



Resistencia de Materiales – 15153

Ensayo de tracción uniaxial

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Oficina 10, Primer piso – Laboratorio de Biomateriales

INGENIERÍA CIVIL MECÁNICA
Agosto - 2017

Índice

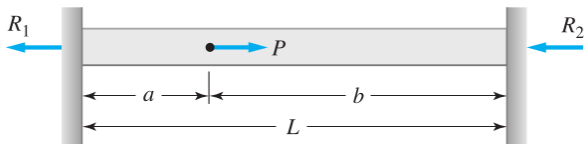
- 1 Introducción
- 2 Diagrama esfuerzo–deformación (σ – ϵ)
- 3 Definiciones básicas
- 4 Curva esfuerzo deformación ingenieril

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Introducción

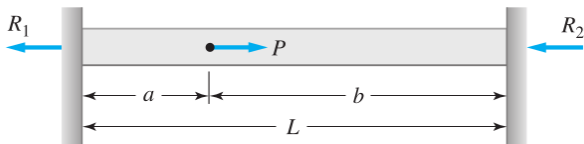
- Hasta ahora sólo hablamos de la resistencia del material en términos de esfuerzo (σ)
- Ahora incluiremos los cambios de forma, deformación (ϵ) uniaxial **elástica**.
- Se estudiarán las relaciones entre deformaciones, equilibrio de fuerzas y relaciones entre σ y $\epsilon \rightarrow$ problemas estáticamente indeterminados.



¿Cuál es el valor de las reacciones?

Introducción

- Hasta ahora sólo hablamos de la resistencia del material en términos de esfuerzo (σ)
- Ahora incluiremos los cambios de forma, deformación (ϵ) uniaxial **elástica**.
- Se estudiarán las relaciones entre deformaciones, equilibrio de fuerzas y relaciones entre σ y $\epsilon \rightarrow$ problemas estáticamente indeterminados.



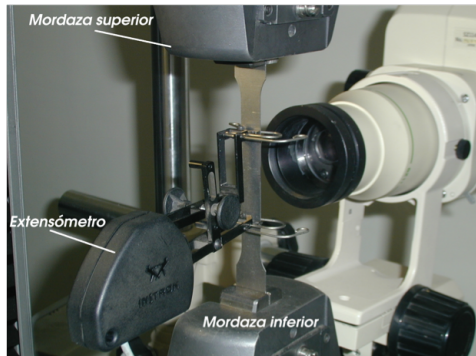
¿Cuál es el valor de las reacciones?

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Ensayo de tracción

- Aplicar un estado uniforme de esfuerzo normal (σ) en una muestra del material (probeta).
- Se registra la carga, el desplazamiento de las mordazas, el desplazamiento entre marcas (extensómetro mecánico u óptico).
- El ensayo se encuentra normado \rightarrow ASTM E8M ó NCh 200 OF74
- Ensayo del tipo destructivo \rightarrow hasta la ruptura





Standard Test Methods for Tension Testing of Metallic Materials¹

This standard is issued under the fixed designation E8/E8M; 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.

1.2 The gage lengths for most round specimens are required to be 4D for E8 and 5D for E8M. The gage length is the most significant difference between E8 and E8M Test Specimens. 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.

1.3 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 A370 and Test Methods B557, and B557M.

1.4 Room temperature shall be considered to be 10 to 38°C [50 to 100°F] unless otherwise specified.

- A370 Test Methods and Definitions for Mechanical Testing of Steel Products
- B557 Test Methods for Tension Testing Wrought and Cast Aluminum- and Magnesium-Alloy Products
- B557M Test Methods for Tension Testing Wrought and Cast Aluminum- and Magnesium-Alloy Products (Metric)
- E4 Practices for Force Verification of Testing Machines
- E6 Terminology Relating to Methods of Mechanical Testing
- E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
- E83 Practice for Verification and Classification of Extensometer Systems
- E345 Test Methods of Tension Testing of Metallic Foil
- E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method
- E1012 Practice for Verification of Test Frame and Specimen Alignment Under Tensile and Compressive Axial Force Application

Máquinas de tracción

Principales fabricantes disponibles en Chile

- INSTRON
- ZWICK

Tipos de máquinas

- Electromecánicas.
 - 1 Cargas máximas 130 kN (13 TON)
 - 2 Velocidades máximas 500 mm/min
 - 3 Fácil control de desplazamiento
 - 4 Difícil control de la carga
- Oleohidráulicas.
 - 1 Cargas máximas 1000 kN (100 TON) (pocas en Chile)
 - 2 Velocidades máximas 100 mm/min
 - 3 Difícil control de desplazamiento
 - 4 Fácil control de la carga

Máquinas de tracción disponibles en el DIMEC



Máquina LOSENHAUSENWERK
Cap. máx. 100kN

Lab. de Sólidos I



Máquina INSTRON
Cap. máx. 100kN

Lab. de Sólidos II

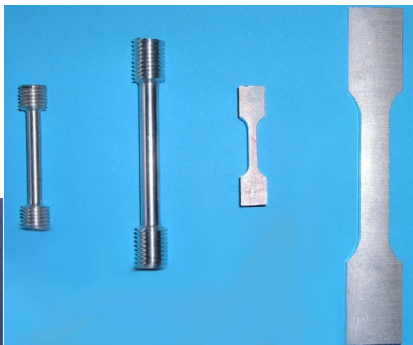


Máquina INSTRON
Cap. máx. 500N

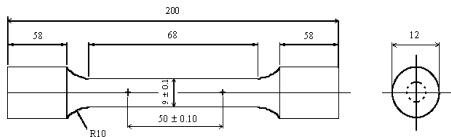
Lab. de Biomateriales

Probetas

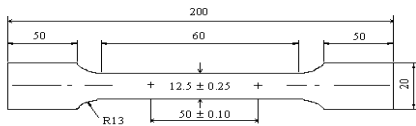
Metales



Probetas típicas del ensayo, normalizadas (ASTM) (*dogbone*)



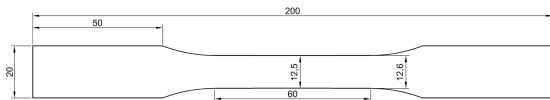
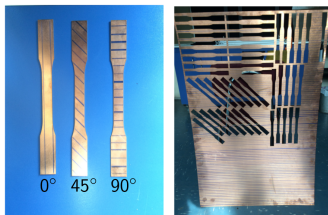
Plano cilíndrica [mm]



Plano plana [mm]

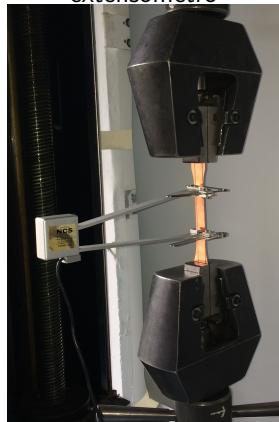
Probetas

Cobre C11000



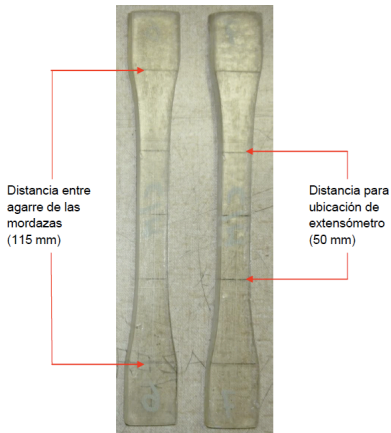
Probetas de chapas de cobre C11000 (ASTM)
(laminado en frío)

Montaje con
extensómetro

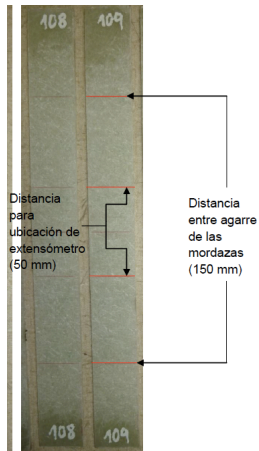


Probetas

Plásticos y materiales compuestos



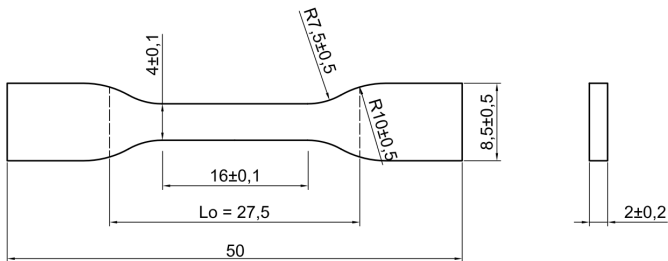
Probeta de resina *ASTM D638*



Probeta material compuesto
ASTM D3039/D3039M

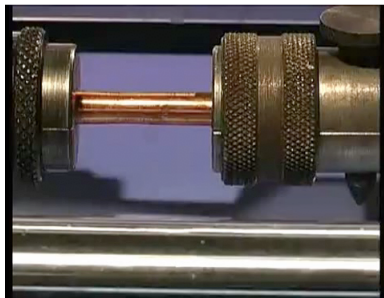
Probetas

Elastómeros

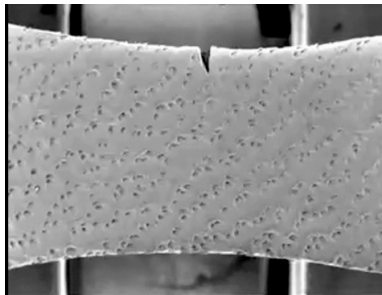


Probeta de poliuretano
ISO 37:2011

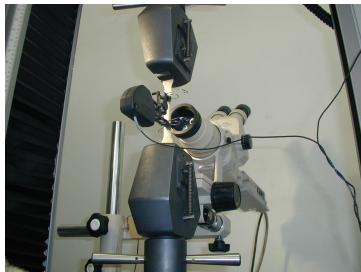
Realización del ensayo



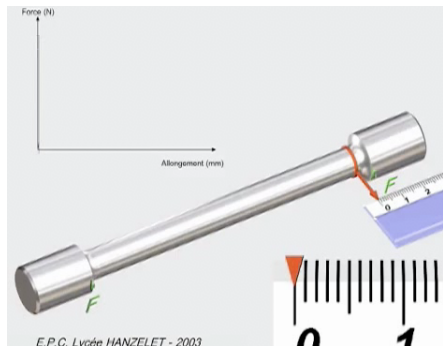
Tracción cobre.



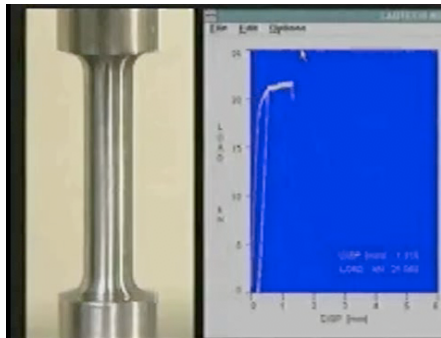
Material compuesto.



Análisis del ensayo



Curva carga-desplazamiento.



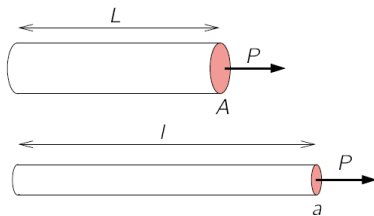
Formación del cuello.

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Medidas de Esfuerzo

- Esfuerzo ingenieril, es el esfuerzo normal calculado considerando el área transversal de la probeta libre de cargas. $\sigma = \frac{P}{A}$
- Esfuerzo real o de Cauchy. Idem al anterior pero considerando el área transversal real (deformada) $\sigma_r = \frac{P}{a}$

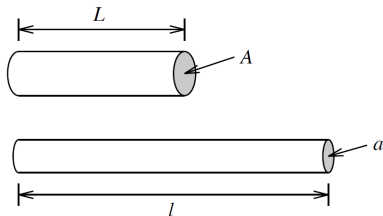


Medidas de Deformación

- Deformación ingenieril $\epsilon = \frac{l-L}{L} = \frac{\delta}{L}$
- Deformación logarítmica ϵ_l . Si se toma una cantidad infinitesimal de desplazamiento (dl) entonces la deformación que se obtiene al estirar una barra de longitud L hasta una longitud l es:

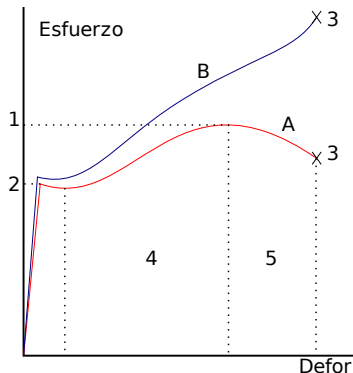
$$\epsilon_l = \int_L^l \frac{dl}{l} = \log l - \log L = \log \frac{l}{L}$$

- Deformación real ϵ_r . Se define al igual que la anterior pero en términos del área transversal inicial y final, es decir: $\epsilon_r = \log \frac{A}{a}$



Curva esfuerzo deformación (aceros)

ingenieril o real

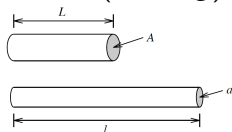


A) Esfuerzo ingenieril $= \sigma = \frac{P}{A}$

B) Esfuerzo real $= \sigma_r = \frac{P}{a}$

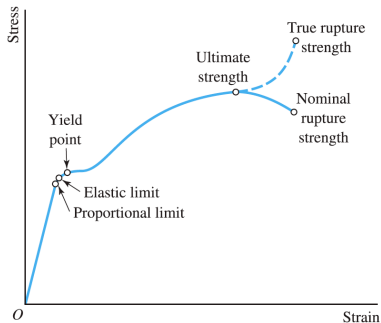
Deformación ingenieril $= \epsilon = \frac{l-l_0}{l_0}$

- 1 Esfuerzo ingenieril máximo (UTS)
- 2 Límite de proporcionalidad
- 3 Punto de rotura (ingenieril \neq real)
- 4 Endurecimiento por deformación
- 5 Estricción (*Necking*)



Curva esfuerzo deformación (metales)

ingenieril o real

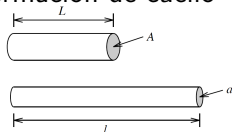


A) **Esfuerzo ingenieril** $= \sigma = \frac{P}{A}$

B) **Esfuerzo real** $= \sigma_r = \frac{P}{a}$

Deformación ingenieril $= \epsilon = \frac{l-l_0}{l_0}$

- 1 **Esfuerzo ingenieril máximo (UTS)**
- 2 **Límite de proporcionalidad**
- 3 **Punto de rotura (ingenieril \neq real)**
- 4 **Endurecimiento por plasticidad**
- 5 **Formación de cuello**



Propiedades mecánicas de metales (Pytel)

TABLE B-1 Average Physical Properties of Common Metals: SI Units

| Metal | Density (kg/m ³) | Temp. coeff. of linear expansion [$\mu\text{m}/(\text{m} \cdot ^\circ\text{C})$] | Proportional limit (MPa) ^a | | Ultimate strength (MPa) | | | Modulus of elasticity (GPa) ^a | | Percentage of elongation (in 50 mm) |
|-----------------------------------|---------------------------------|---|--|--------------|----------------------------|--------------|--------------|---|-----------------|---|
| | | | Tension | Shear | Tension | Comp. | Shear | Tension, <i>E</i> | Shear, <i>G</i> | |
| Steel, 0.2% carbon, hot rolled | 7 850 | { Varies from 11.0 to 13.2 Average is 11.7 } | 240 | 150 | 410 | ^b | 310 | 200 | 80 | 35 |
| 0.2% carbon, cold rolled | 7 850 | | 420 | 250 | 550 | ^b | 420 | 200 | 80 | 18 |
| 0.6% carbon, hot rolled | 7 850 | | 420 | 250 | 690 | ^b | 550 | 200 | 80 | 15 |
| 0.8% carbon, hot rolled | 7 850 | | 480 | 290 | 830 | ^b | 730 | 200 | 80 | 10 |
| Gray cast iron | 7 200 | 10.8 | ^c | ^d | 140 | 520 | ^d | 100 | 40 | Slight |
| Malleable cast iron | 7 200 | 11.9 | 250 | 160 | 370 | ^b | 330 | 170 | 90 | 18 |
| Wrought iron | 7 700 | 12.1 | 210 | 130 | 350 | ^b | 240 | 190 | 70 | 35 |
| Aluminum, cast | 2 650 | 23.1 | 60 | — | 90 | ^b | 70 | 70 | 30 | 20 |
| Aluminum alloy 17ST | 2 700 | 23.1 | 220 | 150 | 390 | ^b | 220 | 71 | 30 | — |
| Brass, rolled (70% Cu, 30% Zn) | 8 500 | 18.7 | 170 | 110 | 380 | ^b | 330 | 100 | 40 | 30 |
| Bronze, cast | 8 200 | 18.0 | 140 | — | 230 | 390 | — | 80 | 35 | 10 |
| Copper, hard-drawn | 8 800 | 16.8 | 260 | 160 | 380 | ^b | — | 120 | 40 | 4 |

^aThe proportional limit and modulus of elasticity for compression may be assumed equal to these values for tension except for cast iron where the proportional limit is approximately 180 MPa.

^bThe ultimate compressive strength for ductile materials may be taken as the yield point, which is slightly greater than the proportional limit in tension.

^cNot well defined; approximately 40 MPa.

^dCast iron fails by diagonal tension.

Propiedades mecánicas de materiales (Hibbeler)

Average Mechanical Properties of Typical Engineering Materials^a
(SI Units)

| Materials | Density ρ (Mg/m ³) | Modulus of Elasticity E (GPa) | Modulus of Rigidity G (GPa) | Yield Strength (MPa) | | | Ultimate Strength (MPa) | | | % Elongation in 50 mm specimen | Poisson's Ratio ν | Coef. of Therm. Expansion α (10 ⁻⁶)/°C | |
|------------------------------|--|------------------------------------|----------------------------------|----------------------|--------------------|-------|-------------------------|--------------------|-----------------|--------------------------------|-----------------------|--|-----|
| | | | | Tens. | Comp. ^b | Shear | Tens. | Comp. ^b | Shear | | | | |
| Metallic | | | | | | | | | | | | | |
| Aluminum Wrought Alloys | 2014-T6 | 2.79 | 73.1 | 27 | 414 | 414 | 172 | 469 | 469 | 290 | 10 | 0.35 | 23 |
| | 6061-T6 | 2.71 | 68.9 | 26 | 255 | 255 | 131 | 290 | 290 | 186 | 12 | 0.35 | 24 |
| Cast Iron Alloys | Gray ASTM 20 | 7.19 | 67.0 | 27 | - | - | - | 179 | 669 | - | 0.6 | 0.28 | 12 |
| | Malleable ASTM A-197 | 7.28 | 172 | 68 | - | - | - | 276 | 572 | - | 5 | 0.28 | 12 |
| Copper Alloys | Red Brass C83400 | 8.74 | 101 | 37 | 70.0 | 70.0 | - | 241 | 241 | - | 35 | 0.35 | 18 |
| | Bronze C86100 | 8.83 | 103 | 38 | 345 | 345 | - | 655 | 655 | - | 20 | 0.34 | 17 |
| Magnesium Alloy | [Am 1004-T61] | 1.83 | 44.7 | 18 | 152 | 152 | - | 276 | 276 | 152 | 1 | 0.30 | 26 |
| Steel Alloys | Structural A36 | 7.85 | 200 | 75 | 250 | 250 | - | 400 | 400 | - | 30 | 0.32 | 12 |
| | Stainless 304 | 7.86 | 193 | 75 | 207 | 207 | - | 517 | 517 | - | 40 | 0.27 | 17 |
| | Tool L2 | 8.16 | 200 | 75 | 703 | 703 | - | 800 | 800 | - | 22 | 0.32 | 12 |
| Titanium Alloy | [Ti-6Al-4V] | 4.43 | 120 | 44 | 924 | 924 | - | 1,000 | 1,000 | - | 16 | 0.36 | 9.4 |
| Nonmetallic | | | | | | | | | | | | | |
| Concrete | Low Strength | 2.38 | 22.1 | - | - | - | 12 | - | - | - | - | 0.15 | 11 |
| | High Strength | 2.38 | 29.0 | - | - | - | 38 | - | - | - | - | 0.15 | 11 |
| Plastic Reinforced | Kevlar 49 | 1.45 | 131 | - | - | - | - | 717 | 483 | 20.3 | 2.8 | 0.34 | - |
| | 30% Glass | 1.45 | 72.4 | - | - | - | - | 90 | 131 | - | - | 0.34 | - |
| Wood Select Structural Grade | Douglas Fir | 0.47 | 13.1 | - | - | - | - | 2.1 ^c | 26 ^d | 6.2 ^d | - | 0.29 ^e | - |
| | White Spruce | 3.60 | 9.65 | - | - | - | - | 2.5 ^c | 36 ^d | 6.7 ^d | - | 0.31 ^e | - |

^aSpecific values may vary for a particular material due to alloy or mineral composition, mechanical working of the specimen, or heat treatment. For a more exact value reference books for the material should be consulted.

^bThe yield and ultimate strengths for ductile materials can be assumed equal for both tension and compression.

^cMeasured perpendicular to the grain.

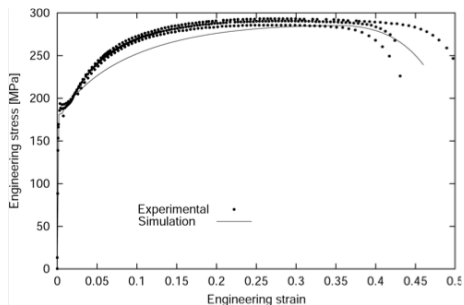
^dMeasured parallel to the grain.

^eDeformation measured perpendicular to the grain when the load is applied along the grain.

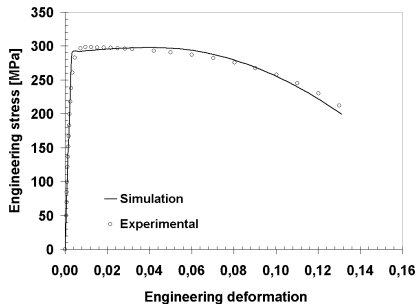
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Curva esfuerzo deformación ingenieril

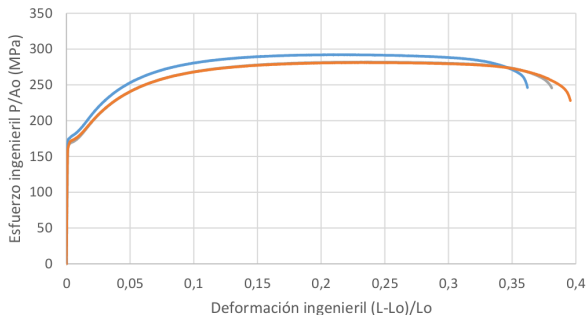


Material A36 (planas)

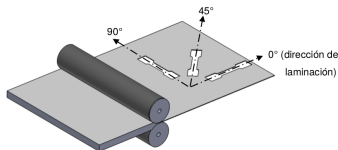


Cobre (cilíndricas)

Tracción Acero EK4 (embutición)

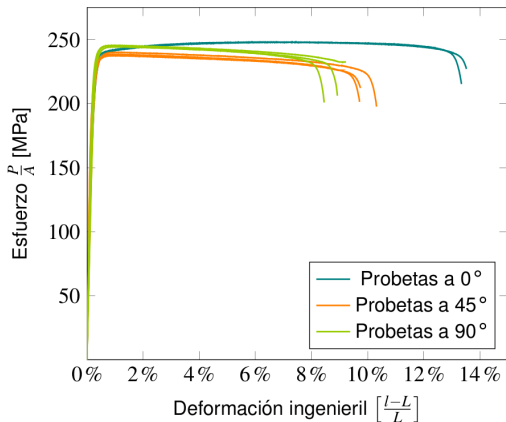


— 0° grados - 2do ensayo — 45° grados - 2do ensayo — 90° grados - 2do ensayo



| Propiedades mecánicas acero EK4 | | | | | |
|---------------------------------|--------------------|---------------------------|-----------------------|--------------------------|------------------------------|
| Probeta | Fuerza máxima (kN) | Esfuerzo máximo UTS (MPa) | Módulo de Young (GPa) | Límite de fluencia (MPa) | Desplazamiento a rotura (mm) |
| 0° | 2,107 | 280,98 | 161,12 | 165,53 | 18,73 |
| 45° | 2,162 | 288,31 | 192,89 | 171,97 | 17,97 |
| 90° | 2,115 | 282,00 | 182,36 | 171,53 | 18,83 |
| Media | 2,128 | 283,76 | 178,79 | 169,68 | 18,51 |
| ± Desviación estándar | 0,024 | 3,24 | 13,21 | 2,94 | 0,38 |

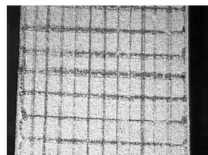
Tracción Cobre C11000 (laminado)



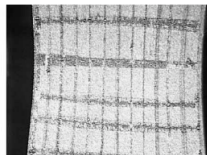
| Dirección | E [GPa] | σ_p [MPa] | σ_y [MPa] | UTS [MPa] | e_{rotura} [mm/mm] |
|-----------|---------|------------------|------------------|-----------|----------------------|
| 0° | 108,7 | 110,0 | 233,8 | 248,1 | 0,134 |
| 45° | 130,3 | 104,5 | 231,1 | 238,7 | 0,097 |
| 90° | 108,0 | 112,9 | 240,1 | 245,1 | 0,088 |

Formación del cuello (*necking*)

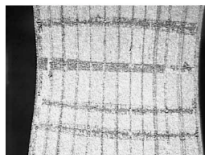
Probetas planas



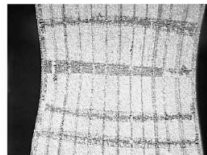
34%



38%



41%



43%



44%



46%

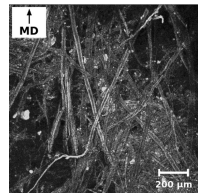
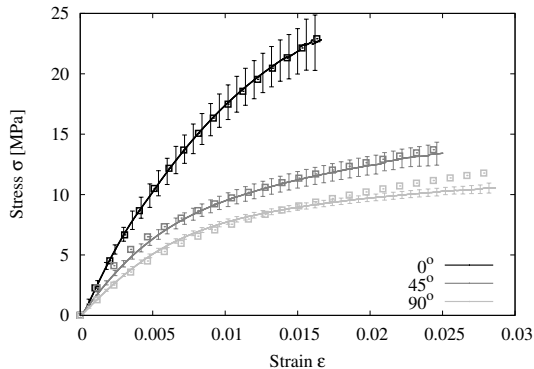


47.0%

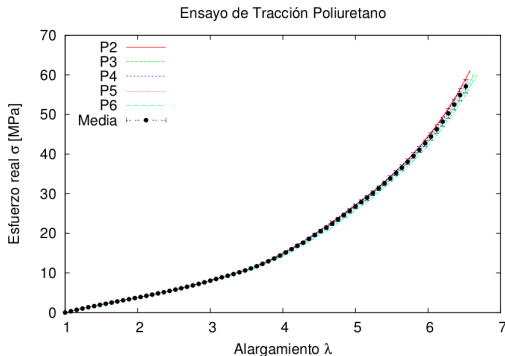


47.1%

Tracción Filtro asfáltico (papel)



Tracción Poliuretano (elastómero)



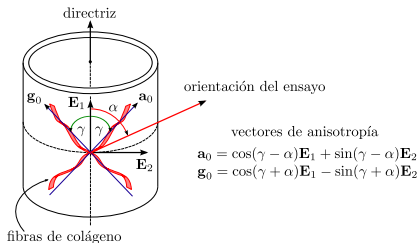
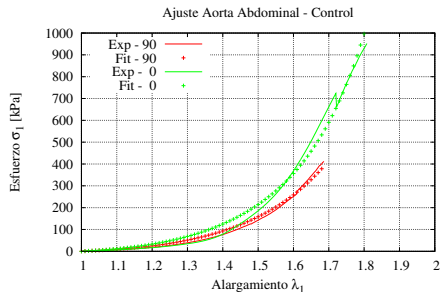
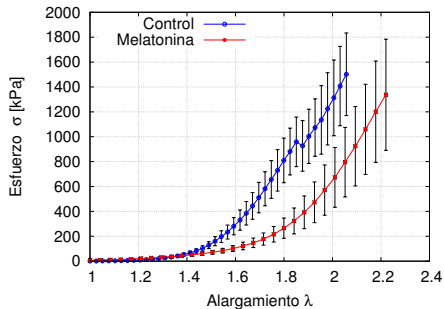
$$\sigma = 2\left(\lambda^2 - \frac{1}{\lambda}\right)\left(c_1 + 2c_2\left(\lambda^2 + \frac{2}{\lambda} - 3\right) + 3c_3\left(\lambda^2 + \frac{2}{\lambda} - 3\right)^2\right).$$

$$\sigma = \frac{P}{a} = \frac{P}{A_0} \cdot \lambda$$

$$\lambda = \frac{L_0 + \delta}{L_0}$$

| Constante | C ₁ | C ₂ | C ₃ | NRMSD |
|-------------|----------------|----------------|----------------|---------|
| Valor [MPa] | 0,451401 | 0,000503503 | 3,79356 e-05 | 0,00664 |

Tracción Arterias (tejido biológico)





Resistencia de Materiales – 15153

Ensayo de tracción uniaxial

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