the gage marks, but in no case shall the reduced width be less than 90 % of the original. The edges of the midlength of the reduced section not less than 20 mm in length shall be parallel to each other and to the longitudinal axis of the specimen within 0.05 mm. Fillets, preferably with a radius of 10 mm but not less than 3 mm, shall be used at the ends of the reduced sections.

6.7.2 Rectangular bars of thickness small enough to fit the grips of the testing machine but of too great width may be reduced in width by cutting to fit the grips, after which the cut surfaces shall be machined or cut and smoothed to ensure failure within the desired section. The reduced width shall be not less than the original bar thickness. Also, one of the types of specimens described in 6.2, 6.3, and 6.4 may be used.

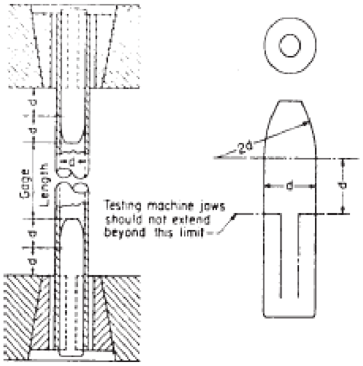
6.8 *Shapes, Structural and Other*—In testing shapes other than those covered by the preceding sections, one of the types of specimens described in 6.2, 6.3, and 6.4 shall be used.

6.9 *Specimens for Pipe and Tube* (Note 11):

6.9.1 For all small tube (Note 11), particularly sizes 25 mm and under in nominal outside diameter, and frequently for larger sizes, except as limited by the testing equipment, it is standard practice to use tension test specimens of full-size tubular sections. Snug-fitting metal plugs shall be inserted far enough into the ends of such tubular specimens to permit the testing machine jaws to grip the specimens properly. The plugs shall not extend into that part of the specimen on which the elongation is measured. Elongation is measured over a length of 5D unless otherwise stated in the product specification. Fig. 11 shows a suitable form of plug, the location of the plugs in the specimen, and the location of the specimen in the grips of the testing machine.

NOTE 11—The term "tube" is used to indicate tubular products in general, and includes pipe, tube, and tubing.

6.9.2 For large-diameter tube that cannot be tested in full section, longitudinal tension test specimens shall be cut as



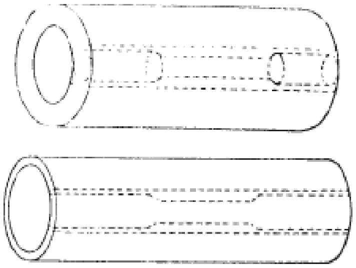
NOTE 1—The diameter of the plug shall have a slight taper from the line limiting the testing machine jaws to the curved section.

FIG. 11 Metal Plugs for Testing Tubular Specimens, Proper Location of Plugs in Specimen and of Specimen in Heads of Testing Machine

indicated in Fig. 12. Specimens from welded tube shall be located approximately 90° from the weld. If the tube-wall thickness is under 20 mm, either a specimen of the form and dimensions shown in Fig. 13 or one of the small-size specimens proportional to the standard 12.5-mm specimen, as mentioned in 6.4.2 and shown in Fig. 8, shall be used. Specimens of the type shown in Fig. 13 may be tested with grips having a surface contour corresponding to the curvature of the tube. When grips with curved faces are not available, the ends of the specimens may be flattened without heating. If the tube-wall thickness is 20 mm or over, the standard specimen shown in Fig. 8 shall be used.

NOTE 12—In clamping of specimens from pipe and tube (as may be done during machining) or in flattening specimen ends (for gripping), care must be taken so as not to subject the reduced section to any deformation or cold work, as this would alter the mechanical properties.

6.9.3 Transverse tension test specimens for tube may be taken from rings cut from the ends of the tube as shown in Fig. 14. Flattening of the specimen may be either after separating as in *A*, or before separating as in *B*. Transverse tension test specimens for large tube under 20 mm in wall thickness shall be either of the small-size specimens shown in Fig. 8 or of the form and dimensions shown for Specimen 2 in Fig. 13. When using the latter specimen, either or both surfaces of the specimen may be machined to secure a uniform thickness, provided not more than 15 % of the normal wall thickness is removed from each surface. For large tube 20 mm and over in wall thickness, the standard specimen shown in Fig. 8 shall be used for transverse tension tests. Specimens for transverse tension tests on large welded tube to determine the strength of welds shall be located perpendicular to the welded seams, with the welds at about the middle of their lengths.



NOTE 1—The edges of the blank for the specimen shall be cut parallel to each other.

FIG. 12 Location from Which Longitudinal Tension Test Specimens Are to Be Cut from Large-Diameter Tube

6.10 *Specimens for Forgings*—For testing forgings, the largest round specimen described in 6.4 shall be used. If round specimens are not feasible, then the largest specimen described in 6.5 shall be used.

6.10.1 For forgings, specimens shall be taken as provided in the applicable product specifications, either from the predominant or thickest part of the forging from which a coupon can be obtained, or from a prolongation of the forging, or from separately forged coupons representative of the forging. When not otherwise specified, the axis of the specimen shall be parallel to the direction of grain flow.

6.11 *Specimens for Castings*—In testing castings either the standard specimen shown in Fig. 8 or the specimen shown in Fig. 15 shall be used unless otherwise provided in the product specifications.

6.11.1 Test coupons for castings shall be made as shown in Fig. 16 and Table 1.

6.12 *Specimen for Malleable Iron*—For testing malleable iron the test specimen shown in Fig. 17 shall be used, unless otherwise provided in the product specifications.

6.13 *Specimen for Die Castings*—For testing die castings the test specimen shown in Fig. 18 shall be used unless otherwise provided in the product specifications.

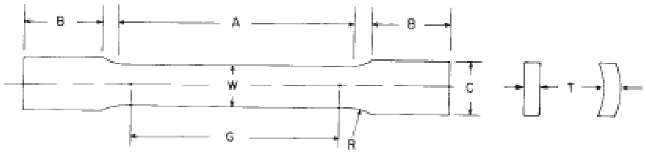
6.14 *Specimens for Powder Metallurgy (P/M) Materials*—For testing powder metallurgy (P/M) materials the test specimens shown in Fig. 19 and Fig. 20 shall be used, unless otherwise provided in the product specifications. When making test specimens in accordance with Fig. 19, shallow transverse grooves, or ridges, may be pressed in the ends to allow gripping by jaws machined to fit the grooves or ridges. Because of shape and other factors, the flat unmachined tensile test specimen (Fig. 19) in the heat-treated condition will have an ultimate tensile strength of 50 % to 85 % of that determined in a machined round tensile test specimen (Fig. 20) of like composition and processing.

7. Procedures

7.1 *Preparation of the Test Machine*— Upon startup or following a prolonged period of machine inactivity, the test machine should be exercised or warmed up to normal operating temperatures to minimize errors that may result from transient conditions.

7.2 *Measurement of Dimensions of Test Specimens*:

7.2.1 To determine the cross-sectional area of a test specimen, measure the dimensions of the cross section at the center of the reduced section. For referee testing of specimens under 5 mm in their least dimension, measure the dimensions where the least cross-sectional area is found. Measure and record the cross-sectional dimensions of tension test specimens 5 mm and



Dimensions, mm							
Nominal Width	Specimen 1	Specimen 2	Specimen 3	Specimen 4	Specimen 5	Specimen 6	Specimen 7
	12.5	40	40	20	20	25	25
G—Gage length	50.0 ± 0.1	50.0 ± 0.1	200.0 ± 0.2	50.0 ± 0.1	100.0 ± 0.1	50.0 ± 0.1	100.0 ± 0.1
W—Width (Note 1)	12.5 ± 0.2	40.0± 2.0	40.0 ± 2.0	20.0 ± 0.7	20.0 ± 0.7	25.0 ± 1.5	25.0 ± 1.5
T—Thickness				measured thickness of specimen			
R—Radius of fillet, min	12.5	25	25	25	25	25	25
A—Length of reduced section, min	60	60	230	60	120	60	120
B—Length of grip section, min (Note 2)	75	75	75	75	75	75	75
C—Width of grip section, approximate (Note 3)	20	50	50	25	25	40	40

NOTE 1—The ends of the reduced section shall not differ in width by more than 0.1 mm for specimens 1–7. There may be a gradual taper in width from the ends to the center, but the width at each end shall be not more than 1 % greater than the width at the center.

NOTE 2—It is desirable, if possible, to make the length of the grip section great enough to allow the specimen to extend into the grips a distance equal to two thirds or more of the length of the grips.

NOTE 3—The ends of the specimen shall be symmetrical with the center line of the reduced section within 1.0 mm for specimens 1, 4, and 5 and 2.5 mm for specimens 2, 3, 6, and 7.

NOTE 4—For circular segments, the cross-sectional area may be calculated by multiplying W and *T*. If the ratio of the dimension *W* to the diameter of the tubular section is larger than about ⅙ , the error in using this method to calculate cross-sectional area may be appreciable. In this case, the exact equaton (see 7.3.2) must be used to determine the area.

NOTE 5—For each specimen type, the radii of all fillets shall be equal to each other within a tolerance of 1.25 mm, and the centers of curvature of the two fillets at a particular end shall be located across from each other (on a line perpendicular to the centerline) within a tolerance of 2.5 mm.

NOTE 6—Specimens with sides parallel throughout their length are permitted, except for referee testing and where prohibited by product specification, provided: (*a*) the above tolerances are used; (*b*) an adequate number of marks are provided for determination of elongation; and (*c*) when yield strength is determined, a suitable extensometer is used. If the fracture occurs at a distance of less than 2*W* from the edge of the gripping device, the tensile properties determined may not be representative of the material. If the properties meet the minimum requirements specified, no further testing is required, but if they are less than the minimum requirements, discard the test and retest.

FIG. 13 Tension Test Specimens for Large-Diameter Tubular Products

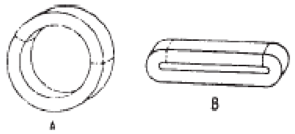


FIG. 14 Location of Transverse Tension Test Specimen in Ring Cut from Tubular Products

over to the nearest 0.02 mm; the cross-sectional dimensions less than 5 mm and not less than 2.5 mm to the nearest 0.01 mm; the cross-sectional dimensions less than 2.5 mm and not less than 0.50 mm to the nearest 0.002 mm; and when practical, the cross-sectional dimensions less than 0.50 mm to at least the nearest 1 % but in all cases to at least the nearest 0.002 mm.

NOTE 13—Accurate and precise measurement of specimen dimensions can be one of the most critical aspects of tension testing, depending on specimen geometry. See Appendix X2 for additional information.

NOTE 14—Rough surfaces due to the manufacturing process such as hot rolling, metallic coating, etc., may lead to inaccuracy of the computed areas greater than the measured dimensions would indicate. Therefore, cross-sectional dimensions of tension test specimens with rough surfaces due to processing may be measured and recorded to the nearest 0.02 mm.

NOTE 15—See X2.9 for cautionary information on measurements taken from coated metal products.

7.2.2 Determine the cross-sectional area of a full-size test specimen of uniform but nonsymmetrical cross section by determining the mass of a length not less than 20 times longer than the largest cross-sectional dimension.

7.2.2.1 Determine the weight to the nearest 0.5 % or less.

7.2.2.2 The cross-sectional area is equal to the mass of the specimen divided by the length and divided by the density of the material.

7.2.3 When using specimens of the type shown in Fig. 13 taken from tubes, the cross-sectional area shall be determined as follows:

If $D/W \leq 6$:

$$\begin{aligned} A = {} & [(W/4) \times (D^2 - W^2)^{1/2}] + [(D^2/4) \\ & \times \arcsin(W/D)] - [(W/4) \times ((D - 2T)^2 - W^2)^{1/2}] \\ & - [((D - 2T)/2)^2 \times \arcsin(W/(D - 2T))] \end{aligned} \tag{1}$$

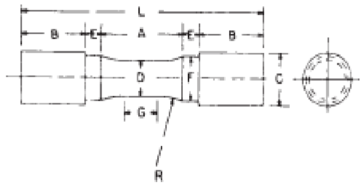
where:

A = exact cross-sectional area, mm^2,
W = width of the specimen in the reduced section, mm,
D = measured outside diameter of the tube, mm, and
T = measured wall thickness of the specimen, mm.

arcsin values to be in radians

If $D/W > 6$, the exact equation or the following equation may be used:

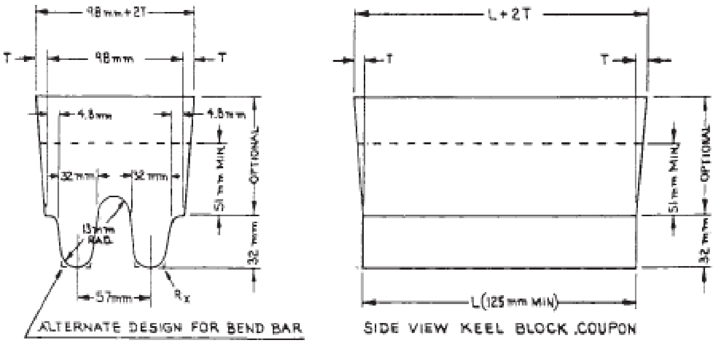
$$A = W \times T \tag{2}$$



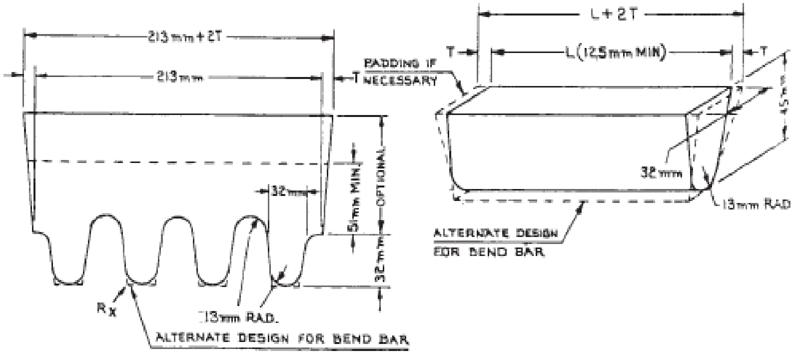
Dimensions, mm			
Nominal Diameter	Specimen 1	Specimen 2	Specimen 3
	12.5	20	30
G—Length of parallel	Shall be equal to or greater than diameter *D*		
D—Diameter	12.5 ± 0.2	20.0 ± 0.4	30.0 ± 0.6
R—Radius of fillet, min	25	25	50
A—Length of reduced section, min	32	38	60
L—Overall length, min	95	100	160
B—Length of end section, approximate	25	25	45
C—Diameter of end section, approximate	20	30	48
E—Length of shoulder, min	6	6	8
F—Diameter of shoulder	16.0 ± 0.4	24.0± 0.4	36.5 ± 0.4

NOTE 1—The reduced section and shoulders (dimensions *A, D, E, F, G,* and *R*) shall be as shown, but the ends may be of any form to fit the holde of the testing machine in such a way that the force shall be axial. Commonly the ends are threaded and have the dimensions *B* and *C* given above.

FIG. 15 Standard Tension Test Specimen for Cast Iron



(*a*) Design for Double Keel Block Coupon



(*b*) Design for Multiple Keel Block Coupon (4 Legs)

(*c*) Design for "Attached" Coupon

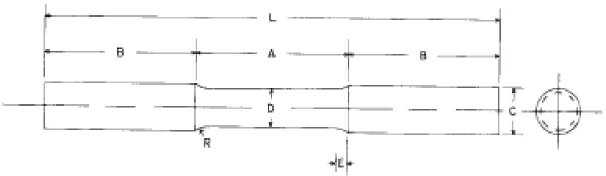
FIG. 16 Test Coupons for Castings (see Table 1 for Details of Design)

TABLE 1 Details of Test Coupon Design for Castings (See Fig. 16)

NOTE 1—*Test Coupons for Large and Heavy Steel Castings:* The test coupons in Fig. 16 are to be used for large and heavy steel castings. However, at the option of the foundry the cross-sectional area and length of the standard coupon may be increased as desired. This provision does not apply to Specification A 356/A 356M.

NOTE 2—*Bend Bar:* If a bend bar is required, an alternate design (as shown by dotted lines in Fig. 16) is indicated.

Log Design (125 mm)		Riser Design	
1. *L* (length)	A 125-mm minimum length will be used. This length may be increased at the option of the foundry to accommodate additional test bars (see Note 1).	1. *L* (length)	The length of the riser at the base will be the same as the top length of the leg. The length of the riser at the top therefore depends on the amount of taper added to the riser.
2. End taper	Use of and size of end taper is at the option of the foundry.	2. Width	The width of the riser at the base of a multiple-leg coupon shall be *n* (57 mm) − 16 mm where *n* equals the number of legs attached to the coupon. The width of the riser at the top is therefore dependent on the amount of taper added to the riser.
3. Height	32 mm		
4. Width (at top)	32 mm (see Note 1).		
5. Radius (at bottom)	13 mm max		
6. Spacing between legs	A 13-mm radius will be used between the legs.		
7. Location of test bars	The tensile, bend, and impact bars will be taken from the lower portion of the leg (see Note 2).		
8. Number of legs	The number of legs attached to the coupon is at the option of the foundry providing they are equispaced according to Item 6.	3. *T* (riser taper)	Use of and size is at the option of the foundry.
		Height	The minimum height of the riser shall be 51 mm. The maximum height is at the option of the foundry for the following reasons: (*a*) many risers are cast open, (*b*) different compositions may require variation in risering for soundness, or (*c*) different pouring temperatures may require variation in risering for soundness.
9. R_s	Radius from 0 to approximately 2 mm		



Dimensions, mm	
D—Diameter	16
R—Radius of fillet	8
A—Length of reduced section	64
L—Overall length	190
B—Length of end section	64
C—Diameter of end section	20
E—Length of fillet	5

FIG. 17 Standard Tension Test Specimen for Malleable Iron

where:

A = approximate cross-sectional area, mm^2,
W = width of the specimen in the reduced section, mm, and
T = measured wall thickness of the specimen, mm.

NOTE 16—See X2.8 for cautionary information on measurements and calculations for specimens taken from large-diameter tubing.

7.3 *Gage Length Marking of Test Specimens*:

7.3.1 The gage length for the determination of elongation shall be in accordance with the product specifications for the material being tested. Gage marks shall be stamped lightly with a punch, scribed lightly with dividers or drawn with ink as preferred. For material that is sensitive to the effect of slight notches and for small specimens, the use of layout ink will aid in locating the original gage marks after fracture.

7.3.2 For materials where the specified elongation is 3 % or less, measure the original gage length to the nearest 0.05 mm prior to testing.

7.4 *Zeroing of the Testing Machine*:

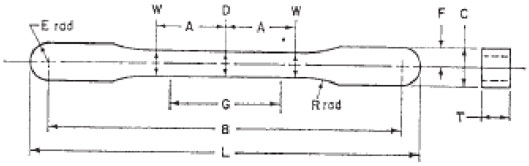
7.4.1 The testing machine shall be set up in such a manner that zero force indication signifies a state of zero force on the specimen. Any force (or preload) imparted by the gripping of the specimen (see Note 17) must be indicated by the force measuring system unless the preload is physically removed prior to testing. Artificial methods of removing the preload on the specimen, such as taring it out by a zero adjust pot or removing it mathematically by software, are prohibited because these would affect the accuracy of the test results.

NOTE 17—Preloads generated by gripping of specimens may be either tensile or compressive in nature and may be the result of such things as:

Dimensions, mm	
G—Gage length	50.0 ± 0.1
D—Diameter (see Note)	6.4 ± 0.1
R—Radius of fillet, min	75
A—Length of reduced section, min	60
L—Overall length, min	230
B—Distance between grips, min	115
C—Diameter of end section, approximate	10

NOTE 1—The reduced section may have a gradual taper from the ends toward the center, with the ends not more than 0.1 mm larger in diameter than the center.

FIG. 18 Standard Tension Test Specimen for Die Castings



Pressing Area = 645 mm^2

NOTE 1—Dimensions specified, except *G* and *T*, are those of the die.

Dimensions, mm	
G—Gage length	25.40 ± 0.8
D—Width at center	5.72 ± 0.03
W—Width at end of reduced section	5.97 ± 0.03
T—Compact to this thickness	3.56 to 6.35
R—Radius of fillet	25.4
A—Half-length of reduced section	15.88
B—Grip length	80.95 ± 0.03
L—Overall length	89.64 ± 0.03
C—Width of grip section	8.71 ± 0.03
F—Half-width of grip section	4.34 ± 0.03
E—End radius	4.34 ± 0.03

FIG. 19 Standard Flat Unmachined Tension Test Specimen for Powder Metallurgy (P/M) Products

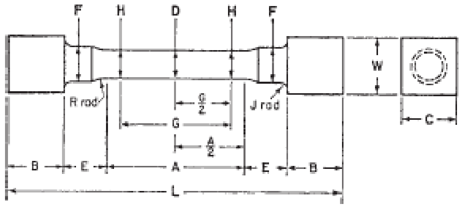
— grip design
— malfunction of gripping apparatus (sticking, binding, etc.)
— excessive gripping force
— sensitivity of the control loop

NOTE 18—It is the operator's responsibility to verify that an observed preload is acceptable and to ensure that grips operate in a smooth manner. Unless otherwise specified, it is recommended that momentary (dynamic) forces due to gripping not exceed 20 % of the material's nominal yield strength and that static preloads not exceed 10 % of the material's nominal yield strength.

7.5 *Gripping of the Test Specimen*:

7.5.1 For specimens with reduced sections, gripping of the specimen shall be restricted to the grip section, because gripping in the reduced section or in the fillet can significantly affect test results.

7.6 *Speed of Testing*:



Approximate Pressing Area of Unmachined Compact = 752 mm^2

Machining Recommendations

1. Rough machine reduced section to 6.35 mm diameter
2. Finish turn 4.75/4.85 mm diameter with radii and taper
3. Polish with 00 emery cloth
4. Lap with crocus cloth

Dimensions, mm	
G—Gage length	25.40 ± 0.8
D—Diameter at center of reduced section	4.75± 0.03
H—Diameter at ends of gage length	4.85± 0.03
R—Radius of fillet	6.35 ± 0.13
A—Length of reduced section	47.63 ± 0.13
L—Overall length (die cavity length)	75, nominal
B—Length of end section	7.88 ± 0.13
C—Compact to this end thickness	10.03 ± 0.13
W—Die cavity width	10.03 ± 0.08
E—Length of shoulder	6.35 ± 0.13
F—Diameter of shoulder	7.88 ± 0.03
J—End fillet radius	1.27 ± 0.13

NOTE 1—The gage length and fillets of the specimen shall be as shown. The ends as shown are designed to provide a practical minimum pressing area. Other end designs are acceptable, and in some cases are required for high-strength sintered materials.

NOTE 2—It is recommended that the test specimen be gripped with a split collet and supported under the shoulders. The radius of the collet support circular edge is to be not less than the end fillet radius of the test specimen.

NOTE 3—Diameters *D* and *H* are to be concentric within 0.03 mm total indicator runout (T.I.R.), and free of scratches and tool marks.

FIG. 20 Standard Round Machined Tension Test Specimen for Powder Metallurgy (P/M) Products

7.6.1 Speed of testing may be defined in terms of (*a*) rate of straining of the specimen, (*b*) rate of stressing of the specimen, (*c*) rate of separation of the two heads of the testing machine during a test, (*d*) the elapsed time for completing part or all of the test, or (*e*) free-running crosshead speed (rate of movement of the crosshead of the testing machine when not under load).

7.6.2 Specifying suitable numerical limits for speed and selection of the method are the responsibilities of the product committees. Suitable limits for speed of testing should be specified for materials for which the differences resulting from the use of different speeds are of such magnitude that the test results are unsatisfactory for determining the acceptability of the material. In such instances, depending upon the material and the use for which the test results are intended, one or more of the methods described in the following paragraphs is recommended for specifying speed of testing.

NOTE 19—Speed of testing can affect test values because of the rate sensitivity of materials and the temperature-time effects.

7.6.2.1 *Rate of Straining*—The allowable limits for rate of straining shall be specified in metres per metre per second. Some testing machines are equipped with pacing or indicating devices for the measurement and control of rate of straining, but in the absence of such a device the average rate of straining can be determined with a timing device by observing the time required to effect a known increment of strain.

7.6.2.2 *Rate of Stressing*—The allowable limits for rate of stressing shall be specified in megapascals per second. Many testing machines are equipped with pacing or indicating devices for the measurement and control of the rate of stressing, but in the absence of such a device the average rate of stressing can be determined with a timing device by observing the time required to apply a known increment of stress.

7.6.2.3 *Rate of Separation of Heads During Tests*—The allowable limits for rate of separation of the heads of the testing machine, during a test, shall be specified in metres per metre of length of reduced section (or distance between grips for specimens not having reduced sections) per second. The limits for the rate of separation may be further qualified by specifying different limits for various types and sizes of specimens. Many testing machines are equipped with pacing or indicating devices for the measurement and control of the rate of separation of the heads of the machine during a test, but in the absence of such a device the average rate of separation of the heads can be experimentally determined by using suitable length-measuring and timing devices.

7.6.2.4 *Elapsed Time*—The allowable limits for the elapsed time from the beginning of force application (or from some specified stress) to the instant of fracture, to the maximum force, or to some other stated stress, shall be specified in minutes or seconds. The elapsed time can be determined with a timing device.

7.6.2.5 *Free-Running Crosshead Speed*—The allowable limits for the rate of movement of the crosshead of the testing machine, with no force applied by the testing machine, shall be specified in metres per metre of length of reduced section (or distance between grips for specimens not having reduced sections) per second. The limits for the crosshead speed may be further qualified by specifying different limits for various types and sizes of specimens. The average crosshead speed can be experimentally determined by using suitable length-measuring and timing devices.

NOTE 20—For machines not having crossheads or having stationary crossheads, the phrase "free-running crosshead speed" may be interpreted to mean the free-running rate of grip separation.

7.6.3 *Speed of Testing When Determining Yield Properties*—Unless otherwise specified, any convenient speed of testing may be used up to one half the specified yield strength or up to one quarter the specified tensile strength, whichever is smaller. The speed above this point shall be within the limits specified. If different speed limitations are required for use in determining yield strength, yield point elongation, tensile strength, elongation, and reduction of area, they should be stated in the product specifications. In the absence of any specified limitations on speed of testing, the following general rules shall apply:

NOTE 21—In the previous and following paragraphs, the yield properties referred to include yield strength and yield point elongation.

7.6.3.1 The speed of testing shall be such that the forces and strains used in obtaining the test results are accurately indicated.

7.6.3.2 When performing a test to determine yield properties, the rate of stress application shall be between 1.15 and 11.5 MPa/s.

NOTE 22—When a specimen being tested begins to yield, the stressing rate decreases and may even become negative in the case of a specimen with discontinuous yielding. To maintain a constant stressing rate in this case would require the testing machine to operate at extremely high speeds and, in many cases, this is not practical. The speed of the testing machine shall not be increased in order to maintain a stressing rate when the specimen begins to yield. In practice, it is simpler to use either a strain rate, a rate of separation of the heads, or a free-running crosshead speed which approximates the desired stressing rate. As an example, use a strain rate that is less than 11.5 MPa/s divided by the nominal Young's Modulus of the material being tested. As another example, find a rate of separation of the heads through experimentation which would approximate the desired stressing rate prior to the onset of yielding, and maintain that rate of separation of the heads through the region that yield properties are determined. While both of these methods will provide similar rates of stressing and straining prior to the onset of yielding, the rates of stressing and straining may be different in the region where yield properties are determined. This difference is due to the change in the rate of elastic deformation of the testing machine, before and after the onset of yielding. In addition, the use of any of the methods other than rate of straining may result in different stressing and straining rates when using different testing machines, due to differences in the stiffness of the testing machines used.

7.6.4 *Speed of Testing When Determining Tensile Strength*—In the absence of any specified limitations on speed of testing, the following general rules shall apply for materials with expected elongations greater than 5 %. When determining only the tensile strength, or after the yield behavior has been recorded, the speed of the testing machine shall be set between 0.05 and 0.5 m/m of the length of the reduced section (or distance between the grips for specimens not having reduced sections) per minute. Alternatively, an extensometer and strain rate indicator may be used to set the strain between 0.05 and 0.5 m/m/min.

NOTE 23—For materials with expected elongations less than or equal to 5 %, the speed of the testing machine may be maintained throughout the test at the speed used to determine yield properties.

NOTE 24—Tensile strength and elongation are sensitive to test speed for many materials (see Appendix X1) to the extent that variations within the range of test speeds given above can significantly affect results.

7.7 *Determination of Yield Strength*—Determine yield strength by any of the methods described in 7.7.1 to 7.7.4. Where extensometers are employed, use only those which are verified over a strain range in which the yield strength will be determined (see 5.4).

NOTE 25—For example, a verified strain range of 0.2 to 2.0 % is appropriate for use in determining the yield strengths of many metals.

NOTE 26—Determination of yield behavior on materials which cannot support an appropriate extensometer (thin wire, for example) is problematic and outside the scope of this standard.

7.7.1 *Offset Method*—To determine the yield strength by the offset method, it is necessary to secure data (autographic or numerical) from which a stress-strain diagram may be drawn. Then on the stress-strain diagram (Fig. 21) lay off *Om* equal to the specified value of the offset, draw *mn* parallel to *OA*, and

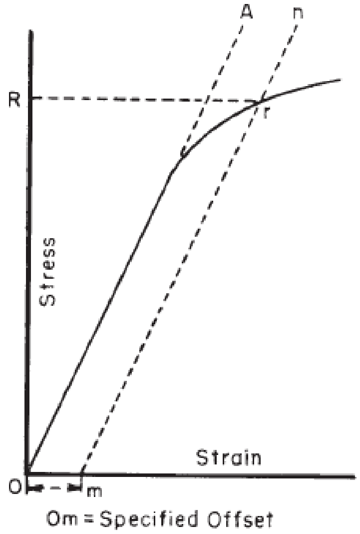


FIG. 21 Stress-Strain Diagram for Determination of Yield Strength by the Offset Method

thus locate *r*, the intersection of *mn* with the stress-strain diagram (Note 32). In reporting values of yield strength obtained by this method, the specified value of offset used should be stated in parentheses after the term yield strength, as follows:

$$\text{yield strength (offset} = 0.2\ \%) = 360\ \text{MPa} \tag{3}$$

In using this method, a Class B2 or better extensometer (see Practice E 83) shall be used.

Note 27—There are two general types of extensometers, averaging and non-averaging, the use of which is dependent on the product tested. For most machined specimens, there are minimal differences. However, for some forgings and tube sections, significant differences in measured yield strength can occur. For these cases, it is recommended that the averaging type be used.

Note 28—When there is a disagreement over yield properties, the offset method for determining yield strength is recommended as the referee method.

7.7.2 *Extension-Under-Load Method*—Yield strength by the extension-under-load method may be determined by: (*1*) using autographic or numerical devices to secure stress-strain data, and then analyzing this data (graphically or using automated methods) to determine the stress value at the specified value of extension, or (*2*) using devices that indicate when the specified extension occurs, so that the stress then occurring may be ascertained (Note 30). Any of these devices may be automatic. This method is illustrated in Fig. 22. The stress at the specified extension shall be reported as follows:

$$\text{yield strength (EUL} = 0.5\ \%) = 360\ \text{MPa} \tag{4}$$

Extensometers and other devices used in determination of the extension shall meet Class B2 requirements (see Practice E 83) at the strain of interest, except where use of low-magnification Class C devices is helpful, such as in facilitating measurement of YPE if observed. If Class C devices are used, this must be reported along with the results.

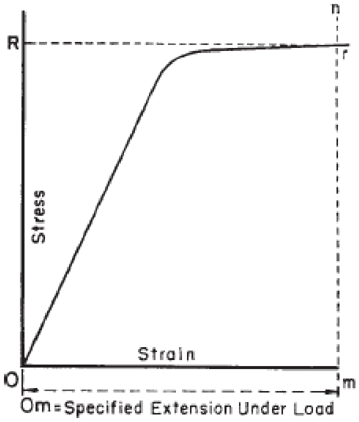


FIG. 22 Stress-Strain Diagram for Determination of Yield Strength by the Extension-Under-Load Method

Note 29—The appropriate value of the total extension must be specified. For steels with nominal yield strengths of less than 550 MPa, an appropriate value is 0.005 mm/mm (0.5 %) of the gage length. For higher strength steels, a greater extension or the offset method should be used.

Note 30—When no other means of measuring elongation are available, a pair of dividers or similar device can be used to determine a point of detectable elongation between two gage marks on the specimen. The gage length shall be 50 mm. The stress corresponding to the load at the instant of detectable elongation may be recorded as the ***approximate*** extension-under-load yield strength.

7.7.3 *Autographic Diagram Method (for materials exhibiting discontinuous yielding)*—Obtain stress-strain (or force-elongation) data or construct a stress-strain (or load-elongation) diagram using an autographic device. Determine the upper or lower yield strength as follows:

7.7.3.1 Record the stress corresponding to the maximum force at the onset of discontinuous yielding as the upper yield strength. This is illustrated in Fig. 23 and Fig. 24.

Note 31—If multiple peaks are observed at the onset of discontinuous yielding, the first is considered the upper yield strength. (See Fig. 24.)

7.7.3.2 Record the minimum stress observed during discontinuous yielding (ignoring transient effects) as the lower yield strength. This is illustrated in Fig. 24.

Note 32—Yield properties of materials exhibiting yield point elongation are often less repeatable and less reproducible than those of similar materials having no YPE. Offset and EUL yield strengths may be significantly affected by force fluctuations occurring in the region where the offset or extension intersects the stress-strain curve. Determination of upper or lower yield strengths (or both) may therefore be preferable for such materials, although these properties are dependent on variables such as test machine stiffness and alignment. Speed of testing may also have a significant effect, regardless of the method employed.

Note 33—Where low-magnification autographic recordings are needed to facilitate measurement of yield point elongation for materials which may have discontinuous yielding, Class C extensometers may be employed. When this is done but the material exhibits no discontinuous yielding, the extension-under-load yield strength may be determined

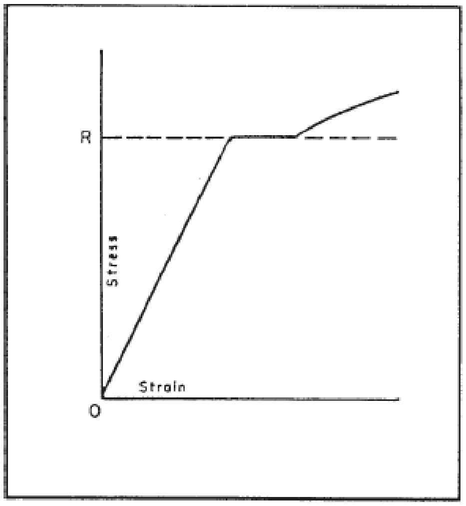


FIG. 23 Stress-Strain Diagram Showing Upper Yield Strength Corresponding with Top of Knee

instead, using the autographic recording (see Extension-Under-Load Method).

7.7.4 *Halt-of-the-Force Method (for materials exhibiting discontinuous yielding)*—Apply an increasing force to the specimen at a uniform deformation rate. When the force hesitates, record the corresponding stress as the upper yield strength.

NOTE 34—The Halt-of-the-Force Method was formerly known as the Halt-of-the-Pointer Method, the Drop-of-the-Beam Method, and the Halt-of-the-Load Method.

7.8 *Yield Point Elongation*—Calculate the yield point elongation from the stress-strain diagram or data by determining the difference in strain between the upper yield strength (first zero slope) and the onset of uniform strain hardening (see definition of YPE and Fig. 24).

NOTE 35—The stress-strain curve of a material exhibiting only a hint of the behavior causing YPE may have an inflection at the onset of yielding with no point where the slope reaches zero (Fig. 25). Such a material has no YPE, but may be characterized as exhibiting an *inflection*. Materials exhibiting inflections, like those with measurable YPE, may, in certain applications, acquire an unacceptable surface appearance during forming.

7.9 *Uniform Elongation (if required)*:

7.9.1 Uniform elongation shall include both plastic and elastic elongation.

7.9.2 Uniform elongation shall be determined using autographic methods with extensometers conforming to Practice E 83. Use a class B2 or better extensometer for materials having a uniform elongation less than 5 %. Use a class C or better extensometer for materials having a uniform elongation greater than or equal to 5 % but less than 50 %. Use a class D or better extensometer for materials having a uniform elongation of 50 % or greater.

7.9.3 Determine the uniform elongation as the elongation at the point of maximum force from the force elongation data collected during a test.

7.9.3.1 Some materials exhibit a yield point followed by considerable elongation where the yield point is the maximum force achieved during the test. In this case, uniform elongation is not determined at the yield point, but instead at the highest force occurring just prior to necking (see Fig. 26).

7.9.3.2 Stress-strain curves for some materials exhibit a lengthy, plateau-like region in the vicinity of the maximum force. For such materials, determine the uniform elongation at the center of the plateau as indicated in Fig. 27 (see also Note 36 below).

NOTE 36—When uniform elongation is being determined digitally, noise in the stress-strain data generally causes many small, local peaks and valleys to be recorded in the plateau region. To accommodate this, the following procedure is recommended:

- Determine the maximum force recorded (after discontinuous yielding).
- Evaluate the sequence of force values recorded before and after the maximum force.
- Digitally define the "plateau" as consisting of all consecutive data points wherein the force value is within 0.5% of the magnitude of the peak force value.
- Determine the uniform elongation as the strain at the mid-point of the "plateau."

7.9.4 *Discussion*—The 0.5% value of Note 36 has been selected arbitrarily. In actual practice, the value should be selected so as to be the minimum figure that is large enough to effectively define the force plateau. This may require that the percentage be about 5 times the amplitude of the force fluctuations occurring due to noise. Values ranging from 0.1% to 1.0 % may be found to work acceptably.

7.10 *Tensile Strength*—Calculate the tensile strength by dividing the maximum force carried by the specimen during the tension test by the original cross-sectional area of the specimen.

NOTE 37—If the upper yield strength is the maximum stress recorded, and if the stress-strain curve resembles that of Fig. 26, it is recommended that the maximum stress *after discontinuous yielding* be reported as the tensile strength. Where this may occur, determination of the tensile strength should be in accordance with the agreement between the parties involved.

7.11 *Elongation*:

7.11.1 In reporting values of elongation, give both the original gage length and the percentage increase. If any device other than an extensometer is placed in contact with the specimen's reduced section during the test, this shall also be noted.

Example: elongation = 30 % increase (50−mm gage length) (5)

NOTE 38—Elongation results are very sensitive to variables such as: (*a*) speed of testing, (*b*) specimen geometry (gage length, diameter, width, and thickness), (*c*) heat dissipation (through grips, extensometers, or other devices in contact with the reduced section), (*d*) surface finish in reduced section (especially burrs or notches), (*e*) alignment, and (*f*) fillets and tapers. Parties involved in comparison or conformance testing should standardize the above items, and it is recommended that use of ancillary devices (such as extensometer supports) which may remove heat from specimens be avoided. See Appendix X1. for additional information on the effects of these variables.

7.11.2 When the specified elongation is greater than 3 %, fit ends of the fractured specimen together carefully and measure the distance between the gage marks to the nearest 0.25 mm for

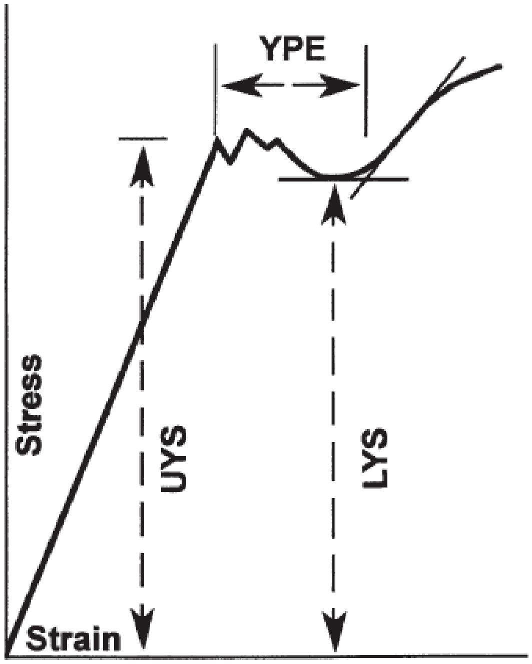


FIG. 24 Stress-Strain Diagram Showing Yield Point Elongation and Upper and Lower Yield Strengths

gage lengths of 50 mm and under, and to at least the nearest 0.5 % of the gage length for gage lengths over 50 mm. A percentage scale reading to 0.5 % of the gage length may be used.

7.11.3 When the *specified* elongation is 3 % or less, determine the elongation of the specimen using the following procedure, except that the procedure given in 7.11.2 may be used instead when the *measured* elongation is greater than 3 %.

7.11.3.1 Prior to testing, measure the original gage length of the specimen to the nearest 0.05 mm.

7.11.3.2 Remove partly torn fragments that will interfere with fitting together the ends of the fractured specimen or with making the final measurement.

7.11.3.3 Fit the fractured ends together with matched surfaces and apply a force along the axis of the specimen sufficient to close the fractured ends together. If desired, this force may then be removed carefully, provided the specimen remains intact.

NOTE 39—The use of a force of approximately 15 MPa has been found to give satisfactory results on test specimens of aluminum alloy.

7.11.3.4 Measure the final gage length to the nearest 0.05 mm and report the elongation to the nearest 0.2 %.

7.11.4 Elongation measured per paragraph 7.11.2 or 7.11.3 may be affected by location of the fracture, relative to the marked gage length. If any part of the fracture occurs outside the gage marks or is located less than 25 % of the elongated gage length from either gage mark, the elongation value obtained using that pair of gage marks may be abnormally low and non-representative of the material. If such an elongation measure is obtained in acceptance testing involving only a minimum requirement and meets the requirement, no further testing need be done. Otherwise, discard the test and retest the material.

7.11.5 Elongation at fracture is defined as the elongation measured just prior to the sudden decrease in force associated with fracture. For many ductile materials not exhibiting a sudden decrease in force, the elongation at fracture can be taken as the strain measured just prior to when the force falls below 10 % of the maximum force encountered during the test.

7.11.5.1 Elongation at fracture shall include elastic and plastic elongation and may be determined with autographic or automated methods using extensometers verified over the strain range of interest (see 5.4). Use a class B2 or better extensometer for materials having less than 5 % elongation, a class C or better extensometer for materials having elongation greater than or equal to 5 % but less than 50 %, and a class D or better extensometer for materials having 50 % or greater elongation. In all cases, the extensometer gage length shall be the nominal gage length required for the specimen being tested. Due to the lack of precision in fitting fractured ends together, the elongation after fracture using the manual methods of the preceding paragraphs may differ from the elongation at fracture determined with extensometers.

7.11.5.2 Percent elongation at fracture may be calculated directly from elongation at fracture data and be reported instead of percent elongation as calculated in paragraphs 7.11.2

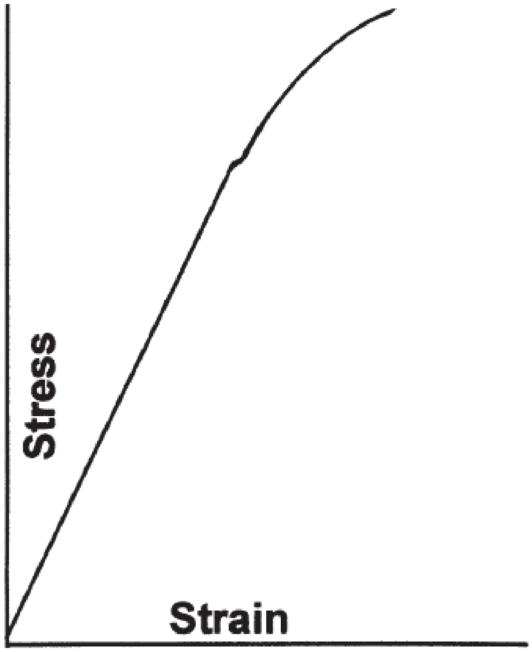


FIG. 25 Stress-Strain Diagram With an Inflection, But No YPE

to 7.11.3. However, these two parameters are not interchangeable. Use of the elongation at fracture method generally provides more repeatable results.

NOTE 40—When disagreements arise over the percent elongation results, agreement must be reached on which method to use to obtain the results.

7.12 *Reduction of Area*:

7.12.1 The reduced area used to calculate reduction of area (see 7.12.2 and 7.12.3) shall be the minimum cross section at the location of fracture.

7.12.2 *Specimens With Originally Circular Cross Sections*—Fit the ends of the fractured specimen together and measure the reduced diameter to the same accuracy as the original measurement.

NOTE 41—Because of anisotropy, circular cross sections often do not remain circular during straining in tension. The shape is usually elliptical, thus, the area may be calculated by $\pi \cdot d_1 \cdot d_2/4$, where d_1 and d_2 are the major and minor diameters, respectively.

7.12.3 *Specimens With Originally Rectangular Cross Sections*—Fit the ends of the fractured specimen together and measure the thickness and width at the minimum cross section to the same accuracy as the original measurements.

NOTE 42—Because of the constraint to deformation that occurs at the corners of rectangular specimens, the dimensions at the center of the original flat surfaces are less than those at the corners. The shapes of these surfaces are often assumed to be parabolic. When this assumption is made, an effective thickness, t_e, may be calculated by: $(t_1 + 4t_2 + t_3)/6$, where t_1 and t_3 are the thicknesses at the corners, and t_2 is the thickness at the mid-width. An effective width may be similarly calculated.

7.12.4 Calculate the reduced area based upon the dimensions determined in 7.12.2 or 7.12.3. The difference between the area thus found and the area of the original cross section expressed as a percentage of the original area is the reduction of area.

7.12.5 If any part of the fracture takes place outside the middle half of the reduced section or in a punched or scribed gage mark within the reduced section, the reduction of area value obtained may not be representative of the material. In acceptance testing, if the reduction of area so calculated meets the minimum requirements specified, no further testing is required, but if the reduction of area is less than the minimum requirements, discard the test results and retest.

7.12.6 Results of measurements of reduction of area shall be rounded using the procedures of Practice E 29 and any specific procedures in the product specifications. In the absence of a specified procedure, it is recommended that reduction of area test values in the range from 0 to 10 % be rounded to the nearest 0.5 % and test values of 10 % and greater to the nearest 1 %.

7.13 *Rounding Reported Test Data for Yield Strength and Tensile Strength*—Test data should be rounded using the procedures of Practice E 29 and the specific procedures in the product specifications. In the absence of a specified procedure

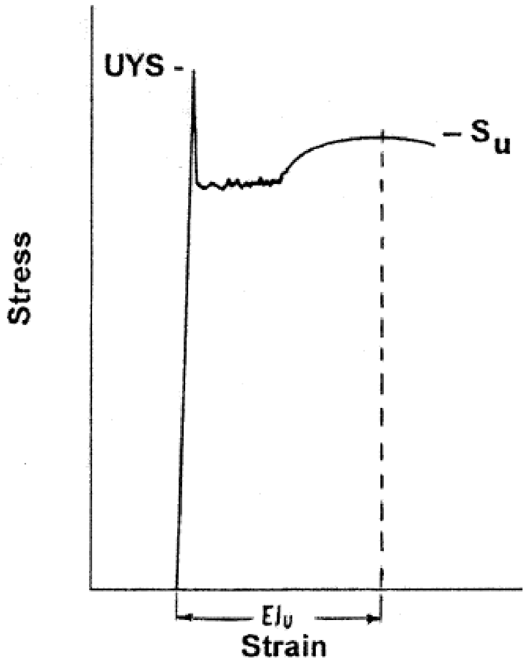


FIG. 26 Stress-Strain Diagram in Which the Upper Yield Strength is the Maximum Stress Recorded

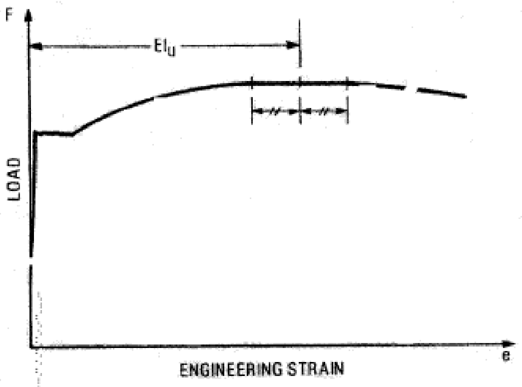


FIG. 27 Load-Strain Diagram for Determination of Uniform Elongation of Steel Sheet Materials Exhibiting a Plateau at Maximum Load

for rounding the test data, one of the procedures described in the following paragraphs is recommended.

7.13.1 For test values up to 500 MPa, round to the nearest 1 MPa; for test values of 500 MPa and up to 1000 MPa, round to the nearest 5 MPa; for test values of 1000 MPa and greater, round to the nearest 10 MPa.

NOTE 43—For steel products, see Test Methods and Definitions A 370.

7.13.2 For all test values, round to the nearest 1 MPa.

NOTE 44—For aluminum- and magnesium-alloy products, see Methods B 557M.

7.13.3 For all test values, round to the nearest 5 MPa.

7.14 *Replacement of Specimens*—A test specimen may be discarded and a replacement specimen selected from the same lot of material in the following cases:

7.14.1 The original specimen had a poorly machined surface,

7.14.2 The original specimen had the wrong dimensions,

7.14.3 The specimen's properties were changed because of poor machining practice,

7.14.4 The test procedure was incorrect,

7.14.5 The fracture was outside the gage length,

7.14.6 For elongation determinations, the fracture was outside the middle half of the gage length, or

7.14.7 There was a malfunction of the testing equipment.

NOTE 45—The tension specimen is inappropriate for assessing some types of imperfections in a material. Other methods and specimens employing ultrasonics, dye penetrants, radiography, etc., may be considered when flaws such as cracks, flakes, porosity, etc., are revealed during a test and soundness is a condition of acceptance.

8. Report

8.1 Test information on materials not covered by a product specification should be reported in accordance with 8.2 or both 8.2 and 8.3.

8.2 Test information to be reported shall include the following when applicable:

8.2.1 Material and sample identification.

8.2.2 Specimen type (Section 6).

8.2.3 Yield strength and the method used to determine yield strength (see 7.7).

8.2.4 Yield point elongation (see 7.8).

8.2.5 Tensile strength (see 7.10).

8.2.6 Elongation (report original gage length, percentage increase, and method used to determine elongation) (see 7.11).

8.2.7 Reduction of area, if required (see 7.12).

8.3 Test information to be available on request shall include:

8.3.1 Specimen test section dimension(s).

8.3.2 Formula used to calculate cross-sectional area of specimens taken from large-diameter tubular products.

8.3.3 Speed and method used to determine speed of testing (see 7.6).

8.3.4 Method used for rounding of test results (see 7.13).

8.3.5 Reasons for replacement specimens (see 7.14).

9. Precision and Bias [3]

9.1 *Precision*—An interlaboratory test program gave the following values for coefficients of variation for the most commonly measured tensile properties:

Coefficient of Variation, %

	Tensile Strength	Yield Strength Offset = 0.02 %	Yield Strength Offset = 0.2 %	Elongation Gage Length = 5 Diameters	Reduction of Area
CV% $_r$	0.9	2.7	1.4	3.0	2.8
CV% $_R$	1.3	4.5	2.3	6.4	4.6

CV% $_r$ = repeatability coefficient of variation in percent within a laboratory

CV %$_R$ = repeatability coefficient of variation in percent between laboratories

9.1.1 The values shown are the averages from tests on six frequently tested metals, selected to include most of the normal range for each property listed above. When these materials are compared, a large difference in coefficient of variation is found. Therefore, the values above should not be tightness; width; workmanship used to judge whether the difference between duplicate tests of a specific material is larger than expected. The values are provided to allow potential users of this test method to assess, in general terms, its usefulness for a proposed application.

9.2 *Bias*—The procedures in Test Methods E 8M for measuring tensile properties have no bias because these properties can only be defined in terms of a test method.

10. Keywords

10.1 accuracy; bending stress; discontinuous yielding; drop-of-the-beam; eccentric force application; elastic extension; elongation; extension-under-load; extensometer; force; free-running crosshead speed; gage length; halt-of-the force; percent elongation; plastic extension; preload; rate of stressing; rate of straining; reduced section; reduction of area; sensitivity; strain; stress; taring; tensile strength; tension testing; yield point elongation; yield strength

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[3] Supporting data can be found in Appendix I and additional data are available from ASTM Headquarters. Request RR: E28-1004 and E28-1006.

APPENDIXES

(Nonmandatory Information)

X1. FACTORS AFFECTING TENSION TEST RESULTS

X1.1 The precision and bias of tension test strength and ductility measurements depend on strict adherence to the stated test procedure and are influenced by instrumental and material factors, specimen preparation, and measurement/testing errors.

X1.2 The consistency of agreement for repeated tests of the same material is dependent on the homogeneity of the material, and the repeatability of specimen preparation, test conditions, and measurements of the tension test parameters.

X1.3 Instrumental factors that can affect test results include: the stiffness, damping capacity, natural frequency, and mass of moving parts of the tensile test machine; accuracy of force indication and use of forces within the verified range of the machine; rate of force application, alignment of the test specimen with the applied force, parallelness of the grips, grip pressure, nature of the force control used, appropriateness and calibration of extensometers, heat dissipation (by grips, extensometers, or ancillary devices), and so forth.

X1.4 Material factors that can affect test results include: representativeness and homogeneity of the test material, sampling scheme, and specimen preparation (surface finish, dimensional accuracy, fillets at the ends of the gage length, taper in the gage length, bent specimens, thread quality, and so forth).

X1.4.1 Some materials are very sensitive to the quality of the surface finish of the test specimen (see Note 8) and must be ground to a fine finish, or polished to obtain correct results.

X1.4.2 Test results for specimens with as-cast, as-rolled, as-forged, or other non-machined surface conditions can be affected by the nature of the surface (see Note 14).

X1.4.3 Test specimens taken from appendages to the part or component, such as prolongs or risers, or from separately produced castings (for example, keel blocks) may produce test results that are not representative of the part or component.

X1.4.4 Test specimen dimensions can influence test results. For cylindrical or rectangular specimens, changing the test specimen size generally has a negligible effect on the yield and tensile strength but may influence the upper yield strength, if one is present, and elongation and reduction of area values.

Comparison of elongation values determined using different specimens requires that the following ratio be controlled:

$$L_0/(A_0)^{1/2} \qquad \text{(X1.1)}$$

where:

L_0 = original gage length of specimen, and

A_0 = original cross-sectional area of specimen.

X1.4.4.1 Specimens with smaller $L_0/(A_0)^{1/2}$ ratios generally give greater elongation and reduction in area values. This is the case, for example, when the width or thickness of a rectangular tensile test specimen is increased.

X1.4.4.2 Holding the $L_0/(A_0)^{1/2}$ ratio constant minimizes, but does not necessarily eliminate, differences. Depending on material and test conditions, increasing the size of the proportional specimen of Fig. 8 may be found to increase or decrease elongation and reduction in area values somewhat.

X1.4.5 Use of a taper in the gage length, up to the allowed 1 % limit, can result in lower elongation values. Reductions of as much as 15 % have been reported for a 1 % taper.

X1.4.6 Changes in the strain rate can affect the yield strength, tensile strength, and elongation values, especially for materials which are highly strain rate sensitive. In general, the yield strength and tensile strength will increase with increasing strain rate, although the effect on tensile strength is generally less pronounced. Elongation values generally decrease as the strain rate increases.

X1.4.7 Brittle materials require careful specimen preparation, high quality surface finishes, large fillets at the ends of the gage length, oversize threaded grip sections, and cannot tolerate punch or scribe marks as gage length indicators.

X1.4.8 Flattening of tubular products to permit testing does alter the material properties, generally nonuniformity, in the flattened region which may affect test results.

X1.5 Measurement errors that can affect test results include: verification of the test force, extensometers, micrometers, dividers, and other measurement devices, alignment and zeroing of chart recording devices, and so forth.

X1.5.1 Measurement of the dimensions of as-cast, as-rolled, as-forged, and other test specimens with non-machined surfaces may be imprecise due to the irregularity of the surface flatness.

X1.5.2 Materials with anisotropic flow characteristics may exhibit non-circular cross sections after fracture and measurement precision may be affected, as a result (see Note 37).

X1.5.3 The corners of rectangular test specimens are subject to constraint during deformation and the originally flat surfaces may be parabolic in shape after testing which will affect the precision of final cross-sectional area measurements (see Note 42).

X1.5.4 If any portion of the fracture occurs outside of the middle of the gage length, or in a punch or scribe mark within the gage length, the elongation and reduction of area values may not be representative of the material. Wire specimens that break at or within the grips may not produce test results representative of the material.

X1.5.5 Use of specimens with shouldered ends ("button-head" tensiles) will produce lower 0.02 % offset yield strength values than threaded specimens.

X1.6 Because standard reference materials with certified tensile property values are not available, it is not possible to rigorously define the bias of tension tests. However, by the use of carefully designed and controlled interlaboratory studies, a reasonable definition of the precision of tension test results can be obtained.

X1.6.1 An interlaboratory test program, (see footnote 7), was conducted in which six specimens each, of six different materials were prepared and tested by each of six different laboratories. Tables X1.1-X1.5 present the precision statistics, as defined in Practice E 691, for: tensile strength, 0.02 % yield strength, 0.2 % yield strength, % elongation in 5D, and % reduction in area. In each table, the first column lists the six materials tested, the second column lists the average of the average results obtained by the laboratories, the third and fifth columns list the repeatability and reproducibility standard deviations, the fourth and sixth columns list the coefficients of variation for these standard deviations, and the seventh and eighth columns list the 95 % repeatability and reproducibility limits.

X1.6.2 The averages (below columns four and six in each table) of the coefficients of variation permit a relative comparison of the repeatability (within-laboratory precision) and reproducibility (between-laboratory precision) of the tension

TABLE X1.1 Precision Statistics—Tensile Strength, MPa

NOTE 1— X is the average of the cell averages, that is, the grand mean for the test parameter,
s_r is the repeatability standard deviation (within-laboratory precision),
s_r/X is the coefficient of variation in %,
s_R is the reproducibility standard deviation (between-laboratory precision),
s_R/X is the coefficient of variation, %,
r is the 95 % repeatability limits,
R is the 95 % reproducibility limits.

Material	X	s_r	s_r/X,%	s_R	s_R/X, %	r	R
EC-H19	176.9	4.3	2.45	4.3	2.45	12.1	12.1
2024-T351	491.3	6.1	1.24	6.6	1.34	17.0	18.5
ASTM A105	596.9	4.1	0.69	8.7	1.47	11.6	24.5
AISI 316	694.6	2.7	0.39	8.4	1.21	7.5	23.4
Inconel 600	685.9	2.9	0.43	5.0	0.72	8.2	13.9
SAE 51410	1253.0	3.2	0.25	7.9	0.63	8.9	22.1
		Averages:	0.91		1.30		

TABLE X1.2 Precision Statistics—0.02 % Yield Strength, MPa

Material	X	s_r	s_r/X,%	s_R	s_R/X, %	r	R
EC-H19	111.4	4.5	4.00	8.2	7.37	12.5	23.0
2024-T351	354.2	5.8	1.64	6.1	1.73	16.3	17.2
ASTM A105	411.4	8.3	2.02	13.1	3.18	23.2	36.6
AISI 316	336.1	16.7	4.97	31.9	9.49	46.1	89.0
Inconel 600	267.1	3.2	1.18	5.2	1.96	8.8	14.7
SAE 51410	723.2	16.6	2.29	21.9	3.02	46.4	61.2
		Averages:	2.68		4.46		

TABLE X1.3 Precision Statistics—0.2 % Yield Strength, MPa

Material	X	s_r	s_r/X,%	s_R	s_R/X, %	r	R
EC-H19	158.4	3.3	2.06	3.3	2.07	9.2	9.2
2024-T351	362.9	5.1	1.41	5.4	1.49	14.3	15.2
ASTM A105	402.4	5.7	1.42	9.9	2.47	15.9	27.8
AISI 316	481.1	6.6	1.36	19.5	4.06	18.1	54.7
Inconel 600	268.3	2.5	0.93	5.8	2.17	7.0	16.3
SAE 51410	967.5	8.9	0.92	15.9	1.64	24.8	44.5
		Averages:	1.35		2.32		

TABLE X1.4 Precision Statistics— % Elongation in 5D

NOTE 1—Length of reduced section = 6D.

Material	X	s_r	s_r/X,%	s_R	s_R/X, %	r	R
EC-H19	14.60	0.59	4.07	0.66	4.54	1.65	1.85
2024-T351	17.99	0.63	3.48	1.71	9.51	1.81	4.81
ASTM A105	25.63	0.77	2.99	1.30	5.06	2.15	3.63
AISI 316	35.93	0.71	1.98	2.68	7.45	2.00	7.49
Inconel 600	41.58	0.67	1.61	1.60	3.86	1.88	4.49
SAE 51410	12.39	0.45	3.61	0.96	7.75	1.25	2.69
		Averages:	2.96		6.36		

TABLE X1.5 Precision Statistics— % Reduction in Area

Material	X	s_r	s_r/X,%	s_R	s_R/X, %	r	R
EC-H19	79.15	1.93	2.43	2.01	2.54	5.44	5.67
2024-T351	30.41	2.09	6.87	3.59	11.79	5.79	10.01
ASTM A105	65.59	0.84	1.28	1.26	1.92	2.35	3.53
AISI 316	71.49	0.99	1.39	1.60	2.25	2.78	4.50
Inconel 600	59.34	0.67	1.14	0.70	1.18	1.89	1.97
SAE 51410	50.49	1.86	3.69	3.95	7.81	5.21	11.05
		Averages:	2.80		4.58		

test parameters. This shows that the ductility measurements exhibit less repeatability and reproducibility than the strength measurements. The overall ranking from the least to the most repeatable and reproducible is: % elongation in 5D, % reduction in area, 0.02 % offset yield strength, 0.2 % offset yield strength, and tensile strength. Note that the rankings are in the same order for the repeatability and reproducibility average coefficients of variation and that the reproducibility (between-laboratory precision) is poorer than the repeatability (within-laboratory precision), as would be expected.

X1.6.3 No comments about bias can be made for the interlaboratory study due to the lack of certified test results for these specimens. However, examination of the test results showed that one laboratory consistently exhibited higher than average strength values and lower than average ductility values for most of the specimens. One other laboratory had consistently lower than average tensile strength results for all specimens.

X2. MEASUREMENT OF SPECIMEN DIMENSIONS

X2.1 Measurement of specimen dimensions is critical in tension testing, and it becomes more critical with decreasing specimen size, as a given absolute error becomes a larger relative (percent) error. Measuring devices and procedures should be selected carefully, so as to minimize measurement error and provide good repeatability and reproducibility.

X2.2 Relative measurement error should be kept at or below 1 %, where possible. Ideally, this 1 % error should include not only the resolution of the measuring device but also the variability commonly referred to as repeatability and reproducibility. (Repeatability is the ability of any operator to obtain similar measurements in repeated trials. Reproducibility is the ability of multiple operators to obtain similar measurements.)

X2.3 Formal evaluation of gage repeatability and reproducibility (GR and R) by way of a GR and R study is highly recommended. A GR and R study involves having multiple operators each take two or three measurements of a number of parts—in this case, test specimens. Analysis, usually done by computer, involves comparing the observed measurement variations to a tolerance the procedure is to determine conformance to. High GR and R percentages (more than 20 %) indicate much variability relative to the tolerance, whereas low percentages (10 % or lower) indicate the opposite. The analysis also estimates, independently, the repeatability and reproducibility.

X2.4 GR and R studies in which nontechnical personnel used different brands and models of hand-held micrometers have given results varying from about 10 % (excellent) to nearly 100 % (essentially useless), relative to a dimensional tolerance of 0.075 mm. The user is, therefore, advised to be very careful in selecting devices, setting up measurement procedures, and training personnel.

X2.5 With a 0.075 mm tolerance, a 10 % GR and R result (exceptionally good, even for digital hand-held micrometers reading to 0.001 mm) indicates that the total variation due to repeatability and reproducibility is around 0.0075 mm. This is less than or equal to 1 %, only if all dimensions to be measured are greater than or equal to 0.75 mm. The relative error in using this device to measure thickness of a 0.25 mm flat tensile specimen would be 3 %, which is considerably more than that allowed for load or strain measurement.

X2.6 Dimensional measurement errors can be identified as the cause of many *out-of-control* signals, as indicated by statistical process control (SPC) charts used to monitor tension testing procedures. This has been the experience of a production laboratory employing SPC methodology and the best hand-held micrometers available (from a GR and R standpoint) in testing of 0.45 mm to 6.35 mm flat-rolled steel products.

X2.7 Factors which affect GR and R, sometimes dramatically, and which should be considered in the selection and evaluation of hardware and procedures include:

X2.7.1 Resolution,
X2.7.2 Verification,
X2.7.3 Zeroing,
X2.7.4 Type of anvil (flat, rounded, or pointed),
X2.7.5 Cleanliness of part and anvil surfaces,
X2.7.6 User-friendliness of measuring device,
X2.7.7 Stability/temperature variations,
X2.7.8 Coating removal,
X2.7.9 Operator techique, and
X2.7.10 Ratchets or other features used to regulate the clamping force.

X2.8 Flat anvils are generally preferred for measuring the dimensions of round or flat specimens which have relatively smooth surfaces. One exception is that rounded or pointed anvils must be used in measuring the thickness of curved specimens taken from large-diameter tubing (see Fig. 13), to prevent overstating the thickness. (Another concern for these curved specimens is the error that can be introduced through use of the equation $A = W \times T$; see 7.2.3.)

X2.9 Heavy coatings should generally be removed from at least one grip end of flat specimens taken from coated products to permit accurate measurement of base metal thickness, assuming (*a*) the base metal properties are what are desired, (*b*) the coating does not contribute significantly to the strength of the product, and (*c*) coating removal can be easily accomplished (some coatings may be easily removed by chemical stripping). Otherwise, it may be advisable to leave the coating intact and determine the base metal thickness by an alternate method. Where this issue may arise, all parties involved in comparison or conformance testing should agree as to whether or not coatings are to be removed before measurement.

X2.10 As an example of how the considerations identified above affect dimensional measurement procedures, consider the case of measuring the thickness of 0.40 mm painted, flat rolled steel specimens. The paint should be removed prior to measurement, if possible. The measurement device used should have flat anvils, must read to 0.001 mm or better, and must have excellent repeatability and reproducibility. Since GR and R is a significant concern, it will be best to use a device which has a feature for regulating the clamping force used, and devices without digital displays should be avoided to prevent reading errors. Before use of the device, and periodically during use, the anvils should be cleaned, and the device should be verified or zeroed (if an electronic display is used) or both. Finally, personnel should be trained and audited periodically to ensure that the measuring device is being used correctly and consistently by all.

X3. SUGGESTED ACCREDITATION CRITERIA FOR LABORATORIES PERFORMING TENSILE TESTS

X3.1 Scope

X3.1.1 The following are specific features that an assessor may check to assess a laboratory's technical competence, if the laboratory is performing tests in accordance with Test Methods E 8 and/or E 8M.

X3.2 Preparation

X3.2.1 The laboratory should follow documented procedures to ensure that machining or other preparation generates specimens conforming to applicable tolerances and requirements of Test Methods E 8 or E 8M. Particularly important are those requirements that pertain to the dimensions and finish of reduced sections, as found in the text and in applicable figures.

X3.2.2 Where gage marks are used, the laboratory should employ documented gage marking procedures to ensure that the marks and gage lengths comply with the tolerances and guidelines of Test Methods E 8 or E 8M.

X3.2.2.1 The gage marking procedure used should not deleteriously affect the test results.

NOTE X3.1—Frequent occurrence of fracturing at the gage marks may indicate that gage marks have excessive depth or sharpness and may be affecting test results.

X3.3 Test Equipment

X3.3.1 As specified in the Apparatus sections of Test Methods E 8 and E 8M, the axis of the test specimen should coincide with the center line of the heads of the testing machine, in order to minimize bending stresses which could affect the results.

X3.3.2 Equipment verification requirements of Practices E 4 and E 83 shall be met. Documentation showing the verification work to have been thorough and technically correct should be available.

X3.3.2.1 Verification reports shall demonstrate that force and extension readings have been taken at the prescribed intervals and that the prescribed runs have been completed.

X3.3.3 Extensometers used shall meet all requirements of Test Methods E 8 or E 8M as to the classification of device to be used for the results determined. For example, an extensometer not meeting the Class B2 requirements of Practice E 83 may not be used in determination of offset yield strengths.

X3.3.4 Before computerized or automated test equipment is put into routine service, or following a software revision, it is recommended that measures be taken to verify proper operation and result interpretation. Guide E 1856 addresses this concern.

X3.3.5 Micrometers and other devices used in measurement of specimen dimensions should be selected, maintained and used in such a manner as to comply with the appendixes of Test Methods E 8 and E 8M on measurement. Traceability to national standards should be established for these devices, and reasonable effort should be employed to prevent errors greater than 1 % from being generated as a result of measurement error, resolution, and rounding practice.

X3.4 Procedures

X3.4.1 The test machine shall be set up and zeroed in such a manner that zero force indication signifies a state of zero force on the specimen, as indicated in the Zeroing of the Test Machine sections of Test Methods E 8 and E 8M.

NOTE X3.2—Provisions should be made to ensure that zero readings are properly maintained, from test to test. These may include, for example, zeroing after a predetermined number of tests or each time, under zero force conditions, the indicator exceeds a predetermined value.

X3.4.2 Upon request, the laboratory should be capable of demonstrating (perhaps through time, force, displacement or extensometer measurements, or both) that the test speeds used conform to the requirements of Test Methods E 8 or E 8M, or other standards which take precedence.

X3.4.3 Upon request, the laboratory should be capable of demonstrating that the offsets and extensions used in determining yield strengths conform to the requirements of Test Methods E 8 or E 8M and are constructed so as to indicate the forces corresponding to the desired offset strain or total strain.

NOTE X3.3—Use caution when performing calculations with extensometer magnification, because the manufacturer may report strain magnification, which relates the strain (not the elongation) to the *x*-axis displacement on the stress strain diagram. A user or assessor interested in an extensometer's magnification may use calibration equipment to determine the ratio between elongation and chart travel or may verify a reported magnification by calculating the Young's modulus from tests of specimens of a known nominal modulus.

X3.4.4 Measurement of elongation shall conform to requirements of Test Methods E 8 or E 8M.

NOTE X3.4—Test Methods E 8 and E 8M permit the measurement and reporting of elongation at fracture in place of elongation, as is often done in automated testing.

X3.4.5 Reduction of area, when required, shall be determined in accordance with the requirements of Test Methods E 8 or E 8M.

X3.4.6 Procedures for recording, calculating, and reporting data and test results shall conform to all applicable requirements of Test Methods E 8 or E 8M. In addition, wherever practical, the procedures should also be in accordance with widely accepted provisions of good laboratory practice, such as those detailed below.

X3.4.6.1 When recording data, personnel should record all figures that are definite, plus the best estimate of the first figure which is uncertain. (If a result is known to be approximately midway between 26 and 27, 26.5 should be the result recorded (not 26, 27, or 26.475).

X3.4.6.2 When performing calculations, personnel should avoid compounding of rounding errors. This may be accomplished by performing one large calculation, rather than several calculations using individual results. Alternatively, if multistep calculations are done, intermediate results should not be rounded before use in subsequent calculations.

X3.4.6.3 In rounding, no final result should retain more significant figures than the least-significant-figure measurement or data point used in the calculation.

X3.5 Retention

X3.5.1 A retention program appropriate for the nature and frequency of testing done in the laboratory should be maintained. Items that may warrant retention for defined time periods include:

X3.5.1.1 Raw data and forms,

X3.5.1.2 Force-elongation or stress-strain charts,

X3.5.1.3 Computer printouts of curves and test results,

X3.5.1.4 Data and results stored on computer discs or hard drives,

X3.5.1.5 Broken specimens,

X3.5.1.6 Excess material,

X3.5.1.7 Test reports, and

X3.5.1.8 Verification reports and certifications.

X3.6 Environment

X3.6.1 All test equipment should be located and connected to power sources in such a manner as to minimize the effects of vibrations and electrical disturbances on raw data collected, stress-strain charts, and operation of equipment.

X3.7 Controls

X3.7.1 Controlled procedures and work instructions should cover all aspects of specimen preparation, tensile testing, and result reporting. These documents should be readily available to all involved in the documented tasks.

X3.7.2 Clear, concise, operating instructions should be maintained for equipment used in specimen preparation and tensile testing. These instructions should be readily available to all qualified operators.

X3.7.3 All applicable verification requirements shall be met, as detailed in X3.3.2.

X3.7.4 It is recommended that special studies and programs be employed to monitor and control tensile testing, because tensile test results are easily affected by operators, measuring devices, and test equipment. Examples of such programs include but are not limited to:

X3.7.4.1 Round-robin studies, proficiency tests, or other cross-checks,

X3.7.4.2 Repeatability and reproducibility (R and R) studies,

X3.7.4.3 Control charting, and

X3.7.4.4 Determination of typical lab uncertainties for each result typically reported.

NOTE X3.5—For nondestructive testing, repeatability and reproducibility are often measured by conducting gage R and R studies, as discussed in Appendix X2 of Test Methods E 8 and E 8M. These studies involve repeated determination of a test result, using a single part or specimen, so gage R and Rs are not directly applicable to mechanical properties, which are obtained through destructive testing. (True differences between even the best duplicate specimens manifest themselves in the form of poorer R and R results than would be obtained for perfect duplicates.) Nevertheless, quasi-R and R studies conducted with these limitations taken into consideration may be helpful in analyzing sources of error and improving reliability of test results.

SUMMARY OF CHANGES

Committee E28 has identified the location of selected changes to this standard since the last issue (E 8M – 03) that may impact the use of this standard. (Approved July 10, 2003)

(1) Section 7.9.3.2 was revised. Note 36 and a discussion were added following this revised section.

Committee E28 has identified the location of selected changes to this standard since the last issue (E 8M – 01) that may impact the use of this standard. (Approved Oct. 10, 2001)

(1) Section 6.5 and it subsections were revised.

(2) Note 10 was deleted and the remaining notes were renumbered.

(3) Appendix X3 was added.

ANEXO B. Norma ASTM E9 Pruebas a compresión

Designation: E 9 – 89a (Reapproved 2000)

An American National Standard

Standard Test Methods of Compression Testing of Metallic Materials at Room Temperature[1]

This standard is issued under the fixed designation E 9; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 These test methods cover the apparatus, specimens, and procedure for axial-load compression testing of metallic materials at room temperature (Note 1). For additional requirements pertaining to cemented carbides, see Annex A1.

NOTE 1—For compression tests at elevated temperatures, see Practice E 209.

1.2 The values stated in inch-pound units are to be regarded as the standard. The metric equivalent values cited in the standard may be approximate.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

B 557 Test Methods for Tension Testing Wrought and Cast Aluminum- and Magnesium-Alloy Products[2]

E 4 Practices for Force Verification of Testing Machines[3]

E 6 Terminology Relating to Methods of Mechanical Testing[3]

E 83 Practice for Verification and Classification of Extensometer[3]

E 111 Test Method for Young's Modulus, Tangent Modulus, and Chord Modulus[3]

E 171 Specification for Standard Atmospheres for Conditioning and Testing Flexible Barrier Materials[4]

E 177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods[5]

E 209 Practice for Compression Tests of Metallic Materials at Elevated Temperatures with Conventional or Rapid Heating Rates and Strain Rates[3]

E 251 Test Methods for Performance Characteristics of Metallic Bonded Resistance Strain Gages[3]

3. Terminology

3.1 *Definitions:* The definitions of terms relating to compression testing and room temperature in Terminology E 6 and Specification E 171, respectively, shall apply to these test methods.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *buckling*—In addition to compressive failure by crushing of the material, compressive failure may occur by (*1*) elastic instability over the length of a column specimen due to nonaxiality of loading, (*2*) inelastic instability over the length of a column specimen, (*3*) a local instability, either elastic or inelastic, over a small portion of the gage length, or (*4*) a twisting or torsional failure in which cross sections rotate over each other about the longitudinal specimen axis. These types of failures are all termed *buckling*.

3.2.2 *column*—a compression member that is axially loaded and that may fail by buckling.

3.2.3 *radius of gyration*—the square root of the ratio of the moment of inertia of the cross section about the centroidal axis to the cross-sectional area:

$$\rho = (I/A)^{1/2} \tag{1}$$

where:

ρ = radius of gyration,
I = moment of inertia of the cross section about centroidal axis (for specimens without lateral support, the smaller value of I is the critical value), and
A = cross-sectional area.

3.2.4 *critical stress*—the axial uniform stress that causes a column to be on the verge of buckling. The critical load is calculated by multiplying the critical stress by the cross-section area.

3.2.5 *buckling equations*—If the buckling stress is less than or equal to the proportional limit of the material its value may be calculated using the Euler equation:

$$S_{cr} = C\pi^2 E/(L/\rho)^2 \tag{2}$$

If the buckling stress is greater than the proportional limit of the material its value may be calculated from the modified Euler equation:

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[1] These test methods are under the jurisdiction of ASTM Committee E28 on Mechanical Testing and are the direct responsibility of Subcommittee E28.04 on Uniaxial Testing.

Current edition approved March 31, 1989. Published May 1989. Originally published as E 9 – 24 T. Last previous edition E 9 – 89.

[2] *Annual Book of ASTM Standards*, Vol 02.02.

[3] *Annual Book of ASTM Standards*, Vol 03.01.

[4] *Annual Book of ASTM Standards*, Vol 15.09.

[5] *Annual Book of ASTM Standards*, Vol 14.02.

$$S_{cr} = C\pi^2 E_t/(L/\rho)^2 \tag{3}$$

where:

S_{cr} = critical buckling stress,
E = Young's modulus,
E_t = tangent modulus at the buckling stress,
L = column length, and
C = end-fixity coefficient.

Methods of calculating the critical stress using Eq 3 are given in Ref **(1)**.[6]

3.2.6 *end-fixity coefficient*—There are certain ideal specimen end-fixity conditions for which theory will define the value of the constant C (see Fig. 1). These values are:

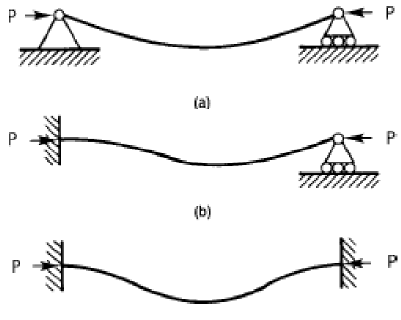

FIG. 1 Diagrams Showing Fixity Conditions and Resulting Buckling of Deformation

Freely rotating ends (pinned or hinged)	$C = 1$ (*a*)
One end fixed, the other free to rotate	$C = 2$ (*b*)
Both ends fixed	$C = 4$ (*c*)

NOTE 2—For flat-end specimens tested between flat rigid anvils, it was shown in Ref **(1)** that a value of $C = 3.75$ is appropriate.

3.2.7 *barreling*—restricted deformation of the end regions of a test specimen under compressive load due to friction at the specimen end sections and the resulting nonuniform transverse deformation as shown schematically and in the photograph in Fig. 2. Additional theoretical and experimental information on barreling as illustrated in Fig. 2 is given in Ref **(2)**.

4. Summary of Test Methods

4.1 The specimen is subjected to an increasing axial compressive load; both load and strain may be monitored either continuously or in finite increments, and the mechanical properties in compression determined.

5. Significance and Use

5.1 *Significance*—The data obtained from a compression test may include the yield strength, the yield point, Young's modulus, the stress-strain curve, and the compressive strength (see Terminology E 6). In the case of a material that does not fail in compression by a shattering fracture, compressive strength is a value that is dependent on total strain and specimen geometry.

5.2 *Use*—Compressive properties are of interest in the analyses of structures subject to compressive or bending loads or both and in the analyses of metal working and fabrication processes that involve large compressive deformation such as forging and rolling. For brittle or nonductile metals that fracture in tension at stresses below the yield strength, compression tests offer the possibility of extending the strain range of the stress-strain data. While the compression test is not complicated by necking as is the tension test for certain metallic materials, buckling and barreling (see Section 3) can complicate results and should be minimized.

6. Apparatus

6.1 *Testing Machines*—Machines used for compression testing shall conform to the requirements of Practices E 4. For universal machines with a common test space, calibration shall be performed in compression.

6.1.1 The bearing surfaces of the heads of the testing machine shall be parallel at all times with 0.0002 in./in. (m/m) unless an alignment device of the type described in 6.3 is used.

6.2 *Bearing Blocks*:

6.2.1 Both ends of the compression specimen shall bear on blocks with surfaces flat and parallel within 0.0002 in./in. (m/m). Lack of initial parallelism can be overcome by the use of adjustable bearing blocks (Note 3). The blocks shall be made of, or faced with, hard material. Current laboratory practice suggests the use of tungsten carbide when testing steel and hardened steel blocks (55 HRC or greater) and when testing nonferrous materials such as aluminum, copper, etc. The specimen must be carefully centered with respect to the testing machine heads or the subpress if used (see 6.3, Alignment Device/Subpress).

NOTE 3—It should be remembered that the object of an adjustable bearing block is to give the specimen as even a distribution of initial load as possible. An adjustable bearing block cannot be relied on to compensate for any tilting of the heads that may occur during the test.

6.2.2 The bearing faces of adjustable bearing blocks that contact the specimen shall be made parallel before the load is applied to the specimen. One type of adjustable bearing block that has proven satisfactory is illustrated in Fig. 3. Another arrangement involving the use of a spherical-seated bearing block that has been found satisfactory for testing material other than in sheet form is shown in Fig. 4. It is desirable that the spherical-seated bearing block be at the upper end of the test specimen (for specimens tested with the load axis vertical). The spherical surface of the block shall be defined by a radius having its point of origin in the flat surface that bears on the specimen.

6.3 *Alignment Device/Subpress*:

6.3.1 It is usually necessary to use an alignment device, unless the testing machine has been designed specifically for axial alignment. The design of the device or subpress is largely dependent on the size and strength of the specimen. It must be designed so that the ram (or other moving parts) does not jam or tilt the device or the frame of the machine as a result of loading. The bearing blocks of the device shall have the same requirements for parallelism and flatness as given in 6.2.1.

6.3.2 The primary requirements of all alignment devices are that the load is applied axially, uniformly, and with negligible

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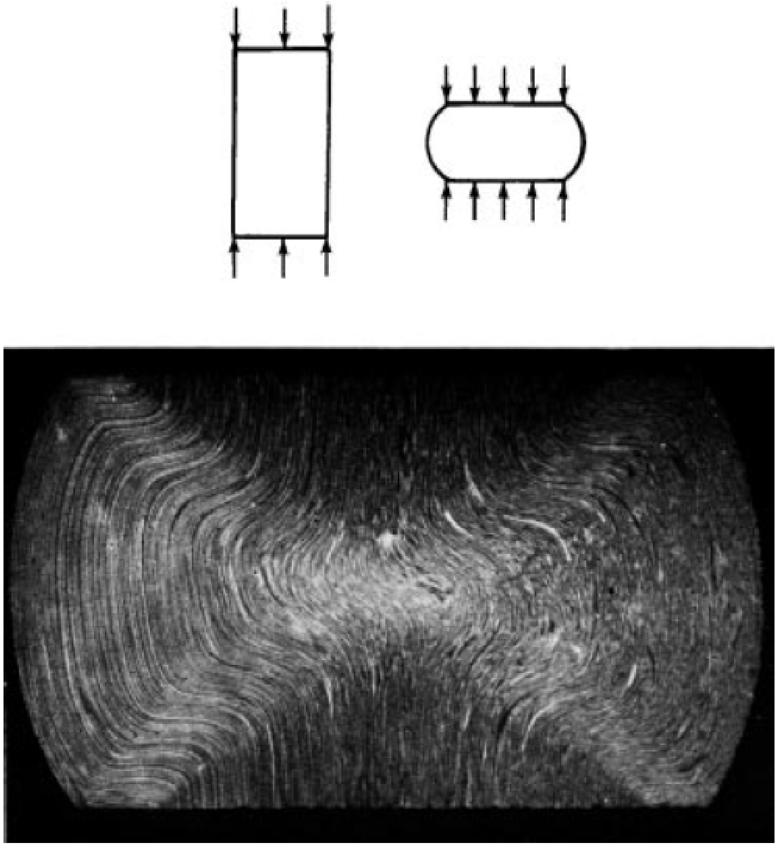
[6] The boldface numbers in parentheses refer to the list of references at the end of this standard.



NOTE 1—A cylindrical specimen of AISI 4340 steel (HRC = 40) was compressed 57 % (see upper diagram). The photo macrograph was made of a polished and etched cross section of the tested specimen. The highly distorted flow lines are the result of friction between the specimen ends and the loading fixture. Note the triangular regions of restricted deformation at the ends and the cross-shaped zone of severe shear.

FIG. 2 Illustration of Barreling

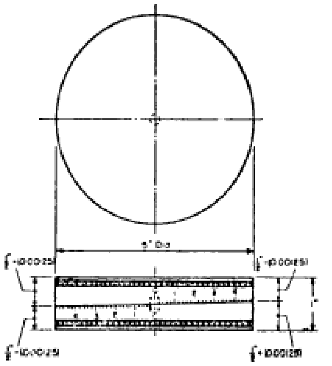


FIG. 3 Adjustable Bearing Block for Compression Testing

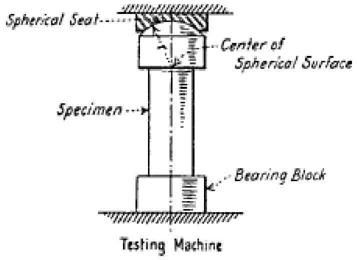


FIG. 4 Spherical-Seated Bearing Block

"slip-stick" friction. An alignment device that has been found suitable is shown in Fig. 5 and described in Ref. (**3**). Other devices of the subpress type have also been used successfully.

6.4 *Compression Testing Jigs*—In testing thin specimens, such as sheet material, some means should be adopted to prevent the specimen from buckling during loading. This may be accomplished by using a jig containing sidesupport plates that bear against the wide sides of the specimen. The jig must afford a suitable combination of lateral-support pressure and spring constant to prevent buckling, but without interfering

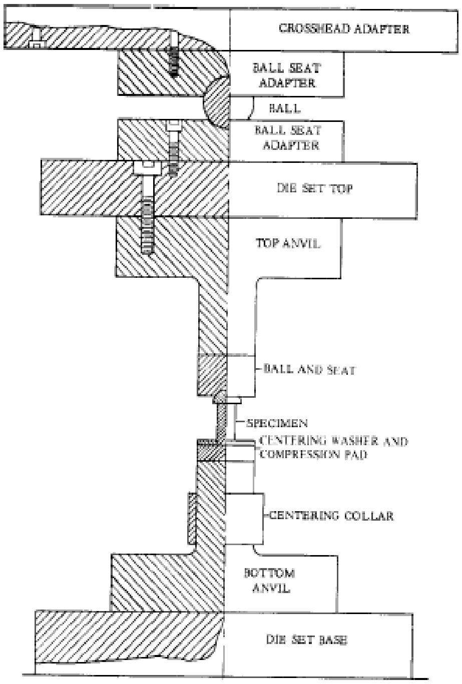


FIG. 5 Example of Compression Testing Apparatus

with axial deformation of the specimen. Although suitable combinations vary somewhat with variations in specimen material and thickness, testing temperatures, and accuracy of alignment, acceptable results can be obtained with rather wide ranges of lateral-support pressure and spring constant. Generally, the higher the spring constant of the jig, the lower the lateral-support pressure that is required. Proper adjustments of these variables should be established during the qualification of the equipment (see 6.6).

6.4.1 It is not the intent of these methods to designate specific jigs for testing sheet materials, but merely to provide a few illustrations and references to jigs that have been used successfully, some of which are cited in Table 1. Other jigs are acceptable provided they prevent buckling and pass the qualification test set forth in 6.6. Compression jigs generally require that the specimen be lubricated on the supported sides to prevent extraneous friction forces from occurring at the support points.

6.5 *Strain Measurements*:

6.5.1 Mechanical or electromechanical devices used for measuring strain shall comply with the requirements for the applicable class described in Practice E 83. The device shall be verified in compression.

6.5.2 Electrical-resistance strain gages (or other single-use devices) may be used provided the measuring system has been verified and found to be accurate to the degree specified in Practice E 83. The characteristics of electrical resistance strain gages have been determined from Test Methods E 251.

6.6 *Qualification of Test Apparatus*— The complete compression-test apparatus, which consists of the testing machine and when applicable, one or more of the following; the alignment device, the jig and the strain-measurement system, shall be qualified as follows:

6.6.1 Conduct tests to establish the elastic modulus or five replicate specimens of 2024-T3 aluminum alloy sheet or 2024-T4 aluminum alloy bar in accordance with Test Method E 111. These qualification specimens shall be machined from sheet or bar in the location specified in Test Methods B 557. The thickness of the sheet or diameter of the bar may be machined to the desired thickness or diameter. It is essential that the extensometer be properly seated on the specimens when this test is performed. When the qualification specimens each provide a modulus value of 10.7×10^6 psi (73.8 GPa) ±5 %, the apparatus qualifies.

6.6.2 The qualification procedure shall be performed using the thinnest rectangular specimen or smallest diameter round specimen to be tested in the apparatus.

7. Test Specimens

7.1 *Specimens in Solid Cylindrical Form*—It is recommended that, where feasible, compression test specimens be in the form of solid circular cylinders. Three forms of solid

TABLE 1 Representative Compression Jigs and Specimen Dimensions for Testing of Thin Sheet[A]

Type of Jig	Ref	Thickness		Width		Length		Gage Length	
		in.	mm	in.	mm	in.	mm	in.	mm
Montgomery-Templin:	(4 and 5)								
General use		0.016 and over	0.40 and over	0.625	16.0	2.64	67.0	1	25
Magnesium alloys		0.016 and over	0.40 and over	0.750[B]	20.0	2.64	67.0	1	25
NACA (Kotanchik et al)	(6)	0.020 and over	0.50 and over	0.53	13.6	2.53	64.5	1	25
Moore-McDonald	(7)	0.032 and over	0.80 and over	0.75[C]	20.0	2.64	67.0	1	25
LaTour-Wolford	(8)	0.010 to 0.020	0.25 to 0.50	0.50	12.5	1.95	49.5	1	25
		0.020 and over	0.50 and over	0.50	12.5	2.00	51.0	1	25
Miller	(9-11)	0.006 to 0.010	0.15 to 0.25	0.48	12.2	2.22	56.5	1	25
		0.010 to 0.020	0.25 to 0.50	0.50	12.5	2.23	56.5	1	25
		0.020 and over	0.50 and over	0.50	12.5	2.25	57.0	1	25
Sandorff-Dillon:	(12)								
General use		0.010 and over	0.25 and over	0.50	12.5	4.12	104.5	2	50
High-strength steel		0.010 and over	0.25 and over	0.50	12.5	3.10	78.5	2	50

[A] See Ref. **(13)** for additional jigs and specimen dimensions.
[B] Reduced to 0.625 in. (16.0 mm) for 1.25 in. (30 mm) at the mid-length.
[C] Reduced to 0.650 in. (16.5 mm) for 1.25 in. (30 mm) at the mid-length.

cylindrical test specimens for metallic materials are recognized, and designated as short, medium-length, and long (Note 4). Suggested dimensions for solid compression test specimens for general use are given in Table 2.

NOTE 4—Short specimens typically are used for compression tests of such materials as bearing metals, which in service are used in the form of thin plates to carry load perpendicular to the surface. Medium-length specimens typically are used for determining the general compressive strength properties of metallic materials. Long specimens are best adapted for determining the modulus of elasticity in compression of metallic materials. The specimen dimensions given in Table 2 have been used successfully. Specimens with a *L/D* (length/diameter ratio) of 1.5 or 2.0 are best adapted for determining the compressive strength of high-strength materials.

7.2 *Rectangular or Sheet-Type Specimens*—Test specimens shall be flat and preferably of the full thickness of the material. Where lateral support is necessary, the width and length are dependent upon the dimensions of the jig used to support the specimen. The length shall be sufficient to allow the specimen to shorten the amount required to define the yield strength, or yield point, but not long enough to permit buckling in the unsupported portion. Specimen dimensions and the various types of jigs are given in Table 1.

7.3 *Preparation of Specimens*—Lateral surfaces in the gage length shall not vary in diameter, width, or thickness by more than 1 % or 0.002 in. (0.05 mm), whichever is less. (If a reduced section is used, this requirement applies only to the surface of the reduced section.) Also, the centerline of all lateral surfaces of the specimens shall be coaxial within 0.01 in. (0.25 mm).

7.3.1 *Surface Finish*—Machined surfaces of specimens shall have a surface finish of 63 µin. (1.6 µm) or better. Machined lateral surfaces to which lateral support is to be applied shall be finished to at least 40 microinches (1.0 µm) arithmetic average.

7.3.2 *Flatness and Parallelism*—The ends of a specimen shall be flat and parallel within 0.0005 in./in. (mm/mm) and perpendicular to the lateral surfaces to within $3'$ of arc. In most cases this requirement necessitates the machining or grinding of the ends of the specimen.

7.3.3 *Edges of Rectangular Specimens*— A width of material equal to at least the thickness of the specimen shall be machined from all sheared or stamped edges in order to remove material whose properties may have been altered. (If a reduced section is used, this requirement applies only to the edges of the reduced section.) Specimens shall be finished so that the surfaces are free of nicks, grooves, and burrs.

TABLE 2 Suggested Solid Cylindrical Specimens[A]

NOTE 1—Metric units represent converted specimen dimensions close to, but not the exact conversion from inch-pound units.

Specimens	Diameter		Length		Approx *L/D* Ratio
	in.	mm	in.	mm	
Short	1.12 ± 0.01	30.0 ± 0.2	1.00 ± 0.05	25.± 1.	0.8
	0.50 ± 0.01	13.0 ± 0.2	1.00 ± 0.05	25. ± 1.	2.0
Medium	0.50 ± 0.01	13.0 ± 0.2	1.50 ± 0.05	38. ± 1.	3.0
	0.80 ± 0.01	20.0 ± 0.2	2.38 ± 0.12	60. ± 3.	3.0
	1.00 ± 0.01	25.0 ± 0.2	3.00 ± 0.12	75. ± 3.	3.0
	1.12 ± 0.01	30.0 ± 0.2	3.38 ± 0.12	85. ± 3.	3.0
Long	0.80 ± 0.01	20.0 ± 0.2	6.38 ± 0.12	160. ± 3.	8.0
	1.25 ± 0.01	32.0 ± 0.2	12.50 min	320 min	10.0

[A] Other length-to-diameter ratios may be used when the test is for compressive yield strength.

7.4 *Gage Length Location*—The ends of the gage length shall not be closer to the ends of the specimen or ends of the reduced section than one half of the width or diameter of the specimen.

8. Procedure

8.1 *Specimen Measurement*—Measure the width and thickness, or the diameter of the specimen with a micrometer along the gage section. Specimen dimensions greater than 0.10 in. (2.5 mm) should be measured to the nearest 0.001 in. (0.02 mm), and those less than 0.10 in. (2.5 mm) should be determined to the nearest 1 % of the dimension being measured. Calculate the average cross-sectional area of the specimen gage section.

8.2 *Cleaning*—Clean the ends of the specimen and fixture bearing blocks with acetone or another suitable solvent to remove all traces of grease and oil.

8.3 *Lubrication*—Bearing surface friction can affect test results (see section 5.2 and Fig. 2). Friction has been successfully reduced by lubricating the bearing surfaces with TFE-fluorocarbon sheet, molybdenum disulfide, and other materials summarized in Ref. (**3**).

8.4 *Specimen Installation*—Place the specimen in the test fixture and carefully align the specimen to the fixture to ensure concentric loading. Also, check that the specimen loading/reaction surfaces mate with the respective surfaces of the fixture. If the fixture has side supports, the specimen sides should contact the support mechanism with the clamping pressure recommended by the fixture manufacturer, or as determined during the fixture verification tests. If screws are used to adjust side support pressure, it is recommended that a torque wrench be utilized to ensure consistent pressure.

8.4.1 *Transducer Attachment*—If required, attach the extensometer or other transducers, or both, to the specimen gage section. The gage length must be at least one half or preferably one diameter away from the ends of the specimen (see 7.4).

8.5 *Load-Strain Range Selection*—Set the load range of the testing machine so the maximum expected load is at least one third of the range selected. Select the strain or deflection scale so that the elastic portion of the load-versus-strain or load-versus-deflection plot on the autographic record, is between 30° and 60° to the load axis.

8.6 *Strain Measurements*—Devices used for measuring strain shall comply with the requirements for the applicable class of extensometer described in Practice E 83. Electrical strain gages, if used, shall have performance characteristics established by the manufacturer in accordance with Test Methods E 251.

8.7 *Testing Speed*—For testing machines equipped with strain-rate pacers, set the machine to strain the specimen at a rate of 0.005 in./in.·min (m/m·min). For machine with load control or with crosshead speed control, set the rate so the specimen is tested at a rate equivalent to 0.005 in./in.·min (m/m·min) strain-rate in the elastic portion. A rate of 0.003

in./in.·min (m/m·min) can be used if the material is strain-rate sensitive.

8.7.1 For machines without strain-pacing equipment or automatic feedback control systems, maintain a constant cross-head speed to obtain the desired average strain-rate from the start of loading to the end point of the test. The average strain-rate can be determined from a time-interval-marked load-strain record, a time-strain graph, or from the time of the start of loading to the end point of test as determined from a time-measuring device (for example, stopwatch). It should be recognized that the use of machines with constant rate of crosshead movement does not ensure constant strain rate throughout a test.

8.7.2 It should also be noted that the free-running crosshead speed may differ from the speed under load for the same machine setting, and that specimens of different stiffnesses may also result in different rates, depending upon the test machine and fixturing. Whatever the method, the specimen should be tested at a uniform rate without reversals or sudden changes. The test rate must also be such that the rate of load change on the specimen being tested, will be within the dynamic response of the measuring systems. This is of particular importance when testing short specimens of high-modulus materials.

8.8 *Test Conduct*—After the specimen has been installed and aligned, and the strain- or deflection-measuring transducer installed, activate the recording device(s) and initiate the test at the prescribed rate. Continue the test at a uniform rate until the test has been completed as stated below.

8.8.1 *Ductile Materials*—For ductile materials, the yield strength or yield point, and sometimes the strength at a strain greater than the yield strain, can be determined. The conduct of the test to determine either the onset of yielding or the compressive strength or both is the same. Materials without sharp-kneed stress-strain diagrams will require that the strain or deflection at yield be initially estimated, and the specimen tested sufficiently beyond the initial estimation to be sure the yield stress can be determined after the test (see 9.3). For materials, exhibiting a sharp-kneed stress-strain curve or a distinctive yield point, the test can be terminated either after a sharp knee or after the drop in load is observed.

8.8.2 *Brittle Materials*—Brittle materials that fail by crushing or shattering may be tested to failure.

8.9 *Number of Specimens*—Specimen blanks shall be taken from bulk materials according to applicable specifications. The number of specimens to be tested should be sufficient to meet the requirements as determined by the test purpose, or as agreed upon between the parties involved. The larger the sample, the greater the confidence that the sample represents the total population. In most cases, between five and ten specimens should be sufficient to determine the compressive properties of a sample with reasonable confidence.

8.10 *Precautions*:

8.10.1 *Buckling*—In compression tests of relatively long, slender specimens that are not laterally supported, the specimens may buckle elastically and fly from the test setup. A protective device should be in place to prevent injury.

8.10.2 *Shattering Fracture*—Some materials may fail in a shattering manner which will cause pieces to be expelled as shrapnel. A protective device should be in place to prevent injury.

9. Calculations

9.1 Determine the properties of the material from the dimensions of the specimen and the stress-strain diagram as described in the following paragraphs. For testing machines that record load units instead of stress, convert the load-versus-strain diagram to units of stress by dividing the load by the original cross-sectional area of the specimen gage section.

9.2 *Modulus of Elasticity*—Calculate the modulus of elasticity as specified in Test Method E 111. If the elastic modulus is the prime quantity to be determined, the procedure given in Test Method E 111 must be followed. Again, the calculation of the modulus shall be according to Section 7 of Test Method E 111.

9.3 *Yield Strength*—To determine the yield strength by the offset method it is necessary to secure data (autographic or numerical) from which a stress-strain diagram may be drawn. Then on the stress-strain diagram (Fig. 6) lay off Om equal to the specified value of offset (conventional offset is 0.002 in./in. (m/m)), draw mn parallel to OA, and thus locate r, the intersection of mn with the stress-strain diagram. The stress corresponding to the point r is the yield strength for the specified offset.

9.3.1 In reporting values of yield strength obtained by these methods, the specified value of offset used should be stated in parentheses after the term yield strength. Thus:

$$\text{Yield strength (offset} = 0.2\ \%) = 52.0\ \text{ksi}\ (359\ MPa) \tag{4}$$

9.3.2 In using these methods, a Class B-2 extensometer, as described in Practice E 83, is sufficiently sensitive for most materials.

NOTE 5—Automatic devices are available that determine offset yield

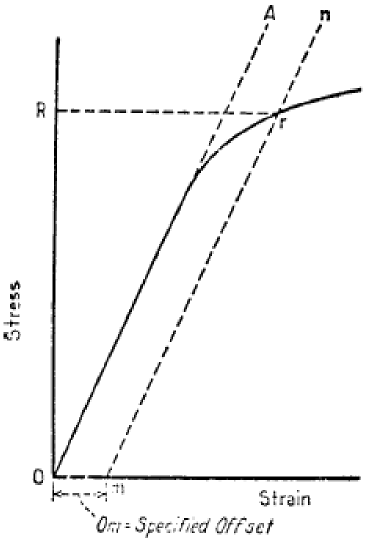


FIG. 6 Stress-Strain Diagram for Determination of Yield Strength by the Offset Method

strength without plotting a stress-strain curve. Such devices may be used if their accuracy has been demonstrated to be satisfactory.

NOTE 6—If the load drops before the specified offset is reached, technically the material does not have a yield strength (for that offset). In this case, the stress at the maximum load before the specified offset is reached may be reported instead of the yield strength and shall be designated as the yield point.

9.4 *Yield Point*—Materials that exhibit a sharp-kneed stress-strain diagram may exhibit a distinct drop in stress with increasing strain. The yield point is the maximum stress attained just prior to the sudden drop in stress. For testing machines without strain- or deflection-recording capabilities, the yield point can be determined by noting the load at which the load dial indicator needle suddenly drops with the testing machine running at a steady rate.

9.5 *Compressive Strength*—For a material that fails in compression by crushing or fracturing, the compressive strength is the maximum stress at or before fracture, as determined by dividing the maximum load by the cross-sectional area. For ductile materials, compressive strength may be determined from the stress-strain diagram at a specified total strain. The strain at which this stress was determined must be specified.

10. Report

10.1 Include the following information in the test report:

10.1.1 *Specimen Material*—Describe the specimen material, alloy, heat treatment, mill batch number, grain direction, etc., as applicable.

10.1.2 *Specimen Configuration*—Include a sketch of the specimen configuration or reference to the specimen drawing.

10.1.3 *Specimen Dimensions*—State the actual measured dimensions for each specimen.

10.1.4 *Test Fixture and Lubricant*—Describe the test fixture or refer to fixture drawings, specifying lubricant used if any.

10.1.5 *Testing Machine*—Include the make, model, and load range of testing machine.

10.1.6 *Speed of Testing*—Record the test rate and mode of control.

10.1.7 *Stress-Strain Diagram*—Include, if possible, the stress-strain diagram with scales, specimen number, test data, rate, and other pertinent information.

10.1.8 *Modulus of Elasticity*—Report the modulus of elasticity when required, as determined according to 9.2.

10.1.9 *Yield Strength*—Report the yield stress or yield point when required and the method of determination, as calculated in 9.3 and 9.4.

10.1.10 *Compressive Strength*—Report the compressive strength for material exhibiting brittle failure. A compressive strength at a specified total strain may be reported for ductile materials. If so, report the strain at which the compressive stress was determined.

10.1.11 *Type of Failure*—When applicable, describe the type of specimen failure.

10.1.12 *Precision and Bias*—State the precision and accuracy of the data reported as applicable in a manner consistent with Practice E 177.

10.1.13 *Anomalies*—State any anomalies that occurred during the test that may have had an effect on the test results.

10.2 For commercial acceptance testing the following sections of 10.1 are considered sufficient: 10.1.1 and 10.1.2, and 10.1.9 and 10.1.11.

11. Precision and Bias

11.1 *Precision*—The following parameters are reported to impact upon the precision of the test methods: specimen buckling, loading surface friction, specimen barreling, and specimen size. The subcommittee is in the process of quantifying these effects.

11.2 *Bias*—There are no available reference standards for destructive type tests such as compression. Therefore, the bias of this test method is an unknown.

12. Keywords

12.1 axial compression; barreling; bearing blocks; buckling; compressometer; sheet compression jig; stress-strain diagram; sub-press; testing machine

ANNEX

(Mandatory Information)

A1. SPECIAL REQUIREMENTS IN THE DETERMINATION OF THE COMPRESSIVE STRENGTH OF CEMENTED CARBIDES

A1.1 Characteristics of Cemented Carbides

A1.1.1 Cemented carbides are manufactured in a range of compositions having hardness from 81.0 to 93.0 HRA and compressive strengths from 300 to over 800 ksi (2100 to 5500 MPa). They fail by shattering fracture (see 8.7.2 and section 8.10.2).

A1.2 Apparatus and Fixtures

A1.2.1 *Bearing Blocks*— Cemented carbide bearing blocks shall be used. They shall be of a hardness such that the block faces will not suffer significant permanent deformation during test (suggested hardness of 92 HRA).

A1.2.2 *Bearing Block Preparation*—The block diameter shall be at least three times the diameter of the specimen. Its thickness shall be at least two thirds the block diameter. Faces of the bearing blocks shall be flat within ±0.0002 in./in. (m/m), parallel within 0.0005 in./in. (m/m), and have a surface finish of 8 µin. (0.2 µm) arithmetic average (aa). The blocks shall be used in conjunction with devices such as those shown in Figs. 3-5.

A1.2.3 The total accumulated lack of parallelism in the test assembly shall not exceed 0.0005 in./in. (m/m).

A1.2.4 In order to minimize detrimental end effects, a shim of 0.001 in. (0.025 mm) in thickness, of standard cold-rolled steel shim stock, shall be interposed between each specimen end and the bearing block. Each shim shall be used only once (see Ref **14**).

A1.3 Test Specimens

A1.3.1 *Size and Shape*— The specimens shall be in the form of circular cylinders 0.375 ± 0.01 in. (10.0 ± 0.2 mm) in diameter and 1.00 ± 0.05 in. (25.0 ± 1.0 mm) long.

A1.3.2 *Preparation of Specimens*—The ends of a specimen shall be plane and normal to its longitudinal axis. They shall be parallel within a maximum of ±0.0005 in./in. (m/m), flat within ±0.0002 in./in. (m/m), and have a surface finish of 8 µin. (0.2 µm) aa.

A1.4 Speed of Testing

A1.4.1 Speed of testing shall be specified in terms of rate of stressing the specimen, and shall not exceed 50.0 ksi (345 MPa)/min.

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Project

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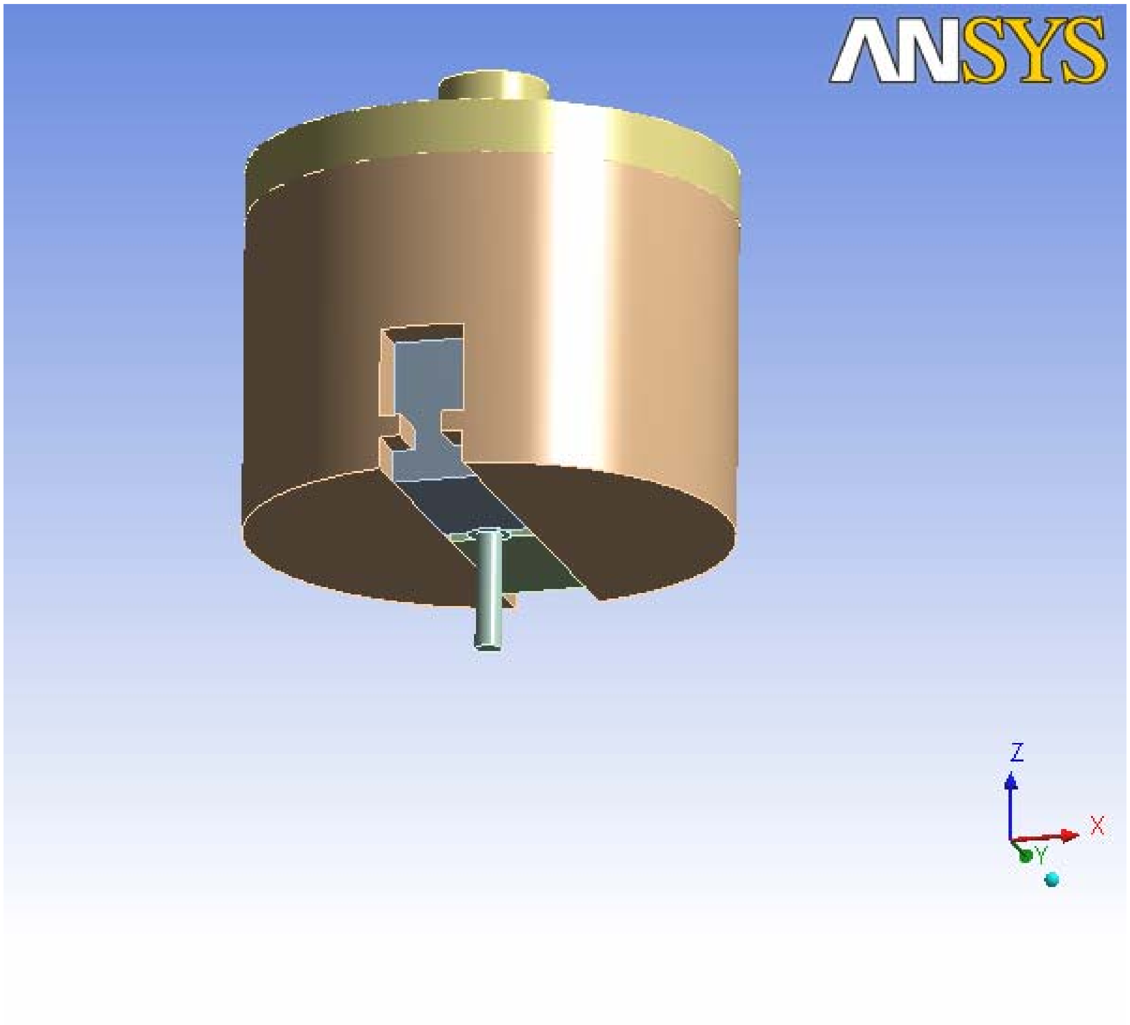


Contents

Units

TABLE 1

Unit System	Metric (m, kg, N, °C, s, V, A)
Angle	Degrees
Rotational Velocity	rad/s

Conjunto total a tensión

Geometry

TABLE 2
Conjunto total a tensión > Geometry

Object Name	*Geometry*
State	Fully Defined
Definition	
Source	E:\Oscar no borrar\Omar Gomez\sist hidr final\Definitivos\ensamble final modificado1.asm
Type	Solid Edge
Length Unit	Meters
Element Control	Program Controlled
Display Style	Part Color
Bounding Box	
Length X	0,2286 m
Length Y	0,2286 m
Length Z	0,27151 m
Properties	
Volume	6,8657e-003 m³
Mass	53,895 kg
Statistics	
Bodies	6
Active Bodies	6
Nodes	44657
Elements	28326
Preferences	
Import Solid Bodies	Yes
Import Surface Bodies	Yes
Import Line Bodies	Yes
Parameter Processing	Yes
Personal Parameter Key	DS
CAD Attribute Transfer	No
Named Selection Processing	No
Material Properties Transfer	No
CAD Associativity	Yes
Import Coordinate Systems	No
Reader Save Part File	No
Import Using Instances	Yes
Do Smart Update	No
Attach File Via Temp File	No
Analysis Type	3-D
Mixed Import Resolution	None

Enclosure and Symmetry Processing	Yes

TABLE 3
Conjunto total a tensión > Geometry > Parts

<table>
<tr><th>Object Name</th><th>placa movil.par: 1</th><th>mordazanueva.par: 1</th><th>mordazanueva.par: 2</th><th>seccion inferior.par: 1</th><th>probeta.par: 1</th></tr>
<tr><td>State</td><td colspan="5">Meshed</td></tr>
<tr><td colspan="6">Graphics Properties</td></tr>
<tr><td>Visible</td><td colspan="5">Yes</td></tr>
<tr><td>Transparency</td><td colspan="5">1</td></tr>
<tr><td colspan="6">Definition</td></tr>
<tr><td>Suppressed</td><td colspan="5">No</td></tr>
<tr><td>Material</td><td>SAE-AISI 1040</td><td colspan="2">SAE-AISI 4340</td><td>SAE-AISI 1040</td><td>Structural Steel</td></tr>
<tr><td>Stiffness Behavior</td><td colspan="5">Flexible</td></tr>
<tr><td>Nonlinear Material Effects</td><td colspan="5">Yes</td></tr>
<tr><td colspan="6">Bounding Box</td></tr>
<tr><td>Length X</td><td>0,127 m</td><td colspan="2">4,e-002 m</td><td>0,2286 m</td><td>3,9203e-002 m</td></tr>
<tr><td>Length Y</td><td>0,127 m</td><td colspan="2">8,5e-002 m</td><td>0,2286 m</td><td>3,9203e-002 m</td></tr>
<tr><td>Length Z</td><td>8,7107e-002 m</td><td colspan="2">6,711e-002 m</td><td>0,15011 m</td><td>8,e-002 m</td></tr>
<tr><td colspan="6">Properties</td></tr>
<tr><td>Volume</td><td>6,7241e-004 m³</td><td colspan="2">1,7622e-004 m³</td><td>4,6774e-003 m³</td><td>1,8529e-005 m³</td></tr>
<tr><td>Mass</td><td>5,2784 kg</td><td colspan="2">1,3833 kg</td><td>36,717 kg</td><td>0,14545 kg</td></tr>
<tr><td>Centroid X</td><td>6,2779e-009 m</td><td>4,5057e-010 m</td><td>-4,5057e-010 m</td><td>6,6368e-005 m</td><td>-9,6758e-012 m</td></tr>
<tr><td>Centroid Y</td><td>-3,6416e-008 m</td><td>-5,3745e-002 m</td><td>5,3745e-002 m</td><td>-1,8419e-010 m</td><td>-4,0273e-012 m</td></tr>
<tr><td>Centroid Z</td><td>0,10834 m</td><td colspan="2">3,3837e-002 m</td><td>7,4476e-002 m</td><td>9,6221e-004 m</td></tr>
<tr><td>Moment of Inertia Ip1</td><td>6,5421e-003 kg·m²</td><td colspan="2">6,4538e-004 kg·m²</td><td>0,21796 kg·m²</td><td>9,1027e-006 kg·m²</td></tr>
<tr><td>Moment of Inertia Ip2</td><td>6,7771e-003 kg·m²</td><td colspan="2">1,1939e-003 kg·m²</td><td>0,19997 kg·m²</td><td>8,3251e-005 kg·m²</td></tr>
<tr><td>Moment of Inertia Ip3</td><td>7,0403e-003 kg·m²</td><td colspan="2">8,825e-004 kg·m²</td><td>0,28238 kg·m²</td><td>8,3251e-005 kg·m²</td></tr>
<tr><td colspan="6">Statistics</td></tr>
<tr><td>Nodes</td><td>4739</td><td colspan="2">2015</td><td>25289</td><td>5389</td></tr>
<tr><td>Elements</td><td>2923</td><td colspan="2">1109</td><td>16875</td><td>3334</td></tr>
</table>

TABLE 4
Conjunto total a tensión > Geometry > Parts

Object Name	*tapa.par:1*
State	Meshed
Graphics Properties	
Visible	Yes
Transparency	1
Definition	
Suppressed	No
Material	Structural Steel
Stiffness Behavior	Flexible
Nonlinear Material Effects	Yes
Bounding Box	
Length X	0,2286 m
Length Y	0,2286 m
Length Z	7,04e-002 m
Properties	
Volume	1,1449e-003 m^3
Mass	8,9875 kg
Centroid X	-4,9514e-012 m
Centroid Y	-2,8961e-010 m
Centroid Z	0,16593 m
Moment of Inertia Ip1	2,7537e-002 kg·m^2
Moment of Inertia Ip2	2,7537e-002 kg·m^2
Moment of Inertia Ip3	5,2482e-002 kg·m^2
Statistics	
Nodes	5210
Elements	2976

Contact

TABLE 5
Conjunto total a tensión > Connections

Object Name	*Contact*
State	Fully Defined
Auto Detection	
Generate Contact On Update	Yes
Tolerance Type	Slider
Tolerance Slider	0,
Tolerance Value	1,0555e-003 m
Face/Face	Yes
Face/Edge	No
Edge/Edge	No
Priority	Include All
Same Body Grouping	Yes
Revolute Joints	Yes
Fixed Joints	Yes

Transparency	
Enabled	Yes

TABLE 6
Conjunto total a tensión > Contact > Contact Regions

Object Name	*placa movil.par:1 To mordazanueva.par:1*	*placa movil.par:1 To mordazanueva.par:2*	*placa movil.par:1 To seccion inferior.par:1*	*mordazanueva.par:1 To seccion inferior.par:1*	*mordazanueva.par:1 To probeta.par:1*
State	Fully Defined				
Scope					
Scoping Method	Geometry Selection				
Contact	2 Faces				1 Face
Target	2 Faces				1 Face
Contact Bodies	placa movil.par:1		seccion inferior.par:1	mordazanueva.par:1	
Target Bodies	mordazanueva.par:1	mordazanueva.par:2	seccion inferior.par:1		probeta.par:1
Definition					
Type	No Separation				
Scope Mode	Manual				
Behavior	Symmetric				
Suppressed	No				
Advanced					
Formulation	Pure Penalty				
Normal Stiffness	Program Controlled				
Update Stiffness	Never				
Thermal Conductance	Program Controlled				
Pinball Region	Program Controlled				

TABLE 7
Conjunto total a tensión > Contact > Contact Regions

Object Name	*mordazanueva.par:2 To seccion inferior.par:1*	*mordazanueva.par:2 To probeta.par:1*	*seccion inferior.par:1 To probeta.par:1*	*seccion inferior.par:1 To tapa.par:1*
State	Fully Defined			

<table>
<tr><th colspan="5">Scope</th></tr>
<tr><td>Scoping Method</td><td colspan="4">Geometry Selection</td></tr>
<tr><td>Contact</td><td>2 Faces</td><td colspan="2">1 Face</td><td>2 Faces</td></tr>
<tr><td>Target</td><td>2 Faces</td><td colspan="2">1 Face</td><td>2 Faces</td></tr>
<tr><td>Contact Bodies</td><td colspan="2">mordazanueva.par:2</td><td colspan="2">seccion inferior.par:1</td></tr>
<tr><td>Target Bodies</td><td>seccion inferior.par:1</td><td colspan="2">probeta.par:1</td><td>tapa.par:1</td></tr>
<tr><th colspan="5">Definition</th></tr>
<tr><td>Type</td><td colspan="2">No Separation</td><td>Bonded</td><td>No Separation</td></tr>
<tr><td>Scope Mode</td><td colspan="3">Manual</td><td>Automatic</td></tr>
<tr><td>Behavior</td><td colspan="4">Symmetric</td></tr>
<tr><td>Suppressed</td><td colspan="4">No</td></tr>
<tr><th colspan="5">Advanced</th></tr>
<tr><td>Formulation</td><td colspan="4">Pure Penalty</td></tr>
<tr><td>Normal Stiffness</td><td colspan="4">Program Controlled</td></tr>
<tr><td>Update Stiffness</td><td colspan="4">Never</td></tr>
<tr><td>Thermal Conductance</td><td colspan="4">Program Controlled</td></tr>
<tr><td>Pinball Region</td><td colspan="4">Program Controlled</td></tr>
</table>

Mesh

TABLE 8
Conjunto total a tensión > Mesh

Object Name	*Mesh*
State	Solved
Defaults	
Physics Preference	Mechanical
Relevance	0
Advanced	
Relevance Center	Coarse
Element Size	Default
Shape Checking	Standard Mechanical
Solid Element Midside Nodes	Program Controlled
Straight Sided Elements	No
Initial Size Seed	Active Assembly
Smoothing	Low
Transition	Fast
Statistics	
Nodes	44657
Elements	28326

Environment

TABLE 9
Conjunto total a tensión > Analysis

Object Name	*Environment*
State	Fully Defined
Definition	
Physics Type	Structural
Analysis Type	Static Structural
Options	
Reference Temp	22, °C

TABLE 10
Conjunto total a tensión > Environment > Analysis Settings

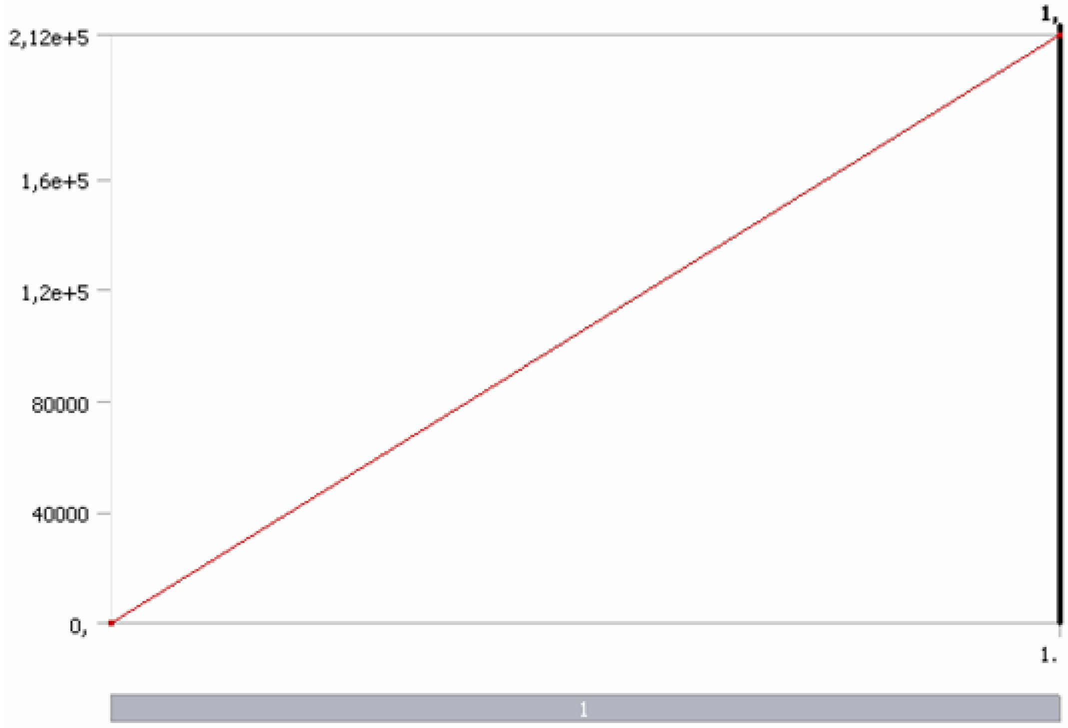
Object Name	*Analysis Settings*
State	Fully Defined
Step Controls	
Number Of Steps	1,
Current Step Number	1,
Step End Time	1, s
Auto Time Stepping	Program Controlled
Solver Controls	
Solver Type	Program Controlled
Weak Springs	Program Controlled
Large Deflection	Off
Inertia Relief	Off
Nonlinear Controls	
Force Convergence	Program Controlled
Moment Convergence	Program Controlled
Displacement Convergence	Program Controlled
Rotation Convergence	Program Controlled
Line Search	Program Controlled
Output Controls	
Calculate Stress	Yes
Calculate Strain	Yes
Calculate Results At	All Time Points
Analysis Data Management	
Solver Files Directory	D:\J. ALEXANDER SUAREZ\Mis documentos\PROYECTO\Omar Gomez\sist hidr final\Definitivos\ARCHIVO ULTIMOS\ANSYS\prueba de

	compresion final y tension Simulation Files\Environment\
Future Analysis	None
Save ANSYS db	No
Delete Unneeded Files	Yes
Nonlinear Solution	No

TABLE 11
Conjunto total a tensión > Environment > Loads

Object Name	*Force*	*Fixed Support*
State	Fully Defined	
Scope		
Scoping Method	Geometry Selection	
Geometry	1 Face	
Definition		
Define By	Vector	
Type	Force	Fixed Support
Magnitude	2,12e+005 N (ramped)	
Direction	Defined	
Suppressed	No	

FIGURE 1
Conjunto total a tensión > Environment > Force



Solution

TABLE 12
Conjunto total a tensión > Environment > Solution

Object Name	*Solution*
State	Solved
Adaptive Mesh Refinement	
Max Refinement Loops	1,
Refinement Depth	2,

TABLE 13
Conjunto total a tensión > Environment > Solution > Solution Information

Object Name	*Solution Information*
State	Solved
Solution Information	
Solution Output	Solver Output
Newton-Raphson Residuals	0
Update Interval	2,5 s
Display Points	All

TABLE 14
Conjunto total a tensión > Environment > Solution > Results

Object Name	*Equivalent Stress*	*Equivalent Stress 2*	*Equivalent Stress 3*	*Equivalent Stress 4*	*Equivalent Stress 5*
State	Solved				
Scope					
Geometry	1 Body				
Definition					
Type	Equivalent (von-Mises) Stress				
Display Time	End Time				
Results					
Minimum	8,8348e+005 Pa	517,28 Pa	8,2275e+005 Pa	4,153e+005 Pa	4,2215e+005 Pa
Maximum	1,7311e+008 Pa	6,8765e+007 Pa	3,8039e+008 Pa	2,5815e+008 Pa	2,6107e+008 Pa
Information					
Time	1, s				
Load Step	1				
Substep	1				
Iteration Number	1				

TABLE 15
Conjunto total a tensión > Environment > Solution > Results

Object Name	*Equivalent Stress 6*
State	Solved
Scope	

Geometry	1 Body
Definition	
Type	Equivalent (von-Mises) Stress
Display Time	End Time
Results	
Minimum	1,7862e+007 Pa
Maximum	2,2516e+009 Pa
Information	
Time	1, s
Load Step	1
Substep	1
Iteration Number	1

TABLE 16
Conjunto total a tensión > Environment > Solution > Stress Safety Tools

Object Name	*Stress Tool*
State	Solved
Definition	
Theory	Max Equivalent Stress
Stress Limit Type	Tensile Yield Per Material

TABLE 17
Conjunto total a tensión > Environment > Solution > Stress Tool > Results

Object Name	*Safety Factor*	*Safety Factor 2*	*Safety Factor 3*	*Safety Factor 4*	*Safety Factor 5*
State	Solved				
Scope					
Geometry	All Bodies	1 Body			
Definition					
Type	Safety Factor				
Display Time	End Time				
Results					
Minimum	0,11103	1,4442	> 10	1,8851	6,1429
Minimum Occurs On	probeta.par:1				
Information					
Time	1, s				
Load Step	1				
Substep	1				
Iteration Number	1				

TABLE 18
Conjunto total a tensión > Environment > Solution > Stress Tool > Results

Object Name	*Safety Factor 6*	*Safety Factor 7*
State	Solved	
Scope		
Geometry	1 Body	

Definition		
Type	Safety Factor	
Display Time	End Time	
Results		
Minimum	6,0741	0,11103
Information		
Time	1, s	
Load Step	1	
Substep	1	
Iteration Number	1	

TABLE 19
Conjunto total a tensión > Environment > Solution > Stress Safety Tools

Object Name	*Stress Tool 2*
State	Solved
Definition	
Theory	Max Equivalent Stress
Stress Limit Type	Tensile Yield Per Material

TABLE 20
Conjunto total a tensión > Environment > Solution > Stress Tool 2 > Results

Object Name	*Safety Factor*
State	Solved
Scope	
Geometry	5 Bodies
Definition	
Type	Safety Factor
Display Time	End Time
Results	
Minimum	1,4442
Minimum Occurs On	tapa.par:1
Information	
Time	1, s
Load Step	1
Substep	1
Iteration Number	1

TABLE 21
Conjunto total a tensión > Environment > Solution > Fatigue Tools

Object Name	*Fatigue Tool*
State	Solved
Materials	
Fatigue Strength Factor (Kf)	1,
Loading	
Type	Zero-Based
Scale Factor	1,
Definition	

Display Time	End Time
Options	
Analysis Type	Stress Life
Mean Stress Theory	Goodman
Stress Component	Equivalent (Von Mises)
Life Units	
Units Name	cycles
1 cycle is equal to	1, cycles

FIGURE 2
Conjunto total a tensión > Environment > Solution > Fatigue Tool

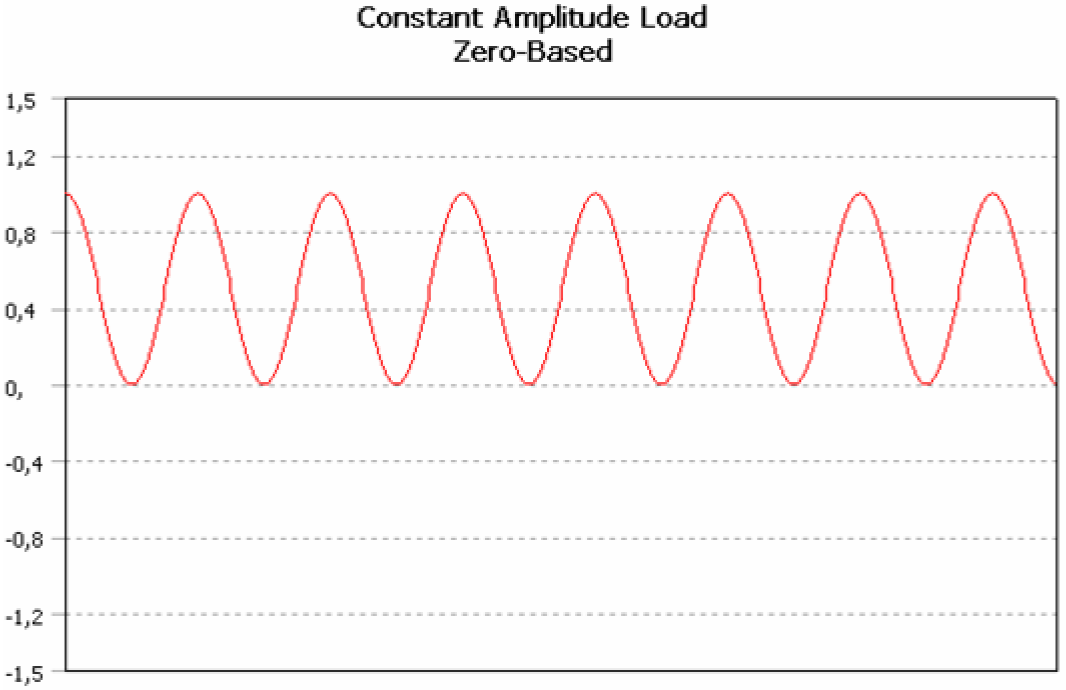


FIGURE 3
Conjunto total a tensión > Environment > Solution > Fatigue Tool

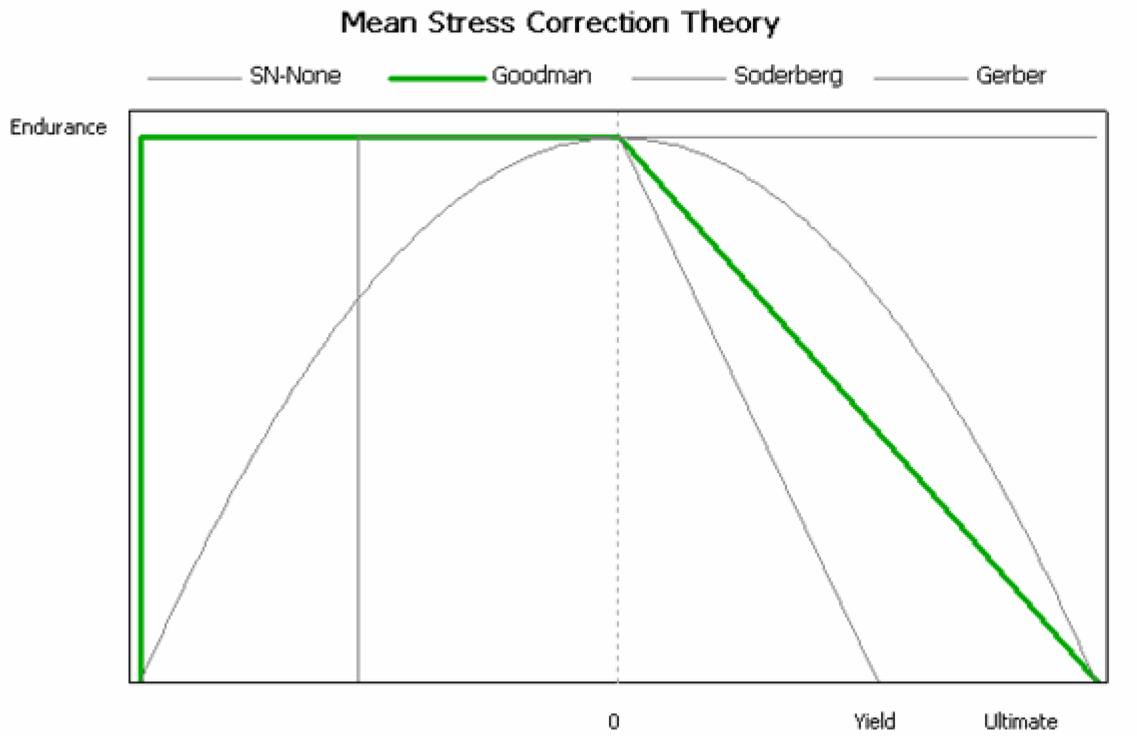


TABLE 22
Conjunto total a tensión > Environment > Solution > Fatigue Tool > Results

Object Name	*Life*	*Safety Factor*
State	Solved	
Scope		
Geometry	5 Bodies	
Definition		
Type	Life	Safety Factor
Design Life		1,e+006 cycles
Results		
Minimum	12752 cycles	0,41201
Minimum Occurs On	seccion inferior.par:1	

Conjunto total a compresión

Geometry

TABLE 23
conjunto total a compresión > Geometry

Object Name	*Geometry*
State	Fully Defined
Definition	
Source	E:\Oscar no borrar\Omar Gomez\sist hidr final\Definitivos\ensamble final modificado1.asm
Type	Solid Edge
Length Unit	Meters
Element Control	Program Controlled
Display Style	Part Color
Bounding Box	
Length X	0,2286 m
Length Y	0,2286 m
Length Z	0,27151 m
Properties	
Volume	6,8657e-003 m^3
Mass	53,895 kg
Statistics	
Bodies	6
Active Bodies	6
Nodes	44657
Elements	28326
Preferences	
Import Solid Bodies	Yes
Import Surface Bodies	Yes
Import Line Bodies	Yes
Parameter Processing	Yes
Personal Parameter Key	DS
CAD Attribute Transfer	No
Named Selection Processing	No
Material Properties Transfer	No
CAD Associativity	Yes
Import Coordinate Systems	No
Reader Save Part File	No
Import Using Instances	Yes
Do Smart Update	No
Attach File Via Temp File	No
Analysis Type	3-D
Mixed Import Resolution	None
Enclosure and Symmetry Processing	Yes

TABLE 24
conjunto total a compresión > Geometry > Parts

Object Name	*placa movil.par: 1*	*mordazanueva.par: 1*	*mordazanueva.par: 2*	*seccion inferior.par: 1*	*probeta.par: 1*
State	Meshed				
Graphics Properties					
Visible	Yes				
Transparency	1				
Definition					
Suppressed	No				
Material	SAE-AISI 1040	SAE-AISI 4340		SAE-AISI 1040	Structural Steel
Stiffness Behavior	Flexible				
Nonlinear Material Effects	Yes				
Bounding Box					
Length X	0,127 m	4,e-002 m		0,2286 m	3,9203e-002 m
Length Y	0,127 m	8,5e-002 m		0,2286 m	3,9203e-002 m
Length Z	8,7107e-002 m	6,711e-002 m		0,15011 m	8,e-002 m
Properties					
Volume	6,7241e-004 m^3	1,7622e-004 m^3		4,6774e-003 m^3	1,8529e-005 m^3
Mass	5,2784 kg	1,3833 kg		36,717 kg	0,14545 kg
Centroid X	6,2779e-009 m	4,5057e-010 m	-4,5057e-010 m	6,6368e-005 m	-9,6758e-012 m
Centroid Y	-3,6416e-008 m	-5,3745e-002 m	5,3745e-002 m	-1,8419e-010 m	-4,0273e-012 m
Centroid Z	0,10834 m	3,3837e-002 m		7,4476e-002 m	9,6221e-004 m
Moment of Inertia Ip1	6,5421e-003 kg·m^2	6,4538e-004 kg·m^2		0,21796 kg·m^2	9,1027e-006 kg·m^2
Moment of Inertia Ip2	6,7771e-003 kg·m^2	1,1939e-003 kg·m^2		0,19997 kg·m^2	8,3251e-005 kg·m^2
Moment of Inertia Ip3	7,0403e-003 kg·m^2	8,825e-004 kg·m^2		0,28238 kg·m^2	8,3251e-005 kg·m^2
Statistics					
Nodes	4739	2015		25289	5389
Elements	2923	1109		16875	3334

TABLE 25
conjunto total a compresión > Geometry > Parts

Object Name	*tapa.par:1*
State	Meshed
Graphics Properties	
Visible	Yes
Transparency	1
Definition	
Suppressed	No
Material	Structural Steel
Stiffness Behavior	Flexible
Nonlinear Material Effects	Yes
Bounding Box	
Length X	0,2286 m
Length Y	0,2286 m
Length Z	7,04e-002 m
Properties	
Volume	1,1449e-003 m³
Mass	8,9875 kg
Centroid X	-4,9514e-012 m
Centroid Y	-2,8961e-010 m
Centroid Z	0,16593 m
Moment of Inertia Ip1	2,7537e-002 kg·m²
Moment of Inertia Ip2	2,7537e-002 kg·m²
Moment of Inertia Ip3	5,2482e-002 kg·m²
Statistics	
Nodes	5210
Elements	2976

Contact

TABLE 26
conjunto total a compresión > Connections

Object Name	*Contact*
State	Fully Defined
Auto Detection	
Generate Contact On Update	Yes
Tolerance Type	Slider
Tolerance Slider	0,
Tolerance Value	1,0555e-003 m
Face/Face	Yes
Face/Edge	No
Edge/Edge	No
Priority	Include All
Same Body Grouping	Yes
Revolute Joints	Yes
Fixed Joints	Yes

Transparency	
Enabled	Yes

TABLE 27
conjunto total a compresión > Contact > Contact Regions

Object Name	*placa movil.par:1 To mordazanueva.par:1*	*placa movil.par:1 To mordazanueva.par:2*	*placa movil.par:1 To seccion inferior.par:1*	*mordazanueva.par:1 To seccion inferior.par:1*	*mordazanueva.par:1 To probeta.par:1*
State	Fully Defined				Suppressed
Scope					
Scoping Method	Geometry Selection				
Contact	2 Faces				1 Face
Target	2 Faces				1 Face
Contact Bodies	placa movil.par:1		seccion inferior.par:1	mordazanueva.par:1	
Target Bodies	mordazanueva.par:1	mordazanueva.par:2	seccion inferior.par:1		probeta.par:1
Definition					
Type	No Separation				
Scope Mode	Manual				
Behavior	Symmetric				
Suppressed	No				Yes
Advanced					
Formulation	Pure Penalty				
Normal Stiffness	Program Controlled				
Update Stiffness	Never				
Thermal Conductance	Program Controlled				
Pinball Region	Program Controlled				

TABLE 28
conjunto total a compresión > Contact > Contact Regions

Object Name	*mordazanueva.par:2 To seccion inferior.par:1*	*mordazanueva.par:2 To probeta.par:1*	*seccion inferior.par:1 To probeta.par:1*	*seccion inferior.par:1 To tapa.par:1*
State	Fully Defined	Suppressed	Fully Defined	

Scope				
Scoping Method	Geometry Selection			
Contact	2 Faces	3 Faces	1 Face	2 Faces
Target	2 Faces	5 Faces	1 Face	2 Faces
Contact Bodies	mordazanueva.par:2		seccion inferior.par:1	
Target Bodies	seccion inferior.par:1	probeta.par:1		tapa.par:1
Definition				
Type	No Separation		Bonded	No Separation
Scope Mode	Manual	Automatic	Manual	Automatic
Behavior	Symmetric			
Suppressed	No	Yes	No	
Advanced				
Formulation	Pure Penalty			
Normal Stiffness	Program Controlled			
Update Stiffness	Never			
Thermal Conductance	Program Controlled			
Pinball Region	Program Controlled			

Mesh

TABLE 29
conjunto total a compresión > Mesh

Object Name	*Mesh*
State	Solved
Defaults	
Physics Preference	Mechanical
Relevance	0
Advanced	
Relevance Center	Coarse
Element Size	Default
Shape Checking	Standard Mechanical
Solid Element Midside Nodes	Program Controlled
Straight Sided Elements	No
Initial Size Seed	Active Assembly
Smoothing	Low
Transition	Fast
Statistics	
Nodes	44657
Elements	28326

Environment

TABLE 30
conjunto total a compresión > Analysis

Object Name	*Environment*
State	Fully Defined
Definition	
Physics Type	Structural
Analysis Type	Static Structural
Options	
Reference Temp	22, °C

TABLE 31
conjunto total a compresión > Environment > Analysis Settings

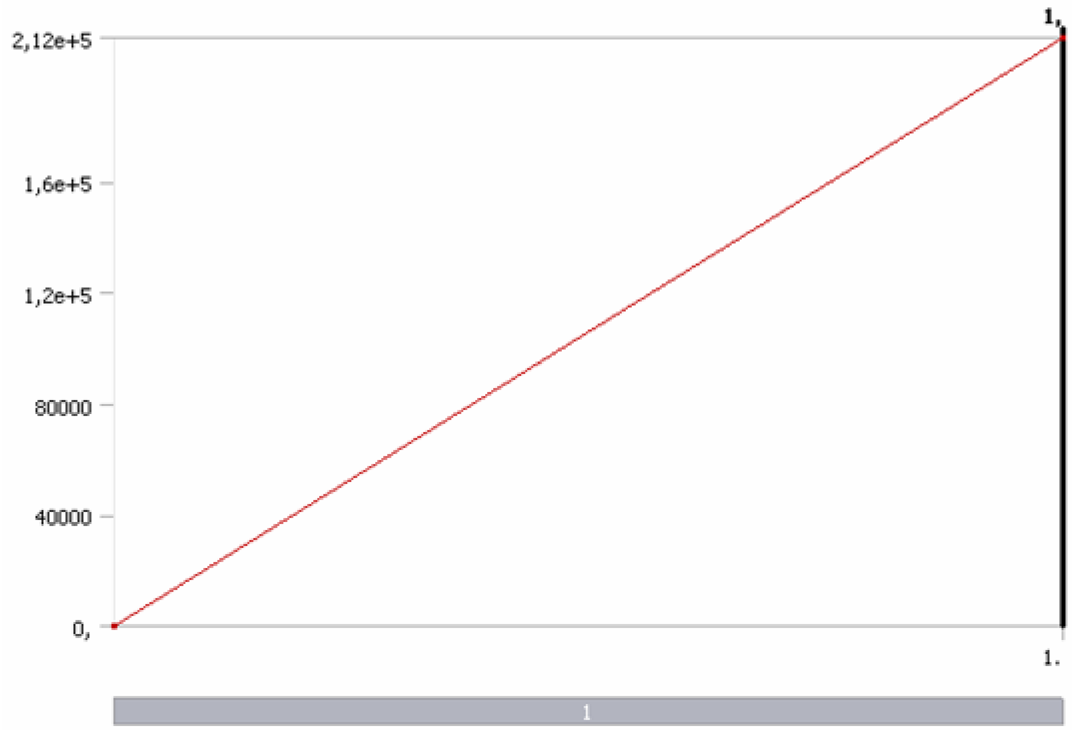
Object Name	*Analysis Settings*
State	Fully Defined
Step Controls	
Number Of Steps	1,
Current Step Number	1,
Step End Time	1, s
Auto Time Stepping	Program Controlled
Solver Controls	
Solver Type	Program Controlled
Weak Springs	Program Controlled
Large Deflection	Off
Inertia Relief	Off
Nonlinear Controls	
Force Convergence	Program Controlled
Moment Convergence	Program Controlled
Displacement Convergence	Program Controlled
Rotation Convergence	Program Controlled
Line Search	Program Controlled
Output Controls	
Calculate Stress	Yes
Calculate Strain	Yes
Calculate Results At	All Time Points
Analysis Data Management	
Solver Files Directory	D:\J. ALEXANDER SUAREZ\Mis documentos\PROYECTO\Omar Gomez\sist hidr final\Definitivos\ARCHIVO ULTIMOS\ANSYS\prueba de

	compresion final y tension Simulation Files\Environment (2)\
Future Analysis	None
Save ANSYS db	No
Delete Unneeded Files	Yes
Nonlinear Solution	No

TABLE 32
conjunto total a compresión > Environment > Loads

Object Name	*Force*	*Fixed Support*
State	Fully Defined	
Scope		
Scoping Method	Geometry Selection	
Geometry	1 Face	
Definition		
Define By	Vector	
Type	Force	Fixed Support
Magnitude	2,12e+005 N (ramped)	
Direction	Defined	
Suppressed	No	

FIGURE 4
conjunto total a compresión > Environment > Force



Solution

TABLE 33
conjunto total a compresión > Environment > Solution

Object Name	*Solution*
State	Solved
Adaptive Mesh Refinement	
Max Refinement Loops	1,
Refinement Depth	2,

TABLE 34
conjunto total a compresión > Environment > Solution > Solution Information

Object Name	*Solution Information*
State	Solved
Solution Information	
Solution Output	Solver Output
Newton-Raphson Residuals	0
Update Interval	2,5 s
Display Points	All

TABLE 35
conjunto total a compresión > Environment > Solution > Results

Object Name	*Equivalent Stress*	*Equivalent Stress 2*	*Equivalent Stress 3*	*Equivalent Stress 4*	*Equivalent Stress 5*
State	Solved				
Scope					
Geometry	1 Body				
Definition					
Type	Equivalent (von-Mises) Stress				
Display Time	End Time				
Results					
Minimum	8,0189e+005 Pa	312,17 Pa	4,8403e+005 Pa	22682 Pa	22955 Pa
Maximum	1,745e+008 Pa	4,2201e+007 Pa	5,1501e+008 Pa	1,112e+008 Pa	1,0952e+008 Pa
Information					
Time	1, s				
Load Step	1				
Substep	1				
Iteration Number	1				

TABLE 36
conjunto total a compresión > Environment > Solution > Results

Object Name	*Equivalent Stress 6*
State	Solved
Scope	
Geometry	1 Body
Definition	
Type	Equivalent (von-Mises) Stress
Display Time	End Time
Results	
Minimum	1,1041e+007 Pa
Maximum	2,2335e+009 Pa
Information	
Time	1, s
Load Step	1
Substep	1
Iteration Number	1

TABLE 37
conjunto total a compresión > Environment > Solution > Stress Safety Tools

Object Name	*Stress Tool*
State	Solved
Definition	
Theory	Max Equivalent Stress
Stress Limit Type	Tensile Yield Per Material

TABLE 38
conjunto total a compresión > Environment > Solution > Stress Tool > Results

Object Name	*Safety Factor*
State	Solved
Scope	
Geometry	5 Bodies
Definition	
Type	Safety Factor
Display Time	End Time
Results	
Minimum	1,3923
Minimum Occurs On	seccion inferior.par:1
Information	
Time	1, s
Load Step	1
Substep	1
Iteration Number	1

Material Data

SAE-AISI 1040

TABLE 39
SAE-AISI 1040 > Constants

Structural	
Young's Modulus	2,e+011 Pa
Poisson's Ratio	0,3
Density	7850, kg/m³
Thermal Expansion	1,2e-005 1/°C
Tensile Yield Strength	7,1705e+008 Pa
Compressive Yield Strength	7,1705e+008 Pa
Tensile Ultimate Strength	8,6184e+008 Pa
Compressive Ultimate Strength	8,6184e+008 Pa
Thermal	
Thermal Conductivity	60,5 W/m·°C
Specific Heat	434, J/kg·°C
Electromagnetics	
Relative Permeability	10000
Resistivity	1,7e-007 Ohm·m

FIGURE 5
SAE-AISI 1040 > Alternating Stress

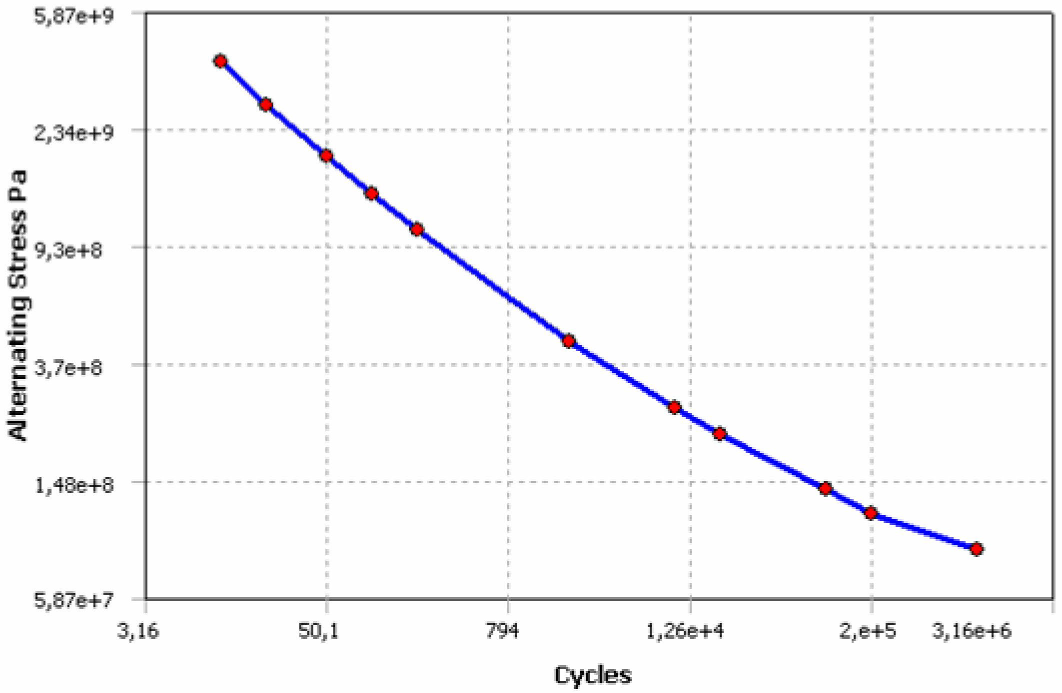


TABLE 40
SAE-AISI 1040 > Alternating Stress > Property Attributes

Interpolation	Log-Log
Mean Curve Type	Mean Stress

TABLE 41
SAE-AISI 1040 > Alternating Stress > Alternating Stress Curve Data

Mean Value Pa
0,

TABLE 42
SAE-AISI 1040 > Alternating Stress > Alternating Stress vs. Cycles

Cycles	Alternating Stress Pa
10,	3,999e+009
20,	2,827e+009
50,	1,896e+009
100,	1,413e+009
200,	1,069e+009
2000,	4,41e+008
10000	2,62e+008
20000	2,14e+008
1,e+005	1,38e+008
2,e+005	1,14e+008
1,e+006	8,62e+007

FIGURE 6
SAE-AISI 1040 > Strain-Life Parameters

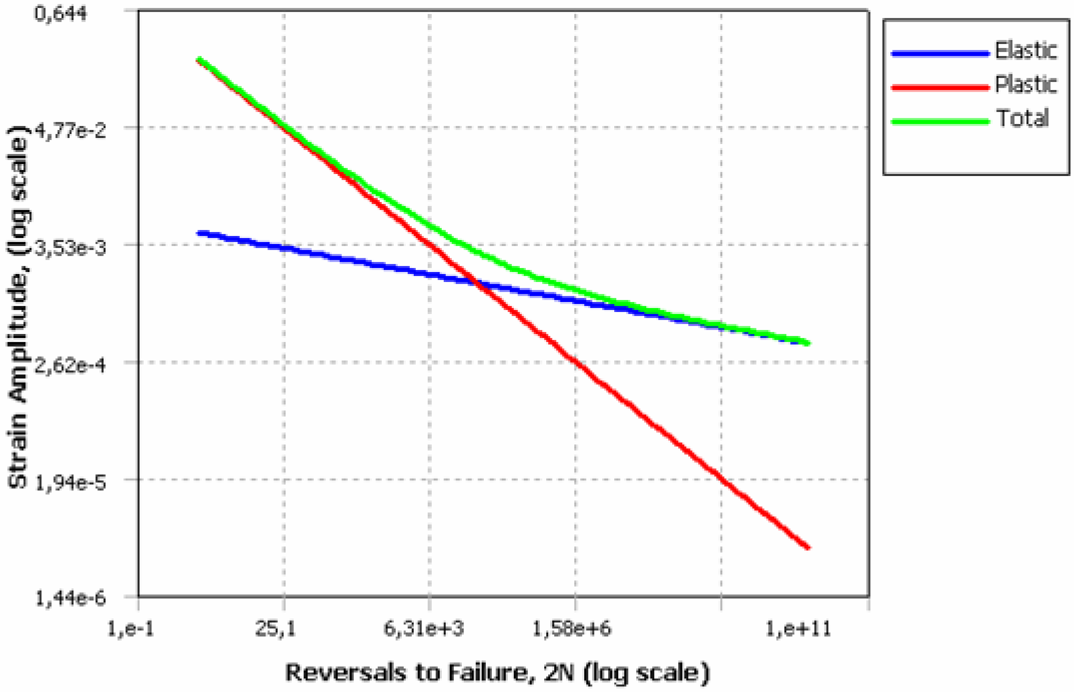


TABLE 43
SAE-AISI 1040 > Strain-Life Parameters > Property Attributes

Display Curve Type	Strain-Life

TABLE 44
SAE-AISI 1040 > Strain-Life Parameters > Strain-Life Parameters

Strength Coefficient Pa	9,2e+008
Strength Exponent	-0,106
Ductility Coefficient	0,213
Ductility Exponent	-0,47
Cyclic Strength Coefficient Pa	1,e+009
Cyclic Strain Hardening Exponent	0,2

SAE-AISI 4340

TABLE 45
SAE-AISI 4340 > Constants

Structural	
Young's Modulus	2,e+011 Pa
Poisson's Ratio	0,3
Density	7850, kg/m³
Thermal Expansion	1,2e-005 1/°C
Tensile Yield Strength	1,5858e+009 Pa
Compressive Yield Strength	1,5858e+009 Pa
Tensile Ultimate Strength	1,7237e+009 Pa
Compressive Ultimate Strength	1,7237e+009 Pa
Thermal	
Thermal Conductivity	60,5 W/m·°C
Specific Heat	434, J/kg·°C
Electromagnetics	
Relative Permeability	10000
Resistivity	1,7e-007 Ohm·m

FIGURE 7
SAE-AISI 4340 > Alternating Stress

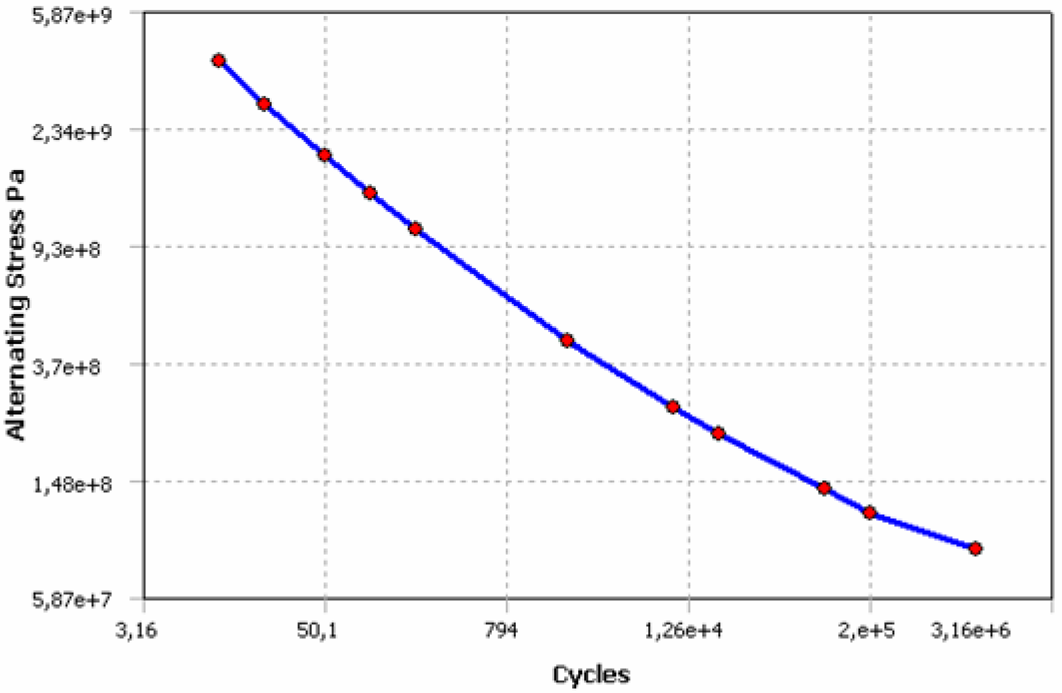


TABLE 46
SAE-AISI 4340 > Alternating Stress > Property Attributes

Interpolation	Log-Log
Mean Curve Type	Mean Stress

TABLE 47
SAE-AISI 4340 > Alternating Stress > Alternating Stress Curve Data

Mean Value Pa
0,

TABLE 48
SAE-AISI 4340 > Alternating Stress > Alternating Stress vs. Cycles

Cycles	Alternating Stress Pa
10,	3,999e+009
20,	2,827e+009
50,	1,896e+009
100,	1,413e+009
200,	1,069e+009
2000,	4,41e+008
10000	2,62e+008
20000	2,14e+008
1,e+005	1,38e+008

2,e+005	1,14e+008
1,e+006	8,62e+007

FIGURE 8
SAE-AISI 4340 > Strain-Life Parameters

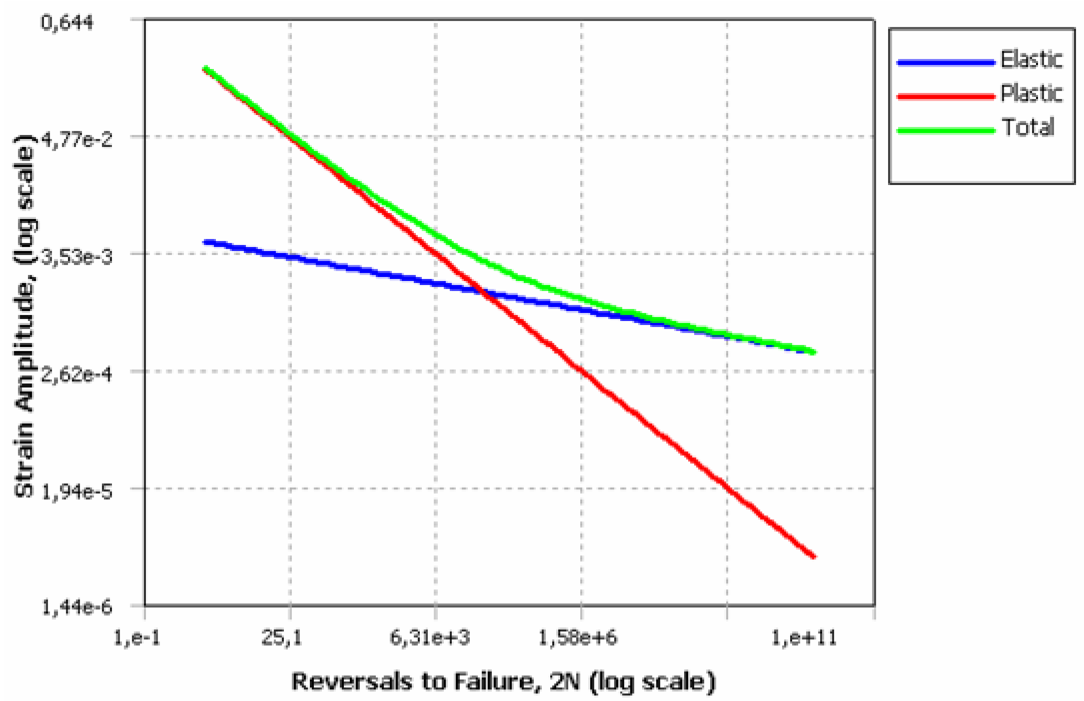


TABLE 49
SAE-AISI 4340 > Strain-Life Parameters > Property Attributes

Display Curve Type	Strain-Life

TABLE 50
SAE-AISI 4340 > Strain-Life Parameters > Strain-Life Parameters

Strength Coefficient Pa	9,2e+008
Strength Exponent	-0,106
Ductility Coefficient	0,213
Ductility Exponent	-0,47
Cyclic Strength Coefficient Pa	1,e+009
Cyclic Strain Hardening Exponent	0,2

Structural Steel

TABLE 51
Structural Steel > Constants

Structural	
Young's Modulus	2,e+011 Pa
Poisson's Ratio	0,3
Density	7850, kg/m³

Thermal Expansion	1,2e-005 1/°C
Tensile Yield Strength	2,5e+008 Pa
Compressive Yield Strength	2,5e+008 Pa
Tensile Ultimate Strength	4,6e+008 Pa
Compressive Ultimate Strength	0, Pa
Thermal	
Thermal Conductivity	60,5 W/m·°C
Specific Heat	434, J/kg·°C
Electromagnetics	
Relative Permeability	10000
Resistivity	1,7e-007 Ohm·m

FIGURE 9
Structural Steel > Alternating Stress

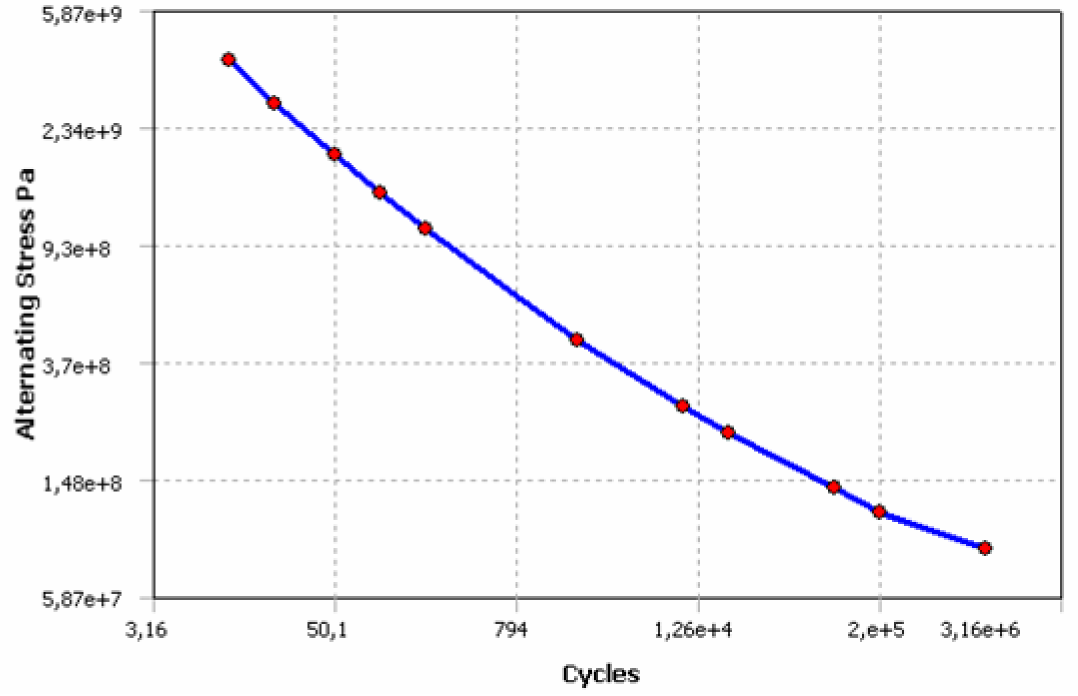


TABLE 52
Structural Steel > Alternating Stress > Property Attributes

Interpolation	Log-Log
Mean Curve Type	Mean Stress

TABLE 53
Structural Steel > Alternating Stress > Alternating Stress Curve Data

Mean Value Pa
0,

TABLE 54
Structural Steel > Alternating Stress > Alternating Stress vs. Cycles

Cycles	Alternating Stress Pa
10,	3,999e+009
20,	2,827e+009
50,	1,896e+009
100,	1,413e+009
200,	1,069e+009
2000,	4,41e+008
10000	2,62e+008
20000	2,14e+008
1,e+005	1,38e+008
2,e+005	1,14e+008
1,e+006	8,62e+007

FIGURE 10
Structural Steel > Strain-Life Parameters

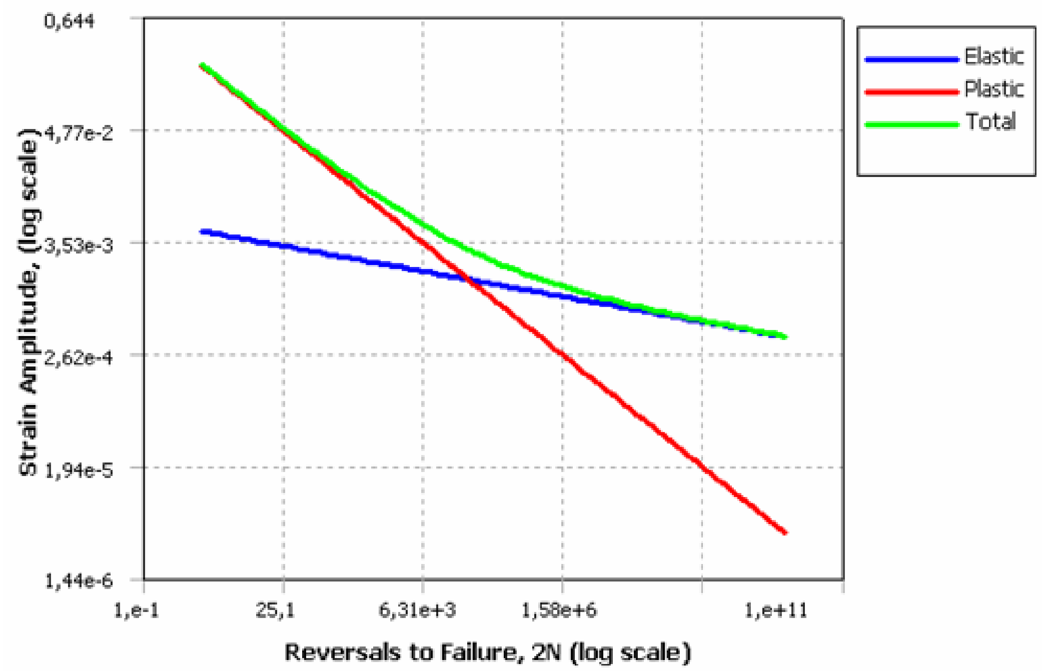


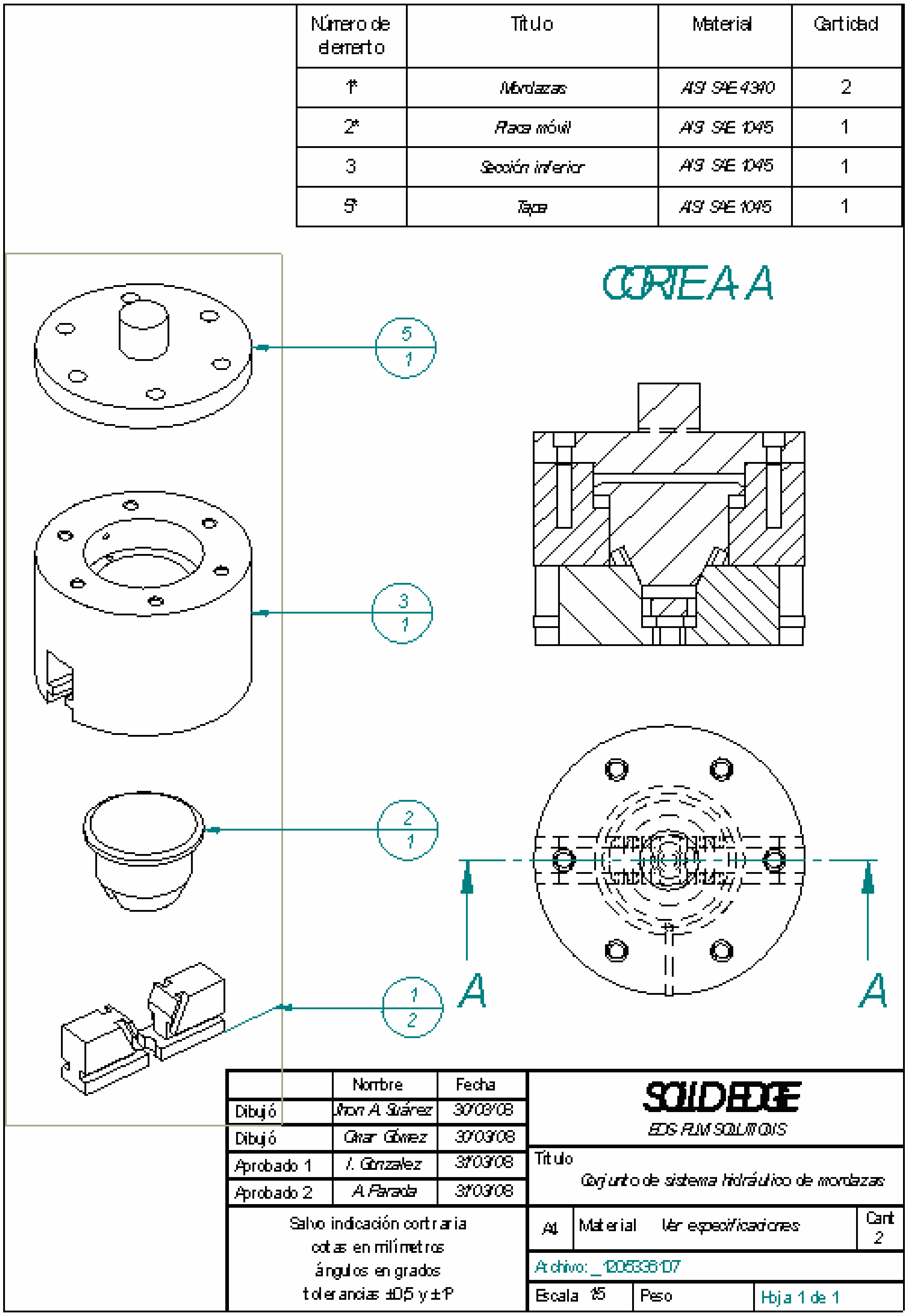
TABLE 55
Structural Steel > Strain-Life Parameters > Property Attributes

Display Curve Type	Strain-Life

TABLE 56
Structural Steel > Strain-Life Parameters > Strain-Life Parameters

Strength Coefficient Pa	9,2e+008
Strength Exponent	-0,106
Ductility Coefficient	0,213
Ductility Exponent	-0,47
Cyclic Strength Coefficient Pa	1,e+009
Cyclic Strain Hardening Exponent	0,2

ANEXO D. Planos



Número de elemento	Título	Material	Cantidad
1*	*Mordazas*	*AISI SAE 4340*	2
2*	*Placa móvil*	*AISI SAE 1045*	1
3	*Sección inferior*	*AISI SAE 1045*	1
5*	*Tapa*	*AISI SAE 1045*	1

	Nombre	Fecha
Dibujó	*Jhon A. Suárez*	30/03/08
Dibujó	*Omar Gómez*	30/03/08
Aprobado 1	*I. Gonzalez*	31/03/08
Aprobado 2	*A. Parada*	31/03/08

Salvo indicación contraria
cotas en milímetros
ángulos en grados
tolerancias ±0.5 y ±1°

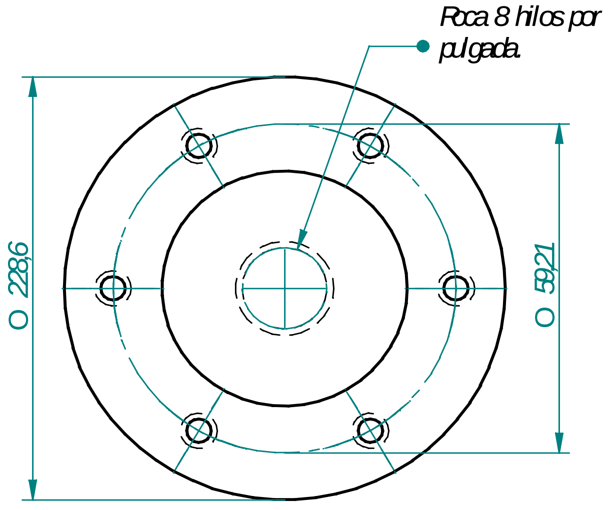
SOLID EDGE
EDS PLM SOLUTIONS

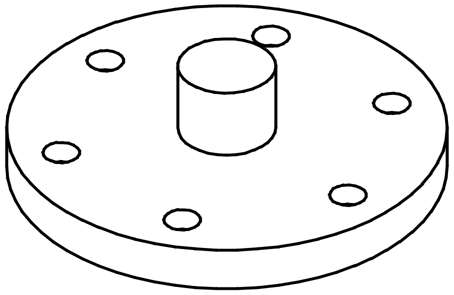
Título
Conjunto de sistema hidráulico de mordazas

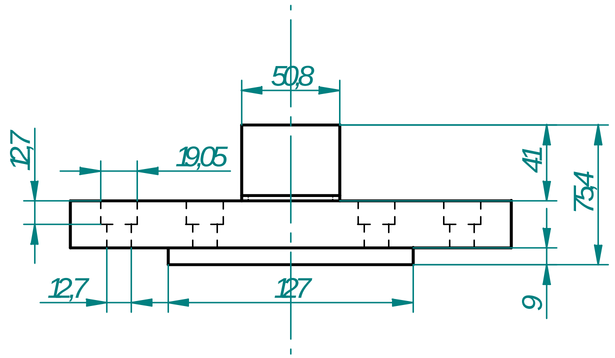
A4 | Material *Ver especificaciones* | Cant 2

Archivo: _1205336107

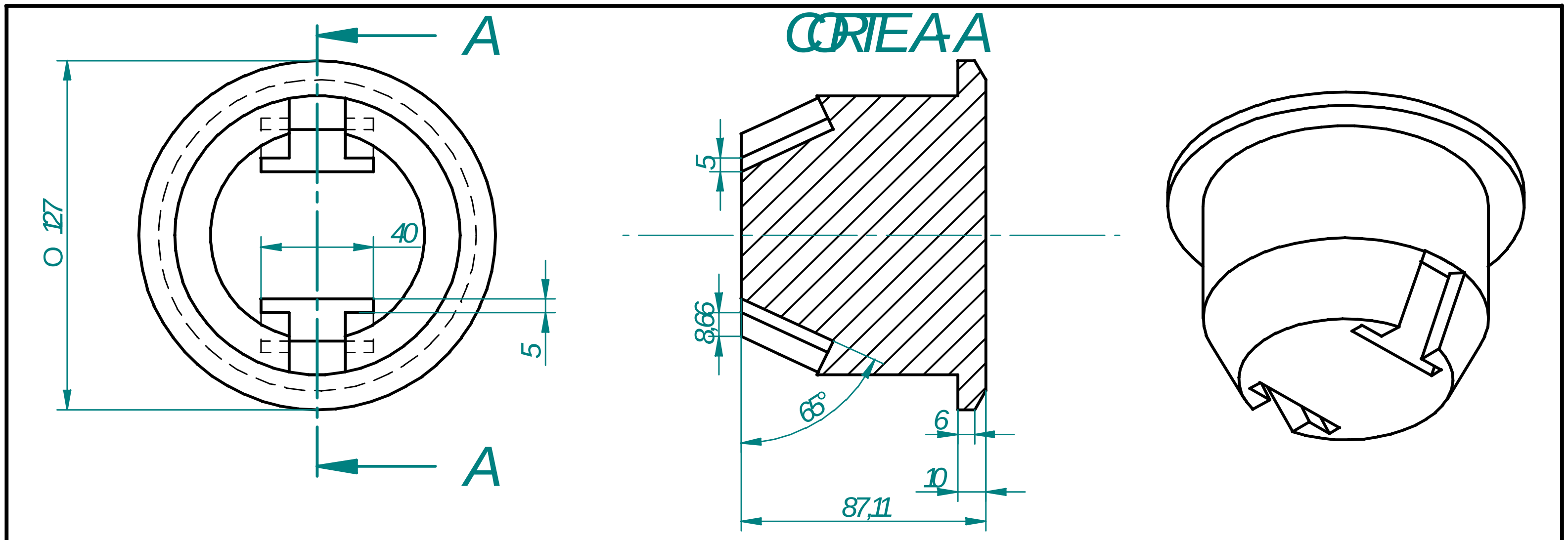
Escala 1:5 | Peso | Hoja 1 de 1

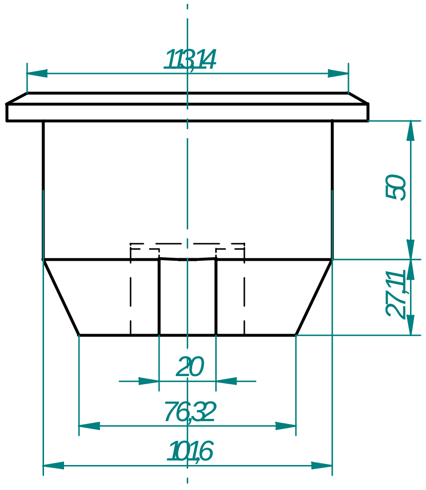






	Nombre	Fecha	
			SOLID EDGE EDS PLM SOLUTIONS
Dibujó	*Jhon A Suarez*	*30/03/08*	Título *Tapa*
Dibujó	*Omar Gómez*	*30/03/08*	
Aprobado 1	*I. Gonzalez*	*31/03/08*	
Aprobado 2	*A Parada*	*31/03/08*	
Salvo indicación contraria cotas en milímetros ángulos en grados tolerancias ±0,5 y ±1º			**A4** Material *Aisi-Sae 1045* Cant 2 Archivo: _1206893802 Escala *1:3* Peso Hoja 1 de 1





	Nombre	Fecha
Dibujó	Jhon A Suarez	30/03/08
Dibujó	Omar Gómez	30/03/08
Aprobado	I. Gonzalez	31/03/08
Aprobado	A Parada	31/03/08

Salvo indicación contraria
cotas en milímetros
ángulos en grados
tolerancias ±0,5 y ±1º

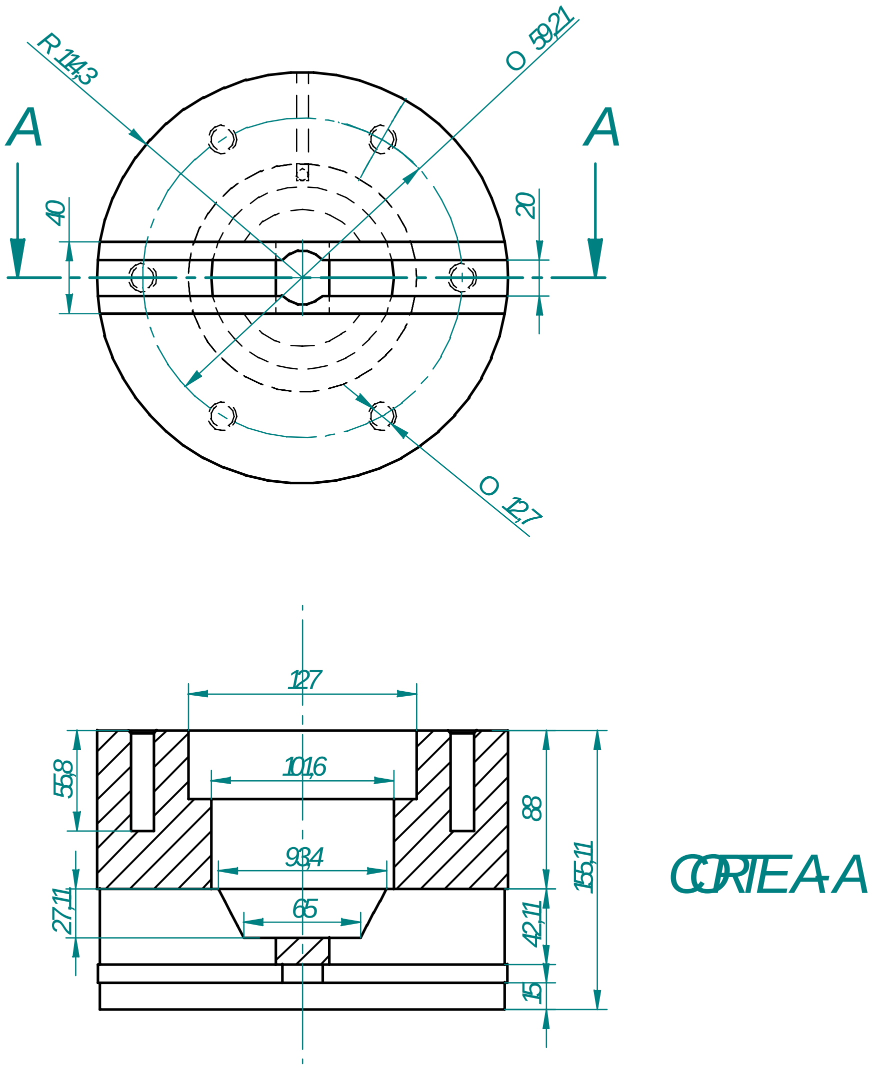
SOLID EDGE
EDS-PLM SOLUTIONS

Título
Placa Móvil

A4	Material AISI-SAE 1045	Cant 2

Archivo: _1206893908

Escala 1:2	Peso	Hoja 1 de 1



	Nombre	Fecha
Dibujó	*Jhon A Suárez*	*30/03/08*
Dibujó	*Omar Gómez*	*30/03/08*
Aprobado 1	*I. Gonzalez*	*31/03/08*
Aprobado 2	*A Parada*	*31/03/08*

Salvo indicación contraria
cotas en milímetros
ángulos en grados
tolerancias ±0,5 y ±1º

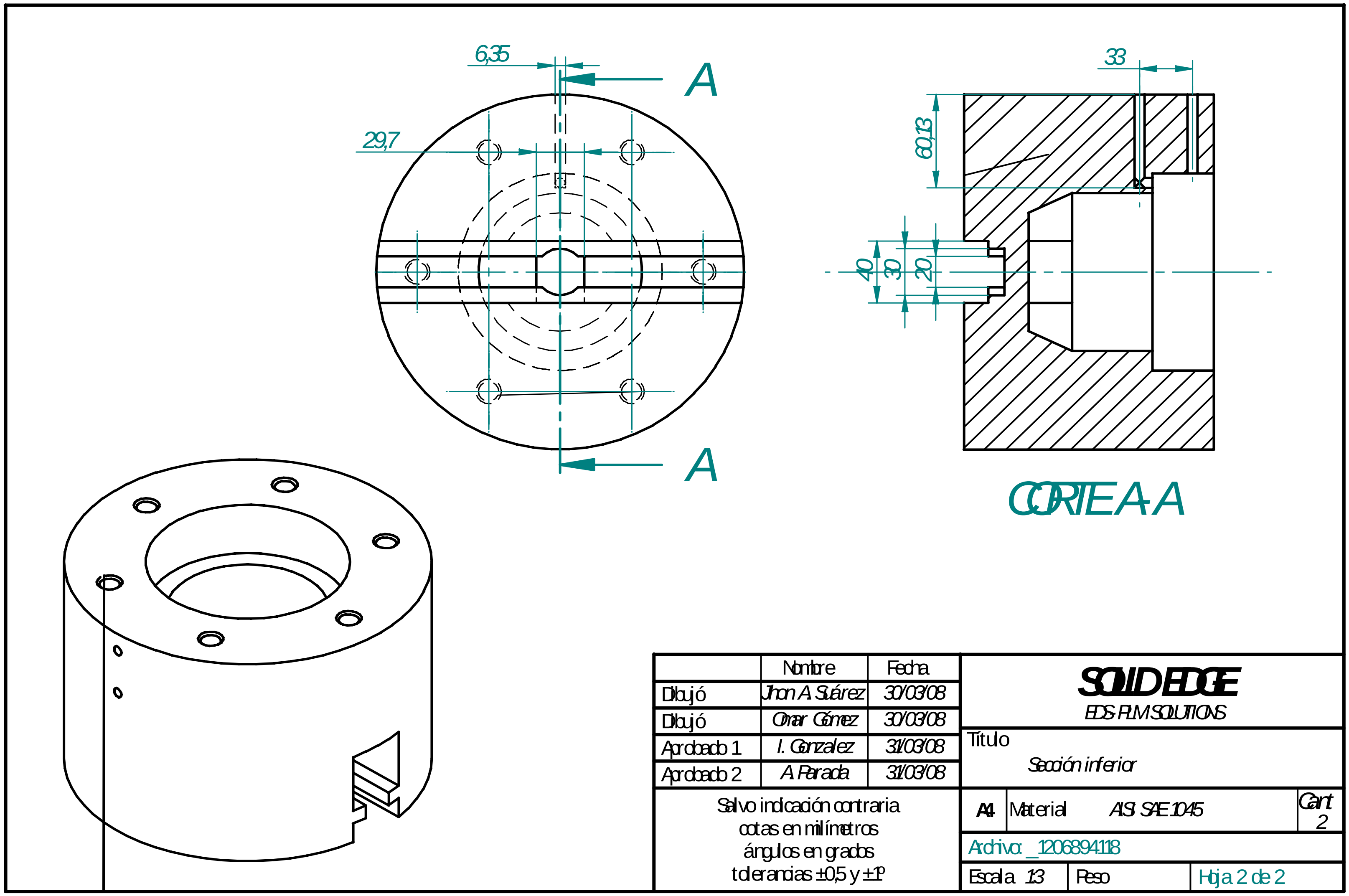
SOLID EDGE
EDS-PLM SOLUTIONS

Título
Sección inferior

A4	Material *AISI SAE 1045*	Cant *2*

Archivo: _1206894006

Escala *1:3*	Peso	Hoja 1 de 2



	Nombre	Fecha
Dibujó	Jhon A Suárez	30/03/08
Dibujó	Omar Gómez	30/03/08
Aprobado 1	I. Gonzalez	31/03/08
Aprobado 2	A Parada	31/03/08

Salvo indicación contraria
cotas en milímetros
ángulos en grados
tolerancias ±0,5 y ±1º

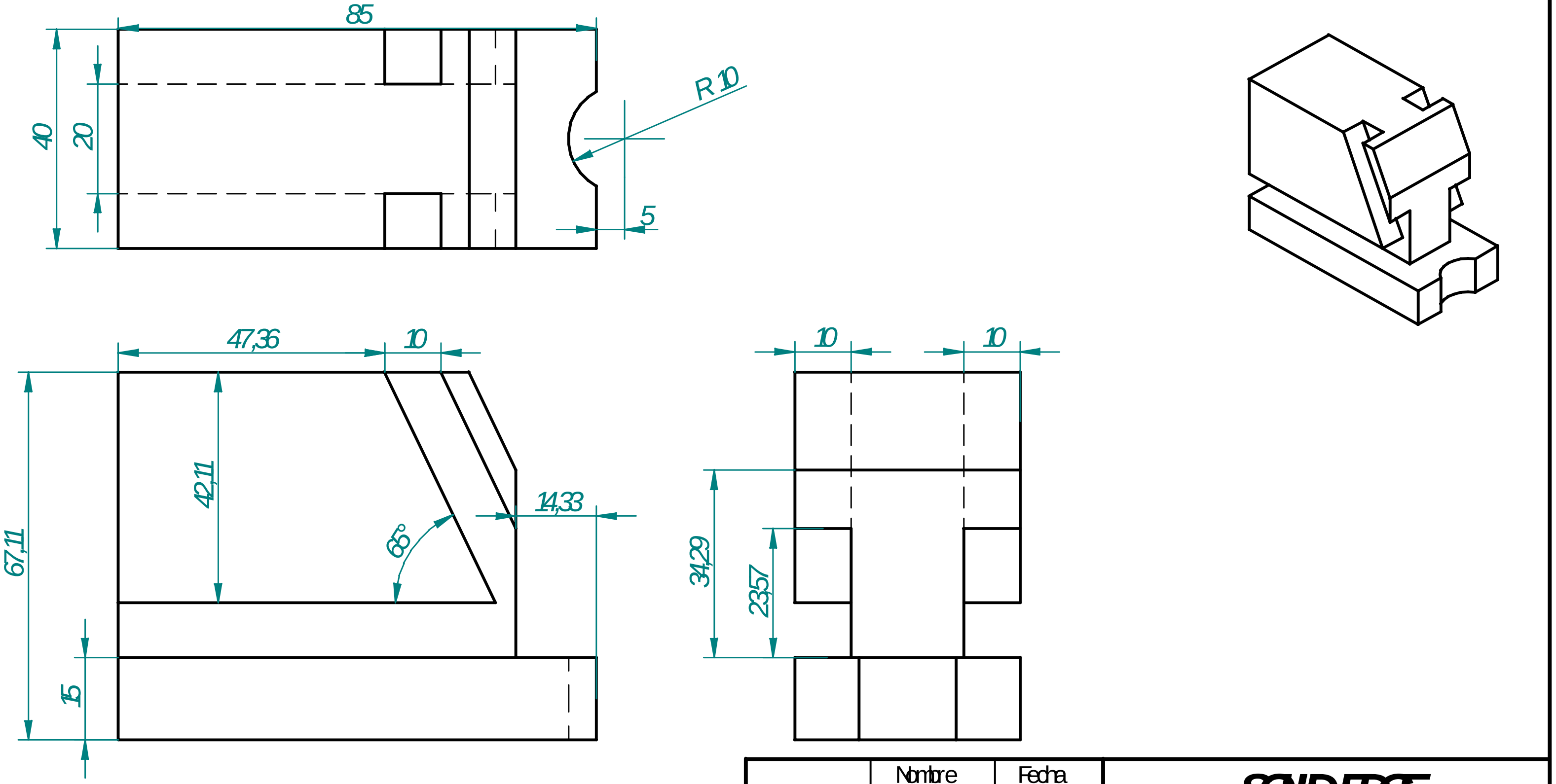
SOLID EDGE
EDS-PLM SOLUTIONS

Título
Sección inferior

A4	Material *AISI SAE 1045*	Cant 2

Archivo: _1206894118

Escala *1:3*	Peso	Hoja 2 de 2



	Nombre	Fecha
Dibujó	*Jhon A Suárez*	*30/03/08*
Dibujó	*Omar Gómez*	*30/03/08*
Aprobado	*I. Gonzalez*	*31/03*
Aprobado	*A Parada*	*31/03/08*

Salvo indicación contraria
cotas en milímetros
ángulos en grados
tolerancias ±0,5 y ±1º

SOLID EDGE
EDS-PLM SOLUTIONS

Título
Mordaza

A4	Material AISI-SAE 4340	*Cant* *4*

Archivo: _1206894209

Escala 1:1	Peso	Hoja 1 de 1

ANEXO E. Calibración de alineación.

INSTRON

Calibración de alineación

¿La alineación afecta los resultados de mis ensayos?

Probablemente; SÍ

Sería erróneo pensar que, simplemente porque su sistema de ensayo de materiales es calibrado periódicamente en cuanto a fuerza, deformación y desplazamiento, usted tiene la garantía de obtener resultados correctos y fiables. La alineación del bastidor puede cambiar por diversos motivos, entre los que se incluyen:

- El cambio de mordazas.
- La instalación de soportes nuevos o la sustitución de los antiguos.
- El cambio de posición de la cruceta fija.
- El desgaste o la rotura de los soportes o de los componentes del bastidor.

Como resultado de ello, la importancia de una correcta alineación está siendo reconocida cada día más por:

- Los organismos de acreditación.
- Las principales corporaciones aeroespaciales.

En el sector aeroespacial, cada día aumenta más la necesidad de demostrar que los sistemas de ensayo cumplen los requisitos de alineación especificados en numerosas normas ASTM que hacen referencia a los esfuerzos de flexión o a la alineación.

¿Qué es alineación?

- Concentricidad.
- Angularidad (paralelismo).

¿Por qué es necesaria una buena alineación?

La manera más fácil de someter una probeta a esfuerzos no deseados es flexionándola. La manera más fácil de flexionarla es colocándola inicialmente en una alineación incorrecta y/o de manera no uniforme, mediante:

- La aplicación de un desplazamiento angular - flexión tipo C.
- La aplicación de un desplazamiento concéntrico - flexión tipo S.

Muchas normas expresan la calidad de los ensayos en términos de % de flexión, p.ej. < 5% de deformación nominal o de amplitud de deformación (ver página siguiente).

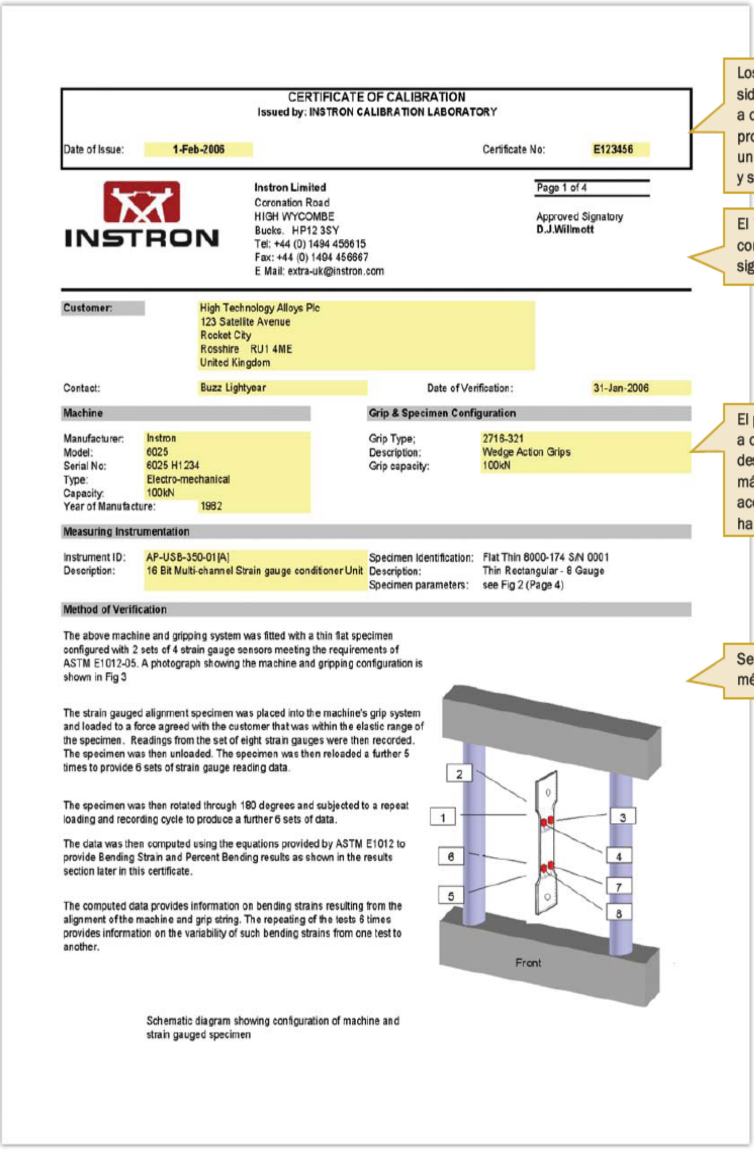
EXTRA INSTRON SERVICES

Normas ASTM con requisitos de alineación

Ensayo	Norma	Flexión máxima permitida	Punto de de medición
Ensayo de tracción a alta temperatura, en probeta testigo de material metálico	ASTM E 21-92	10%	Cualquiera de los extremos de la sección paralela, en dos puntos de una probeta testigo
Fluencia, fractura en fluencia y límite de fluencia	ASTM E 139	10%	Cualquiera de los extremos de la sección paralela, en dos puntos de una probeta testigo
Tracción, con entalla, para determinar el tiempo de rotura	ASTM E 292	10%	Centro de la sección paralela de una probeta testigo
Ensayo de tracción con entalla aguda	ASTM E 602	10%	Centro de la sección paralela y en diferentes puntos de una probeta testigo
Ensayos de fluencia y fractura de metales	BS 3500	10%	No especificado
Ensayos de tracción de cerámicas de alto rendimiento, a temperatura ambiente y a alta temperatura	JIS R 1606	10%	Centro de la sección paralela de una probeta de sección transversal circular
Fluencia y fractura en fluencia, en condiciones de calentamiento rápido	ASTM E 150	7,5%	———
Ensayos de relajación de esfuerzos en tracción	ASTM E 328	7,5%	———
Ensayos de relajación de esfuerzos en compresión	ASTM E 328	5%	———
Ensayos de fatiga axial bajo amplitud constante	ASTM E 466	5%	Cualquiera de los extremos de la sección paralela de una probeta testigo o de la probeta real
Fatiga a bajo número de ciclos, bajo amplitud constante	ASTM E 606	5%	Cualquiera de los extremos de la sección paralela de una probeta testigo
Ensayos de tracción en cerámicas monolíticas	ASTM C 1273-94	5%	Cualquiera de los extremos de la sección paralela y en cuatro puntos de una probeta testigo, sea una probeta simulada o una probeta real
Ensayos de tracción en composites de matriz de cerámica con refuerzo de fibra	ASTM C1274-94	5%	Cualquiera de los extremos de la sección paralela y en cuatro puntos de una probeta testigo, sea una probeta simulada o una probeta real
Fatiga a bajo número de ciclos, controlada por la deformación axial	ISO/TC164/ SC5/WG2/N1	5%	Uno de los tres planos instrumentados de una probeta testigo
Crecimiento de grietas por fatiga	ISO/TC164/ SC5/WG6/N3	5%	Uno de los tres planos instrumentados de una probeta testigo
Fatiga a bajo número de ciclos, bajo amplitud constante, a altas temperaturas	Código de prácticas del HTMTC	5%	Cualquiera de los extremos de la sección paralela y en del diferentes puntos de una probeta testigo
Módulo elástico, tangente y de cuerda	ASTM E 111	3%	No especificado
Fatiga controlada por deformación, bajo amplitud constante	BS 7270	2%	No especificado
Ensayos de tracción a alta temperatura, en materiales metálicos	EN 10002-5	———	Verificación recomendada de acuerdo con la norma ASTM E 1012
Fatiga a bajo número de ciclos	NFA 03403	10%	No especificado
Ensayos de tracción y compresión de composites de matriz de cerámica	ENV 658	———	Verificación recomendada de acuerdo con la norma ASTM E 1012

Ejemplar de obsequio del Código de prácticas del HTMTC de 1995

Certificado de verificación de alineación



CERTIFICATE OF CALIBRATION
Issued by: INSTRON CALIBRATION LABORATORY

Date of Issue: **1-Feb-2006**
Certificate No: **E123456**

INSTRON

Instron Limited
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HIGH WYCOMBE
Bucks. HP12 3SY
Tel: +44 (0) 1494 456615
Fax: +44 (0) 1494 456667
E Mail: extra-uk@instron.com

Page 1 of 4

Approved Signatory
D.J.Willmott

Customer:
High Technology Alloys Plc
123 Satellite Avenue
Rocket City
Rosshire RU1 4ME
United Kingdom

Contact: Buzz Lightyear
Date of Verification: 31-Jan-2006

Machine

Manufacturer: Instron
Model: 6025
Serial No: 6025 H1234
Type: Electro-mechanical
Capacity: 100kN
Year of Manufacture: 1982

Grip & Specimen Configuration

Grip Type; 2716-321
Description: Wedge Action Grips
Grip capacity: 100kN

Measuring Instrumentation

Instrument ID: AP-USB-350-01[A]
Description: 16 Bit Multi-channel Strain gauge conditioner Unit

Specimen Identification: Flat Thin 8000-174 S/N 0001
Description: Thin Rectangular - 8 Gauge
Specimen parameters: see Fig 2 (Page 4)

Method of Verification

The above machine and gripping system was fitted with a thin flat specimen configured with 2 sets of 4 strain gauge sensors meeting the requirements of ASTM E1012-05. A photograph showing the machine and gripping configuration is shown in Fig 3

The strain gauged alignment specimen was placed into the machine's grip system and loaded to a force agreed with the customer that was within the elastic range of the specimen. Readings from the set of eight strain gauges were then recorded. The specimen was then unloaded. The specimen was then reloaded a further 5 times to provide 6 sets of strain gauge reading data.

The specimen was then rotated through 180 degrees and subjected to a repeat loading and recording cycle to produce a further 6 sets of data.

The data was then computed using the equations provided by ASTM E1012 to provide Bending Strain and Percent Bending results as shown in the results section later in this certificate.

The computed data provides information on bending strains resulting from the alignment of the machine and grip string. The repeating of the tests 6 times provides information on the variability of such bending strains from one test to another.

Schematic diagram showing configuration of machine and strain gauged specimen

Los certificados de Instron• han sido diseñados para ayudarle a cumplir los requisitos de su programa de calidad. Todos llevan un número de certificado único y su fecha de expedición.

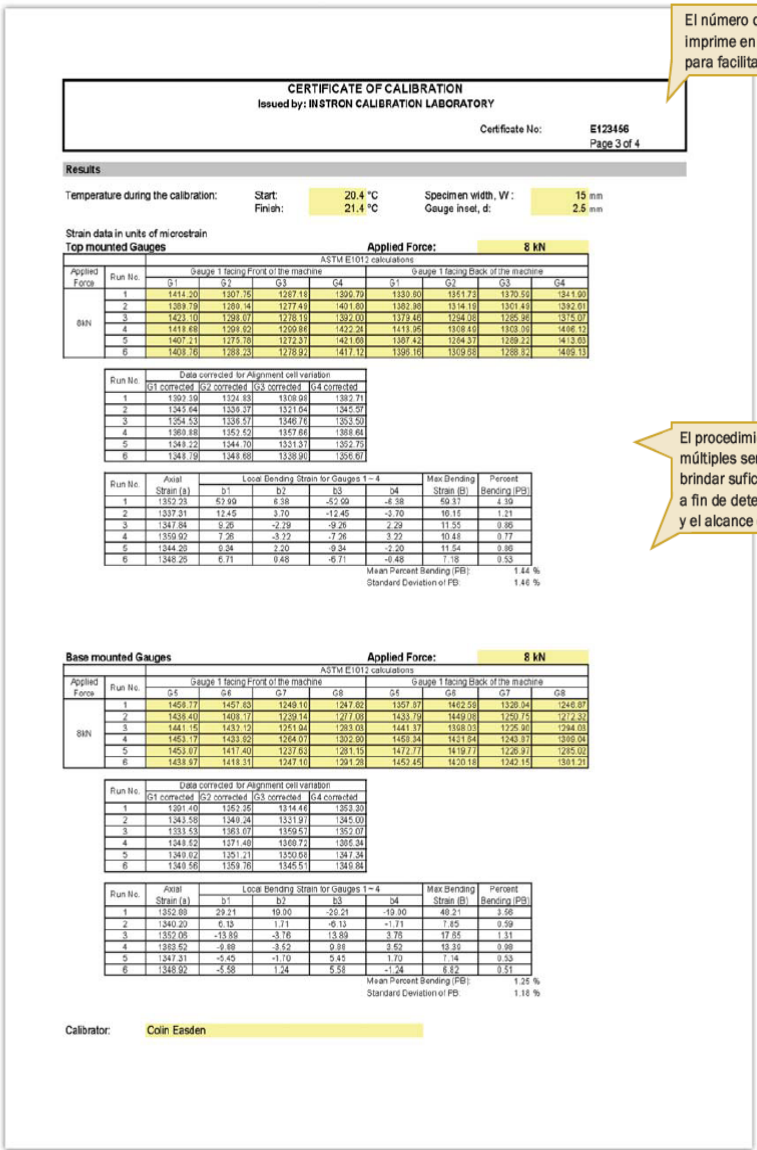
El informe del trabajo es comprobado y verificado por un signatario autorizado.

El procedimiento es aplicable a cualquier sistema, y la descripción detallada de la máquina elimina toda duda acerca de los parámetros que han sido verificados.

Se define el alcance detallado del método de verificación.

Certificado de verificación de alineación

El número del certificado se imprime en todas las páginas para facilitar las consultas.



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Certificate No: **E123456**
Page 3 of 4

Results

Temperature during the calibration: Start: 20.4 °C Finish: 21.4 °C

Specimen width, W : 15 mm
Gauge inset, d: 2.5 mm

Strain data in units of microstrain

Top mounted Gauges **Applied Force:** **8 kN**

		ASTM E1012 calculations							
Applied Force	Run No.	Gauge 1 facing Front of the machine				Gauge 1 facing Back of the machine			
		G1	G2	G3	G4	G1	G2	G3	G4
8kN	1	1414.20	1307.75	1287.18	1390.79	1330.60	1351.73	1370.50	1341.90
	2	1389.79	1280.14	1277.49	1401.80	1382.98	1314.19	1301.49	1392.61
	3	1423.10	1298.07	1278.19	1392.00	1379.46	1294.08	1285.96	1375.07
	4	1418.68	1298.92	1299.86	1422.24	1413.95	1308.49	1303.09	1406.12
	5	1407.21	1275.78	1272.37	1421.68	1387.42	1284.37	1289.22	1413.63
	6	1408.76	1288.23	1278.92	1417.12	1396.16	1309.68	1288.82	1409.13

Run No.	Data corrected for Alignment cell variation			
	G1 corrected	G2 corrected	G3 corrected	G4 corrected
1	1392.39	1324.83	1308.98	1382.71
2	1345.64	1336.37	1321.64	1345.57
3	1354.53	1336.57	1346.76	1353.50
4	1360.88	1352.52	1357.66	1368.64
5	1348.22	1344.70	1331.37	1352.75
6	1348.79	1348.68	1338.90	1356.67

Run No.	Axial Strain (a)	Local Bending Strain for Gauges 1 – 4				Max Bending Strain (B)	Percent Bending (PB)
		b1	b2	b3	b4		
1	1352.23	52.99	6.38	-52.99	-6.38	59.37	4.39
2	1337.31	12.45	3.70	-12.45	-3.70	16.15	1.21
3	1347.84	9.26	-2.29	-9.26	2.29	11.55	0.86
4	1359.92	7.26	-3.22	-7.26	3.22	10.48	0.77
5	1344.28	9.34	2.20	-9.34	-2.20	11.54	0.86
6	1348.26	6.71	0.48	-6.71	-0.48	7.18	0.53

Mean Percent Bending (PB): 1.44 %
Standard Deviation of PB: 1.46 %

Base mounted Gauges **Applied Force:** **8 kN**

		ASTM E1012 calculations							
Applied Force	Run No.	Gauge 1 facing Front of the machine				Gauge 1 facing Back of the machine			
		G5	G6	G7	G8	G5	G6	G7	G8
8kN	1	1458.77	1457.83	1249.10	1247.82	1357.87	1462.59	1328.04	1246.87
	2	1436.40	1408.17	1239.14	1277.08	1433.79	1449.08	1250.75	1272.32
	3	1441.15	1432.12	1251.94	1283.08	1441.37	1398.03	1225.90	1294.03
	4	1453.17	1433.92	1264.07	1302.90	1458.34	1431.64	1243.87	1309.04
	5	1453.07	1417.40	1237.63	1281.15	1472.77	1419.77	1228.97	1285.02
	6	1438.97	1418.31	1247.10	1291.28	1452.45	1420.18	1242.15	1301.21

Run No.	Data corrected for Alignment cell variation			
	G1 corrected	G2 corrected	G3 corrected	G4 corrected
1	1391.40	1352.35	1314.46	1353.30
2	1343.58	1340.24	1331.97	1345.00
3	1333.53	1363.07	1359.57	1352.07
4	1348.52	1371.48	1368.72	1365.34
5	1340.02	1351.21	1350.68	1347.34
6	1340.56	1359.76	1345.51	1349.84

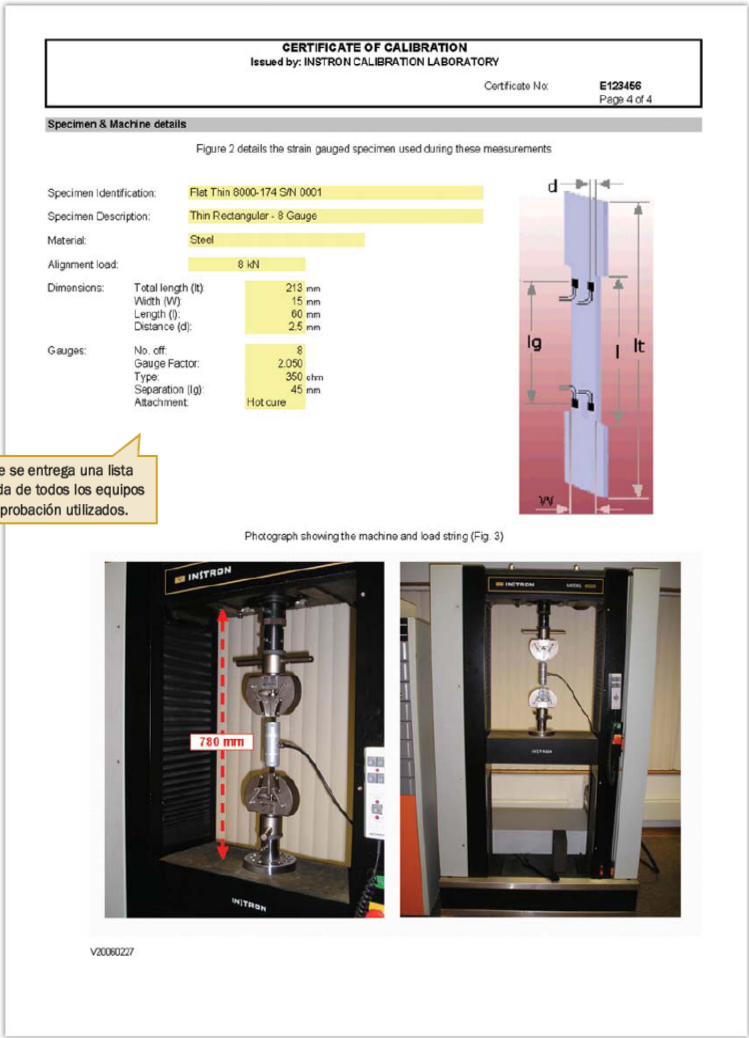
Run No.	Axial Strain (a)	Local Bending Strain for Gauges 1 ~ 4				Max Bending Strain (B)	Percent Bending (PB)
		b1	b2	b3	b4		
1	1352.88	29.21	19.00	-29.21	-19.00	48.21	3.56
2	1340.20	6.13	1.71	-6.13	-1.71	7.85	0.59
3	1352.06	-13.89	-3.76	13.89	3.76	17.65	1.31
4	1363.52	-9.88	-3.52	9.88	3.52	13.39	0.98
5	1347.31	-5.45	-1.70	5.45	1.70	7.14	0.53
6	1348.92	-5.58	1.24	5.58	-1.24	6.82	0.51

Mean Percent Bending (PB): 1.25 %
Standard Deviation of PB: 1.18 %

Calibrator: Colin Easden

El procedimiento proporciona múltiples series de ensayos par brindar suficiente información a fin de determinar la repetibilidad y el alcance de los resultados.

Certificado de verificación de alineación



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Specimen & Machine details

Figure 2 details the strain gauged specimen used during these measurements

Specimen Identification: Flat Thin 8000-174 S/N 0001
Specimen Description: Thin Rectangular - 8 Gauge
Material: Steel
Alignment load: 8 kN

Dimensions:
Total length (lt): 213 mm
Width (W): 15 mm
Length (l): 60 mm
Distance (d): 2.5 mm

Gauges:
No. off: 8
Gauge Factor: 2.050
Type: 350 ohm
Separation (lg): 45 mm
Attachment: Hot cure

Photograph showing the machine and load string (Fig. 3)

V20060227

Siempre se entrega una lista detallada de todos los equipos de comprobación utilizados.

¿Cómo puede saber si la alineación de su máquina de ensayo es correcta?

La flexión de la probeta es un parámetro clave para conocer la alineación de una máquina de ensayo. Para ello, usted puede:

- Utilizar una célula de alineación con deformación calibrada para realizar la verificación de la máquina y la alineación de la línea de carga; o
- Utilizar una probeta típica con deformación calibrada.

A continuación, es necesario que realice una serie de ensayos y algunos cálculos minuciosos. La ASTM ha establecido la norma ASTM E 1012, en la que describe los requisitos y los cálculos que deben realizarse. Con frecuencia se menciona esta norma como método aceptable para la comprobación y cuantificación de la alineación de una máquina de ensayo de materiales.

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Page 2 of 4

Calculations

ASTM E1012 Method - The following calculations are taken from ASTM E1012 Section 11 for Thin Rectangular Specimens [Four Strain Sensors]

For four strain gauges as described in ASTM E1012 Fig 2b, then;

Axial strain:

$$a = \frac{(e_5 + e_6 + e_7 + e_8)}{4}$$

Where e5, e6, e7 & e8 are the measured strain signals from the the four strain gauges. Strain signals e5 to e8 are generated from strain gauges G1 to G4 at the top of the specimen or G5 to G8 for the bottom of the specimen.

Equivalent strains at the centre of the four faces, if strain sensors were possible to be mounted as per a rectangular specimen:

$$e_1 = a - [a - (e_5 + e_8)/2][w/(w - 2d)]$$
$$e_3 = a - [a - (e_6 + e_7)/2][w/(w - 2d)]$$
$$e_2 = (e_5 + e_6)/2$$
$$e_4 = (e_7 + e_8)/2$$

Where w = width of specimen

Where d = distance from edge of specimen to centre line of strain gauge

Local bending strains are calculated as:

$$b_1 = e_1 - a$$
$$b_2 = e_2 - a$$
$$b_3 = e_3 - a$$
$$b_4 = e_4 - a$$

Therefore, Maximum bending strain (B):

$$B = |b_1 - b_3|/2 + |b_2 - b_4|/2$$

Percent Bending (PB):

$$PB = 100\,(B/a)$$

Las ecuaciones características para calcular el porcentaje de flexión varían en dependencia de la geometría de la probeta y del número de extensómetros utilizados.

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Standard Practice for Verification of Specimen Alignment Under Tensile Loading[1]

1. Scope

1.1 Included in this practice are methods covering the determination of the amount of bending that occurs during the loading of notched and unnotched tensile specimens in the elastic range and to plastic strains less than 0.002. These methods are particularly applicable to the force application rates normally used for tension testing, creep testing, and uniaxial fatigue testing.

2. Referenced Documents

2.1 *ASTM Standards:*

E 6 Terminology Relating to Methods of Mechanical Testing[2]

3. Terminology

3.1 The terms in Terminology E 6 apply. Other terms used in connection with specimen alignment are defined as follows:

3.2 *Definitions:*

3.2.1 *alignment*—the condition of a testing machine and load train (including the test specimen) which influences the introduction of bending moments into a specimen during tensile loading.

3.2.2 *apparatus*—the load-train, strain gages, and other details of the equipment to be used for testing, excluding the test specimen.

3.2.3 *axial strain*—the average of the longitudinal strains measured at the surface on opposite sides of the longitudinal axis of symmetry of the specimen by two strain-sensing devices located at the mid-length of the reduced section.

3.2.4 *bending strain*—the difference between the strain at the surface and the axial strain (see Fig. 1). In general, the bending strain varies from point to point around and along the reduced section of the specimen. Bending strain is calculated as shown in Section 11.

3.2.5 *eccentricity*—the distance between the line of action of the applied force and the axis of symmetry of the specimen in a plane perpendicular to the longitudinal axis of the specimen.

3.2.6 *maximum bending strain*—the largest value of bending strain at the position along the length of the reduced section of a straight unnotched specimen at which bending is measured. (For notched specimens, see 4.9.)

3.2.7 *notched section*—the section perpendicular to the longitudinal axis of symmetry of the specimen where the cross-sectional area is intentionally at a minimum value in order to serve as a stress raiser.

3.2.8 *nominal percent bending in notched specimens*—the percent bending in a hypothetical (unnotched) specimen of uniform cross section—equal to the minimum cross section of the notched specimen, the eccentricity of the applied force in the hypothetical, and the notched specimens being the same. (See 11.5.) (This definition is not intended to define strain at the root of the notch.)

3.2.9 *percent bending*—the bending strain times 100 divided by the axial strain.

3.2.10 *rated force*—a force at which the alignment is being measured.

3.2.11 *reduced section*—that part of the specimen length between the fillets.

4. Significance and Use

4.1 It has been shown that bending stresses that inadvertently occur due to misalignment between the applied force and the specimen axes during tensile forces can affect the test results. In recognition of this effect, some test methods include a statement limiting the misalignment which is permitted. The purpose of this practice is to provide a reference for test methods and practices that require tensile loading under conditions where alignment is important. The objective is to implement the use of common terminology and methods for verification of alignment of loading fixtures and test specimens.

4.2 Axiality requirements and verifications should be *optional* when testing is performed for acceptance of materials for minimum strength and ductility requirements. This is because the effects, if any, especially excessive bending, would be expected to reduce strength and ductility properties and give conservative results. There may be no benefit from improved axiality when testing high ductility materials to determine conformance with minimum properties. Whether or not to improve axiality, should be a matter of negotiation between the material producer and the user.

5. Verification of Alignment

5.1 For ease of reference in other practices, test methods,

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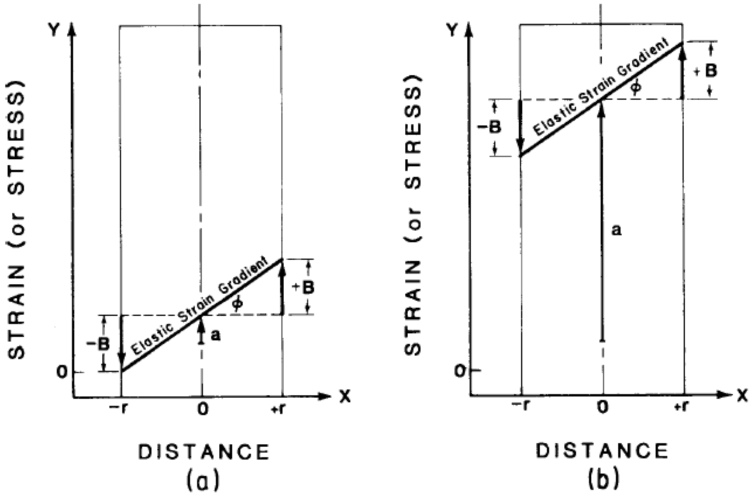
[1] This practice is under the jurisdiction of ASTM Committee E-28 on Mechanical Testing and is the direct responsibility of Subcommittee E28.04 on Uniaxial Testing.

Current edition approved August 10, 1999. Published September 1999. Originally published as E 1012 – 89. Last previous edition E 1012 – 97.

[2] *Annual Book of ASTM Standards,* Vol 03.01.



NOTE 1—A bending strain, ±*B*, is superimposed on the axial strain, *a*, for low-axial strain (or stress) in (*a*) and high-axial strain (or stress) in (*b*). For the same bending strain ±*B*, a high-percent bending is indicated in (*a*) and a low-percent bending is indicated in (*b*).

FIG. 1 Schematic Representations of Bending Strains (or Stresses) That May Accompany Uniaxial Loading

and product specifications, the most commonly used methods for verifying alignment are listed in Section 6.

5.2 A numerical requirement for alignment should specify the force, specimen dimensions, and temperature at which the measurement is to be made.

5.2.1 The force at which the bending strain is specified may be stated in terms of a yield strength or other nominal specimen stress.

NOTE 1—For an offset-load train, percent bending decreases with increasing applied force. (See Curves A, B, and C in Fig. 2.) However, in some instances, percent bending may increase with increasing applied force. (See Curve D in Fig. 2.)

5.3 Alignment requirements can refer to the apparatus (Type A) or to a single test (Type T). Those applied to the test apparatus should be referred to as follows: ASTM Standard Practice E 1012, Type A, Method (followed by the suitable number from 6.1). Those applied to a specific test should be similar with a "T" substituted for the "A."

5.3.1 Verifications of Type A shall be made using a specimen and apparatus made to the same drawing and of the same materials as those that will be used during testing, except that any specimen notches be eliminated. The same specimen may be used for successive verifications. The materials and design should be such that only elastic strains occur at the rated force.

NOTE 2—To avoid damage to the verification specimen, the sum of the axial strain (see section 4.4) and the maximum bending strain (see section 4.8) should not exceed the elastic limit.

5.3.2 Verifications of Type T shall be made on the specimen to be tested just prior to or during the testing and without removing the specimen from the testing machine or making any other adjustments that would affect alignment during the period between verification and testing.

NOTE 3—Maintaining a small force on the specimen between verification and testing is necessary to retain alignment.

6. Methods of Verification of Alignment

6.1 The following methods may be applied to either the verification of alignment of the apparatus or during a specific test. (In general, they are in order of decreasing rigor and cost.)

6.1.1 *Method 1*—The specification measure of alignment is determined either at the test conditions (Type A) or during the test (Type T). This requires an array of strain sensors (for example, see Fig. 3 and 10.6) at two or more longitudinal positions along the reduced section. The strain sensors or components of the strain sensors must be attached to the specimen. Position the strain sensors so as to minimize the portion of the measured strain due to notches or fillets. (If a specific specimen configuration is required, specify the location of the strain sensors.)

NOTE 4—When verifying alignment for apparatus (Type A), bending values may be considered to vary linearly with temperature at temperatures between those at which alignment was measured.

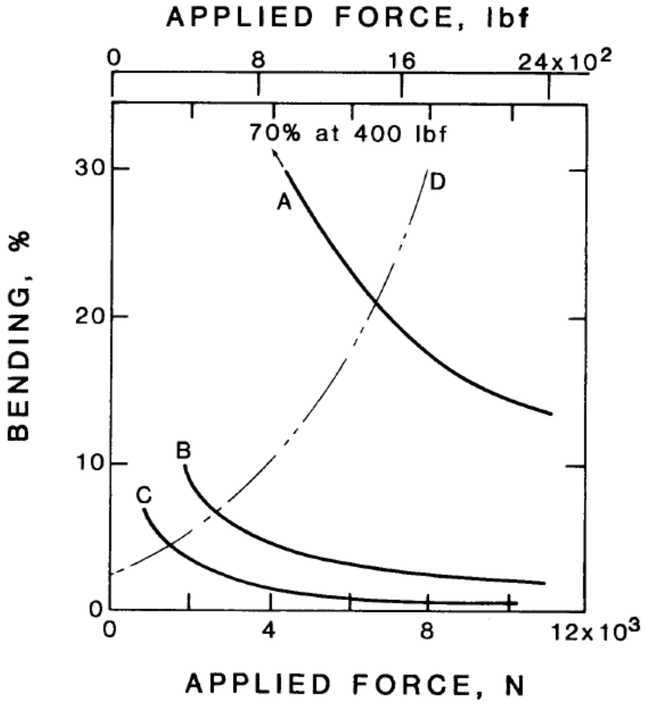
6.1.2 *Method 2*—Identical to Method 1, with the following exceptions:

6.1.2.1 An array of strain sensors are centered at the mid-length of the reduced section of an unnotched specimen, or over the notch of a notched specimen (Note 2 applies).

6.1.2.2 If an extensometer is used on a notched specimen, the gage length should be at least 1.5 times the distance from the notch to the nearest fillet, but no closer to the tangent point of the nearest fillet than one-half of the reduced section diameter or width.

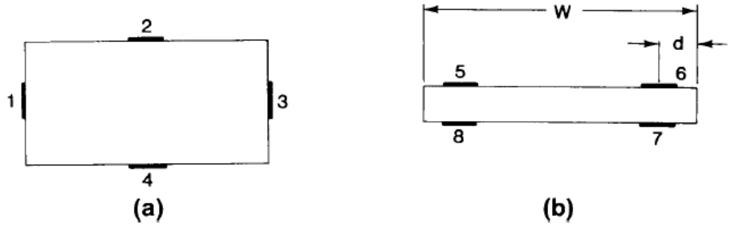
6.1.2.3 Note 4 does not apply.

6.1.3 *Method 3*—Test fixtures, machine, and specimens are dimensionally inspected for compatibility with good alignment



NOTE 1—Curve A: Machine 1, threaded grip ends **(11)**
NOTE 2—Curve B: Machine 2, buttonhead grip ends **(11)**
NOTE 3—Curve C: Machine 3, grips with universal couplings **(7)**
NOTE 4—Curve D: schematic representation of a possible response from an offset load train **(16)**

FIG. 2 Effects of Applied Force on Percent Bending for Different Testing Machines and Gripping Methods



(a)

(b)

NOTE 1—*w* equals width of specimen.
NOTE 2—*d* equals distance from edge of specimen to centerline of strain sensor.

FIG. 3 Locations of Strain Sensors on Specimens of Rectangular Cross Section (Numbers Indicate Positions of Strain Sensors)

and are examined visually or with suitable instrumentation to establish that wear, distortion, or other damage do not significantly affect alignment.

NOTE 5—When there is disagreement over the results of this test, Methods 1 or 2 for verifying alignment are recommended as the preferred method.

7. Apparatus

7.1 The readings from the individual strain sensors shall be repeatable at the rated force within 10 % of the permitted bending strain, during five successive force applications made after the first force application without reducing the applied force to less than 5 % of the rated force.

7.2 When multiple strain sensors are used as in 6.1.1 and 6.1.2, specimen size limitations may dictate the use of electrical resistance strain gages rather than extensometers employing mechanical linkages. Strain sensors, such as mechanical, optical, or electrical extensometers, as well as wire resistance or foil strain gages, can provide useful displacement data. The sensitivity of displacement measurement required by an applicable standard or specification depends on the amount of bending permitted.

7.3 For verification by Method 2, a single *extensometer* of the nonaveraging type may be used by rotating it to various positions around the perimeter during successive force applications and repeating the measurements as described in 10.5. In general, repeated force applications are not permitted in Type T tests (see 5.3) because they may affect the subsequently measured results.

NOTE 6—Repositioning the extensometer around the specimen does not usually give highly precise and reproducible results, but nevertheless is a technique which is useful for detecting large amounts of bending.

7.4 For determining maximum bending strain during Type T Tests (see 5.3), the use of three or four separate extensometers or an extensometer with multiple strain sensors which reads strain at three or more positions about the perimeter is recommended.

7.5 In most cases, the strain sensors will reference displacements between points on the specimen surfaces. However, it is also possible to reference displacements of surfaces attached to the specimen. Such an arrangement might consist of two plates firmly fixed to each end of the gage length of a specimen which is free of initial bending. Displacement measurements are made between corresponding pairs of points on these plates. Each pair of points is in a plane containing the specimen axis and is equally distant from this axis. For specimens of circular cross section, it is recommended that three or four pairs of points be used. A suitable extensometer may then be used to measure the displacement of the pairs of points as force is applied to the specimen. The strain at the specimen surface in the plane containing the pairs of points may, for small displacements, be taken equal to the strain computed at the measurement points multiplied by the ratio of the distance between the specimen applied force axis and the specimen surface to the distance from this axis to the measurement points. An apparatus that measures displacements at points external to the specimen surfaces should be qualified by showing that the bending strains calculated from these measurements agree with those calculated from strains measured directly on the specimen surface using the same application of force.

NOTE 7—When multiple extensometers are used, the strain may be determined by arithmetically averaging outputs. Electrical outputs are thought to be more accurate and reproducible than mechanical outputs.

8. Test Specimen

8.1 This practice refers to cylindrical specimens, thick rectangular specimens, and thin rectangular specimens.

8.2 This practice is valid for metallic and nonmetallic test specimens.

8.3 Quality of machining of test specimens is critical, for example, straightness, concentricity, flatness, and surface finish.

NOTE 8—Geometry and dimensions of test specimens taken from different product forms are described in the Test Specimen section of Test Methods E 8.

9. Calibration and Standardization

9.1 When three or more strain measurements are made at one or more longitudinal positions, the bending strains are determined from ratios of strain measurements. Consequently, the absolute accuracies of the extensometers are not significant. The sensitivities and reproducibilities of the instruments used are significant. All sensors should be calibrated by the same means (see Method E 83) and correction factors should be applied, if necessary, to bring their readings into agreement.

10. Procedure

10.1 Temperature variations during the verification test should be within the limits specified in the methods or practices which require the alignment verification.

10.2 The zero-force reference value of the strain sensors should be measured at a force no greater than approximately 1 % of that force at which the alignment verification is to be made.

10.3 To verify the alignment of the testing apparatus, repeated force applications are necessary. The amount of bending introduced by the load-train depends on the relative position of the various components which transmit force to the specimen and also on the care with which these parts are machined and assembled. Aspects of the test specimen, such as straightness and concentricity, are critical.

10.4 Repeated loadings should include assembly and disassembly of the components of the load-train, including the test specimen. Rotation in 90° increments (0°, 90°, 180°, 270°, repeat 0°) are recommended for a systematic study of the effects of rotational position of components of the load-train. Calculate the bending value for each combination of the components of the load-train. The maximum value should not exceed the specified values in the standard practices, testing methods, or material specifications.

10.5 When using a single, nonaveraging extensometer to evaluate apparatus (Type A), move the extensometer from one side of the specimen to the opposite at the rated force, then rotate 90° at the lower force limit (see 10.2), and repeat the process. Calculate a bending value from the four readings, that is, the readings from two applications of force and two removals of force. Remove the specimen from the grips, and repeat the loading force application sequence for systematic rotations of the components of the load-train as described in 10.3. The largest bending strain resulting from this procedure should not exceed the values permitted by the standard practices, testing methods or material specifications.

10.6 *Location of Strain Sensors*:

10.6.1 *Cylindrical Specimens*—To measure strain, place the strain sensors at equally spaced positions around the circumference of specimens of circular cross section.

10.6.2 *Thick Rectangular Specimens*—If the specimen is of sufficient thickness, to measure strain, place the four strain sensors at the center of each side of the specimens of the rectangular cross section (see Positions 1 through 4 in Fig. 3a).

10.6.3 *Thin Rectangular Specimens*—If the specimen thickness is not sufficient, then place the four strain sensors on opposite sides of the wide faces, near the edges, and equidistant from them (see Positions 5 through 8 in Fig. 3b).

10.6.4 If eight strain gages are used for determination of maximum bending strain, place the gages opposing each other across the specimen longitudinal axis, with two pairs near the upper end of the reduced portion and two pairs near the lower end. The errors in the bending strains are less than the difference between the highest and the lowest value of the four values of axial strain.

NOTE 9—For sheet specimens where the foregoing placement of strain sensors cannot be made, axial strain can be determined using two sets of back-to-back sensors which are equidistant from the longitudinal midpoint of the specimen. (For example, see Fig. 3b.)

NOTE 10—Mechanical hysteresis in the strain sensor may influence the strain measurement.

11. Calculation and Interpretation of Results

11.1 Results of interest usually include axial strain, local bending strains, maximum bending strain, and percent bending.

11.1.1 *Cylindrical Specimens, Three Strain Sensors*—For three strain gages or extensometers, equally spaced around the circumference of a specimen of circular-cross section in a place perpendicular to and at the center of the gage length, see the following equations:

$$\text{axial strain, } a = (e_1 + e_2 + e_3)/3 \tag{1}$$

where:

e_1, e_2, and e_3 = measured strains at the three locations, and where $e_1 \geq e_2 \geq e_3$.

$$\begin{aligned} b_1 &= e_1 - a \\ b_2 &= e_2 - a \\ b_3 &= e_3 - a \end{aligned} \tag{2}$$

where:

b = bending strain.

$$\theta = \tan^{-1}[(2/\sqrt{3})(b_2/b_1 + 1/2)] \tag{3}$$

where:

θ = direction of maximum bending and is measured from the highest-reading strain sensor toward the next highest-reading strain sensor. Finally,

$$B = b_1/\cos\theta \tag{4}$$

where:

B = maximum bending strain.

$$PB = (B/a) \times 100 \tag{5}$$

where:

PB = percent bending.

11.1.2 *Cylindrical Specimens, Four Strain Sensors*—For four strains gages or extensometers, equally spaced around the circumference of specimens of circular cross section, see the following equations:

$$\text{axial strain, } a = (e_1 + e_2 + e_3 + e_4)/4 \tag{6}$$

where e_1, e_2, e_3, and e_4 are the measured strains at the four locations and the subscript indicates the order around the specimen.

$$\begin{aligned} \text{local bending strain, } b_1 &= e_1 - a \\ b_2 &= e_2 - a \\ b_3 &= e_3 - a \\ b_4 &= e_4 - a \end{aligned} \tag{7}$$

and maximum bending strain,

$$B = 1/2\sqrt{(b_1 - b_3)^2 + (b_2 - b_4)^2} \tag{8}$$

and

$$PB = (B/a) \times 100 \tag{9}$$

11.1.3 *Thick Rectangular Specimens, Four Strain Sensors*—

11.1.3.1 For thick specimens of rectangular cross section with strain sensors placed as described in 10.6.2 and Fig. 3a, see the following equation:

$$\text{axial strain, } a = (e_1 + e_2 + e_3 + e_4)/4 \tag{10}$$

where e_1 and e_3 are measured strains at the center of the specimen thickness on opposite faces, and e_2 and e_4 are corresponding values for the wide faces.

11.1.3.2 The local bending strains b_1, b_2, b_3, b_4 are calculated by the equations in 11.1.2.

11.1.3.3 The maximum bending strain, B, is calculated from the following equation:

$$B = |b_1 - b_3|/2 + |b_2 - b_4|/2 \tag{11}$$

11.1.3.4 Percent bending, PB, is calculated as follows:

$$PB = (B/a) \times 100 \tag{12}$$

11.1.4 *Thin Rectangular Specimens, Four Strain Sensors*—

11.1.4.1 For thin specimens of rectangular cross section with strain sensors placed as described in 10.6.3 and shown in Fig. 3b, see the following equation:

$$\text{axial strain, } a = (e_5 + e_6 + e_7 + e_8)/4 \tag{13}$$

11.1.4.2 Equivalent strains at the center of the four faces, if strain sensor placement were possible as shown in Fig. 3a, are given by:

$$\begin{aligned} e_1 &= a - [a - (e_5 + e_8)/2][w/(w - 2d)] \\ e_3 &= a - [a - (e_6 + e_7)/2][w/(w - 2d)] \\ e_2 &= (e_5 + e_6)/2 \\ e_4 &= (e_7 + e_8)/2 \end{aligned} \tag{14}$$

where, as shown in Fig. 3b:

w = width of the broad face, and

d = distance from edge of specimen to position of strain sensor.

11.1.4.3 The maximum bending strain B, and the percent bending, PB, are calculated from the equations in 11.1.3.3 and 11.1.3.4.

11.1.4.4 The equations for the rectangular cross section, given in 11.1.3, are used to complete the calculation.

11.1.5 For tests on notched specimens of circular cross section, the nominal percent bending at the root of the notch is obtained by calculating the percent bending in the reduced section as described in 11.1.1 or 11.1.2 and multiplying the result by the ratio of the diameter of the reduced section to the diameter at the root of the notch.

11.1.6 For tests on notched specimens of rectangular cross section with the notch root axis in the thickness direction, the nominal percent bending is calculated as follows:

$$\frac{[b_1(h/h') + b_2]}{a} \times 100 \tag{15}$$

where:

h = the distance between the notched sides adjacent to the notch,

h' = the distance between notch roots, and b_1, b_2 are defined in 11.1.2.

11.1.6.1 Similarly, when the notches are in the width face, the nominal percent bending is calculated as follows:

$$\frac{b_1 + [b_2(h/h')]}{a} \times 100 \tag{16}$$

12. Report

12.1 Report the following information:

12.1.1 Values of bending strain or percent bending, and method used, including the location of the strain sensors. (See Section 6.)

12.1.2 Test temperature.

12.1.3 Rated maximum force used in verification.

12.1.4 Description of specimen (material and dimensions).

12.1.5 Description of strain measuring equipment, including precision and sensitivity and method of fastening strain sensors to specimens.

12.1.6 Description of load-train, including method of gripping, dimensions of pull bars, types of couplings and joints, and length of load train.

12.1.7 Sample calculation.

12.1.8 Estimate of precision and bias, if strains were measured at four locations. (See Section 13.)

13. Precision and Bias

13.1 The precision of the measurement of specimen alignment under applied tensile forces varies with such test conditions as temperature, stress, configuration of load train, and material. At present, the available data are not of a type that permits meaningful analysis of the precision of the measurement. It is the intention of Committee E-28 to obtain the necessary data from an interlaboratory test program based on this practice.

13.2 The bias of the measurement of specimen alignment under tensile loading varies with such test conditions as temperature, stress, quality of machining of test specimens, and load-train components and material. Since the bending strains used to measure alignment are determined from ratios of strain measurements from three or more strain sensors, the absolute accuracy of the strain sensor calibration is not important (see 9.1). No direct measure of bias is available, because the identical test conditions cannot be duplicated during a calibration run and an actual test.

APPENDIX

(Nonmandatory Information)

X1. SOURCES AND EFFECTS OF MISALIGNMENT UNDER TENSILE LOADING

X1.1 Source of Misalignment

X1.1.1 The usual procedure in a uniaxial tension test is to apply a tensile force to a specimen through grips attached to a load-train and then correlate the strain response of the specimen, as measured with an appropriate extensometer, with the applied stress. In the case of ideal alignment, the top and bottom grip centerlines are precisely in line with one another and with the centerlines of other components of the loading train. Moreover, they are precisely in line with the specimen centerline. Finally, the specimen is symmetric about its centerline. Departures from the ideal situation are caused by poor alignment of the top and bottom grip centerline, poor conformance of specimen centerline to top and bottom grip centerlines, and asymmetric machining of the test specimen itself. A combination of these three sources of misalignment always operates in any test under tensile forces. The occurrence of misalignment is recognized in the ASTM standards referenced in Section 2.

X1.1.2 The characteristic elastic strain gradients resulting from misalignment are such that the extreme elastic strains occur at the surface. These gradients can significantly influence the results of a tension test, especially results at strains less than 0.002 where significant plastic strain and accompanying strain hardening have not yet contributed to evening out the gradients. Therefore, it is important to recognize the effects of misalignment on the stresses and strains measured in studies of the fracture strength of materials in a brittle state, stress-rupture life, creep, notched-tensile specimens, fatigue, plastic microstrain, alloy strengthening, and surface-sensitive strength.

X1.1.3 The objective of any effort to improve alignment is to bring the centerlines of all load-train components into precise alignment. Logically, the first piece of hardware on which to focus attention is the testing machine itself. Testing machines as-received from manufacturers may have deviations between top and bottom grip centerline positions of 0.001 to 0.125 in. (0.03 to 3.18 mm). Moreover, further misalignment may develop as applied forces cause machine frame deflection or as nonaxial crosshead separation occurs. In the worst case, deviations in this range have been reported to lead to eccentricities resulting in a 50 to 100 % difference between extreme surface bending strains and average strain.

X1.1.4 After the testing machine comes a consideration of the tolerances specified for the machining of load-train components and test specimens. In ordinary machine shop practice, tolerances usually range from ±0.002 to ±0.010 in. (±0.05 to ±0.25 mm). These tolerances may cause poor alignment when the components of a loading train are assembled, for example, in the worst case, these tolerances have been reported to lead to eccentricities resulting in a 50 to 100 % difference between extreme surface bending strains and average strain.

X1.1.5 There are two further considerations for the development of good alignment. One deals with the type of couplings in the load-train, such as threaded-versus-nonthreaded joints, spherical seats and universal joints with low friction, cross flexures, fluid couplings, and other couplings which tend not to transmit a bending stress. The other relates to specimen design, such as length and length-to-diameter ratio. The approach to promoting good alignment has been discussed in several papers **(1-11).**[3]

X1.2 Effects of Misalignment on Test Results

X1.2.1 Bending stresses associated with misalignment between the load-train and the specimen axes have been shown to affect the results of tension tests **(12-16).** In routine tension tests of most engineering materials, bending stresses will be insignificant if sufficient plastic flow occurs during the test to eliminate the bending stresses. However, when testing under conditions where plastic flow is limited by inherent brittleness of the test specimen material, or by need for measurements near the elastic limit, or when plasticity is confined to a small volume (specimens with stress concentration such as notches), small misalignment may give rise to variable bending stresses which have noticeable effects on the test results. For example, Morrison **(8)** noted that the yield stress of carefully machined mild steel specimens tested in torsion exhibited a ±1 % variation from the mean, whereas the yield stresses of the same steel specimens tested in tension exhibited a ±5 % variation. Morrison concluded that the larger variation in tensile yield stresses resulted from misalignment rather than from microstructural variations, and he stated that "with the ordinary standard of accuracy in cutting the screwed ends of the specimens, the slackness in the thread was quite sufficient to allow the specimen to take up and retain under load an eccentricity in the shackles which would account for the variation in results."

X1.2.2 Schmieder et al **(9, 10)** found that bending ranged from 5 to 27 % and depended on specimen coupling to the load-train, prior force application, and type of testing machine. These authors concluded that "most of the nonaxiality of loading appears to be due to loose threads or machining imperfections in the couplings." Jones and Brown **(11)** demonstrated that, at fixed stress, simply rotating a load-train component through 360° about the longitudinal axis changed the percentage of bending by a factor of more than 5, from 8 to 43 %. In an experiment with other equipment, Jones and Brown **(11)** found that bending could be varied between about 2 and 14 %, depending on the relative rotational positions of the specimen and of the top and bottom grips. Hence, a fourth item which influences bending might be added to the three cited by Schmieder et al, namely, the rotational registry of the components of the load-train.

X1.2.3 Robinson **(12)** reported a 40 to 60 % decrease in the uniaxial tension–tension fatigue life of steel bolts when the bending microstrain increased by a factor of two. Jones et al **(13)** demonstrated a continuous decrease (ranging from 80 to 90 %) of notch-rupture life of a chromium-molybdenum-vanadium steel, at 60 ksi 1000°F (414 MPa 538°C), as eccentricity increased from a negligible value to 0.1 in. (2.5 mm). Christ **(14)** showed that results of plastic microstrain studies and other pre-yield studies are ambiguous unless effects of misalignment on the average microstrain are recognized. Attention was directed to this point by McVetty **(15)** as early as 1928, but it has been frequently overlooked since then.

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[3] The boldface numbers in parentheses refer to the list of references at the end of this practice.

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Anexo F. Costos

COSTOS

DISEÑO Y CONSTRUCCIÓN DE UN SISTEMA DE MORDAZAS HIDRÁULICAS PARA LA MÁQUINA DE PRUEBAS UNIVERSAL INSTRON MODELO 1323

Descripción	Cantidad	Valor unitario	Valor Total
Adquisición de software Solid Edge V14.	1	$ 70.000	$ 70.000
Adquisición de software Ansys workbench 8.1.	1	$ 70.000	$ 70.000
Fotocopias para bibliografía.	1	$ 100.000	$ 100.000
Compra de acero para construcción de conjuntos.	2	$ 800.000	$ 1.600.000
Construcción de conjuntos de mordazas.	2	$ 2.000.000	$ 4.000.000
Compra de electro válvula direccional 4/3, centro tandem, 110 v marca EQUS.	1	$ 312.000	$ 312.000
Construcción de probetas de 12,5 mm - 9 mm - 6 mm para pruebas.	17	$ 10.000	$ 170.000
Tortillería grado 8, 1/2" * 2¼"	18	$ 5.000	$ 90.000
Compra de accesorios (racores, T´s, reducciones, teflón industrial).	1	$ 150.000	$ 150.000
Mangueras grafada R1 con acoples de 5/16" * 2 mts.	2	$ 100.000	$ 200.000
Mangueras grafada R1 con acoples de 1/4" *0,6 mts.	6	$ 65.000	$ 390.000
Impresiones.	7	$ 40.000	$ 280.000
Otros.	1	$ 150.000	$ 150.000
TOTAL	**$**		**7.582.000**