# HEI Initiative

## HEI Call 2

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Trainer of the lesson Copper Processing via CNC Milling Machine

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# Copper Processing via CNC Milling Machine

The topics covered in this presentation are :

- Copper and Copper Alloys
- Computer Aided Design Software
- Computer Numerical Control Machines
- Computer Aided Manufacturing Software

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# Copper Processing via CNC Milling Machine

## Domain 1: Copper Characteristics

- Copper Properties
- Hardness Tests
- Copper Alloys and their uses
- Speeds and Feeds Table

## Domain 2: Computer Aided Design

- Introduction to CAD
- Video Documentary
- Design of the Part

## Domain 3: Computer Numerical Control Machines

- CNC Machines History
- Safety Assessments
- Fixturing and Zeroing Techniques

## Domain 4: Computer Aided Manufacturing

- Introduction to CAM
- Part from CAD to CAM
- Mill Setup
- Operation Process

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# Copper Characteristics

# 01

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# Copper Properties

- Copper is a chemical element with atomic number 29. Is found in group 11 and period 4 of the periodic table of elements.
- It is metallic red-orange in color.
- Under room temperature and standard pressure (0 °C - 1 Atm), is in its solid phase, having a melting point of 1084.62 °C at 1 Atm.
- It was found in the Middle East about 9000BC.

# Physicochemical Properties of Copper

- Atomic Weight : 63.54 amu (Atomic Mass Unit)
- Electron Configuration : $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^{10}\ 4s^1$
- Oxidation States: +1,+2
- Relative Density: 8.95 $Kg/m^3$
- State on STP: Solid
- Melting Point: 1084.62 °C
- Boiling Point: 2561.85 °C
- Crystal Structure: FCC
- Electrical Conductivity: 5.9×107 Siemens/m
- Thermal Conductivity: 386.00 W/(m*K) at 20 °C

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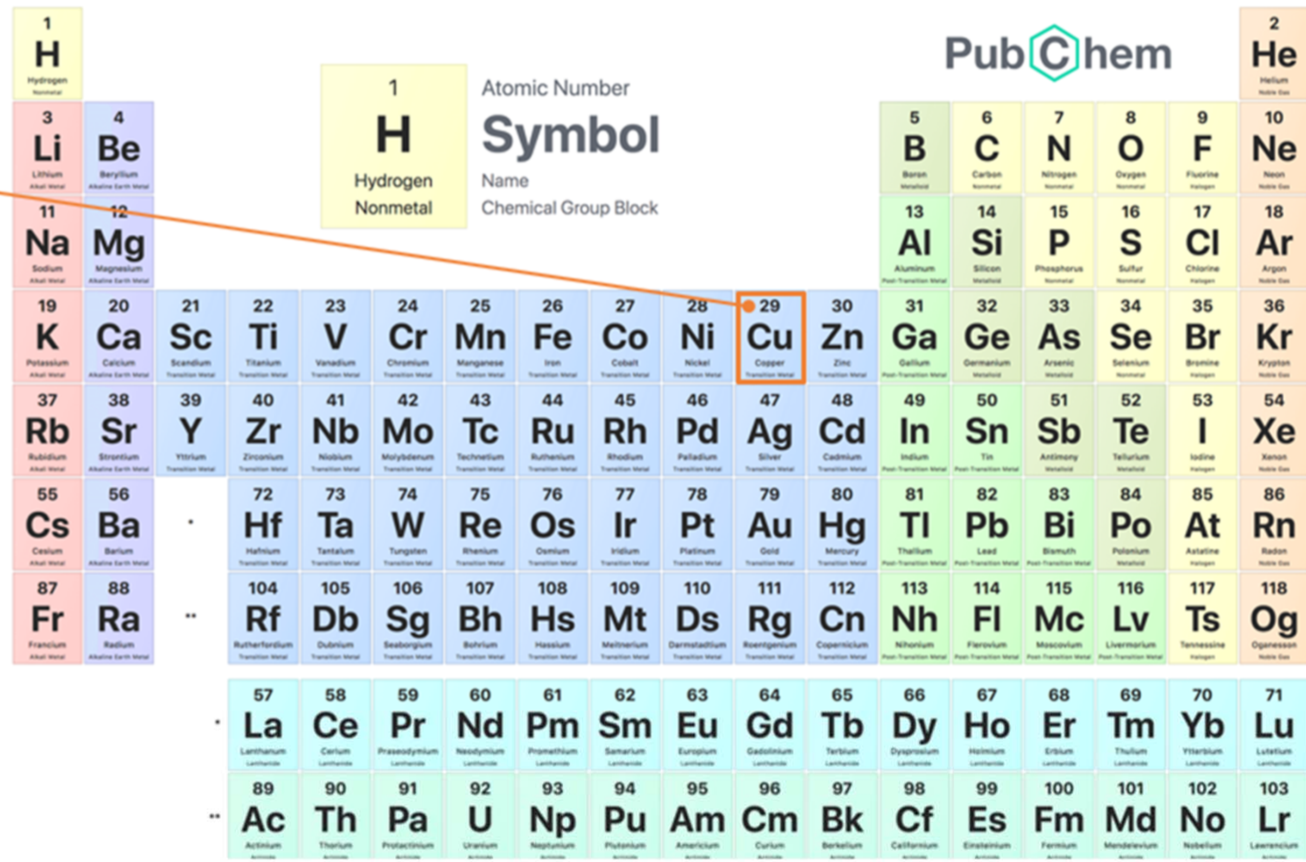
# PERIODIC TABLE OF ELEMENTS

ELEMENT PROPERTIES

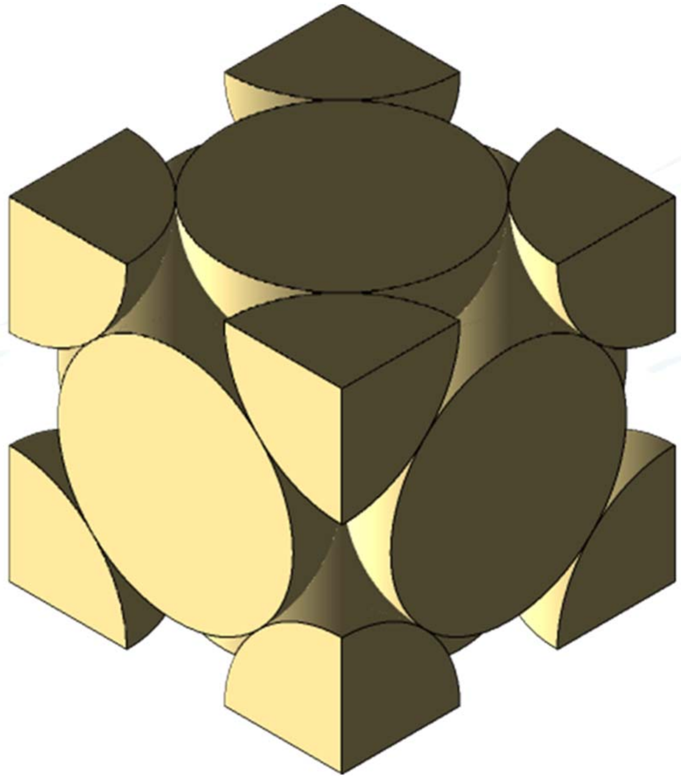
29
Cu
Copper
Transition Metal

| | |
|---|---|
| Standard State | Solid |
| Atomic Mass | 63.55 u |
| Electron Configuration | $[Ar]4s^1 3d^{10}$ |
| Oxidation States | +2, +1 |
| Electronegativity (Pauling Scale) | 1.9 |
| Atomic Radius (van der Waals) | 140 pm |
| Ionization Energy | 7.726 eV |
| Electron Affinity | 1.228 eV |
| Melting Point | 1357.77 K |
| Boiling Point | 2835 K |
| Density | 8.933 g/cm³ |
| Year Discovered | Ancient |



# Crystal Structure of Copper

Face Centered Cubic (fcc) configuration: Atoms are located at the edges and the face centers of the crystal lattice



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# Mechanical Properties of Copper

- Hardness: Soft (89 Brinell, 100 Vickers)
- Deformation Type: Plastic (Malleable)
- Ductile material – High plastic deformation before failure.
- Elastic Modulus: 110 GPa
- Bulk Modulus: 140 GPa
- Shear Modulus: 46 GPa
- Poisson’s Ratio: 0.34
- Yield Strength: 210 Mpa
- Tensile Strength: 275 MPa

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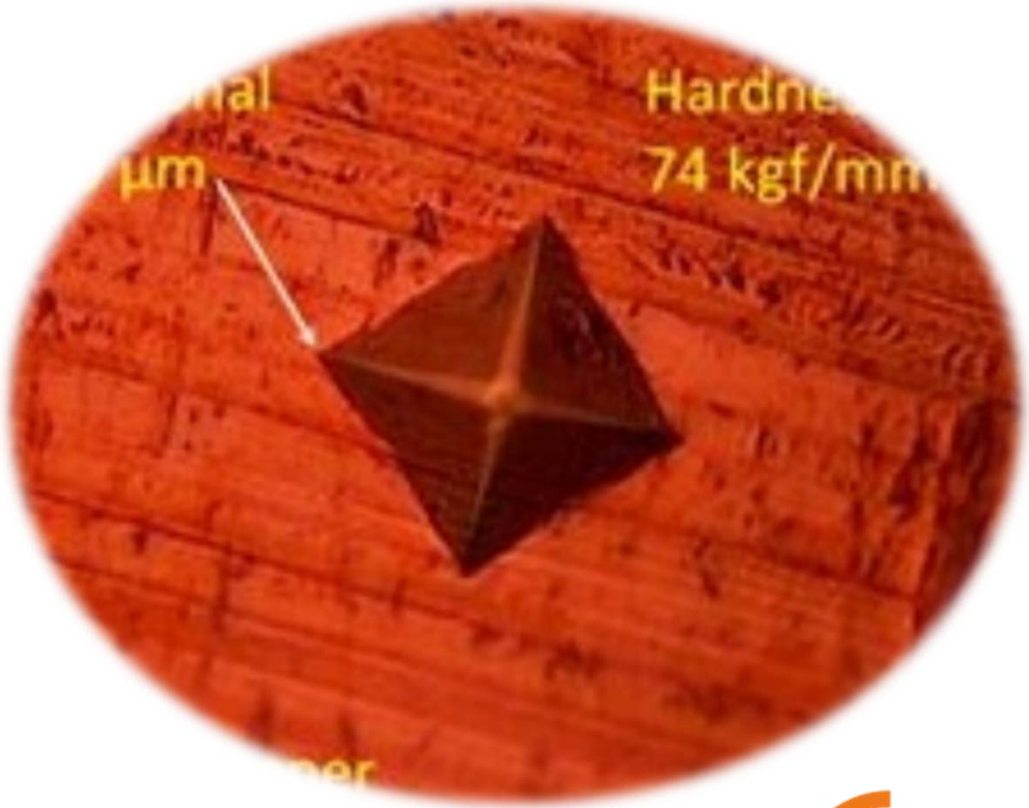
# Hardness Tests

Hardness describes the resistance that a material exhibits to permanent indentation or marking by scratches. Hardness is not a material property, rather a value ascribed to a material as a result of empirical testing.

- Brinell Hardness Test
- Vickers Hardness Test
- Rockwell Hardness Test



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# Brinell Hardness Test

A spherical shaped cemented carbide indenter exerts a force on the specimen's surface. The plastic deformation on the specimen’s surface is the result of the hardness test.

The force applied to the specimen is user defined.

$$\mathrm{HB} = \frac{2F}{\pi D\left(D-\sqrt{D^2-d^2}\right)}$$

Where :

- HB: Brinell Result
- F: Force Applied (User Defined)
- D: Diameter of the spherical shaped cemented carbide (Constant)
- d: Diameter of the deformed surface of the specimen


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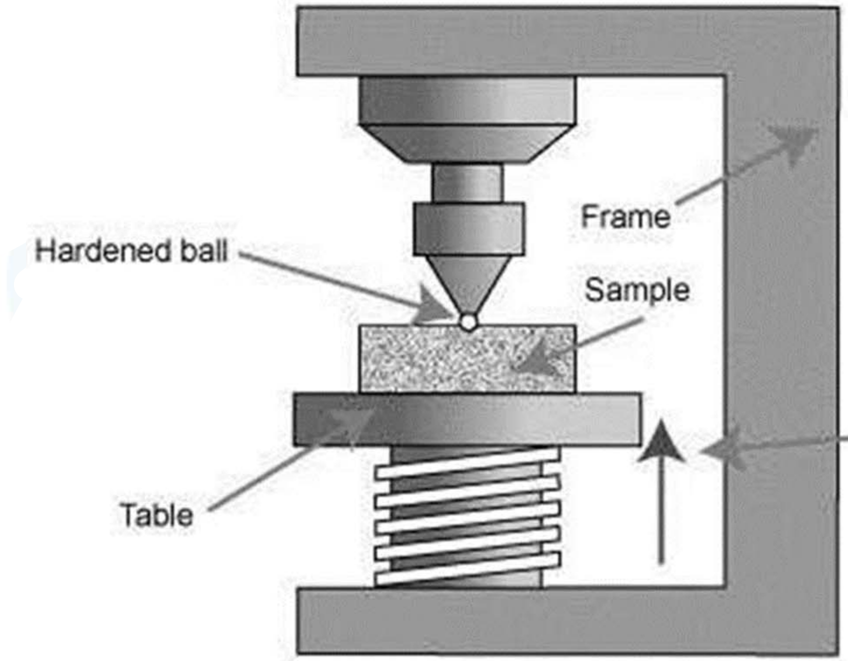
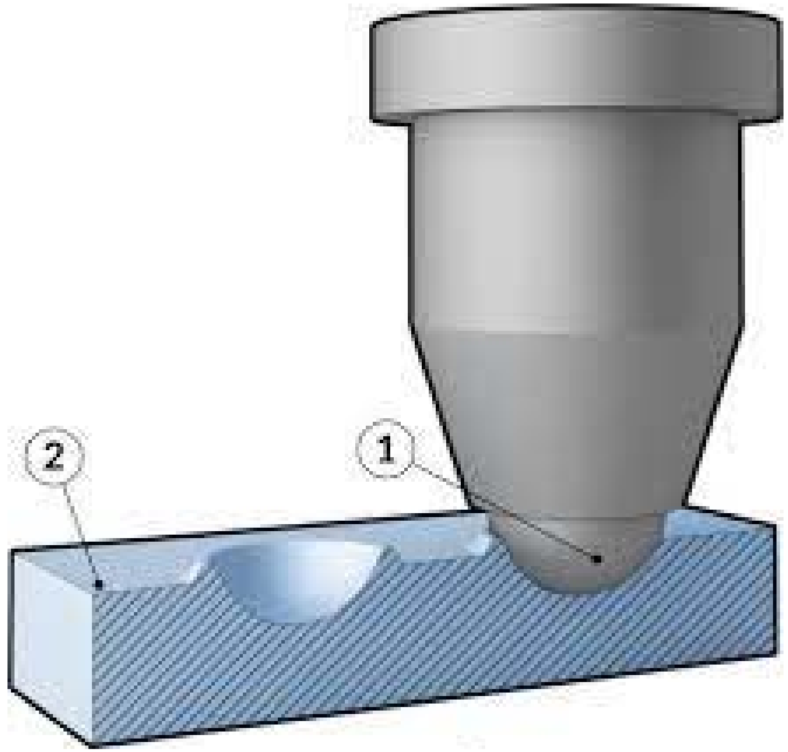
# Brinell Hardness Test



# Vickers Hardness Test

A pyramid shaped industrial diamond indenter exerts a force on the specimen's surface. The plastic deformation on the specimen’s surface is the result of the hardness test.

The force applied to the specimen is user defined.

$$\mathrm{HV} = \frac{F}{A}$$

Where :

- HV: Vickers Result
- F: Force Applied (User Defined)
- A: Surface Area of the deformity. $\mathrm{A} = \frac{d^2}{2\sin(136°/2)}$
- d: the maximum distance between diagonals of the deformity.

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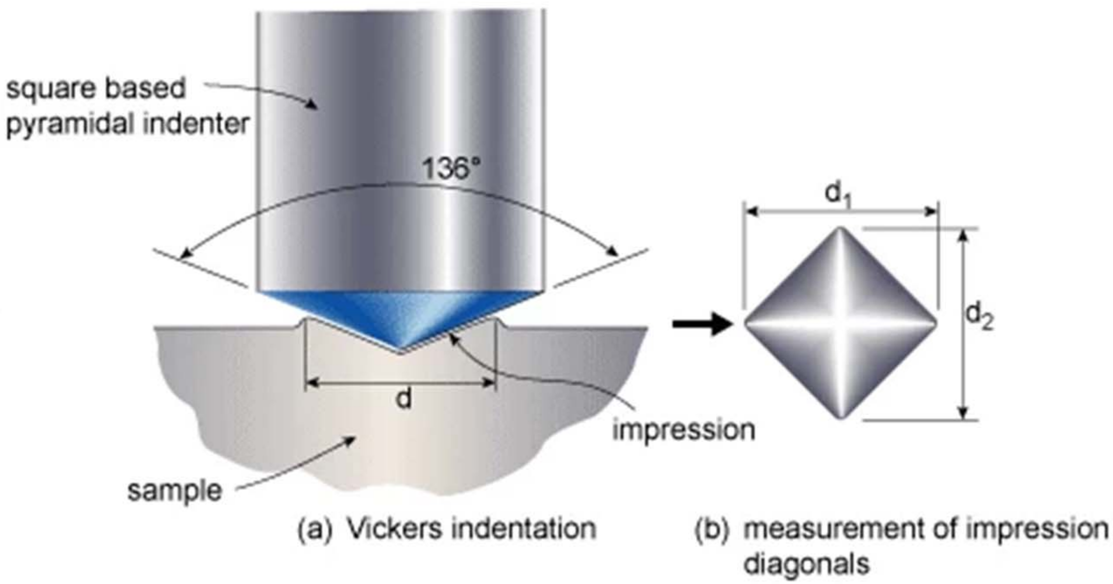
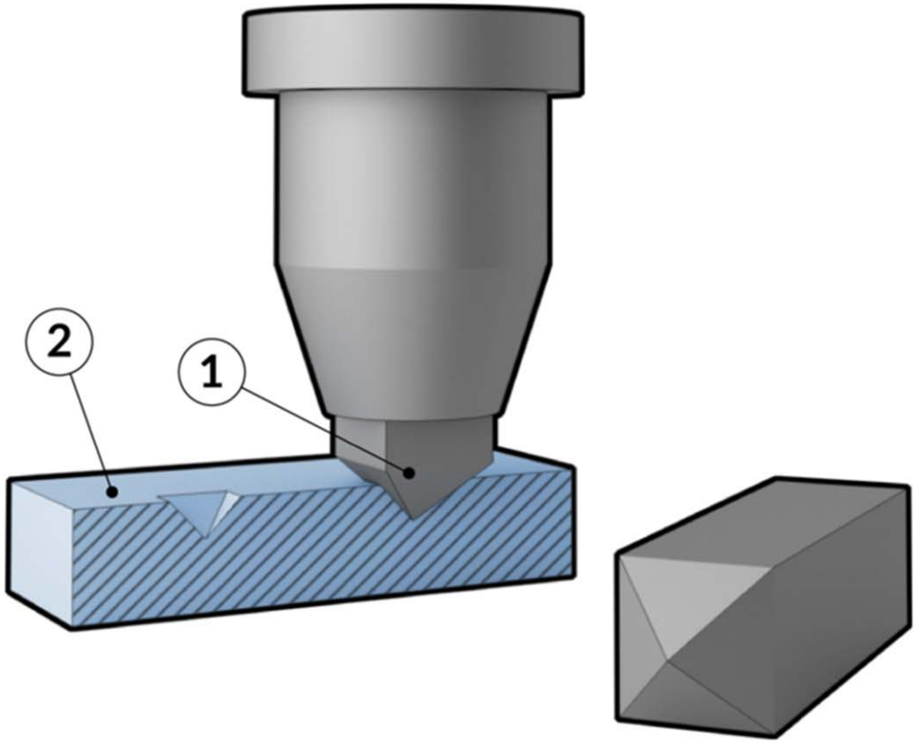
# Vickers Hardness Test

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# Rockwell Hardness Test

The Rockwell Hardness Test uses a diamond cone or hardened steel ball to indent the material being tested. Each time a test is performed, two forces are applied to the sample. First, the indenter is forced into the test material under a preliminary minor force. This depth is recorded. Then, with the minor force still applied, an additional force is introduced. This is known as the major load, and it increases the depth of penetration on the sample. The Major force is then removed, and the force on the sample is returned to the minor force. The increase in the depth of penetration that results from applying and removing the major force is used to calculate the Rockwell Hardness value.

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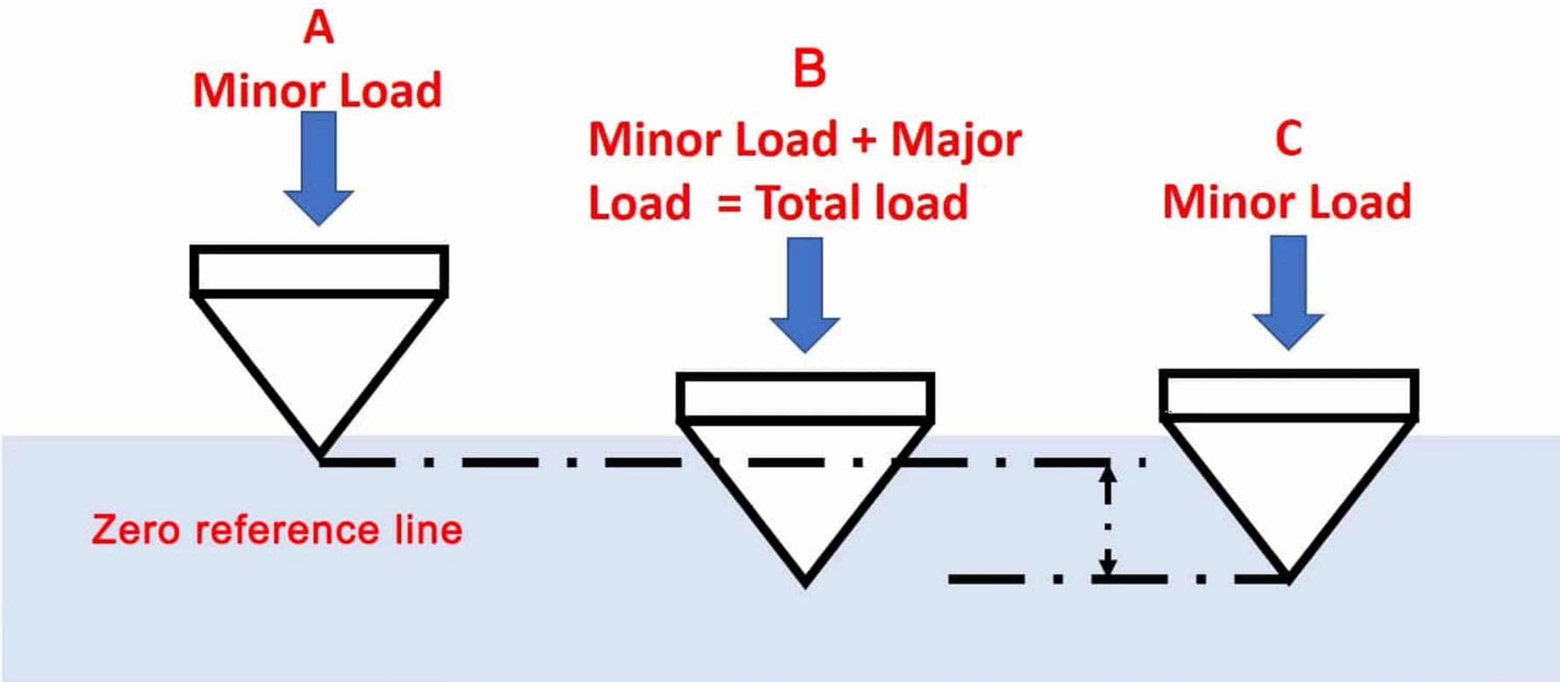
# Rockwell Hardness Test



## Hardness Test Video



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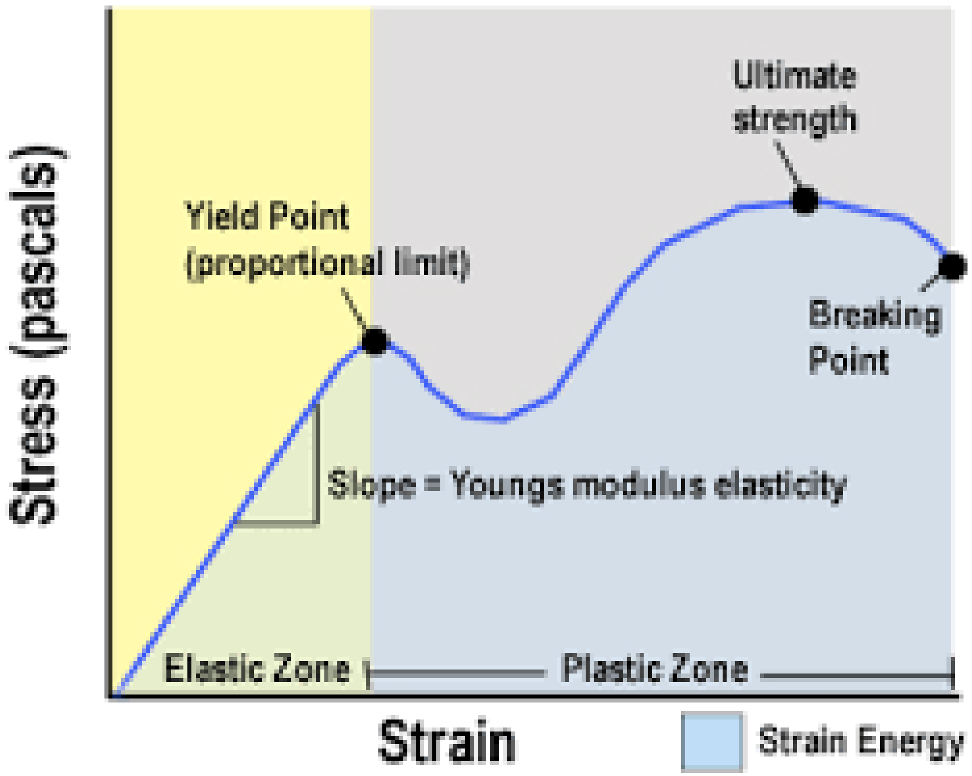
# Elastic Modulus

Elastic modulus or Young's modulus (*E*) is the unit of measurement of an object's resistance to being deformed elastically (i.e., non-permanently) when a stress is applied to it. The elastic modulus is an important mechanical property that measures the tensile or compressive stiffness of a solid when force is applied at the elastic zone. The elastic modulus of an object is defined as the slope of its stress–strain curve in the elastic deformation region. A stiffer material will have a higher elastic modulus.

$$E = \frac{stress}{strain}$$





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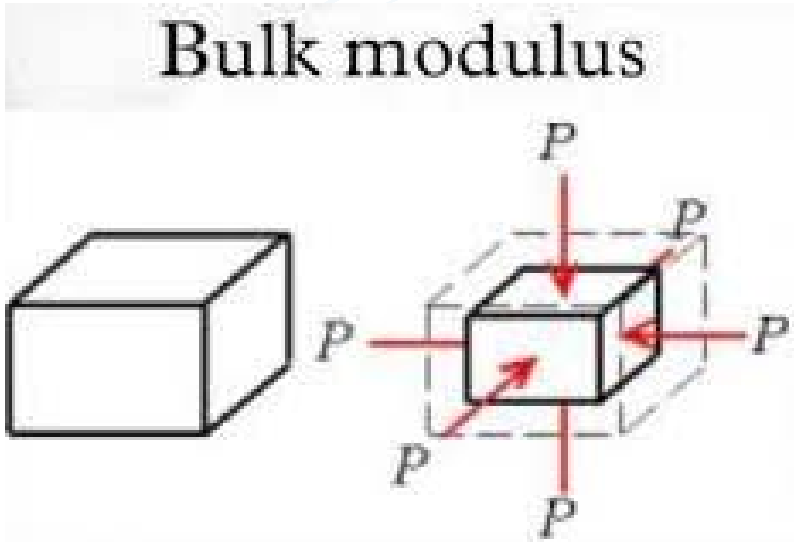
# Bulk Modulus

The bulk modulus K or B of an object is a measure of how resistant to compression the substance is. It is defined as the ratio of the infinitesimal pressure increase to the resulting relative decrease of the volume.

$$K = \frac{\textbf{bulk stress}}{\textbf{bulk strain}}$$





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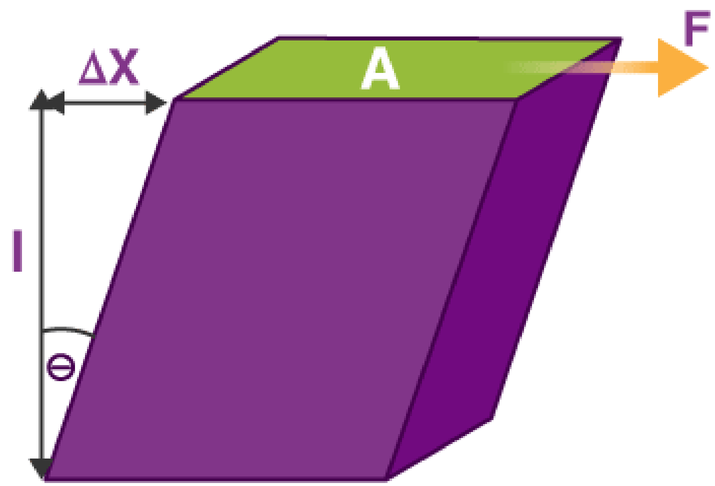
# Shear Modulus

Shear modulus or modulus of rigidity, denoted by *G*, or sometimes S or $\mu$, is a measure of the elastic shear stiffness of a material and is defined as the ratio of shear stress to the shear strain.

$$G = \frac{shear\ stress}{shear\ strain}$$




Shear Modulus

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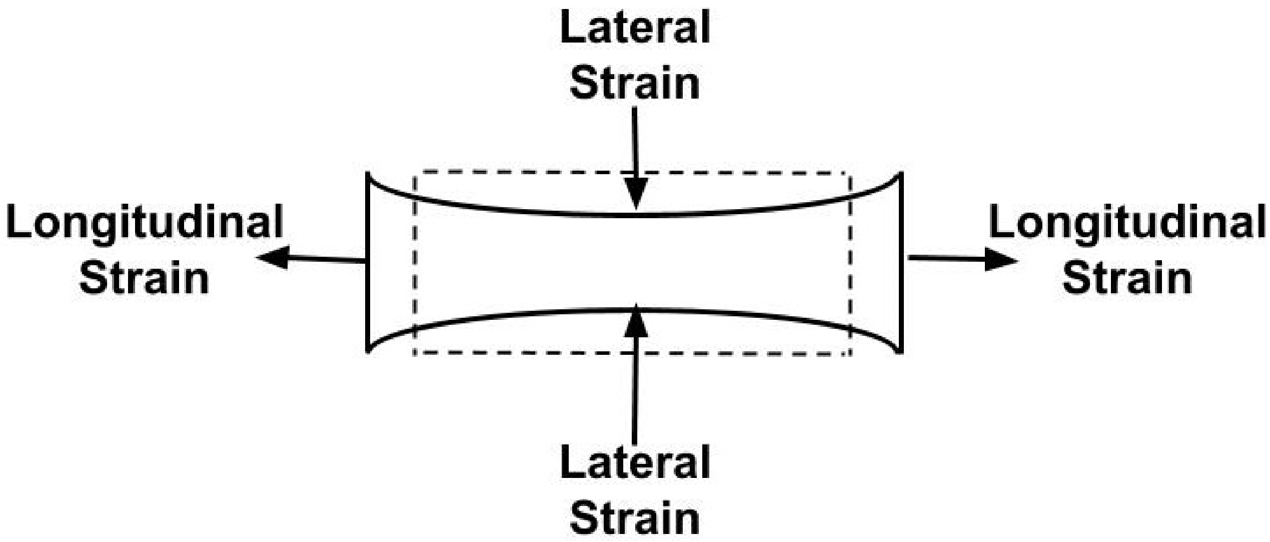
# Poisson's Ratio

Poisson's ratio is defined as the ratio of the lateral strain (change at the width per unit width of a material) to that of the axial strain (change at the length) under the influence of the same force. It is a material property and remains constant.

$$\nu = \frac{lateral\ strain}{longitudinal\ strain}$$




$$\text{Poisson's Ratio} = \frac{\text{Lateral Strain}}{\text{Longitudinal Strain}}$$

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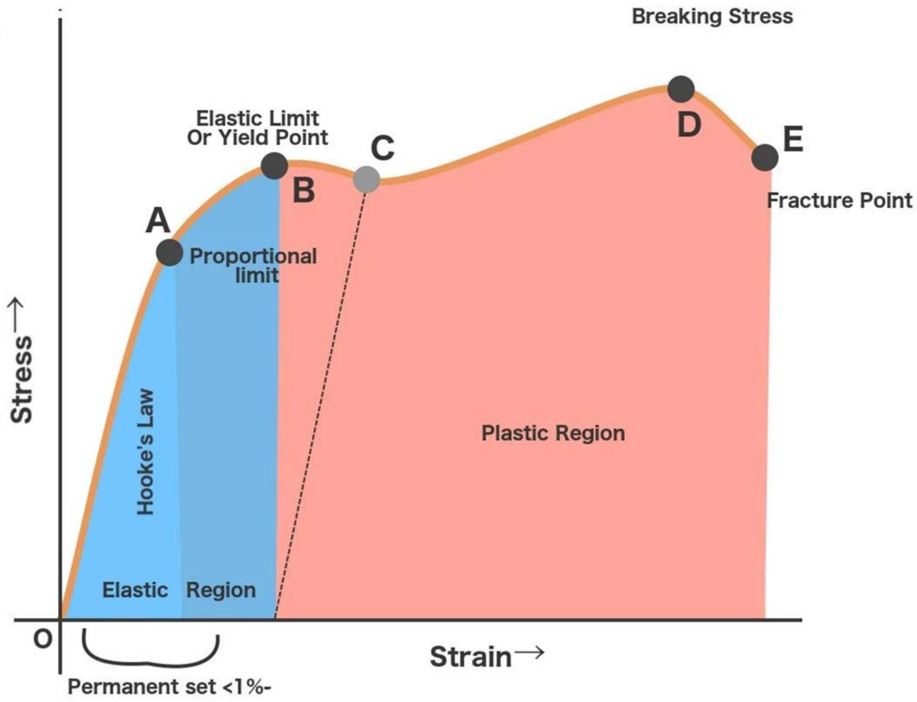
# Yield Strength

Yield strength is the term used to refer to an indication of the maximum stress that can be developed in a substance without causing it to plastically deform. Yield strength is the stress point at which a material becomes permanently deformed, providing a useful approximation of that material's elastic limit. Before reaching the yield point, the material will deform elastically, but it will always revert to its original shape upon removal of the applied stress. Once the yield point is exceeded, a small fraction of the deformation experienced will become permanent and irreversible.

$$\sigma_y = \frac{\mathit{force}}{\mathit{cross\ sectional\ area}}$$

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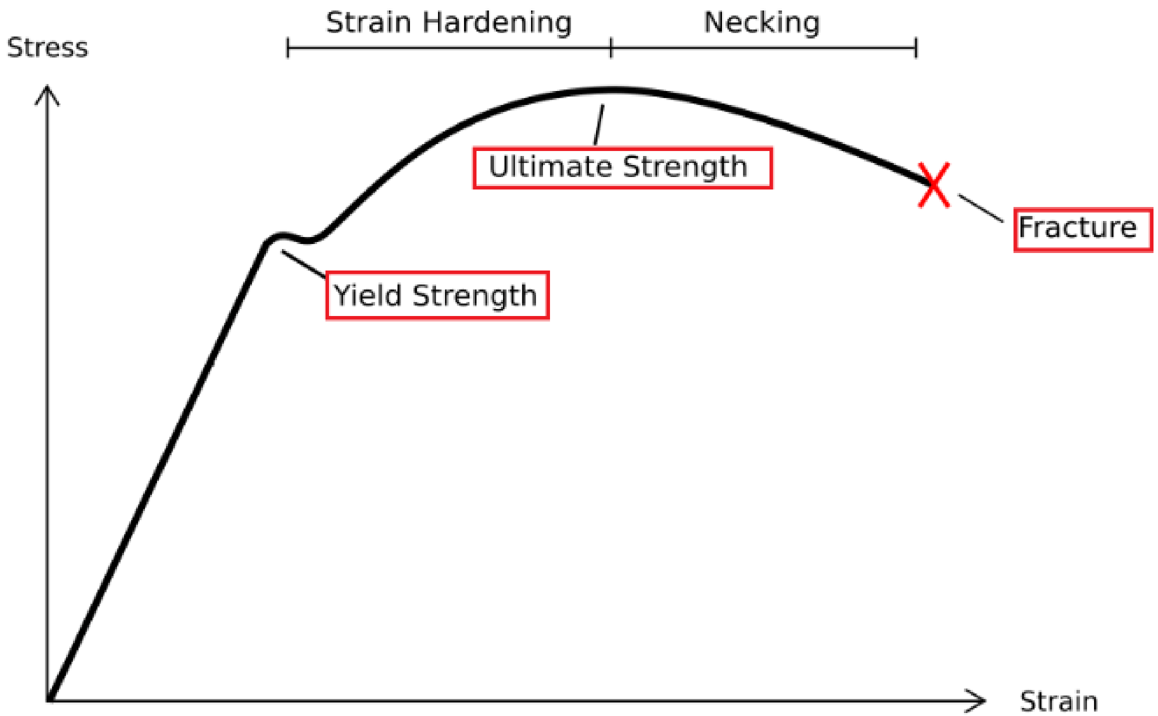
# Tensile Strength

Ultimate tensile strength is the maximum stress that a material can withstand while being stretched or pulled before breaking. In brittle materials the ultimate tensile strength is close to the yield point, whereas in ductile materials the ultimate tensile strength can be higher. The ultimate tensile strength is usually found by performing a tensile test and recording the engineering stress versus strain. The highest point of the stress–strain curve is the ultimate tensile strength and has units of stress.

$$\sigma_{max} = \frac{\textit{maximum load}}{\textit{cross sectional area}}$$



# Copper Alloys

- Brass
- Bronze
- Electrolytic Tough Pitch
- Beryllium Copper

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# Brass

Alloy of Copper and Zinc (Cu – Zn)

Types of Brass:

- Admiralty Brass: 69% Copper, 30% Zinc and 1% Tin
- Aich's alloy: 60.66% Copper, 36.58% Zinc, 1.02% Tin, and 1.74% Iron
- Alpha brass: Less than 35% Zinc
- Prince's metal or Prince Rupert's metal: Alpha brass containing 75% Copper and 25% Zinc
- Alpha-beta brass, Muntz metal, or duplex brass: 35-45% Zinc
- Aluminum brass: Contains Aluminium
- Arsenical brass: Contains Arsenic and frequently Aluminum
- Beta brass: 45-50% Zinc
- Cartridge brass: 30% Zinc
- Common brass, or rivet brass: 37% Zinc

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# Brass

Alloy of Copper and Zinc (Cu – Zn)

Types of Brass:

- Dezincification resistant brass: Small percentage of Arsenic
- Gilding metal: 95% Copper and 5% Zinc
- High brass: 65% Copper and 35% Zinc
- Leaded brass: Alpha-beta brass with an addition of lead
- Lead-free brass: Less than 0.25% Lead content
- Low brass: 20% Zinc
- Manganese brass: 70% Copper, 28.7% Zinc, and 1.3% Manganese
- Muntz metal: 60% Copper, 40% Zinc, and a trace of Iron
- Naval brass: 40% Zinc and 1% Tin
- Nickel brass: 70% Copper, 24.5% Zinc, and 5.5% Nickel

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# Brass

Alloy of Copper and Zinc (Cu – Zn)

Types of Brass:

- Nordic gold: 89% Copper, 5% Aluminium, 5% Zinc, and 1% Tin
- Red brass: 85% Copper, 5% Tin, 5% Lead, and 5% Zinc
- Rich low brass (Tombac): 15% Zinc
- Tonval brass (also called CW617N, CZ122, or OT58): Copper-Lead-Zinc alloy
- White brass: more than 50% Zinc
- Yellow brass: 33% Zinc

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# Brass

Alloy of Copper and Zinc (Cu – Zn)

Uses of Brass Alloys:

- Admiralty Brass: Used to inhibit dezincification.
- Aich's alloy: Corrosion resistance, hardness, and toughness make it useful for marine applications.
- Alpha brass: Malleable, can be worked cold, used in pressing, forging, or similar applications. Alpha brasses have only one phase, with face-centered cubic crystal structure.
- Prince's metal or Prince Rupert's metal: It's named for Prince Rupert of the Rhine and used to imitate gold.
- Alpha-beta brass, Muntz metal, or duplex brass: Suited for hot working. It contains both $\alpha$ and $\beta'$ phase. The $\beta'$-phase is body-centered cubic and is harder and stronger than $\alpha$. Alpha-beta brasses are usually worked hot.

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# Brass

Alloy of Copper and Zinc (Cu – Zn)

Uses of Brass Alloys:

- Aluminum brass: Corrosion resistant. It's used for seawater service and in Euro coins (Nordic gold).
- Arsenical brass: Used for boiler fireboxes.
- Beta brass: It can only be worked hot, produces a hard, strong metal that is suitable for casting.
- Cartridge brass: Good cold-working properties. Used for ammunition cases.
- Common brass, or rivet brass: Standard for cold working.
- Dezincification resistant brass: Dezincification resistant brass.
- Gilding metal: Softest type of common brass, used for ammunition jackets.

# Brass

Alloy of Copper and Zinc (Cu – Zn)

Uses of Brass Alloys:

- High brass: High tensile strength and is used for springs, rivets, and screws.
- Leaded brass: Easily machined.
- Lead-free brass: As defined by California Assembly Bill AB 1953 contains "not more than 0.25 percent lead content".
- Low brass: Ductile brass used for flexible metal hoses and bellows.
- Manganese brass: Used in making golden dollar coins in the United States.
- Muntz metal: Used as a lining on boats.
- Naval brass: Similar to admiralty brass.

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# Brass

Alloy of Copper and Zinc (Cu – Zn)

Uses of Brass Alloys:

- Nickel brass: Used to make pound coins in the pound sterling currency.
- Nordic gold: Used in 10, 20, and 50 cents in euro coins.
- Red brass: American term for the copper-zinc-tin alloy known as gunmetal considered both a brass and a bronze. Red brass usually contains 85% copper, 5% tin, 5% lead, and 5% zinc. Red brass may be copper alloy C23000, which is 14 to 16% zinc, 0.05% iron and lead, and the remainder copper. Red brass also may refer to ounce metal, another copper-zinc-tin alloy.
- Rich low brass (Tombac): Used for jewelry.
- Tonval brass (also called CW617N, CZ122, or OT58): Copper-lead-zinc alloy

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# Brass

Alloy of Copper and Zinc (Cu – Zn)

Uses of Brass Alloys:

- White brass: Brittle. White brass may also refer to certain nickel silver alloys as well as Cu-Zn-Sn alloys with high proportions (typically 40%+) of tin and/or zinc, as well as predominantly zinc casting alloys with a copper additive.
- Yellow brass: American term for 33% zinc brass.

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# Free Cutting Brass

- Nuts, Bolts, Threaded Parts
- Terminals
- Jets
- Taps
- Injectors
- Valve Bodies
- Balance Weights
- Pipe or Water Fittings

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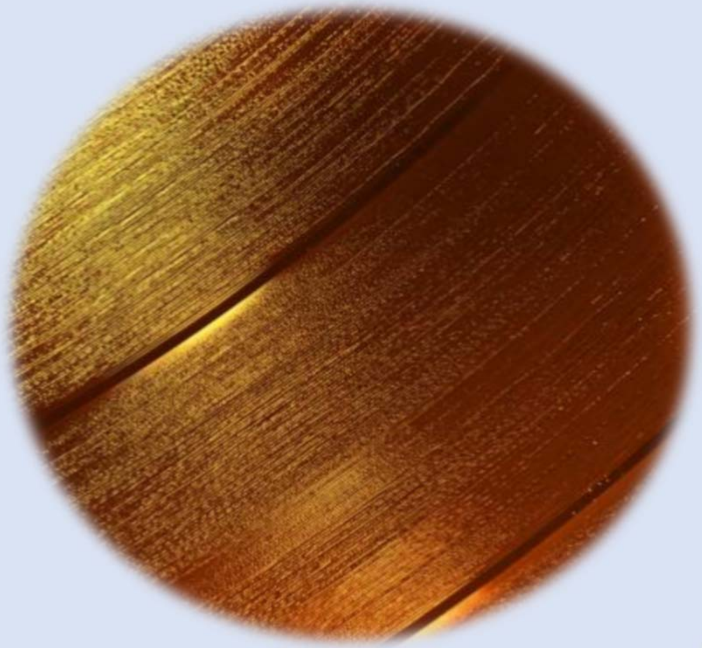
# Gilding Metal (Red Brass)

- Architectural fascias
- Grillwork
- Jewelry
- Ornamental Trim
- Badges
- Door Handles
- Marine Hardware
- Primer Caps
- Pen, Pencil and Lipstick Tubes



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# Engraving Brass

- Appliance Rim
- Clock Components
- Builders Hardware
- Gear Meters

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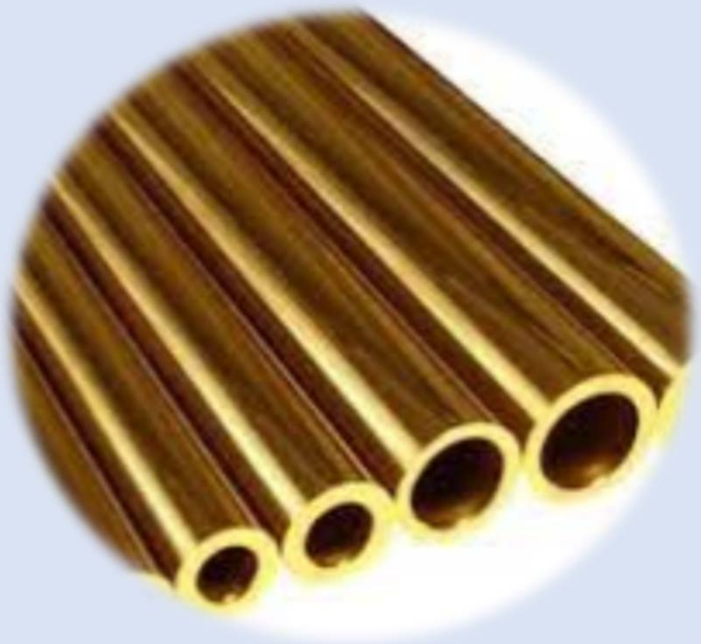
# Arsenical Brass

- Heat Exchangers
- Drawn and Spun Containers
- Radiator Cores, Rubes, and Tanks
- Electrical Terminals
- Plugs and Lamp Fittings
- Locks
- Cartridge Casings



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# High Tensile Brass

- Marine Engines
- Hydraulic Equipment Fittings
- Locomotive Axle Boxes
- Pump Casting
- Heavy Rolling Mill Housing Nuts
- Heavy Load Wheels
- Valve Guides
- Bushes Bearings
- Swash Plates
- Battery Clamps

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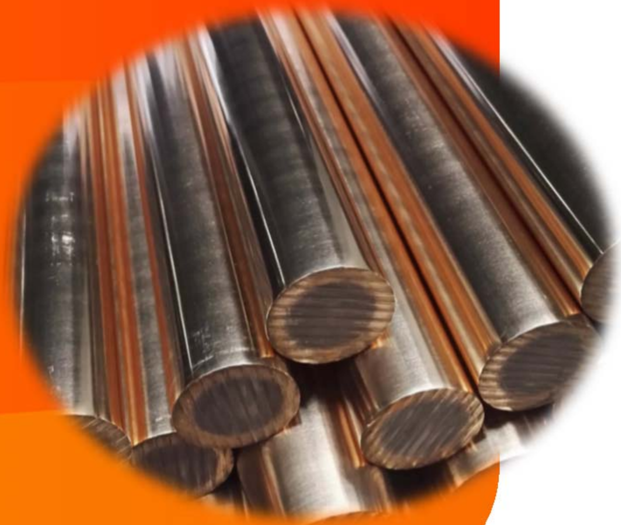
# Bronze

Alloy of Copper and Tin (Cu – Sn)

Types of Bronze:

- Aluminum Bronze: 6% - 12% Aluminum, 6% Iron and 6% Nickel
- Phosphor Bronze: 0.5% - 1% Tin, 0.01% - 0.35% Phosphorous
- Silicon Bronze: 20% Zinc, 6% Silicone
- Manganese Bronzes: Contains Manganese
- Nickel Silver: Contains Copper, Tin and Nickel
- Copper Nickel:  2% - 30% Nickel



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# Bronze

Alloy of Copper and Tin (Cu – Sn)

Uses of Bronze:

- Aluminum Bronze: Strength and corrosive-resistant Properties. Used in marine hardware, sleeve bearings, and pumps that transport corrosive fluids.
- Phosphor Bronze: Strength, fine grain, durability, high fatigue resistance, and a low coefficient of friction. Used to manufacture anti-corrosive equipment, as well as, electrical components, washers, springs, bellows, and more.
- Silicon Bronze: Manufacturing of pumps and valves parts.
- Manganese Bronzes: used in primarily for heavy duty mechanical products. They provide moderately good corrosion resistance. Brackets, Shafts, Gears, Structural parts, Screw down nuts, Slow-speed heavy load bearings, Gears, Gibbs and cams, Free machine parts, Lever arms, Light duty gears, Marine fittings, Valve stems, Propellers for salt and fresh water, Machinery parts substituting for steel and malleable iron.

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# Bronze

Alloy of Copper and Tin (Cu – Sn)

Uses of Bronze:

- Nickel Silver: The nickel content renders the metal a silver color, while the copper and tin provide tensile strength and corrosive-resistant qualities. It is used to make musical instruments, optical equipment, food and beverage equipment, and more.
- Copper Nickel: It is strong and corrosive-resistant. High thermal stability, making it useful in the manufacturing of electronic components, marine equipment, ship hulls, and more.

# Electrolytic Tough Pitch Copper

High Purity Copper refined by electrolytic refining process

Uses of Electrolytic Tough Pitch Copper:

Cause of its high purity it has excellent electrical conductor and it is used in Structural power wiring, power distribution cable, appliance wire, communications cable, automotive wire and cable, and magnet wire.

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# Beryllium Copper

Copper Beryllium Alloy: Contains 0.5% - 3% Beryllium

Uses of Beryllium Copper :

Beryllium copper combines high strength with non-magnetic and non-sparking qualities.

It has excellent metalworking, forming, and machining properties. It has many specialized applications in tools for hazardous environments, musical instruments, precision measurement devices, bullets, and aerospace. Beryllium alloys present a toxic inhalation hazard during manufacture.

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# Speeds and Feeds Table

While processing a material we have to determine some parameters to prevent damages that may occur. These damages can be wears of the cutting tool, the machine, the processed part or the spindle of the machine. As well as these parameters can affect the machining process giving good surface finish with clean continuous precision cuts without vibrations.

Brass :

| | | 2 Flute | | | 3 Flute | | | 4 Flute | | | 6 Flute | | | 8 Flute | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Milling Dia. | Feed Per tooth | SFM | RPM | IPM | SFM | RPM | IPM | SFM | RPM | IPM | SFM | RPM | IPM | SFM | RPM | IPM |
| 0.125 | .0005 | 2000 | 61,120 | 61.12 | 2000 | 61,120 | 91.68 | 2000 | 61,120 | 122.24 | 2000 | 61,120 | 183.36 | 2000 | 61,120 | 244.48 |
| 0.250 | .0010 | 2000 | 30,560 | 61.12 | 2000 | 30,560 | 91.68 | 2000 | 30,560 | 122.24 | 2000 | 30,560 | 183.36 | 2000 | 30,560 | 244.48 |
| 0.375 | .0015 | 2000 | 20,373 | 61.12 | 2000 | 20,373 | 91.68 | 2000 | 20,373 | 122.24 | 2000 | 20,373 | 183.36 | 2000 | 20,373 | 244.48 |
| 0.500 | .0020 | 2000 | 15,280 | 61.12 | 2000 | 15,280 | 91.68 | 2000 | 15,280 | 122.24 | 2000 | 15,280 | 183.36 | 2000 | 15,280 | 244.48 |
| 0.625 | .0020 | 2000 | 12,224 | 48.90 | 2000 | 12,224 | 73.34 | 2000 | 12,224 | 97.79 | 2000 | 12,224 | 146.69 | 2000 | 12,224 | 195.58 |
| 0.750 | .0025 | 2000 | 10,187 | 50.93 | 2000 | 10,187 | 76.40 | 2000 | 10,187 | 101.87 | 2000 | 10,187 | 152.80 | 2000 | 10,187 | 203.73 |
| 0.875 | .0030 | 2000 | 8,731 | 52.39 | 2000 | 8,731 | 78.58 | 2000 | 8,731 | 104.78 | 2000 | 8,731 | 157.17 | 2000 | 8,731 | 209.55 |
| 1.000 | .0035 | 2000 | 7,640 | 53.48 | 2000 | 7,640 | 80.22 | 2000 | 7,640 | 106.96 | 2000 | 7,640 | 160.44 | 2000 | 7,640 | 213.92 |
| 1.125 | .0035 | 2000 | 6,791 | 47.54 | 2000 | 6,791 | 71.31 | 2000 | 6,791 | 95.08 | 2000 | 6,791 | 142.61 | 2000 | 6,791 | 190.15 |
| 1.250 | .0035 | 2000 | 6,112 | 42.78 | 2000 | 6,112 | 64.18 | 2000 | 6,112 | 85.57 | 2000 | 6,112 | 128.35 | 2000 | 6,112 | 171.14 |
| 1.375 | .0035 | 2000 | 5,556 | 38.89 | 2000 | 5,556 | 58.34 | 2000 | 5,556 | 77.79 | 2000 | 5,556 | 116.68 | 2000 | 5,556 | 155.58 |
| 1.500 | .0040 | 2000 | 5,093 | 40.75 | 2000 | 5,093 | 61.12 | 2000 | 5,093 | 81.49 | 2000 | 5,093 | 122.24 | 2000 | 5,093 | 162.99 |
| 1.625 | .0040 | 2000 | 4,702 | 37.61 | 2000 | 4,702 | 56.42 | 2000 | 4,702 | 75.22 | 2000 | 4,702 | 112.84 | 2000 | 4,702 | 150.45 |

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# Speeds and Feeds Table

While processing a material we have to determine some parameters to prevent damages that may occur. These damages can be wears of the cutting tool, the machine, the processed part or the spindle of the machine. As well as these parameters can affect the machining process giving good surface finish with clean continuous precision cuts without vibrations.

Brass :

| Milling Dia. | Feed Per tooth | SFM | RPM | IPM | SFM | RPM | IPM | SFM | RPM | IPM | SFM | RPM | IPM | SFM | RPM | IPM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.750 | .0040 | 2000 | 4,366 | 34.93 | 2000 | 4,366 | 52.39 | 2000 | 4,366 | 69.85 | 2000 | 4,366 | 104.78 | 2000 | 4,366 | 139.70 |
| 1.875 | .0040 | 2000 | 4,075 | 32.60 | 2000 | 4,075 | 48.90 | 2000 | 4,075 | 65.19 | 2000 | 4,075 | 97.79 | 2000 | 4,075 | 130.39 |
| 2.000 | .0045 | 2000 | 3,820 | 34.38 | 2000 | 3,820 | 51.57 | 2000 | 3,820 | 68.76 | 2000 | 3,820 | 103.14 | 2000 | 3,820 | 137.52 |
| 2.125 | .0045 | 2000 | 3,595 | 32.36 | 2000 | 3,595 | 48.54 | 2000 | 3,595 | 64.72 | 2000 | 3,595 | 97.07 | 2000 | 3,595 | 129.43 |
| 2.250 | .0045 | 2000 | 3,396 | 30.56 | 2000 | 3,396 | 45.84 | 2000 | 3,396 | 61.12 | 2000 | 3,396 | 91.68 | 2000 | 3,396 | 122.24 |
| 2.375 | .0045 | 2000 | 3,217 | 28.95 | 2000 | 3,217 | 43.43 | 2000 | 3,217 | 57.90 | 2000 | 3,217 | 86.85 | 2000 | 3,217 | 115.81 |
| 2.500 | .0045 | 2000 | 3,056 | 27.50 | 2000 | 3,056 | 41.26 | 2000 | 3,056 | 55.01 | 2000 | 3,056 | 82.51 | 2000 | 3,056 | 110.02 |
| 3.000 | .0045 | 2000 | 2,547 | 22.92 | 2000 | 2,547 | 34.38 | 2000 | 2,547 | 45.84 | 2000 | 2,547 | 68.76 | 2000 | 2,547 | 91.68 |
| 3.500 | .0050 | 2000 | 2,183 | 21.83 | 2000 | 2,183 | 32.74 | 2000 | 2,183 | 43.66 | 2000 | 2,183 | 65.49 | 2000 | 2,183 | 87.31 |
| 4.000 | .0050 | 2000 | 1,910 | 19.10 | 2000 | 1,910 | 28.65 | 2000 | 1,910 | 38.20 | 2000 | 1,910 | 57.30 | 2000 | 1,910 | 76.40 |
| 4.500 | .0050 | 2000 | 1,698 | 16.98 | 2000 | 1,698 | 25.47 | 2000 | 1,698 | 33.96 | 2000 | 1,698 | 50.93 | 2000 | 1,698 | 67.91 |
| 5.000 | .0055 | 2000 | 1,528 | 16.81 | 2000 | 1,528 | 25.21 | 2000 | 1,528 | 33.62 | 2000 | 1,528 | 50.42 | 2000 | 1,528 | 67.23 |
| 5.500 | .0055 | 2000 | 1,389 | 15.28 | 2000 | 1,389 | 22.92 | 2000 | 1,389 | 30.56 | 2000 | 1,389 | 45.84 | 2000 | 1,389 | 61.12 |
| 6.000 | .0060 | 2000 | 1,273 | 15.28 | 2000 | 1,273 | 22.92 | 2000 | 1,273 | 30.56 | 2000 | 1,273 | 45.84 | 2000 | 1,273 | 61.12 |

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Bronze and Copper Alloys:

| | | 2 Flute | | | 3 Flute | | | 4 Flute | | | 6 Flute | | | 8 Flute | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Milling Dia. | Feed Per tooth | SFM | RPM | IPM | SFM | RPM | IPM | SFM | RPM | IPM | SFM | RPM | IPM | SFM | RPM | IPM |
| 0.125 | .0005 | 1500 | 45,840 | 45.84 | 1500 | 45,840 | 68.76 | 1500 | 45,840 | 91.68 | 1500 | 45,840 | 137.52 | 1500 | 45,840 | 183.36 |
| 0.250 | .0010 | 1500 | 22,920 | 45.84 | 1500 | 22,920 | 68.76 | 1500 | 22,920 | 91.68 | 1500 | 22,920 | 137.52 | 1500 | 22,920 | 183.36 |
| 0.375 | .0015 | 1500 | 15,280 | 45.84 | 1500 | 15,280 | 68.76 | 1500 | 15,280 | 91.68 | 1500 | 15,280 | 137.52 | 1500 | 15,280 | 183.36 |
| 0.500 | .0020 | 1500 | 11,460 | 45.84 | 1500 | 11,460 | 68.76 | 1500 | 11,460 | 91.68 | 1500 | 11,460 | 137.52 | 1500 | 11,460 | 183.36 |
| 0.625 | .0020 | 1500 | 9,168 | 36.67 | 1500 | 9,168 | 55.01 | 1500 | 9,168 | 73.34 | 1500 | 9,168 | 110.02 | 1500 | 9,168 | 146.69 |
| 0.750 | .0025 | 1500 | 7,640 | 38.20 | 1500 | 7,640 | 57.30 | 1500 | 7,640 | 76.40 | 1500 | 7,640 | 114.60 | 1500 | 7,640 | 152.80 |
| 0.875 | .0030 | 1500 | 6,549 | 39.29 | 1500 | 6,549 | 58.94 | 1500 | 6,549 | 78.58 | 1500 | 6,549 | 117.87 | 1500 | 6,549 | 157.17 |
| 1.000 | .0035 | 1500 | 5,730 | 40.11 | 1500 | 5,730 | 60.17 | 1500 | 5,730 | 80.22 | 1500 | 5,730 | 120.33 | 1500 | 5,730 | 160.44 |
| 1.125 | .0035 | 1500 | 5,093 | 35.65 | 1500 | 5,093 | 53.48 | 1500 | 5,093 | 71.31 | 1500 | 5,093 | 106.96 | 1500 | 5,093 | 142.61 |
| 1.250 | .0035 | 1500 | 4,584 | 32.09 | 1500 | 4,584 | 48.13 | 1500 | 4,584 | 64.18 | 1500 | 4,584 | 96.26 | 1500 | 4,584 | 128.35 |
| 1.375 | .0035 | 1500 | 4,167 | 29.17 | 1500 | 4,167 | 43.76 | 1500 | 4,167 | 58.34 | 1500 | 4,167 | 87.51 | 1500 | 4,167 | 116.68 |
| 1.500 | .0040 | 1500 | 3,820 | 30.56 | 1500 | 3,820 | 45.84 | 1500 | 3,820 | 61.12 | 1500 | 3,820 | 91.68 | 1500 | 3,820 | 122.24 |
| 1.625 | .0040 | 1500 | 3,526 | 28.21 | 1500 | 3,526 | 42.31 | 1500 | 3,526 | 56.42 | 1500 | 3,526 | 84.63 | 1500 | 3,526 | 112.84 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.750 | .0040 | 1500 | 3,274 | 26.19 | 1500 | 3,274 | 39.29 | 1500 | 3,274 | 52.39 | 1500 | 3,274 | 78.58 | 1500 | 3,274 | 104.78 |
| 1.875 | .0040 | 1500 | 3,056 | 24.45 | 1500 | 3,056 | 36.67 | 1500 | 3,056 | 48.90 | 1500 | 3,056 | 73.34 | 1500 | 3,056 | 97.79 |
| 2.000 | .0045 | 1500 | 2,865 | 25.79 | 1500 | 2,865 | 38.68 | 1500 | 2,865 | 51.57 | 1500 | 2,865 | 77.36 | 1500 | 2,865 | 103.14 |
| 2.125 | .0045 | 1500 | 2,696 | 24.27 | 1500 | 2,696 | 36.40 | 1500 | 2,696 | 48.54 | 1500 | 2,696 | 72.80 | 1500 | 2,696 | 97.07 |
| 2.250 | .0045 | 1500 | 2,547 | 22.92 | 1500 | 2,547 | 34.38 | 1500 | 2,547 | 45.84 | 1500 | 2,547 | 68.76 | 1500 | 2,547 | 91.68 |
| 2.375 | .0045 | 1500 | 2,413 | 21.71 | 1500 | 2,413 | 32.57 | 1500 | 2,413 | 43.43 | 1500 | 2,413 | 65.14 | 1500 | 2,413 | 86.85 |
| 2.500 | .0045 | 1500 | 2,292 | 20.63 | 1500 | 2,292 | 30.94 | 1500 | 2,292 | 41.26 | 1500 | 2,292 | 61.88 | 1500 | 2,292 | 82.51 |
| 3.000 | .0045 | 1500 | 1,910 | 17.19 | 1500 | 1,910 | 25.79 | 1500 | 1,910 | 34.38 | 1500 | 1,910 | 51.57 | 1500 | 1,910 | 68.76 |
| 3.500 | .0050 | 1500 | 1,637 | 16.37 | 1500 | 1,637 | 24.56 | 1500 | 1,637 | 32.74 | 1500 | 1,637 | 49.11 | 1500 | 1,637 | 65.49 |
| 4.000 | .0050 | 1500 | 1,433 | 14.33 | 1500 | 1,433 | 21.49 | 1500 | 1,433 | 28.65 | 1500 | 1,433 | 42.98 | 1500 | 1,433 | 57.30 |
| 4.500 | .0050 | 1500 | 1,273 | 12.73 | 1500 | 1,273 | 19.10 | 1500 | 1,273 | 25.47 | 1500 | 1,273 | 38.20 | 1500 | 1,273 | 50.93 |
| 5.000 | .0055 | 1500 | 1,146 | 12.61 | 1500 | 1,146 | 18.91 | 1500 | 1,146 | 25.21 | 1500 | 1,146 | 37.82 | 1500 | 1,146 | 50.42 |
| 5.500 | .0055 | 1500 | 1,042 | 11.46 | 1500 | 1,042 | 17.19 | 1500 | 1,042 | 22.92 | 1500 | 1,042 | 34.38 | 1500 | 1,042 | 45.84 |
| 6.000 | .0060 | 1500 | 955 | 11.46 | 1500 | 955 | 17.19 | 1500 | 955 | 22.92 | 1500 | 955 | 34.38 | 1500 | 955 | 45.84 |

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# Computer Aided Design

# 02

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# Introduction to CAD

CAD (Computer Aided Design) is the use of computer software to design a component and perform various operations to construct (3D printing additive manufacturing, CNC machining) or analyze the mechanical properties of it (Topology Optimization, Computational Fluid Dynamics, Finite Element Analysis, etc)

CAD software advantages :

- Efficiency in the quality of design
- Increase in the Engineer's productivity
- Improve record keeping through better documentation and communication

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# Introduction to CAD

Types of CAD software:

- 2D CAD
- 3D CAD
- 3D Wireframe and Surface Modelling

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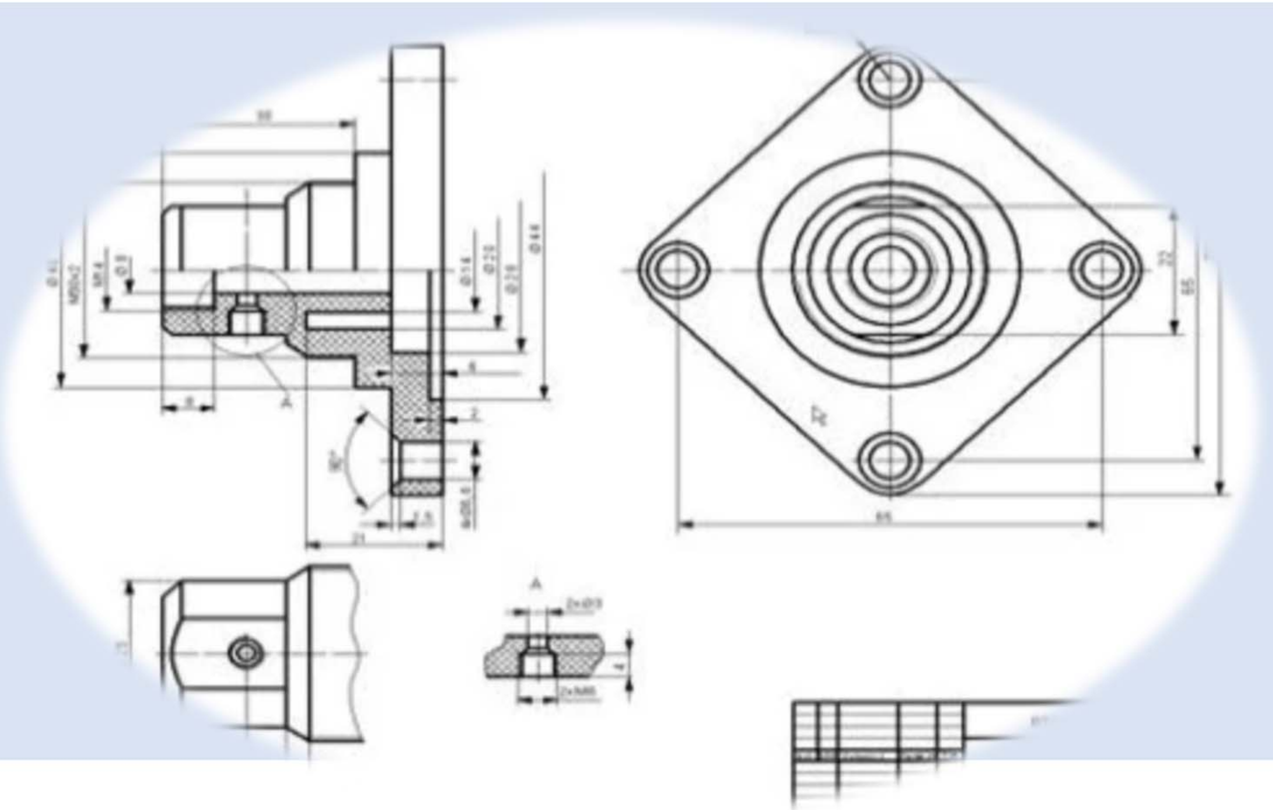
# 2D CAD



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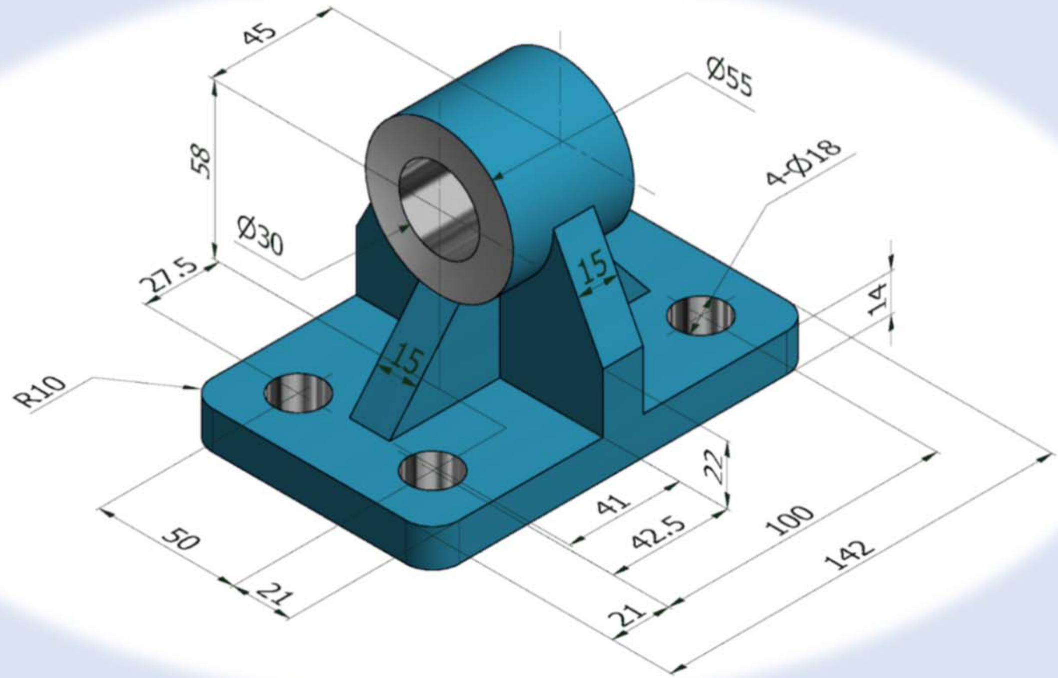
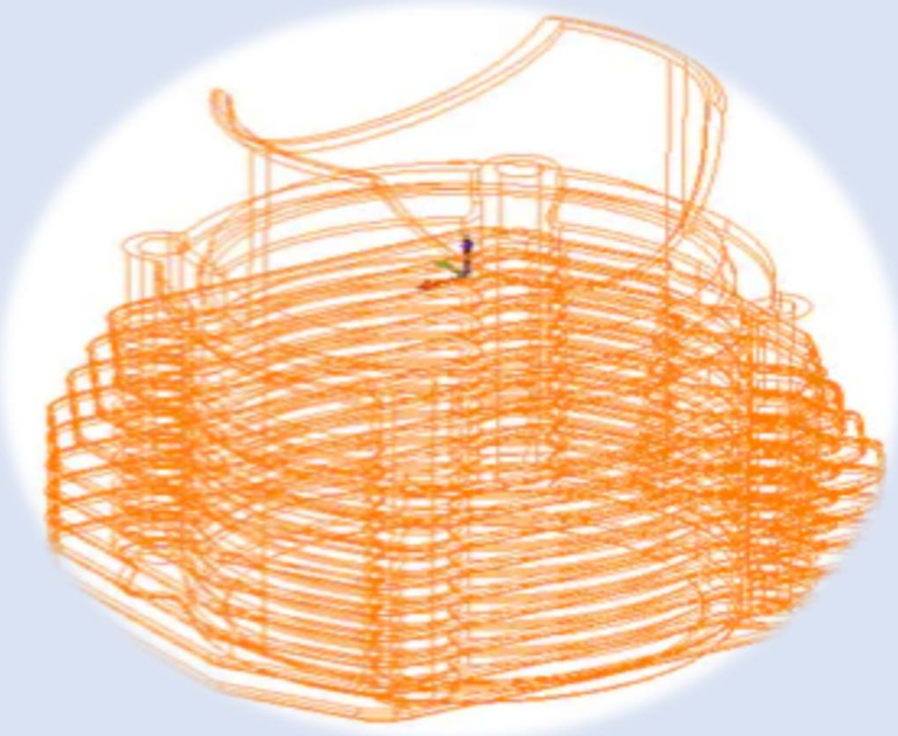
## 3D CAD



# 3D Wireframe and Surface Modelling



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# History of CAD

Initially used by Douglas T. Ross, the term 'computer-aided design' was introduced in the early 1950s. Ross, a researcher at the Massachusetts Institute of Technology (MIT), was working with military radar technology and computer display systems. Ross worked on projects that pioneered early CAD technology – such as Automatically Programmed Tools (APT), which led to the creation of AED (Automated Engineering Design). Ross would host conferences at MIT to discuss the expanding technologies with other early practitioners in the industry.

One of the first uses of what might be called CAD was deployed by Patrick Hanratty at the General Motors Research Laboratories. Hanratty developed Design Automated by Computer (DAC), which is thought to be the first CAD system that involved interactive graphics. This was the first commercial CAD/CAM software system, and involved a numerical control programming tool named PRONTO, which he developed in 1957. As such, Hanratty is often referred to as 'the father of CAD/CAM'.

The first true CAD software was called Sketchpad, developed by Ivan Sutherland in the early 1960s as part of his PhD thesis at MIT (Massachusetts Institute of Technology). Sketchpad was especially innovative CAD software because the designer interacted with the computer graphically by using a light pen to draw on the computer's monitor.

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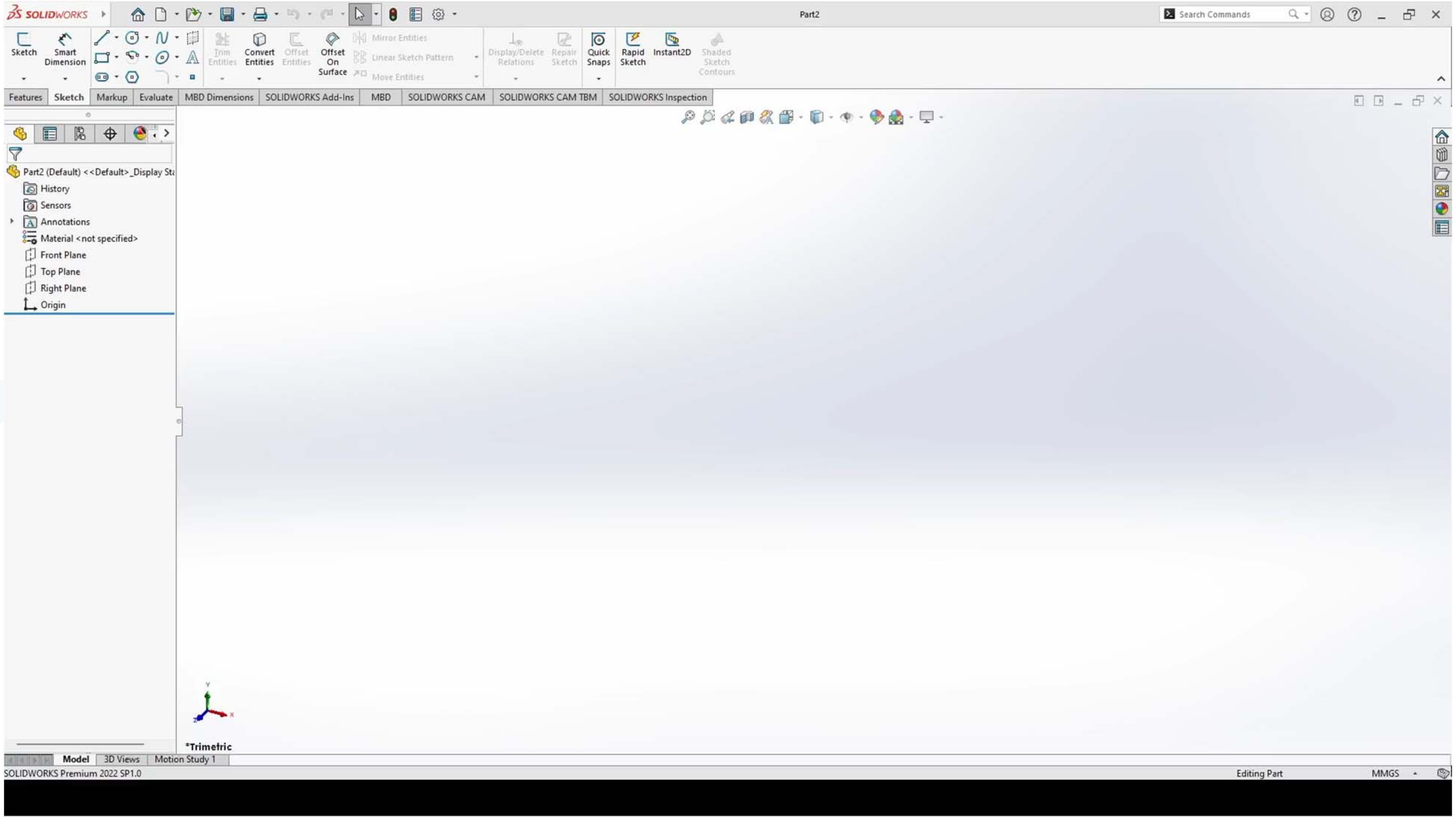
## CAD Documentary

# Design of the Part - SolidWorks



# Computer Numerical Control Machines

# 03

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# Introduction to CNC Machines

CNC machining is a manufacturing process in which a computer directs machines using programming codes to make a product. CNC (Computer Numerical Control) machining is a subtractive manufacturing process. This means that the computer program directs these tools (for example, drills, mills, and lathes) to constantly chip away at a workpiece. This continues until the desired product is formed.

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# CNC Machines History

The first CNC machine was credited to James Parsons in 1949. Parsons was a computer pioneer who worked on an Air Force Research Project. The research was on how to produce helicopter blades and better aircraft skin.
Parsons was able to calculate helicopter airfoil coordinates with an IBM 602A multiplier. He then fed the data into a punched card, which he used on a swiss jig borer. This information led to the manufacture of many helicopter blades and aircraft skins. According to the accepted CNC history, this was considered the first CNC machine. Parson would later receive the Joseph Maria Jacquard Memorial Awards for his work.

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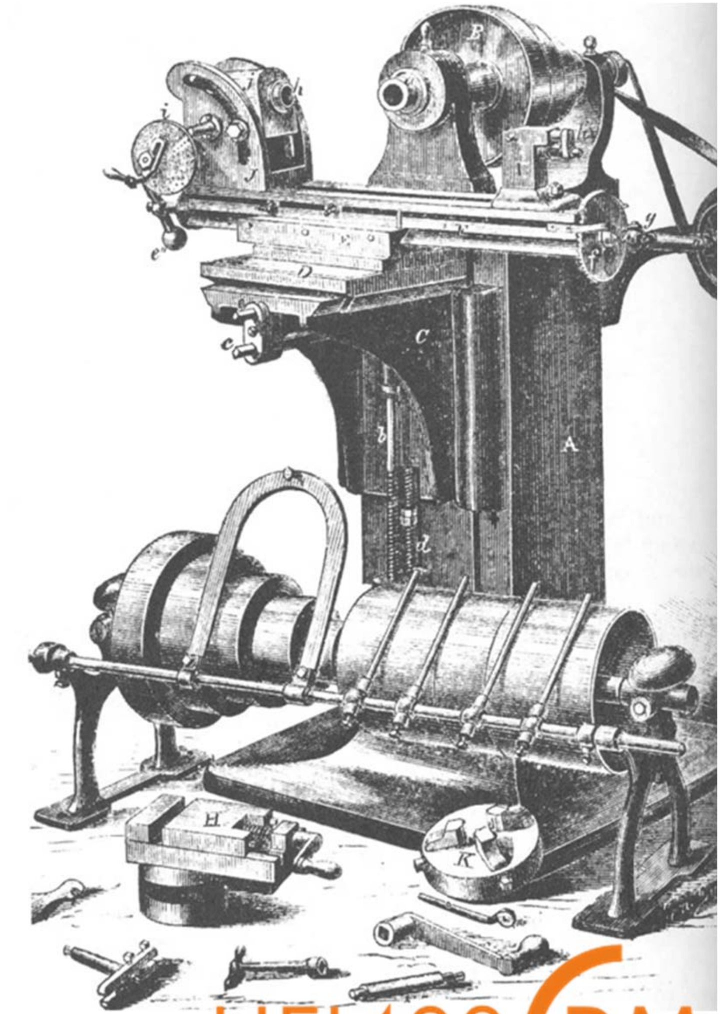

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# CNC Machines Documentary

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# Advantages and Limitations of CNC machining:

| Advantages | Limitations |
|---|---|
| Constant Use With Minimal Maintenance | Cost |
| Precision | Size Limitations of CNC |
| Accuracy | Operator Error |
| Versatility | |
| Simulated Models or Prototypes | |
| More Capability | |
| High Production and Scalability | |
| Uniform Product | |
| Design Retention | |

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# Possible Dangers

The main possible dangers of handling a CNC machine are:

- Flying debris
- Pull of clothing and linen in the machine
- Maintenance injuries
- Injuries related to repetitive stress

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# Safety Assessments

- Ensure proper maintenance
- Personal protective equipment needed
- Proper training  required

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# Fixturing Techniques

Milling Vise


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# Fixturing Techniques

## Plates, Plate Fixtures, and Clamps

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# Fixturing Techniques

Step Clamps

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# Fixturing Techniques

Toe Clamps

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# Fixturing Techniques

Chucks and Collets: For Round Parts

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# Fixturing Techniques

5-Axis Workholding

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# Zeroing Techniques

Edge Finder

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# Zeroing Techniques

3D Taster


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# Zeroing Techniques

CNC Probe


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# Computer Aided Manufacturing

# 04

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# Introduction to CAM

Computer Aided Manufacturing (CAM) is the use of software and computer-controlled machinery to automate a manufacturing process.

Based on that definition, you need three components for a CAM system to function:

- Software that tells a machine how to make a product by generating toolpaths.
- Machinery that can turn raw material into a finished product.
- Post Processing converts toolpaths into a language machines can understand.

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# Introduction to CAM

Computer Aided Manufacturing software prepares a model for machining by working through several actions, including:

- Checking if the model has any geometry errors that will impact the manufacturing process.
- Creating a toolpath for the model, a set of coordinates the machine will follow during the machining process.
- Setting any required machine parameters, including cutting speed, voltage, cut/pierce height, etc.
- Configuring nesting where the CAM system will decide the best orientation for a part to maximize machining efficiency

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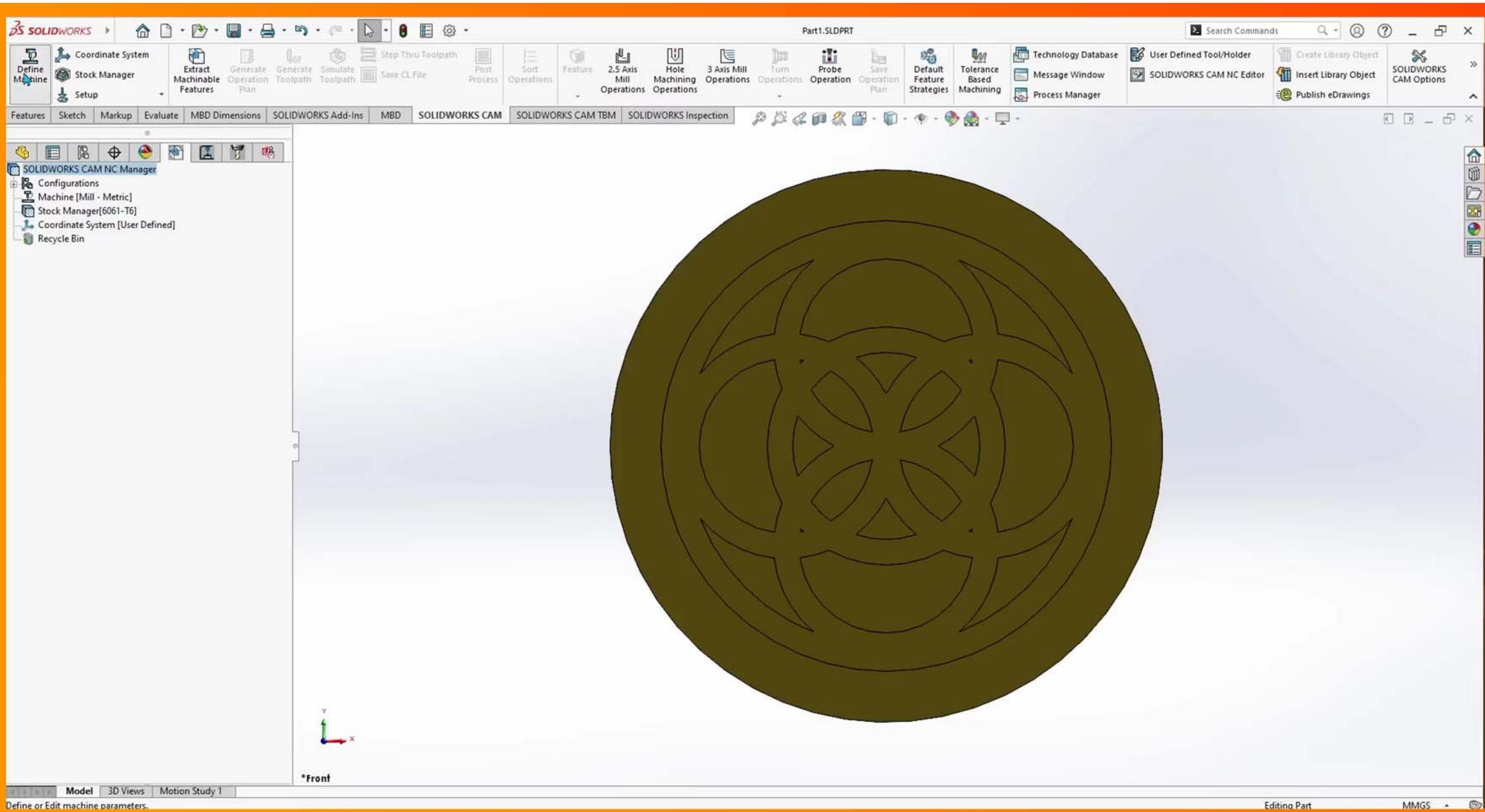
# Part from CAD to CAM video

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# Thank you!


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