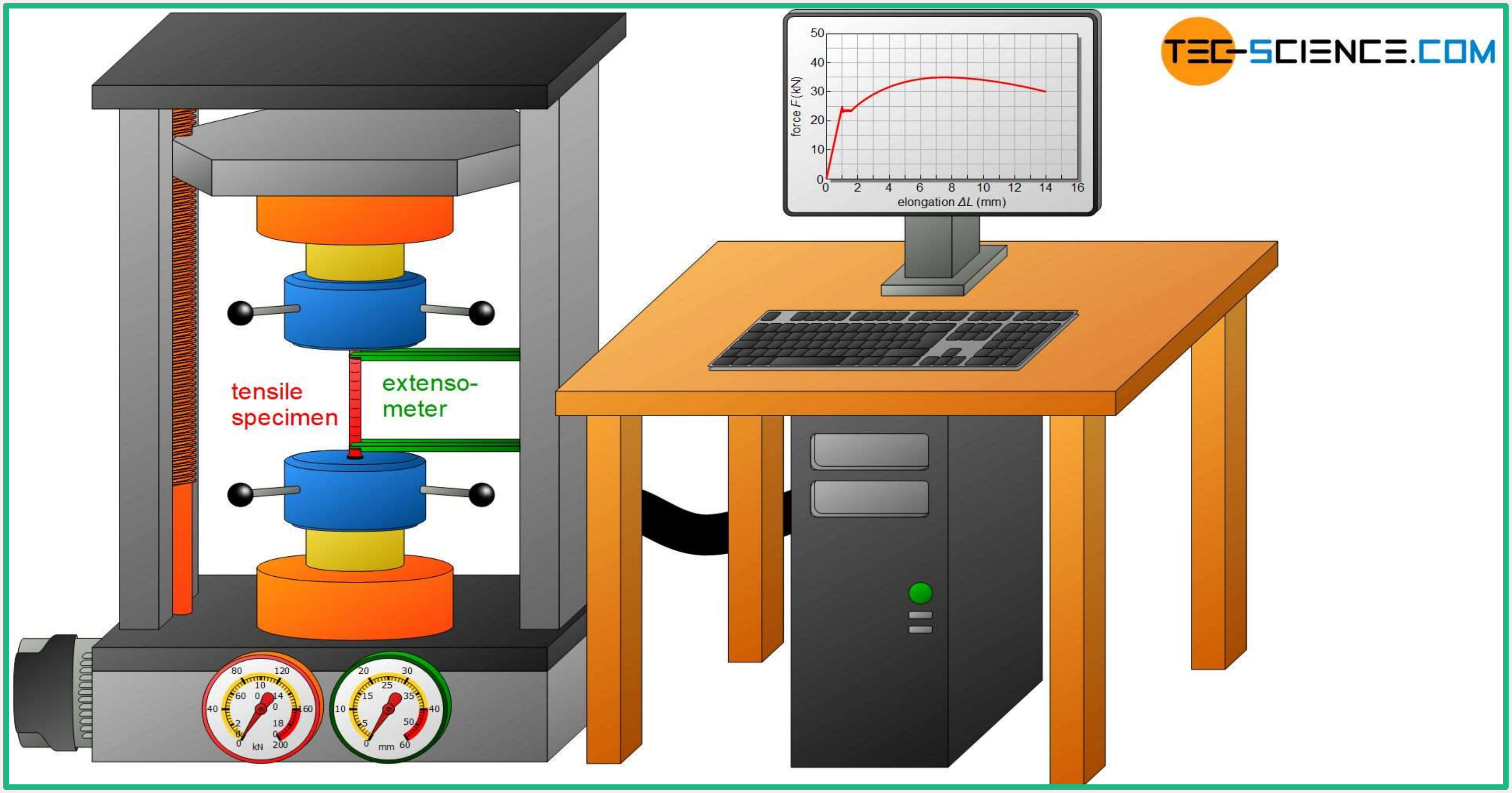
MATERIALS

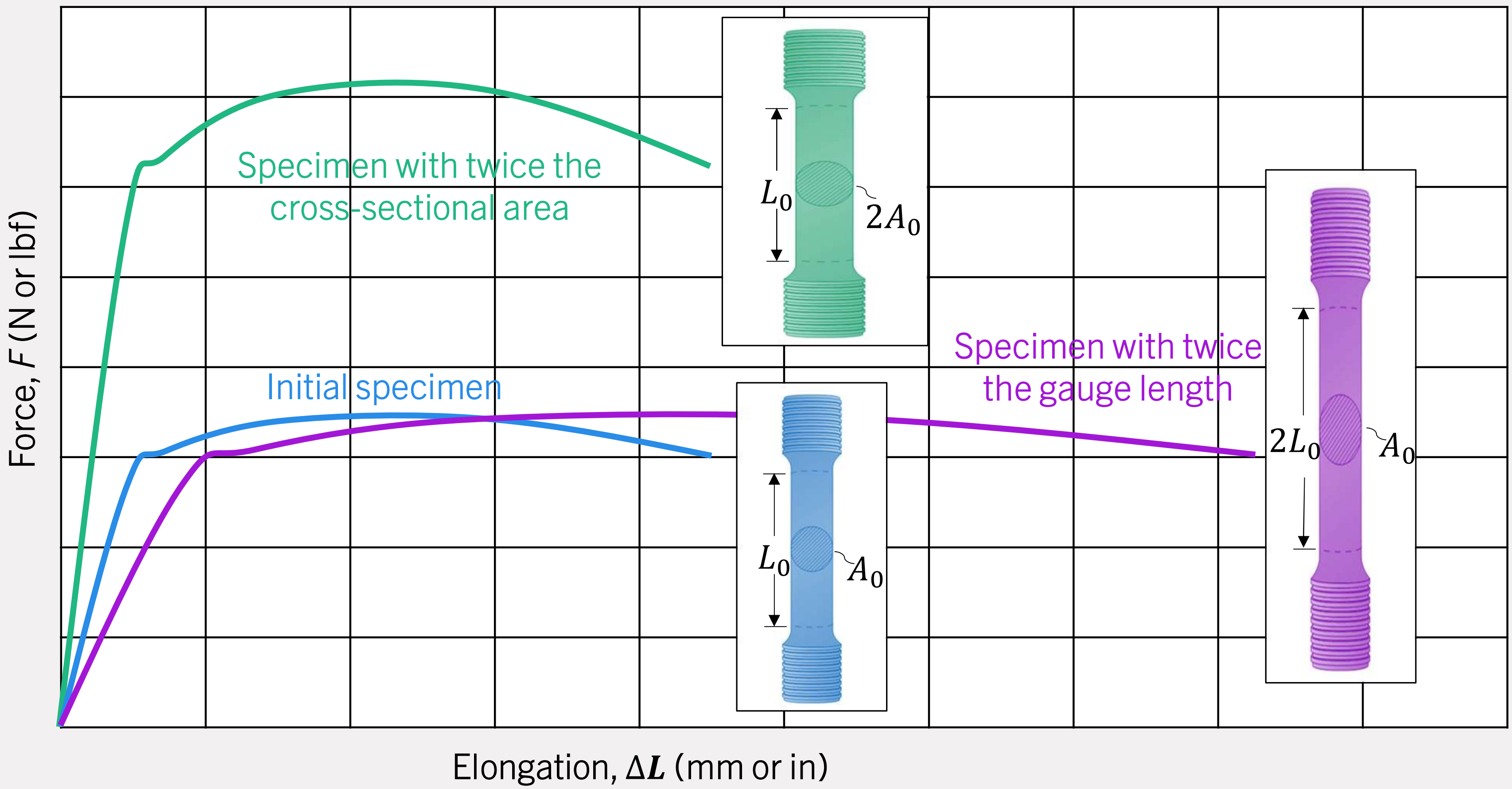
MET 4501

LEAH GINSBERG, PH.D.

TYPICAL TENSILE TEST SET UP



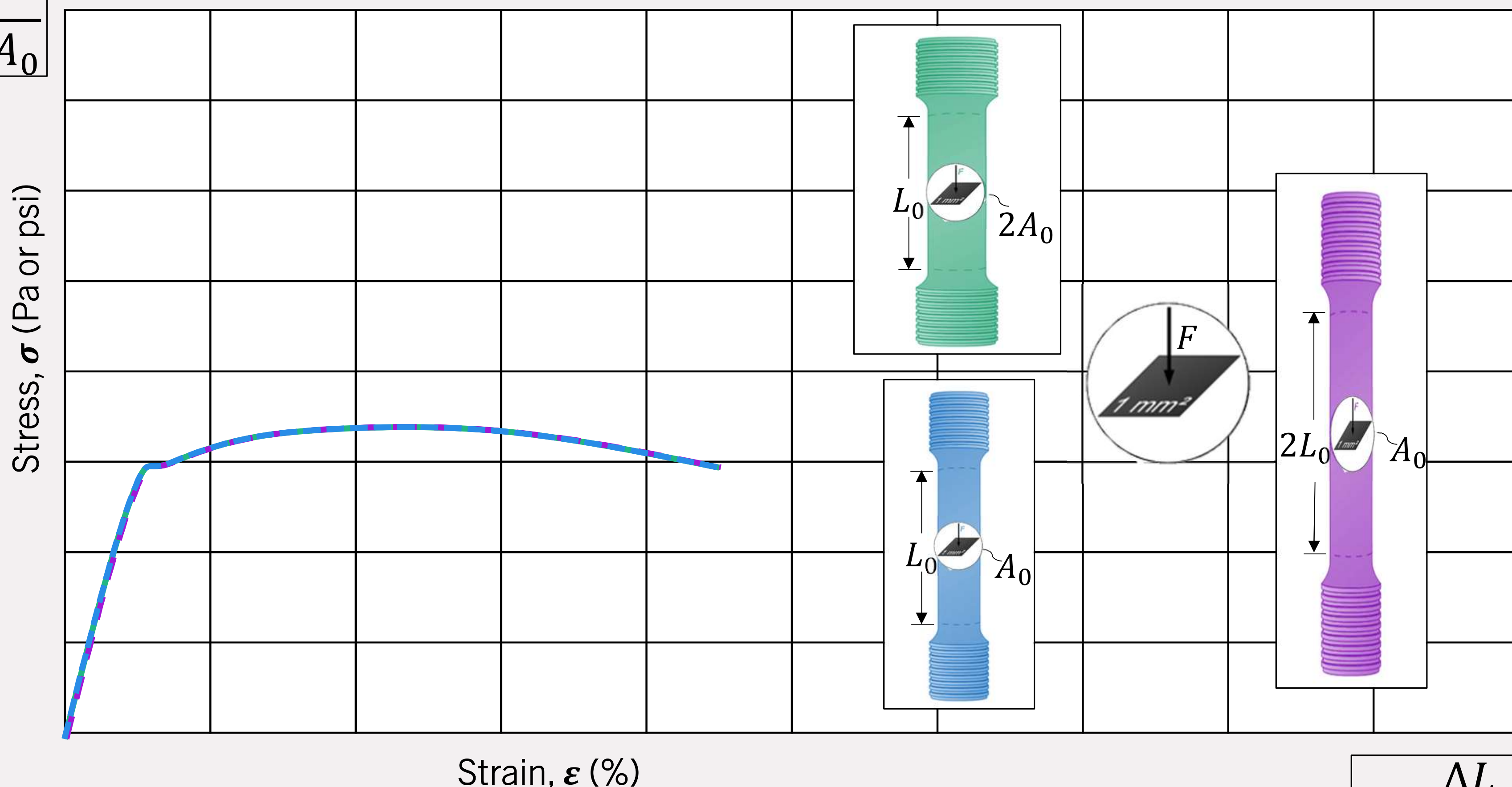
FORCE-ELONGATION



Graphic modified from https://www.tec-science.com/material-science/material-testing/tensile-test/

STRESS-STRAIN

$$\sigma = \frac{F}{A_0}$$

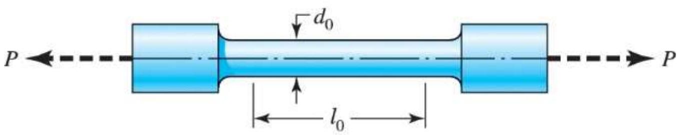


$$\varepsilon = \frac{\Delta L}{L_0} * 100\%$$

Graphic modified from https://www.tec-science.com/material-science/material-testing/tensile-test/

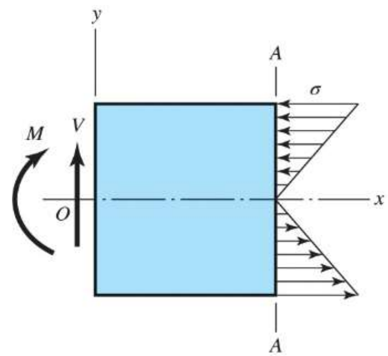
TYPES OF LOADING (REVIEW)

AXIAL



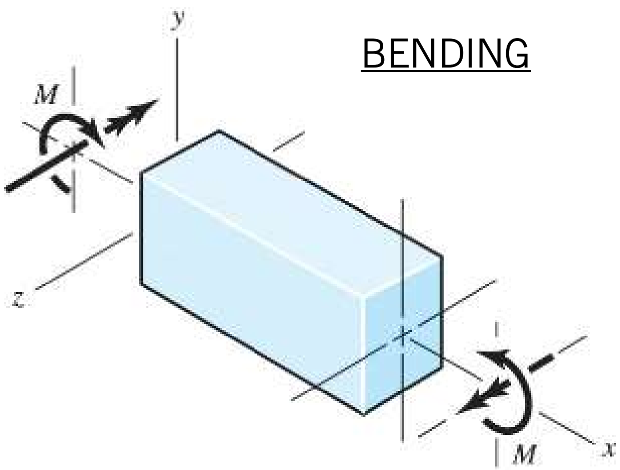
$$\sigma = \frac{P}{A_0}$$

TRANSVERSE SHEAR



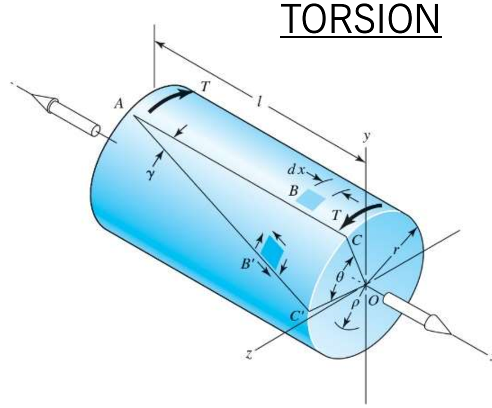
$$\tau = \frac{VQ}{Ib}$$

BENDING



$$\sigma_{\max} = \frac{Mc}{I}$$

TORSION



$$\tau_{\max} = \frac{Tr}{J}$$

AISI/SAE STEEL NUMBERING SYSTEM

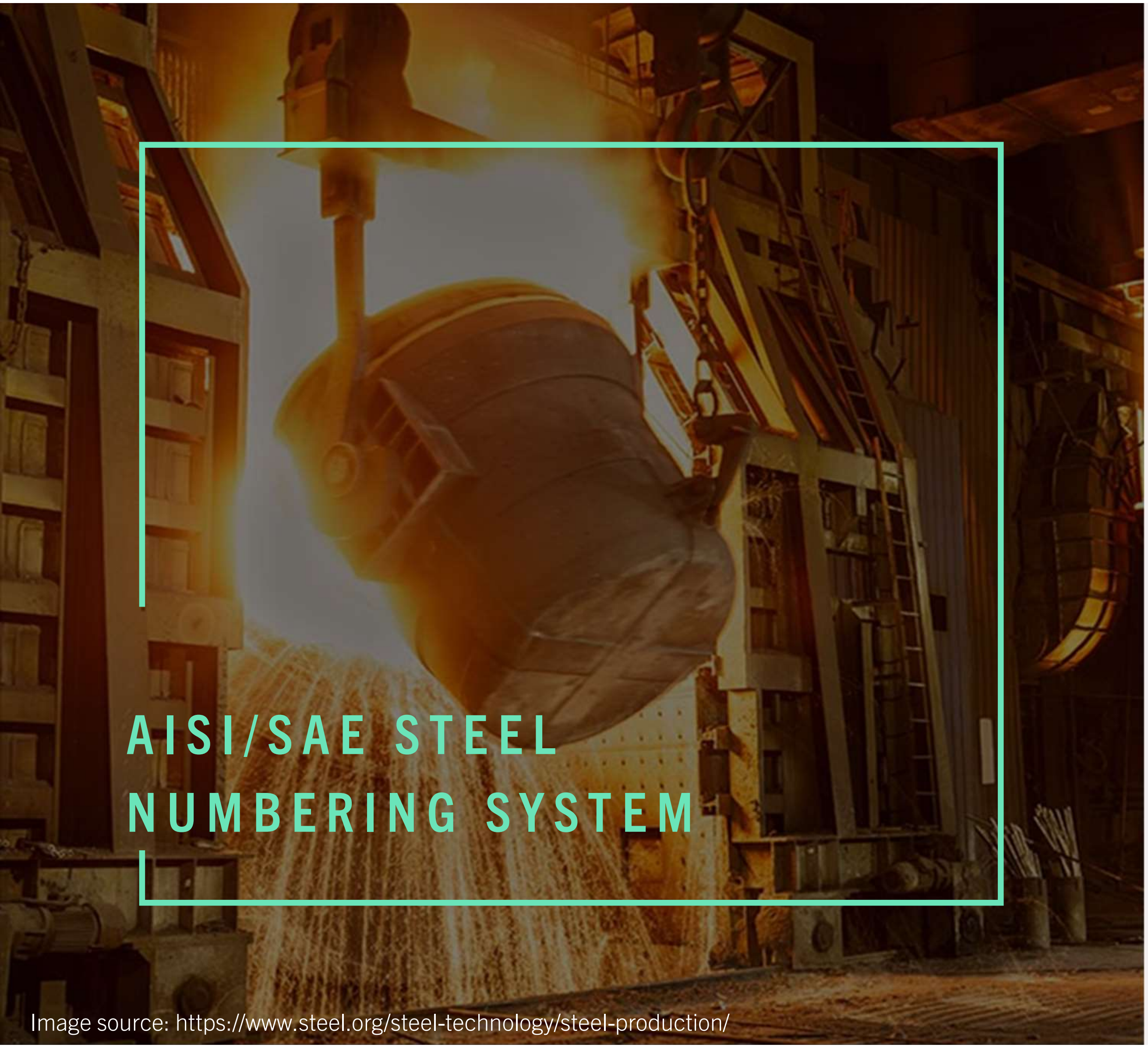


Image source: https://www.steel.org/steel-technology/steel-production/

Steel is an alloy of iron and carbon.

- In its pure form, iron is soft and generally not useful as an engineering material.

The mechanical properties of steel can be changed.

- Add carbon
  - 0.05-2% carbon by weight
  - Cast iron is steel with more than 2% carbon by weight
- Alloying
  - Manganese greater than 1.65%, silicon over 0.5%, copper above 0.6%, or other minimum quantities of alloying elements such as chromium, nickel, molybdenum, vanadium, or tungsten are present.
- Heat treatment

Steel type	Carbon % (by weight)	Also called	Ductility	Machinability	Weldable	Tensile strength	Can be hardened or strengthened with heat treatment	Cost	How formed	Applications
Low-Carbon Steel										
Medium-Carbon Steel										
High-Carbon Steel										
Ultra-High-Carbon Steel										

HOW ARE STEELS NUMBERED?

The Society of Automotive Engineers (SAE) published the Unified Numbering System for Metals and Alloys (UNS) in 1975. The American Iron and Steel Institute (AISI) adopted a similar system.

The UNS numbering system includes six characters.

- The letter prefix designates the material.
  - G: carbon and alloy steels
  - A: aluminum alloys
  - C: copper-base alloys
  - S: stainless or corrosion-resistant steels
- The first pair of digits gives the composition, excluding the carbon content.
- The second pair of digits gives the approximate carbon content.
- The last digit is for special situations. The SAE and/or AISI numbering system is the middle four digits of the UNS number.

G10	Plain carbon
G11	Free-cutting carbon steel with more sulfur or phosphorus
G13	Manganese
G23	Nickel
G25	Nickel
G31	Nickel-chromium
G33	Nickel-chromium
G40	Molybdenum
G41	Chromium-molybdenum
G43	Nickel-chromium-molybdenum
G46	Nickel-molybdenum
G48	Nickel-molybdenum
G50	Chromium
G51	Chromium
G52	Chromium
G61	Chromium-vanadium
G86	Chromium-nickel-molybdenum
G87	Chromium-nickel-molybdenum
G92	Manganese-silicon
G94	Nickel-chromium-molybdenum

Table source: Section 2-8 in the Shigley text

HOT WORKING AND COLD DRAWING

WHAT ARE CD AND HR?

During hot working processes, the metal is heated above its recrystallization temperature.

- Hot rolling (HR) creates a bar of a particular shape or dimension.
- Extrusion is applying large pressure to heated metal, forcing it to flow through an orifice.
- Forging is modern-day blacksmithing, using hammers, presses, or forging machines.

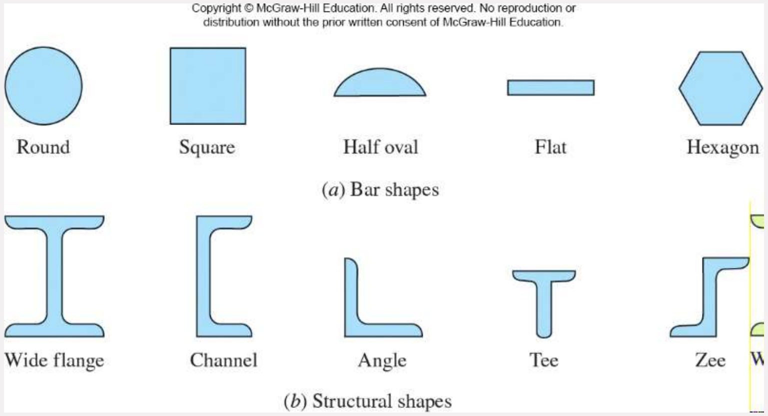


Image source: https://finemetal.ro/what-is-hot-working-of-metals/

WHAT ARE CD AND HR?

During cold working processes, the metal is formed at room temperature.

- Spinning works sheet metal around a rotating form into a circular shape.
- Stamping includes punch-press operations of blanking, coining, forming, and shallow drawing.
- Cold rolling is used to produce wide flats and sheets.
- Cold drawing (CD) is the process where hot rolled bars are cleaned and then drawn through a die that reduces the size 1/16 or 1/32 inch.
  - Cold drawn steel usually needs to be drawn multiple times through different dies to achieve the right size, leading to higher production costs.

Compared to hot worked parts, cold worked parts have a bright new finish, are more accurate, and require less machining.

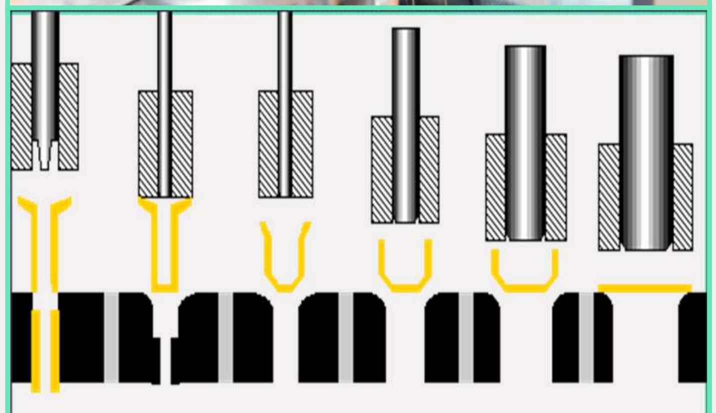


Image source: https://www.ulbrich.com/blog/types-of-cold-working-processes/

EXAMPLE QUESTION

For the following applications, is HR steel or CD steel more appropriate?

Railroad tracks HR Steel

Metal furniture CD Steel

Structural I-beams HR Steel

Machine keys CD Steel

Image source: https://www.ulbrich.com/blog/types-of-cold-working-processes/

MATERIAL HARDNESS

Hardness is resistance of a material to deformation by a pointed tool.

Hardness testing is nondestructive in most cases.

- The hardness number (R_B or R_C) is read directly from a dial in Rockwell hardness tests.
- In Brinell hardness tests, the hardness (H_B) is the applied load divided by the spherical surface area of the indentation.
  - For many materials, the relationship between S_{ut} and H_B is roughly linear.

STRENGTH AND HARDNESS

For many materials, relationship between ultimate strength and Brinell hardness number is roughly linear.

For steels

$$S_u = \begin{cases} 0.5\ H_B & \text{kpsi} \\ 3.4\ H_B & \text{MPa} \end{cases} \qquad \textbf{(2-36)}$$

For cast iron

$$S_u = \begin{cases} 0.23\ H_B - 12.5\ \text{kpsi} \\ 1.58\ H_B - 86\ \text{MPa} \end{cases} \qquad \textbf{(2-37)}$$

HEAT TREATMENTS

OVERVIEW OF HEAT TREATMENTS

Heat treatments are time- and temperature-controlled processes.

Steels are heat treated for multiple reasons.

- To relieve residual stresses.
  - Residual stresses are stresses that remain in a part in the absence of external loading or thermal gradients.
- To modify material properties including hardness (strength), ductility, and toughness (the material's ability to absorb energy).

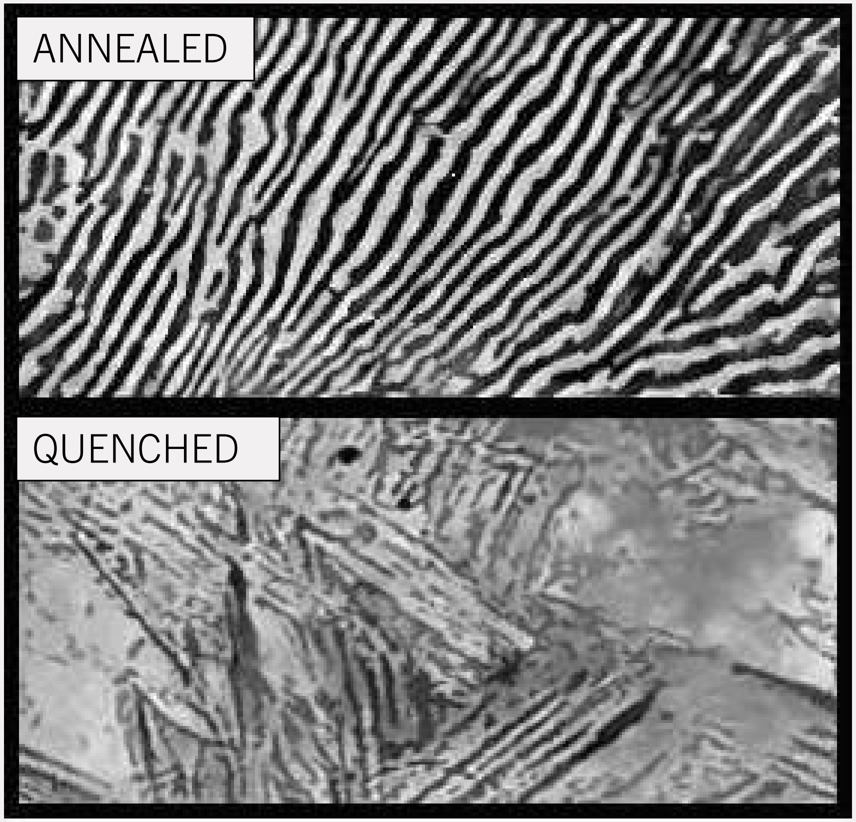
Steel castings after undergoing 12-hour 1,200 °C (2,190 °F) heat treatment.

ANNEALING

Annealing is used to soften a material, make it more ductile, relieve residual stresses, and refine the grain structure.

- Material is heated to 100 degrees F above the critical temperature.
- Held at this temperature until carbon dissolves and diffuses through the material.
- Cools slowly, usually in the furnace where it was heated.

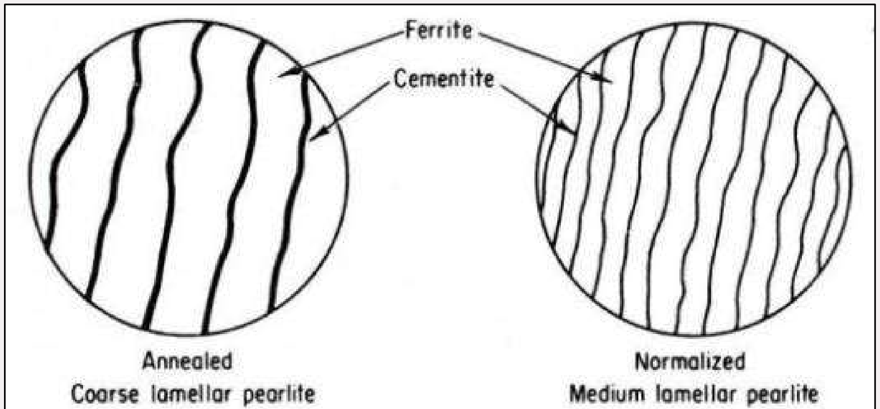
Annealing is most often used to soften a metal for cold working, to improve machinability, or to enhance properties like electrical conductivity.



NORMALIZING

Normalizing is a subset of annealing.

- Heated to a slightly higher temperature.
- Cools more quickly.
- Material is harder than fully annealed steel.



Difference in pearlitic structure due to annealing and normalizing

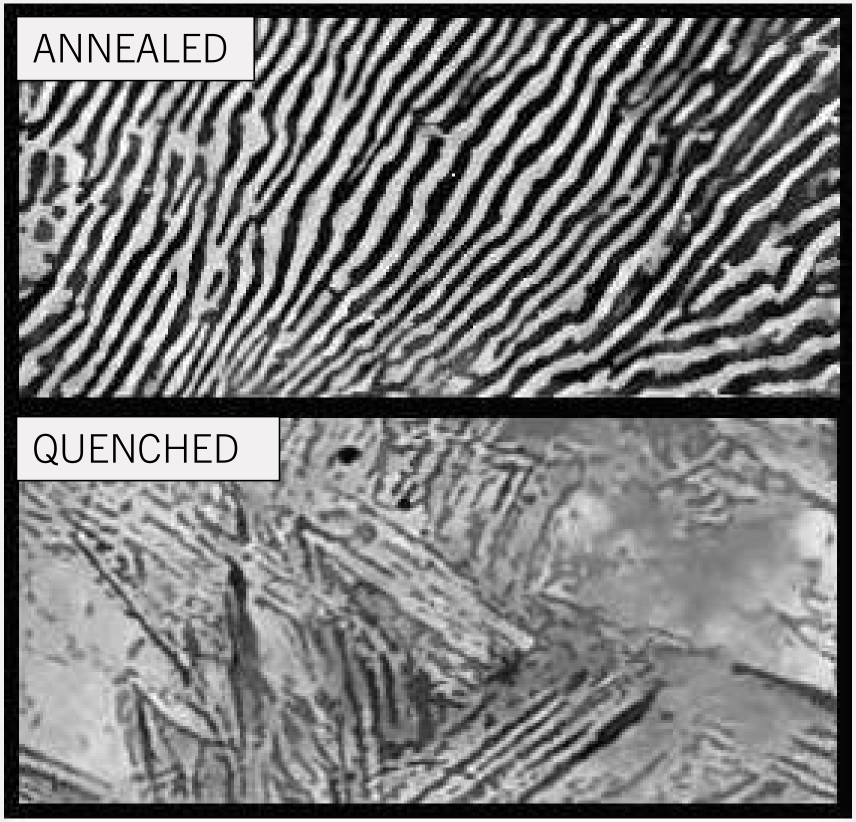


Image source: https://practicalmaintenance.net/?p=1329

QUENCHING

Quenching is a controlled cooling rate.

- After being quenched, the metal is very hard, but it is brittle.
- Controlled cooling rate prevents full annealing.
- Less pearlite, more martensite and/or bainite.

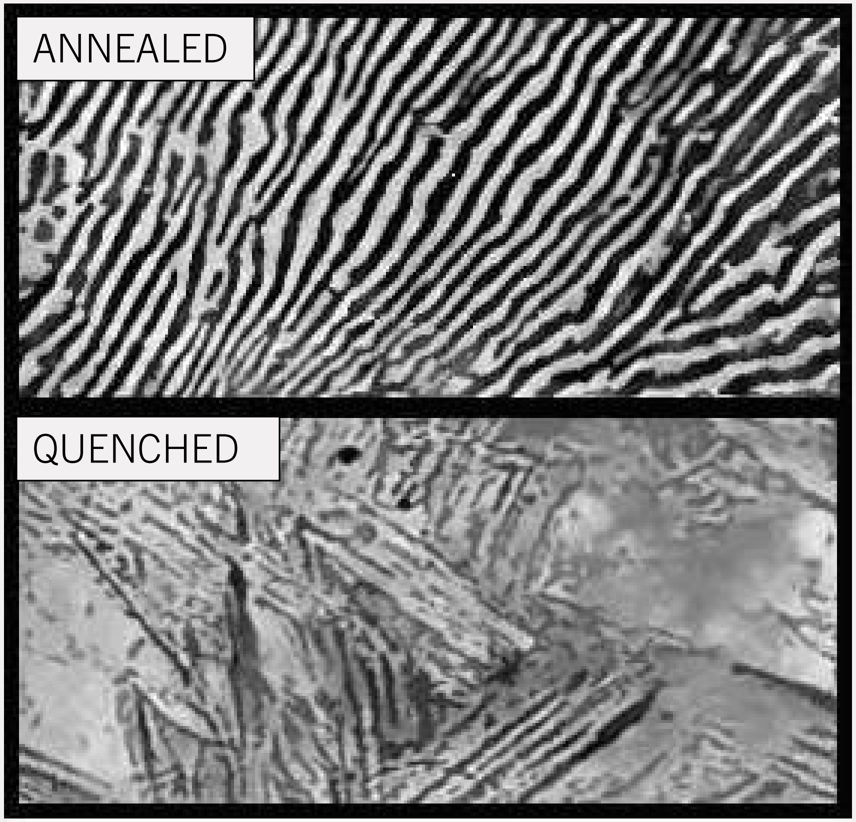


Image source: https://practicalmaintenance.net/?p=1329

TEMPERING

Tempering reheats the steel to a temperature lower than the critical temperature, and then cools the steel in still air.

- Adjusts ductility, hardness, and toughness to the desired levels.
- The tempering colors can be used to judge the final properties of the tempered steel.
- Very hard tools are often tempered in the light to the dark straw range, whereas springs are often tempered to the blue.

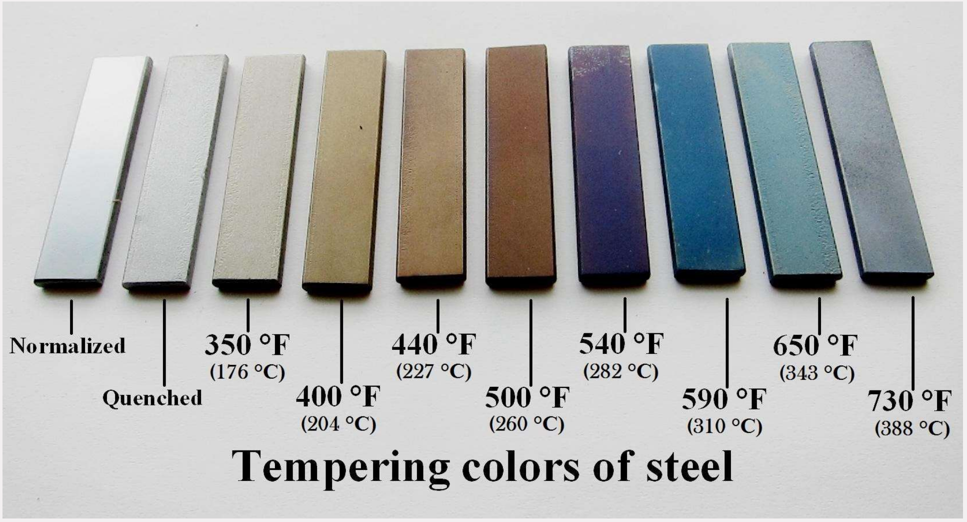


Image source: https://practicalmaintenance.net/?p=1329

CASE HARDENING

Case hardening is a process to increase hardness on outer surface, while retaining ductility and toughness in the core.

- Addition of carbon to outer surface by exposure to high carbon solid, liquid, or gas at elevated temperature.
- Can also achieve case hardening by heat treating only the outer surface, for example, induction hardening or flame hardening.

A flame-hardened sprocket. The discoloration around the teeth delineates the area that was rapidly heated and then quenched.

Image source: https://practicalmaintenance.net/?p=1329

EXAMPLE QUESTION

A steel shaft experiences high torque starts and stops. During running, the shaft experiences moderate shocks.

Which is the best choice for heat treating the shaft?

(a) Annealing

(b) Quenching

(c) Tempering

(d) Case Hardening


QUESTIONS?

DEFINITIONS

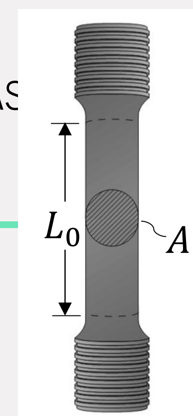
EN
E
RK
SPECIFIC

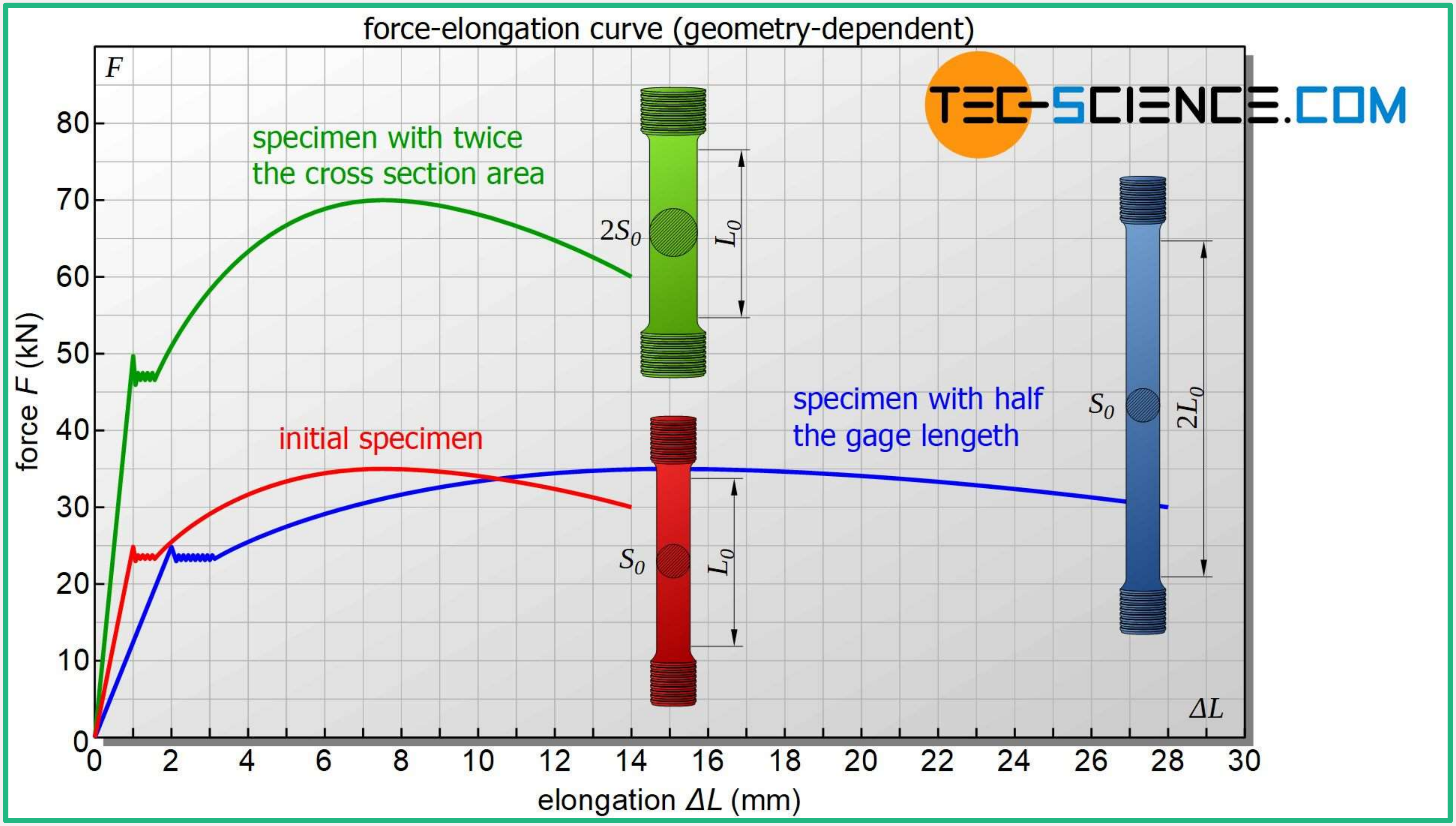
DESIGN

TO DESIGN IS TO FORMULATE A PLAN FOR THE SATISFACTION OF A SPECIFIED NEED.

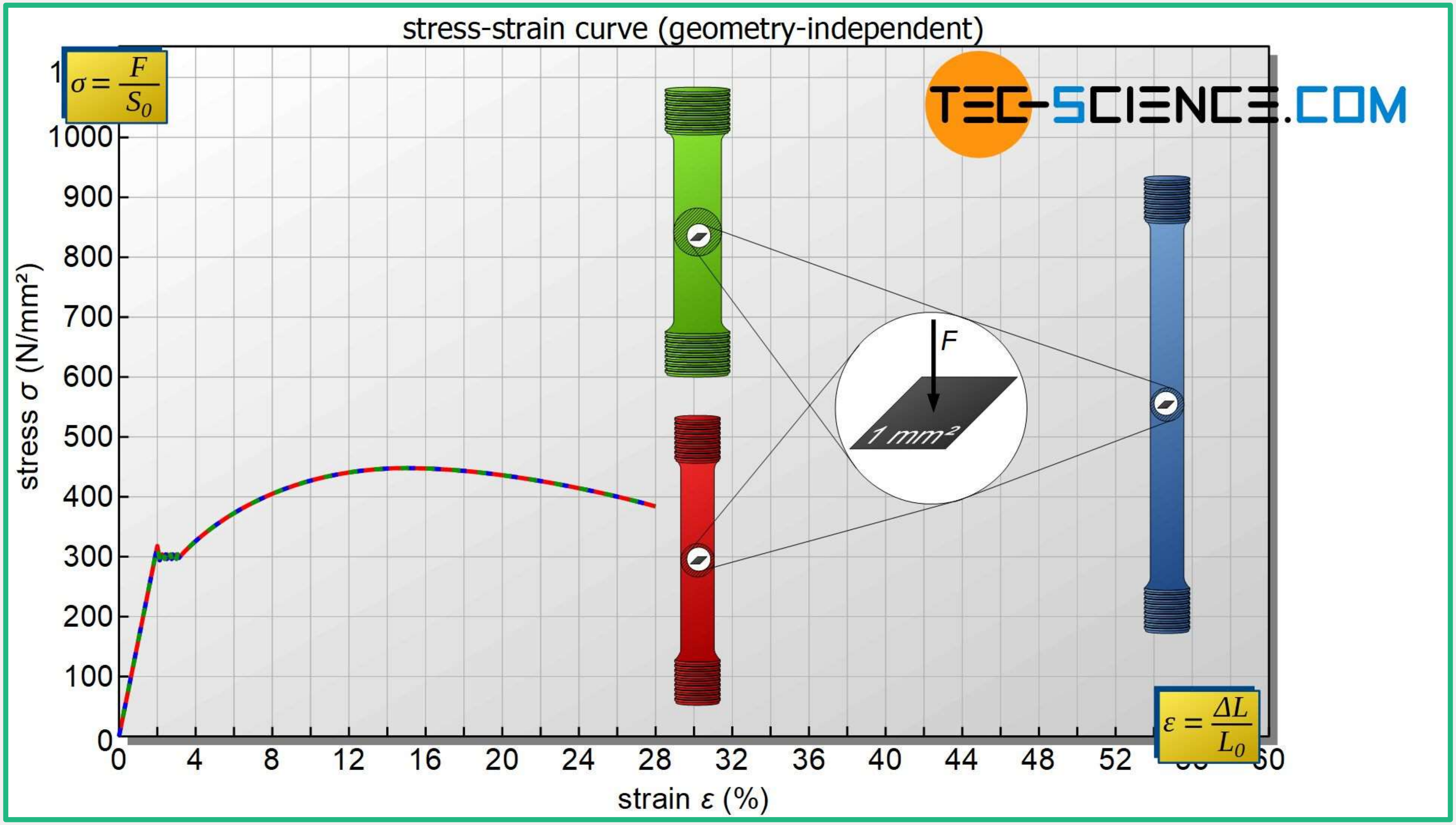
IT IS A DECISION-MAKING PROCESS.

IT IS NOT THE SAME AS G
A NEW DEVICE.





force-elongation curve (geometry-dependent)
F
tec-science.com
specimen with twice
the cross section area
2S0
L0
specimen with half
the gage lengeth
S0
2L0
initial specimen
S0
L0
ΔL
force F (kN)
elongation ΔL (mm)
0
10
20
30
40
50
60
70
80
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30


stress-strain curve (geometry-independent)
$\sigma = \frac{F}{S_0}$
stress σ (N/mm²)
1000
900
800
700
600
500
400
300
200
100
0
0 4 8 12 16 20 24 28 32 36 40 44 48 52
strain ε (%)
$\varepsilon = \frac{\Delta L}{L_0}$
F
1 mm²
TEC-SCIENCE.COM