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Chapter 2: Deformative Manufacturing

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Outline

I.A | Deformative Manufacturing

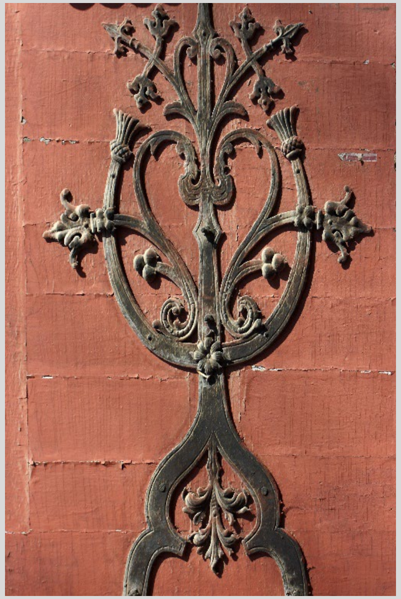
- Deformative manufacturing represents processes where we transform the material from Form A to Form B without the addition or subtraction of material.
- The fundamental concept is that the volume of materials remains unchanged throughout the process.
- Forging, Rolling, Casting are examples of Deformative Manufacturing.

Chapter 2

Chapter 7

I.A | Deformative Manufacturing

- **Forging** is one of the earliest manufacturing processes used by humans.
  - ~ 4000 B.C. copper was forged to make weapons & tools - very limited variety of shapes
  - Until 19th century forging was a highly desired skill/trade and blacksmiths well respected. A lot of the Nordic (Viking) mythology has smith as hero!
  - Strongly correlated w/ casting process development
- **Casting** is also one of the earlier manufacturing processes.
  - ~ 3200 B.C. copper was first cast in Mesopotamia to make weapons, art & tools - very limited variety of shapes
  - ~ 500 B.C. iron melting process introduced by Chinese
  - ~ 1500 Europeans managed to cast iron gun barrels
  - With introduction of Bessemer steel making process in 1856 (in Europe / industrial scale – ~11th century/non-industrial scale outside Europe) the basis for industrial scale production was set





For More Check

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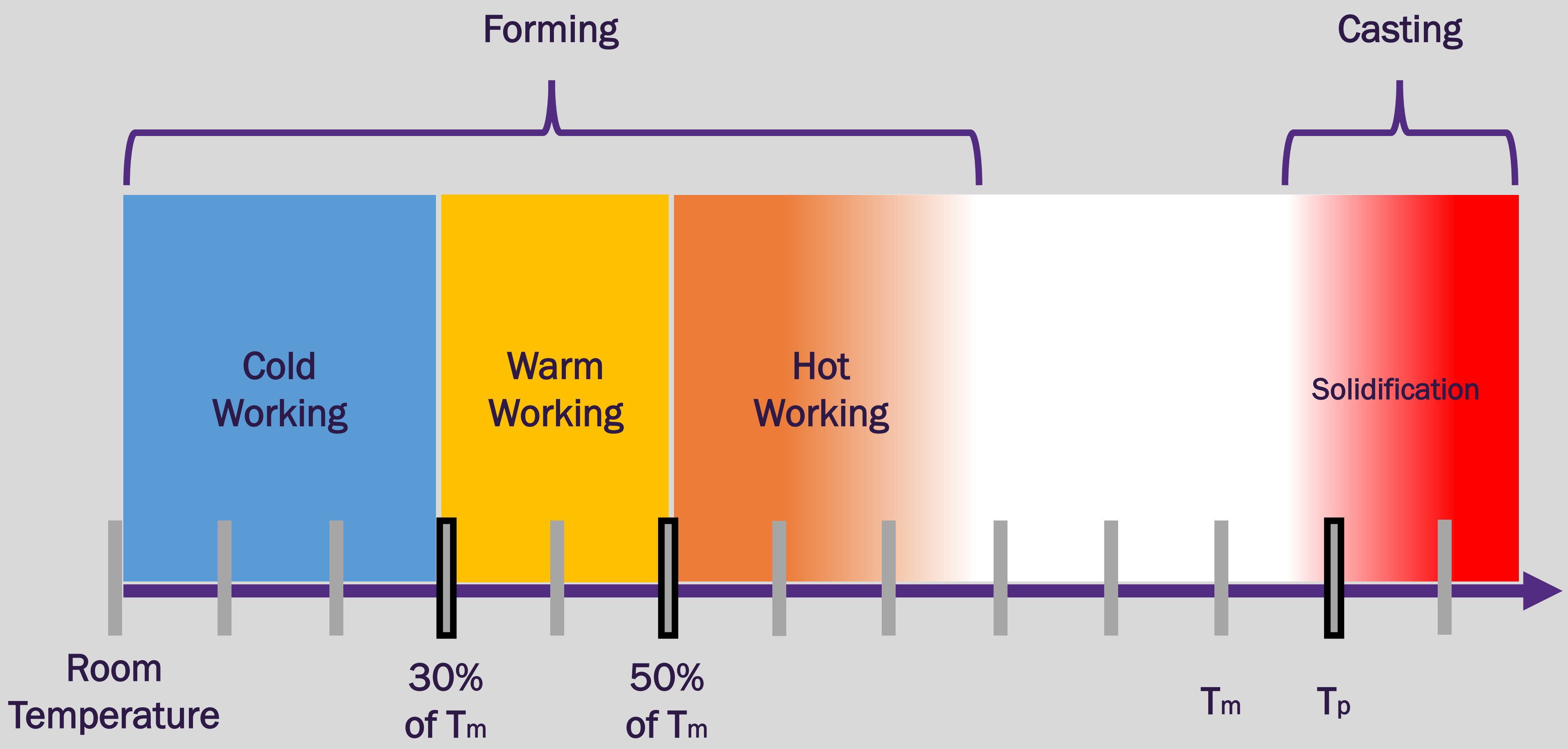
Deformative Manufacturing: Forming and Casting



Effect of Temperature

Forming

- **Cold working (CW)**
  - Shaping of material at room temperature (below recrystallization temperature)
  - Positive effect: Work hardening (strain hardening) strengthens metal through plastic deformation (but material becomes more brittle)
- **Warm working (WW)**
  - Shaping of material elevated above room temperature but below recrystallization temperature
  - Trade-off between hot and cold working
- **Hot working (HW)**
  - Shaping of material above the recrystallization temperature but below melting temperature
  - Positive effect: Properties (e.g., toughness, ductility, elongation) improve / less force required to transform ingots
- **Casting**
  - Shaping of material above the recrystallization temperature and melting temperature

Recrystallization

- **Recrystallization**
  - Dislocations in metal material move to grain boundaries and/or move to the material surface
  - Material becomes "strain-free"
- **Recrystallization temperature**
  - Temperature at which 95 percent of recrystallization is complete within one hour
  - Different metals have different recrystallization temperatures (e.g., Al 300 °F, Fe 840 °F & Ni 1,100 °F)
- **Energy**
  - Recrystallization is a function of the total energy
  - Total energy = strain energy + thermal energy
  - Effect: The more strain energy is induced, the less thermal energy is required (the more cold working is performed, the lower recrystallization temperature)

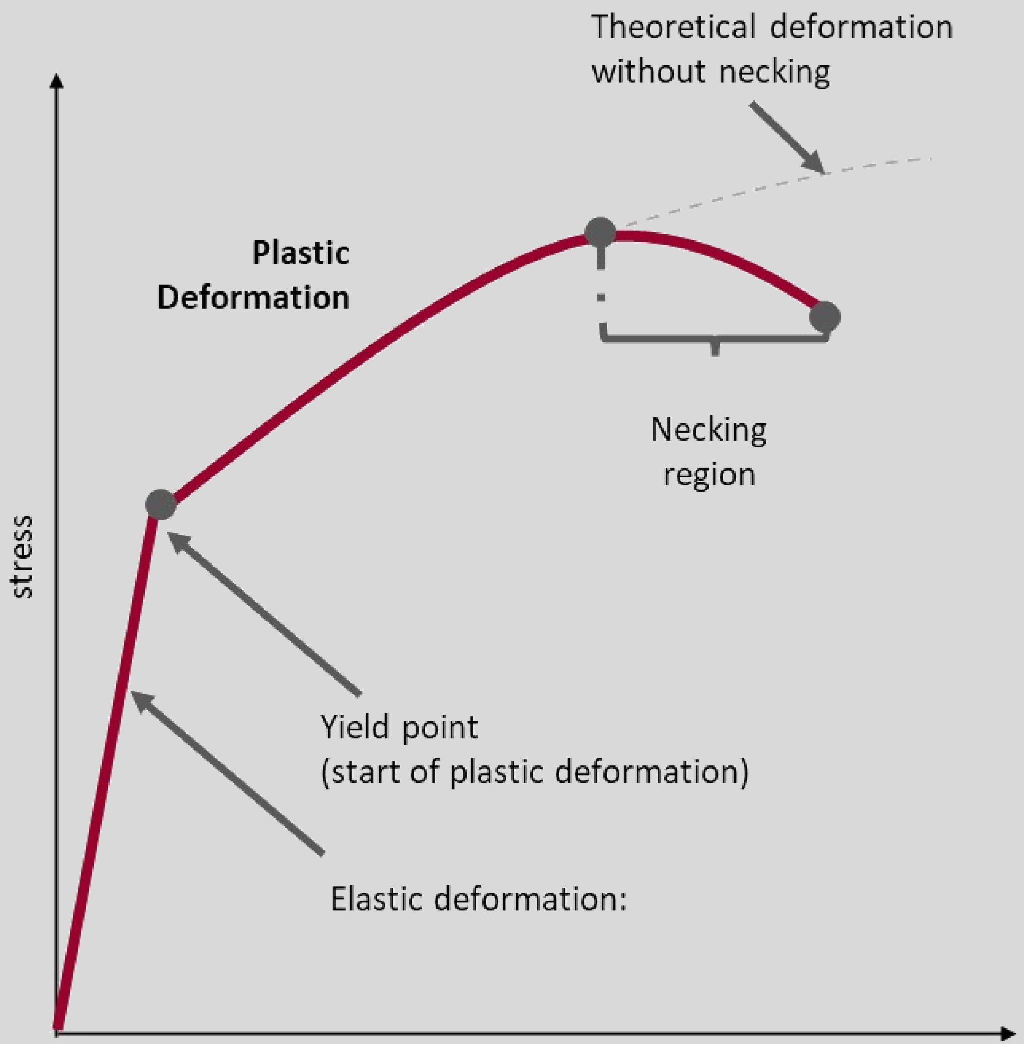
Engineering Design vs. Manufacturing

- **Design guidelines for Forging**
  - Rib height to rib thickness ratio not to exceed 6:1
  - Part must be designed with an appropriate draft angle (standard degree: 1 +/- 0.5)
  - Add additional material for secondary (machining) processes and plan the parting line (where dies meet)
  - No sharp corners – plan with appropriate radii
  - Minimum (~0.2in) / maximum (~10in) wall thickness (varies to some extent)
  - Consider achievable surface finish (and plan for secondary processing if necessary)

- **Design guidelines for Casting**
  - Design uniform sections when possible
  - Include draft angle
  - Plan ejection pins & parting line (die casting)
  - Avoid sharp corners / angles and use rounded corners
  - Include buttresses / ribs to support material flow
  - Design wall thickness uniformly (uniform cross-section)
  - Reflect shrinkage in casting design
  - Add additional material for secondary (machining) processes

Understanding Material Behavior I

- Elastic Deformation
  - Temporary shape change (self-reversing)
  - Hooke's Law (one dimensional): $\sigma = Ee$
  - E = Young's modulus (stiffness of material)
- Plastic Deformation (Where Manufacturing Happens)
  - Permanent change of shape
  - Stress in material larger than yield strength
- Flow stress
  - Stress needed to achieve a plastic deformation (strain) on a material
  - Flow stress of material is influenced by: Strain rate, temperature, etc.
- **Metals with low yield strength and high ductility are best suited for forging**
  - Yield strength decreases with higher temperatures
  - Ductility increases with higher temperatures



Understanding Material Behavior I

- **Engineering strain**

$$e = (L-Lo) / Lo$$

Where **L = final length** and **Lo = original length**

- **Engineering strain rate**

$$e = v / Lo$$

Where **v = velocity** and **Lo = original length**

- **True strain**

$$\varepsilon = \ln(L / Lo)$$

Where **L = final length** and **Lo = original length**

- **True strain rate**

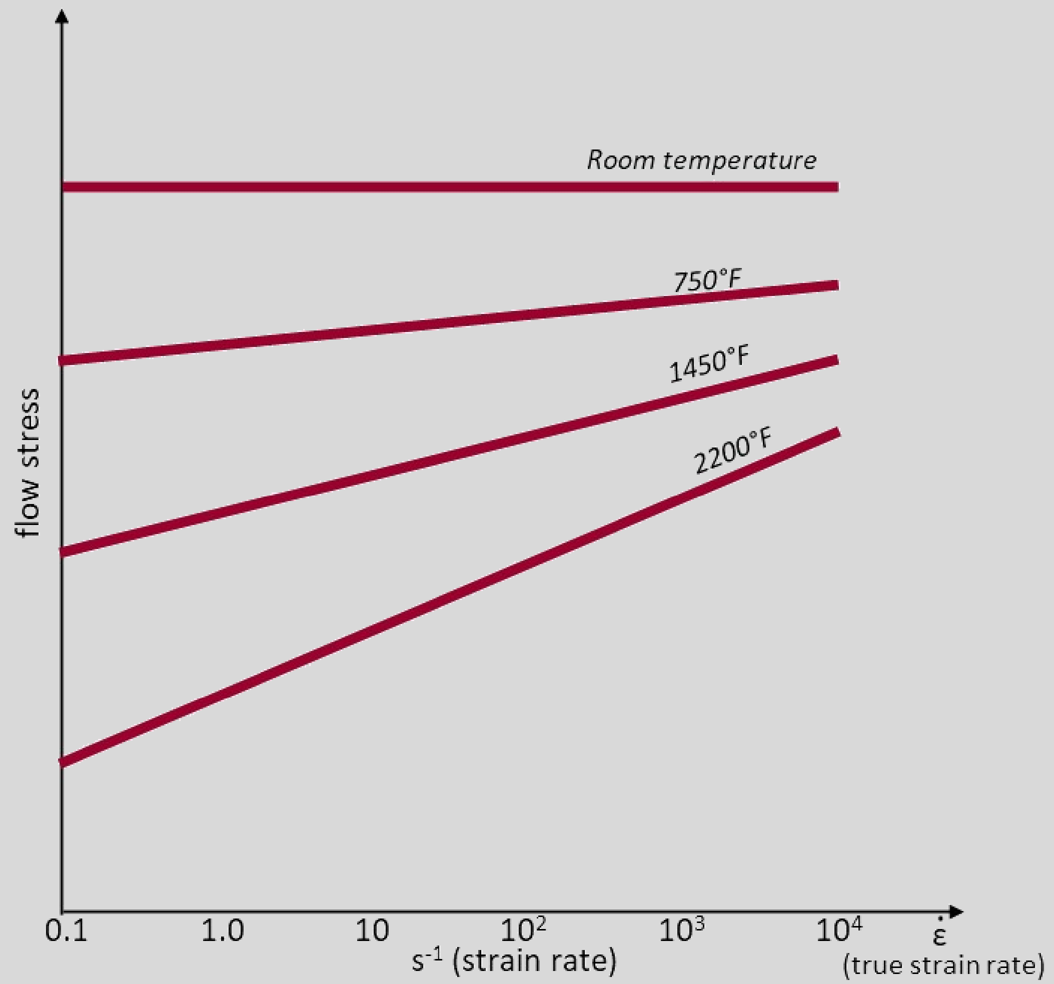
$$\varepsilon = v/L$$

Where **L = final length** and **v = velocity**

- **Flow stress / mean flow stress**

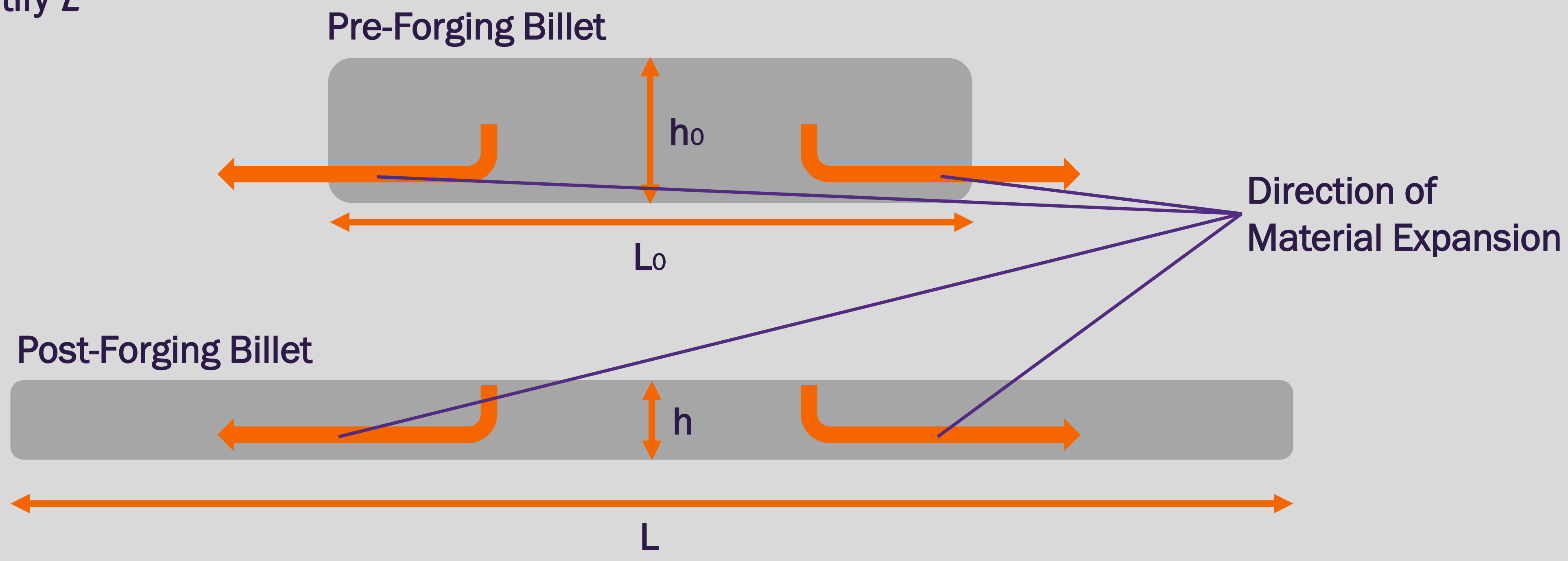
$$Yf = K\varepsilon n \quad / \quad Yf = (K\varepsilon n)/(1+n)$$

Where **K = strength coefficient; n = strain hardening exponent; ε = true strain**



Understanding Material Behavior I

How to Identify *L*



Example:

$\varepsilon = ln(L/L_0) = ln(2/1) = 0.69$

$\varepsilon = ln(h/h_0) = ln(1/0.5) = -0.69$

Negative Value Indicates Compression Instead of Tension
<u>BUT</u> Value is Always Understood as Positive

Knowledge Check

Determine the flow stress experienced during compression of a cylinder from a length of 50 mm to a length of 25 mm. The material has a strength coefficient of 200 MPa and a strain hardening of 0.2

A. 172.32 MPa
B. 185.86 MPa
C. 212.21 MPa
D. 235.21 MPa

Knowledge Check

Determine the flow stress experienced during compression of a cylinder from a length of 50 mm to a length of 25 mm. The material has a strength coefficient of 200 MPa and a strain hardening of 0.2

A. 172.32 MPa
B. **185.86 MPa**
C. 212.21 MPa
D. 235.21 MPa

$\varepsilon = \ln(L/L_0) = \ln(25/50) = -0.69$

A negative value indicates compression instead of tension **BUT value is always understood as positive**

$Y_f = K\varepsilon^n = 200(0.69)^{0.2} = 185.86$ MPa

Knowledge Check

What is the mean flow stress for the previous exercise?

A. 154.88 MPa
B. 189.86 MPa
C. 252.81 MPa
D. 335.76 MPa

Knowledge Check

What is the mean flow stress for the previous exercise?

A. **154.88 MPa**
B. 189.86 MPa
C. 252.81 MPa
D. 335.76 MPa

$Y_f = (K\varepsilon^n)/(1+n)$

$Y_f = 185.86/1.2$

$Y_f = 154.88$ MPa

Class Exercise

Two experiments, using tensile tests, gave

- Yield stress of 230 MPa at 0.40 Strain
- Yield stress of 260 MPa at 0.70 Stran

? Determine the strain hardening exponent as well as the strength coefficient.

Class Exercise

Two experiments, using tensile tests, gave

- Yield stress of 230 MPa at 0.40 Strain
- Yield stress of 260 MPa at 0.70 Stran

? Determine the strain hardening exponent as well as the strength coefficient.

$Y_f = K\varepsilon^n$

230 = K 0.4 ^{n} (I) → **ln(230) = ln(K) + n . ln(0.4)**

260 = K 0.7 ^{n} (II) → **ln(260) = ln(K) + n . ln(0.7)**

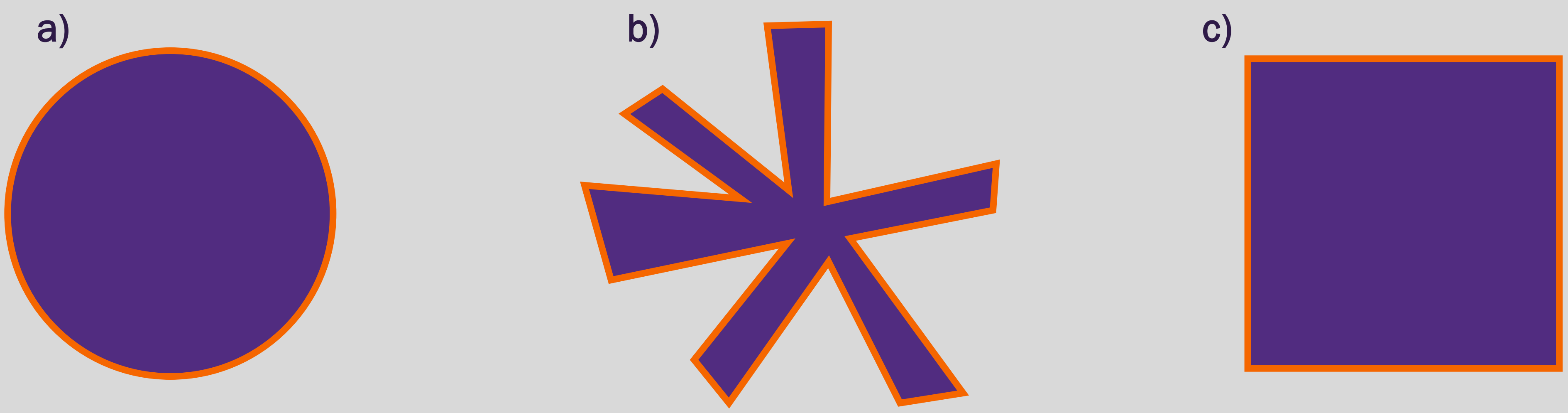
n = [ln(260)-ln(230)] / [ln(0.7)-ln(0.4)] **= 0.219**

K = 260/0.7^0.219 **= 281.13 MPa**

Shape Factor

- Shape undergoing deformation have an influence on the **'next'** force needed to pursue the operation
- The **influence of shape** is captured via different experimental trials and is relevant to the manufacturing process

- ***Force = Flow Stress x Area***
- However, think of deforming the below cross sections a), b) and c), they have the same area, do they require the same amount of force?



Shape Factor

- In extrusion, the shape factor is trying to compare the shape to a circle having the same area as the extruded shape

$$K_x = 0.98 + 0.02\,(C_x / C_c)^{2.25}$$

- *Where:*
  - *Cx = perimeter of non-circular extruded section;*
  - *Co = perimeter of a circle that has the same cross-sectional area as extruded section*

- In forging, we are further integrating the coefficient of friction
- As you further continue the forging operation, your shape factor increases: the shape is flatter and thus D is bigger, and h is smaller

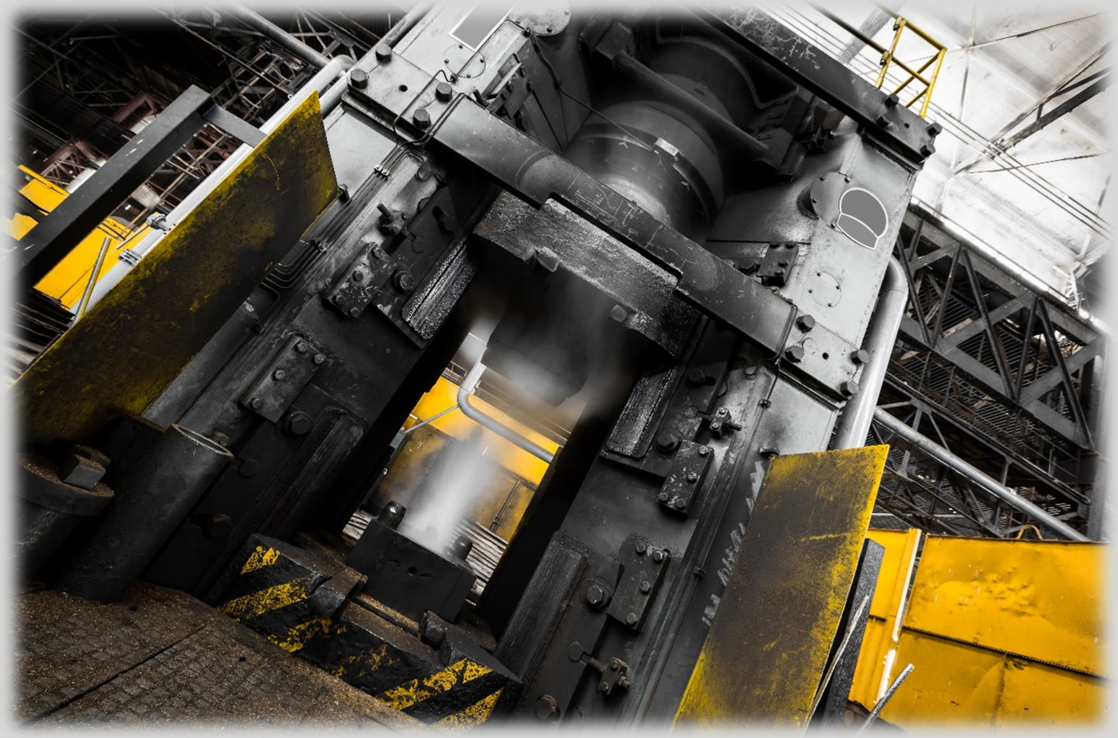
$$K_f = 1 + (0.4\,\mu\, D/h)$$

Forging

Section I

I.A | Theoretical Concept: What is Forging?

- Forging Operations Induce
  - Shape changes on the work piece
  - By plastic deformation
  - Under forces applied (hammering or pressing)
  - By various tools and dies
- Different Classifications Used
  - *Material:* Bulk vs. Sheet (most common)
  - *Operating temperature:* Hot (vs. Warm) vs. Cold
  - *Mode:* Steady vs. non-steady state vs. mixed
  - *Type of stress:* Compression vs. Tension vs. Bending, etc.
  - *Flow:* Homogeneous vs. Semi-homogeneous vs. Inhomogeneous
  - *Succession/Operation:* Primary vs. Secondary



For More Check

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World's Biggest Hydraulic Press

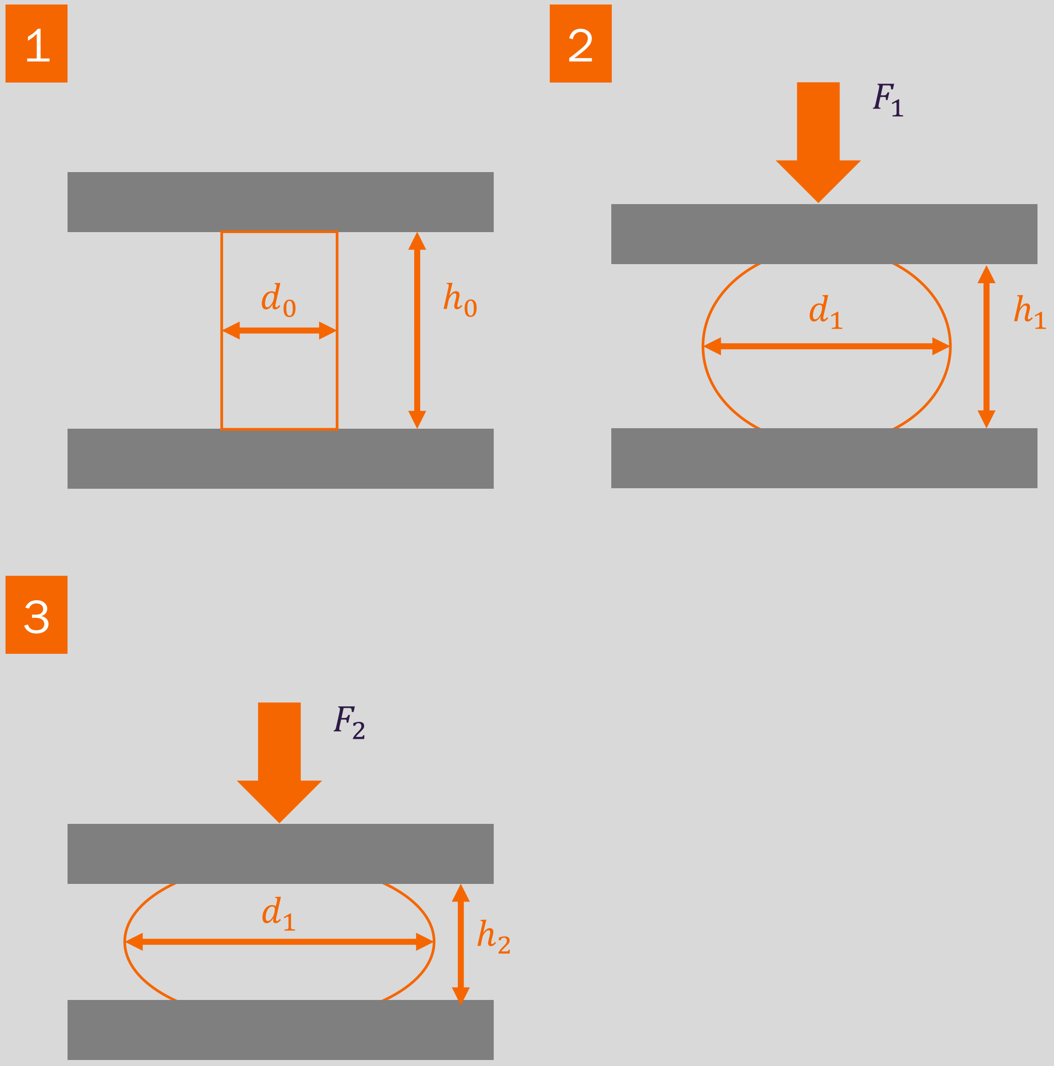
- Biggest forging hydraulic press in the world:
  - 80,000 ton closed-die hydraulic press
  - Shanghai Electric Group, Shanghai, Chin
- Runner Ups:
  - 75,000 tons (Russia)
  - 65,000 tons (France
  - 50,000 tons (USA)
- Example use cases:
  - Aerospace: Landing gear for A380 -> Russian forge
- Trivia: Born out of necessity by Germany during WWII as there was a shortage of steel and a more brittle (but lighter) material had to be used. The process was highly successful and used in the Messerschmidt Me262 jets. The US brought the processing technology to Pittsburgh while the Russians took the original German equipment.

[1]

[1] Source: https://blogs.wsj.com/chinarealtime/2014/12/03/under-pressure-the-10-story-machine-china-hopes-will-boost-its-aviation-industry/

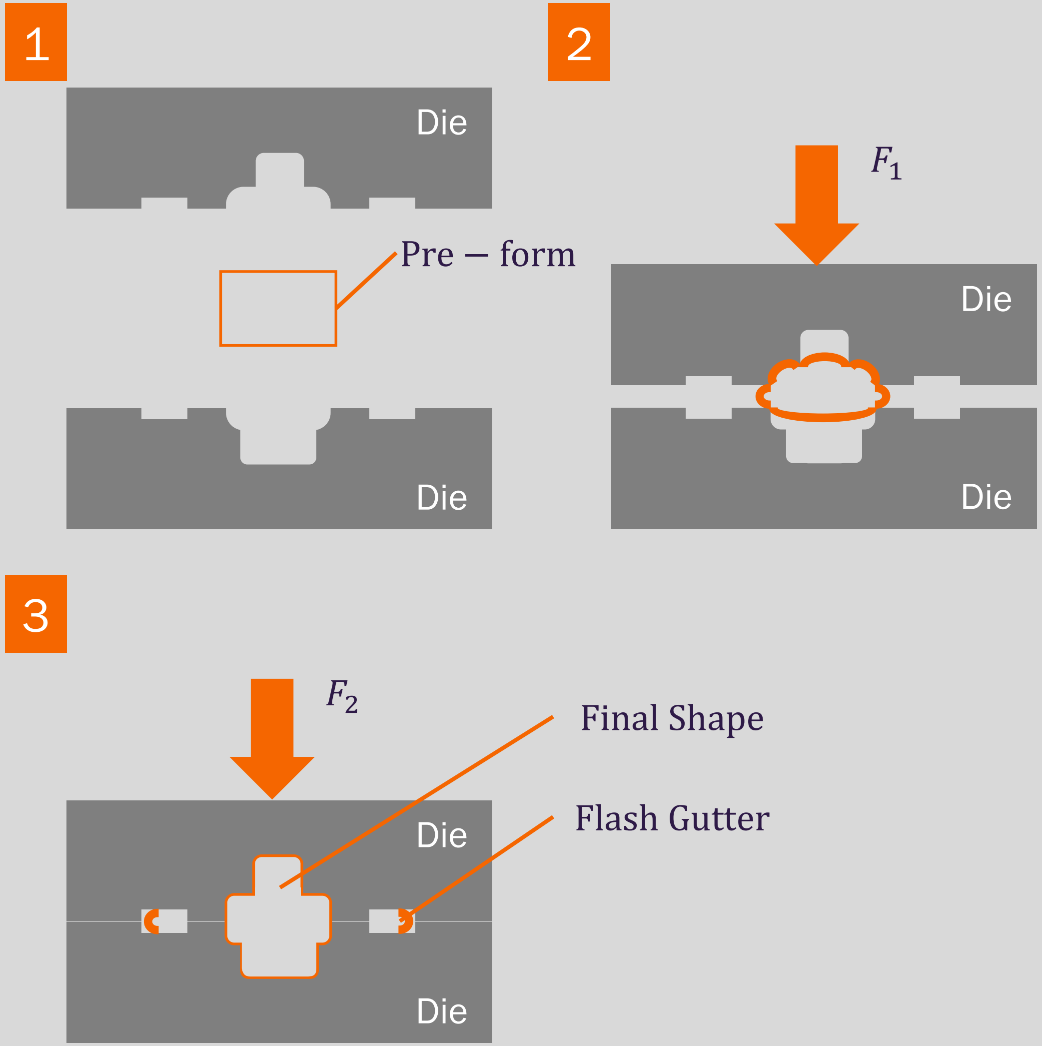
I.B | Categorization: Open Die Forging

- Open Die Forging is the simplest form of (industrial) forging
- No specialized tooling required (high flexibility)
- Work piece deformed between two flat (or simple shaped) dies
- Process of choice when:
  - Work piece very large or
  - Small batch size
- Often used as primary shaping process to pre-form the work piece for subsequent closed-die forging
- Bulging of work piece is (undesired) side effect of this forging process
- Safety issue: flash occurs



I.B | Categorization: Impression Die Forging

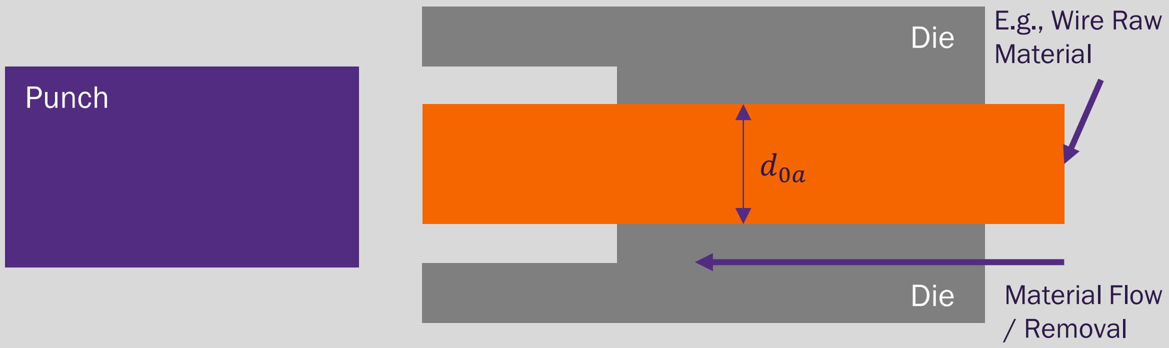
- Impression Die (or Closed Die) Forging is a more complex form of (industrial) forging
- Work piece is shaped under high pressure between two dies with cavity in form of desired design
- Enables close dimensional tolerance (e.g., for coins)
- Impression (or closed) dies are expensive (Only economical for larger batch sizes)
- Flash gutter:
    - Small amount of material forced out of impression die cavity, forming flash
    - Flash solidifies (cools down) fast and in the process becomes increasingly resistant to deformation
    - This way, additional pressure is built up within die cavity that supports material flow into previously unfilled impressions
- Impression die may contain recesses allowing work piece to transform into 3D shapes with complex surfaces



I.B | Categorization: Upset Forging

- Upset forging describes deformative transformation of shape by changing the diameter by **compressing the length**
- Most common application: **Fasteners** of various kind (-> thus widely used)
- Both hot and cold upset forging possible
- Generally, **high throughput** operation
- Applicable work pieces range from wires with **small** diameter to bars with **large diameters** (~ 10in)
- **Main rule** of upset forging:
  - Length of to-be-deformed material restricted to max. 3x diameter (without adapted/special tooling) to prevent buckling

1



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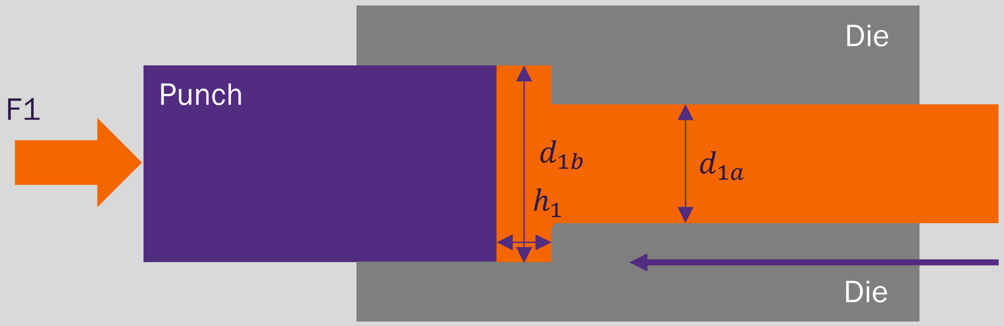
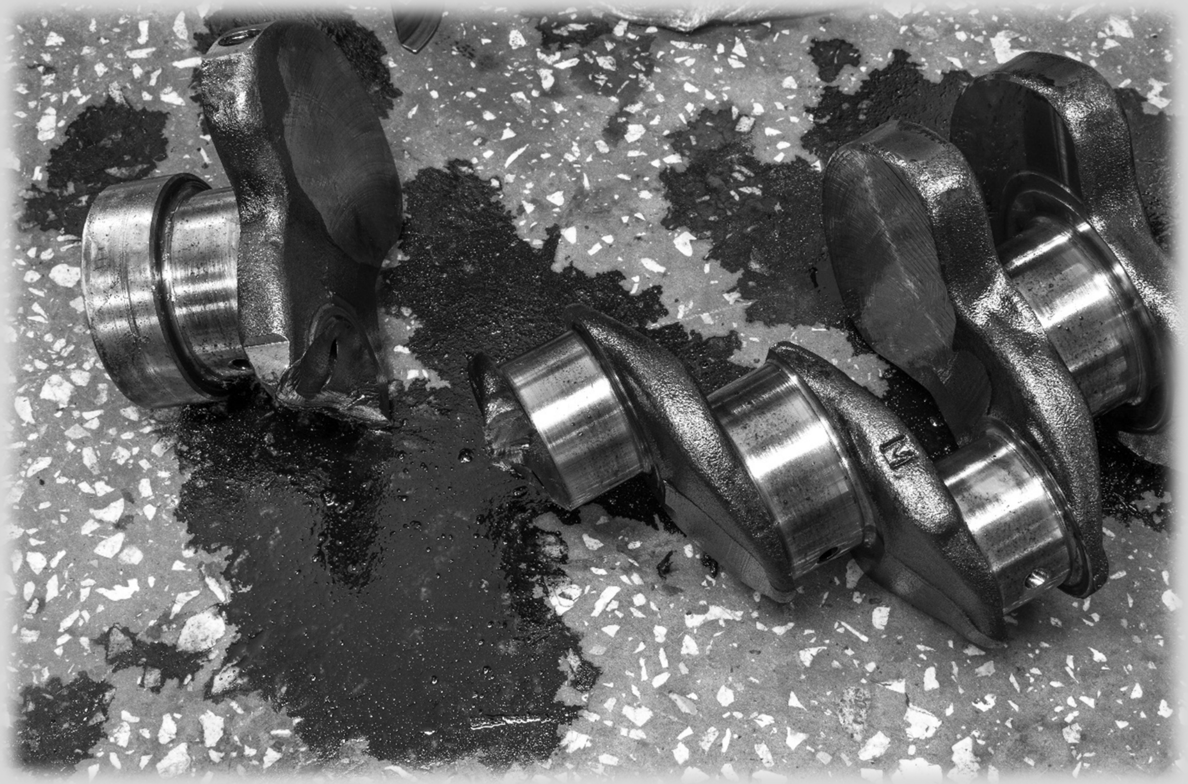


I.C | Categorization: Upset Forging

- Incomplete die filling
- Die misalignment
- Forging laps
- Incomplete forging penetration
- (Material) Property variation (due to micro structural differences)
- Pitted surface (due to oxide scales, occurring at high temperature, sticking on die(s))
- Buckling (mainly common in upset forging) (due to high compressive stress)
- Surface cracking (due to temperature differential between surface and center, and/or excessive working of surface at too low temperature)
- Micro-cracking (due to residual stress)



Knowledge Check

Determine the shape factor for an open forging manufacturing process where the current forge diameter is 0.2m, the height of the specimen is 40cm and the coefficient of friction at the die-tool interface is 0.5

A. 0.9
B. 1.1
C. 1.3
D. 1.5

Knowledge Check

Determine the shape factor for an open forging manufacturing process where the current forge diameter is 0.2m, the height of the specimen is 40cm and the coefficient of friction at the die-tool interface is 0.5

A. 0.9

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D. 1.5

$K_f = 1 + (0.4\ \mu\ D/h)$

$K_f = 1 + (0.4\ 0.5\ 0.2/0.4)$

Knowledge Check

What does the value of the shape factor represent?

A. How to better design the shape
B. A correction factor for the force value needed for a forging operation
C. It estimates the cost of manufacturing

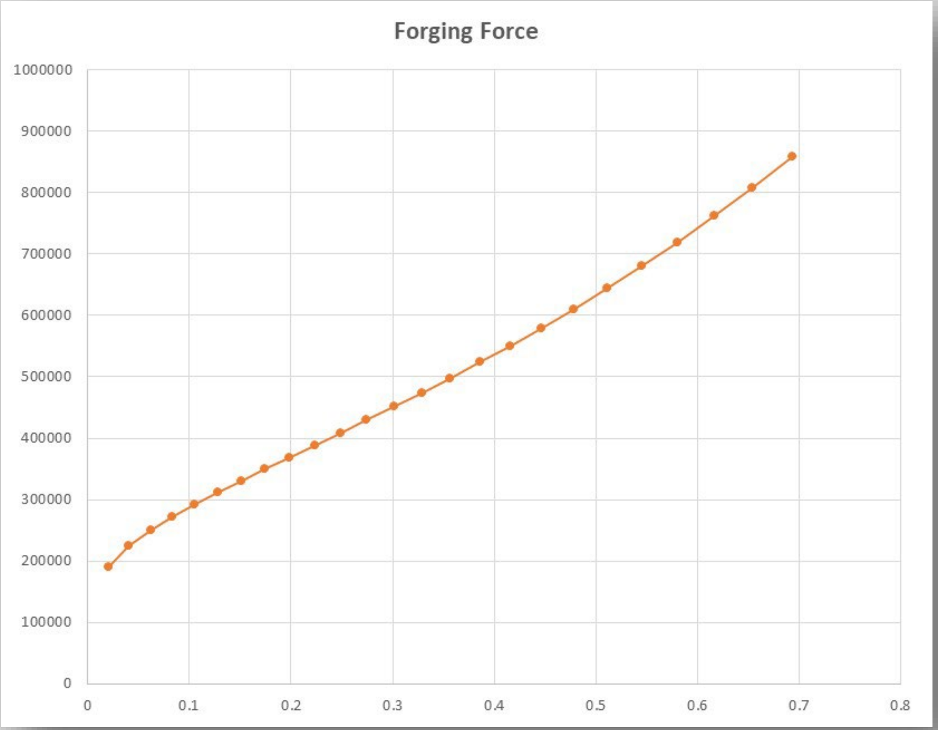
Knowledge Check

What does the value of the shape factor represent?

A. How to better design the shape
B. **A correction factor for the force value needed for a forging operation**
C. It estimates the cost of manufacturing

Class Exercise

A material with the following properties (K = 300 MPa; n = 0.2) is open forged to half its height. The original shape is cylindrical having a height of 50 cm and a diameter of 40 cm. Given a coefficient of friction of 0.25 create a graph showing the incremental value of the forging force function of the strain.



Extrusion

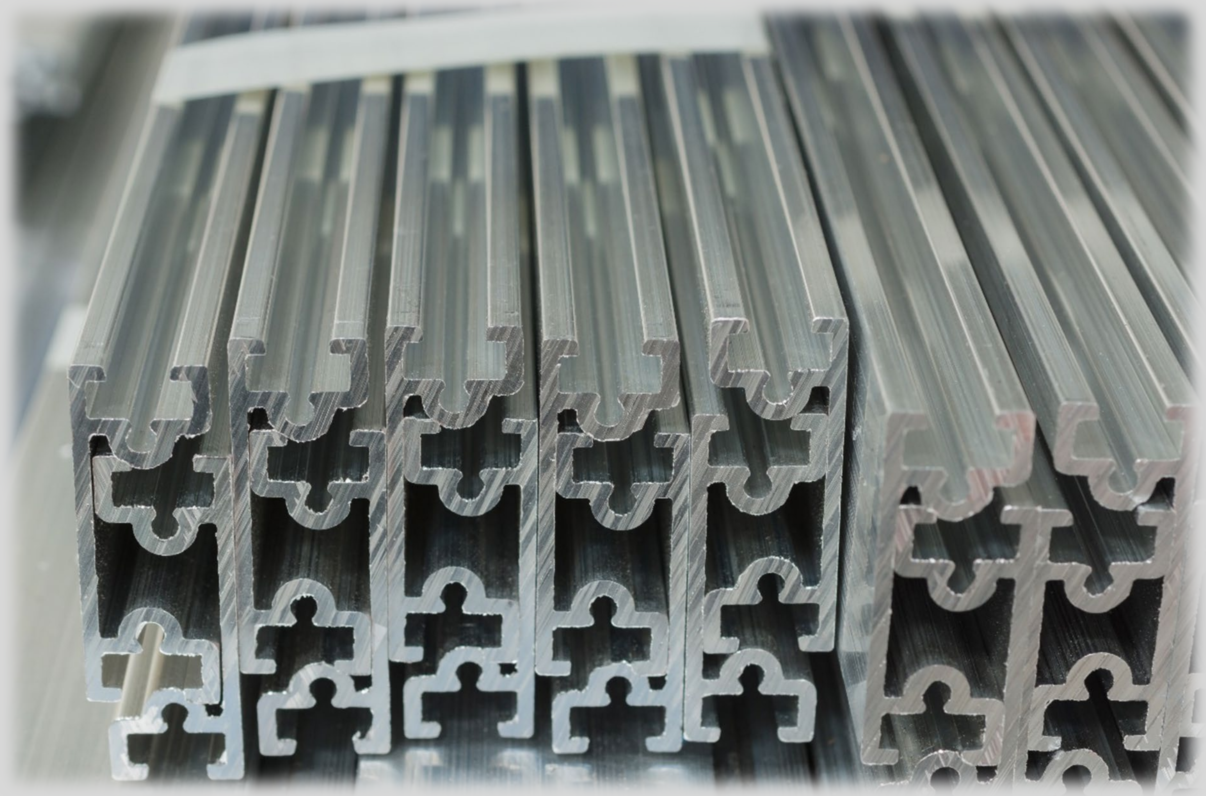
Section II

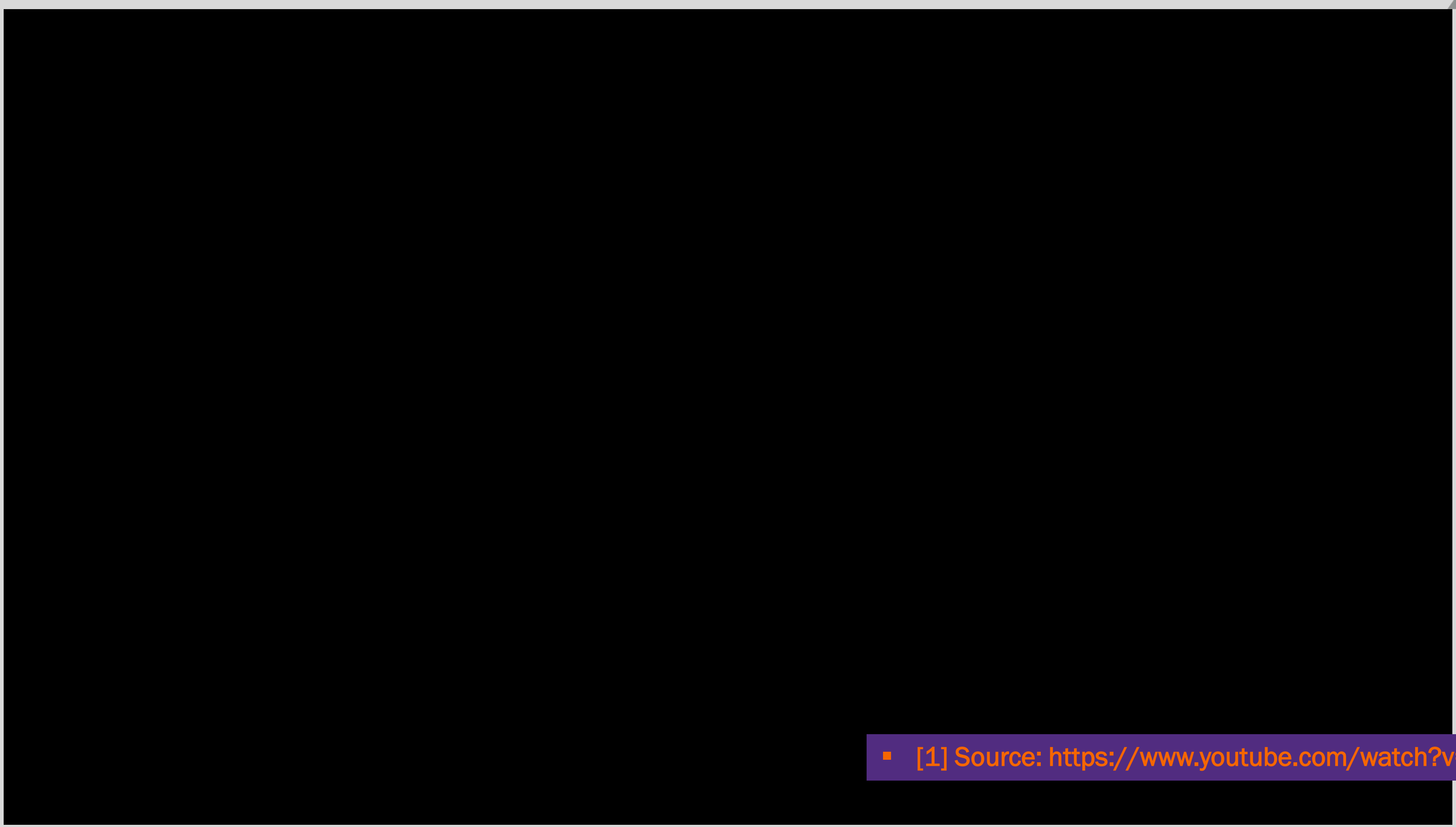
[1] https://www.rapiddirect.com/blog/what-is-composite-material-types-uses/

ability-in-manufacturing-industry-4-0-a-path-towards-a-greener-future-4b511053137f

II.A | Theoretical Concept: What is Extrusion?

- Extrusion a deformative manufacturing process (compression forming) by which metal billet is **reduced in cross-section** and/or formed in a different (constant) cross-sectional shape by forcing it to flow through a (or multiple) die orifice(s) under high pressure
- Metal (hot) extrusion is mainly used to produce cylindrical bars, hollow tubes or as intermediate shapes for drawn rod, cold extrusion or forged products
- Most metals are hot extruded due to required forces
- Complex shapes can be extruded from softer metals such as aluminum

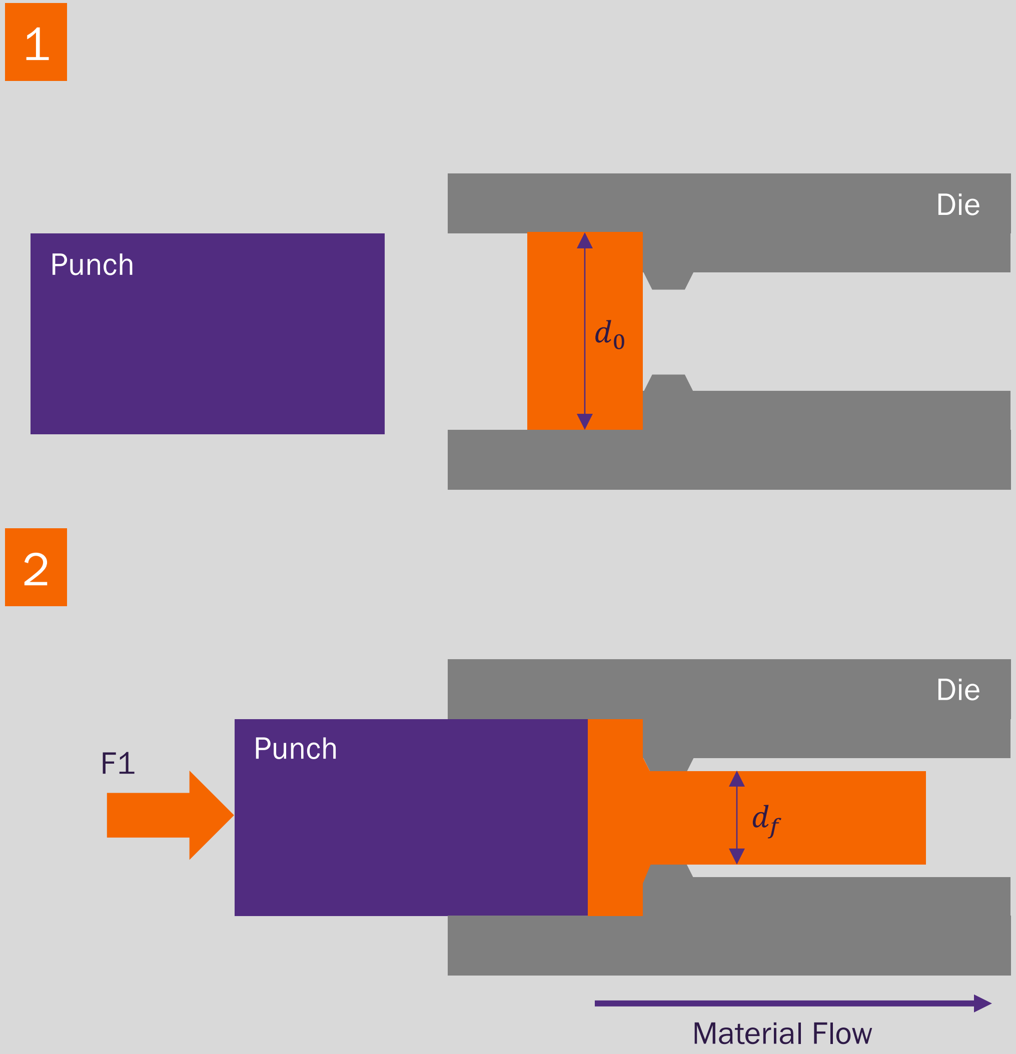




- [1] Source: https://www.youtube.com/watch?v=Y75IQksBb0M

II.B | Categorization: Direct Extrusion

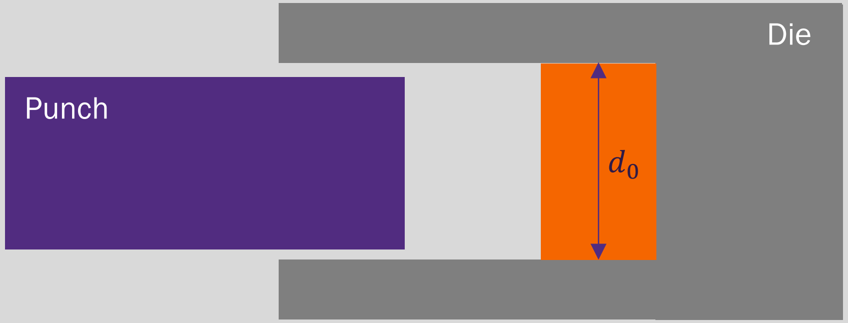
- Material is forced forward by a punch through the die orifice, producing a smaller cross-section (diameter decreases, length increases) than the initial blank
- Also known as Forward Extrusion
- Friction increases the extrusion force
- ~75% reduction is possible with using direct extrusion



II.B | Categorization: Indirect Extrusion

- Material is **formed around the punch** by being forced backward around the punch within the die, producing hollow parts with solid bottoms
- Die is mounted on the punch (also referred to as ram)
- The bottoms of the hollow parts should be thicker than the walls
- Also known as Backward Extrusion
- Area reductions of ~20-75% are possible with indirect extrusion

1



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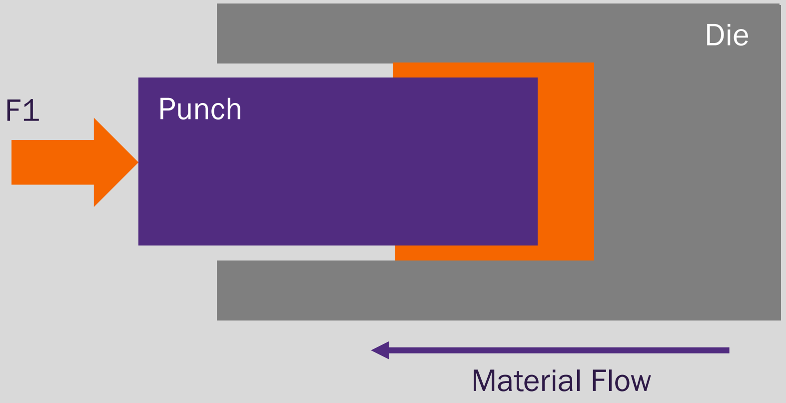
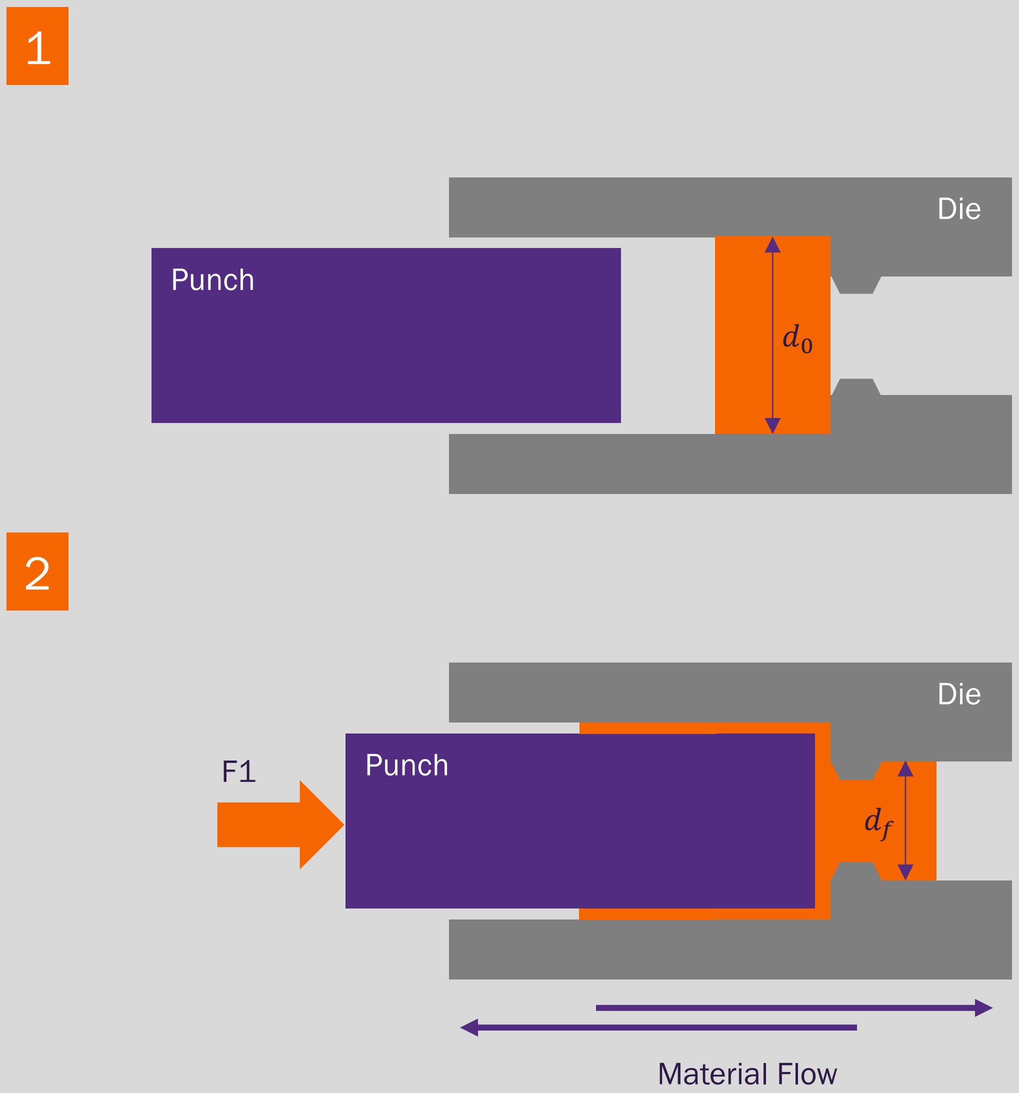


II.B | Categorization: Combined Extrusion

- Material is formed around the punch by being forced backward around the punch within the die and forced forward by the punch
- Many designs include both extrusion forms therefore, both forms are applied simultaneously to minimize production cost
- There are a wide variety of different combinations possible depending on the creativity of the design and manufacturing engineer



II.C | Extrusion Process Parameters: Shape Factor & Extrusion Ratio

- **Extrusion shape factor**

  $$K_x = 0.98 + 0.02\,(C_x / C_c)^{2.25}$$

- *Where:*

  C_x = perimeter of non-circular extruded section;

  C_o = perimeter of a circle that has the same cross-sectional area as extruded section

- **Extrusion (reduction) ratio:**

  $r_x = A_o / A_f$

- **True strain:**

  $\varepsilon = \ln(r_x)$

- Assumptions: all sections circular, ideal deformation, no friction

- **True strain WITH friction:**

  $\varepsilon_x = a + b * \ln(r_x)$

- *Where: a = ~0.8 and b = ~1.2-1.5 (b increases with die angle)*

- **Required (punch) pressure:**

  $p = Y_f \ln(r_x)$

- **Direct extrusion:**

  $p = Y_f\,(\varepsilon_x + 2L/D_o)$

  (with shape factor): $p = K_x\,Y_f\,(\varepsilon_x + 2L/D_o)$

- **Indirect extrusion:**

  $p = Y_f\ \varepsilon_x$

  (with shape factor): $p = K_x\ Y_f\ \varepsilon_x$

- **Punch force:**

  $F = p\,A_o$

- **Power requirement:**

  $P = F\,v$

II.D | Shape Factor

1. Calculate perimeter *Cx* of final shape
2. Calculate cross-sectional area *Ax* of final shape
3. Calculate perimeter of circle *Cc* with the same cross-sectional area as *Ax*

   Cc = 2 * (Pi * Ax).5

4. Computing Shape Factor *Kx*

   Kx = 0.98 + 0.02 (Cx / Cc)2.25

II.D | Shape Factor | Example

- Final shape perimeter

  Cx = 4 in

- Final shape cross-sectional area

  Ax = 1 in2

- Circle w/ Ax perimeter

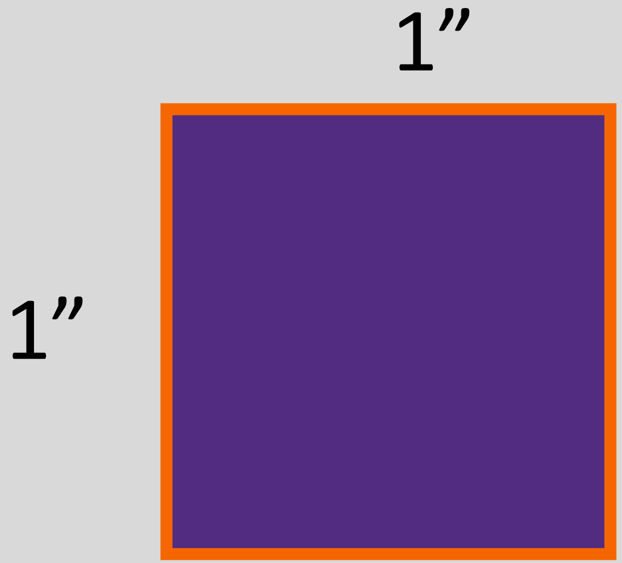
  Cc = 2 * (Pi * Ax).5 = 3.545 in

- Computing Shape Factor

  Kx = 0.98 + 0.02 (Cx / Cc)2.25

  = 0.98 + 0.02(4/3.545)2.25

  = 1.00624



Knowledge Check

What is the shape factor of a circle whose diameter is 20mm ?

A. 0.95
B. 0.97
C. 1
D. 2.13

Knowledge Check

What is the shape factor of a circle whose diameter is 20mm ?

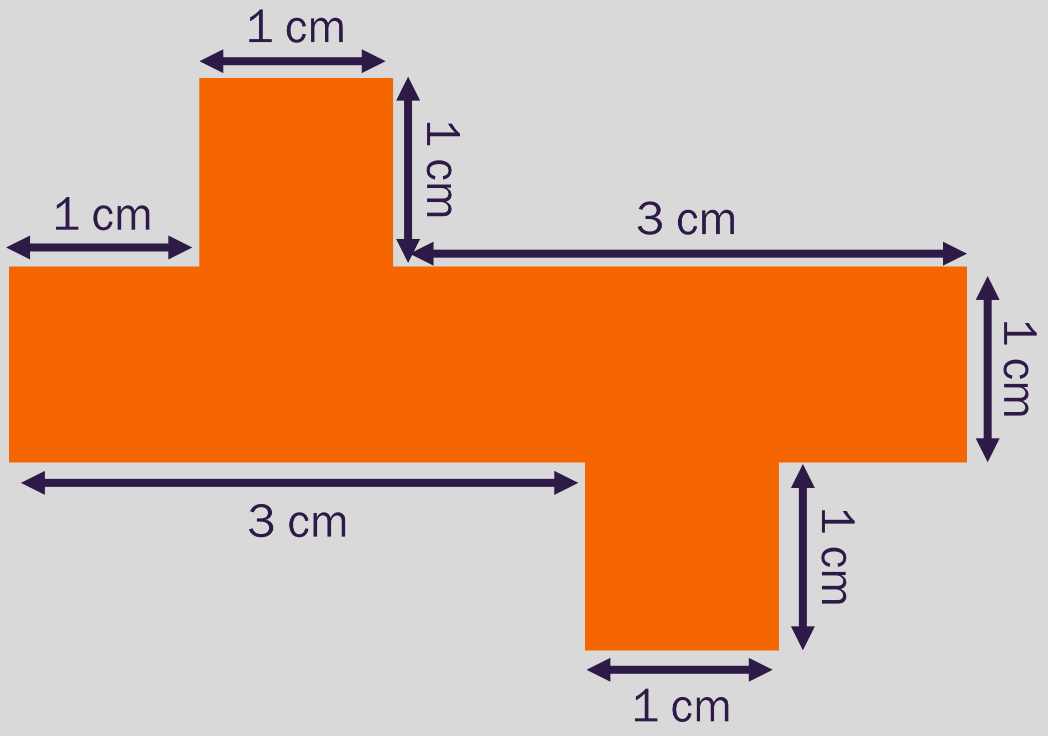
A. 0.95
B. 0.97
C. 1
D. 2.13

We do not need to compute shape factors for circular shape as Cc and Cx are the same, the shape factor is 1 …

Knowledge Check

What is the shape factor of the shape below?

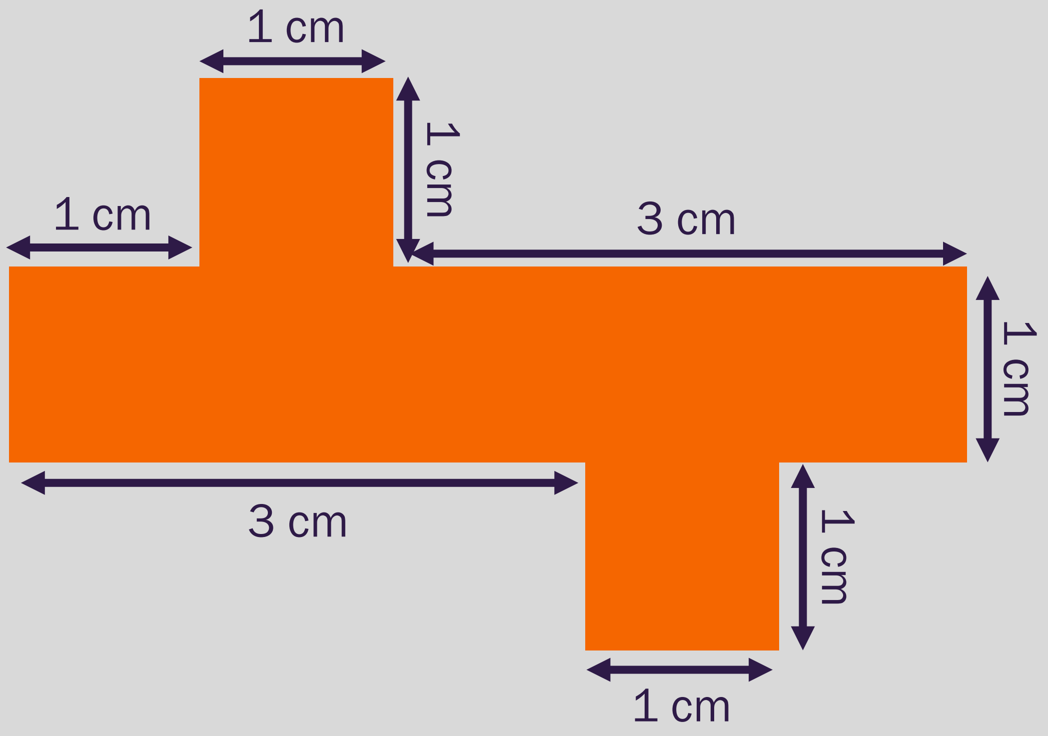
A. 0.96
B. 1.22
C. 1.04
D. 2.11
E. 17.8



Knowledge Check

What is the shape factor of the shape below?

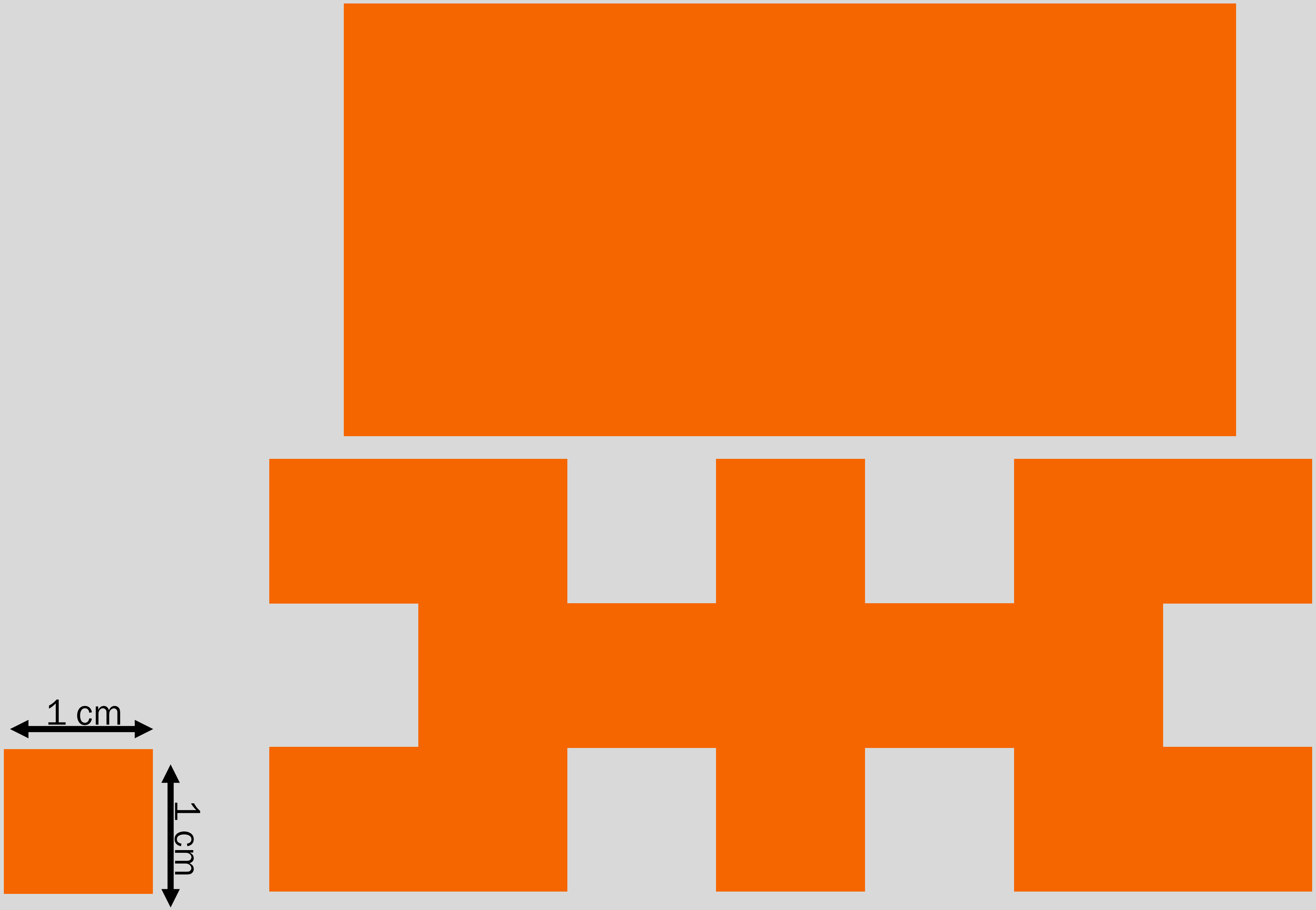
A. 0.96
B. 1.22
C. 1.04
D. 2.11
E. 17.8



Class Exercise | Indirect Extrusion

- Compute:
  - Strain
  - Extrusion Strain
  - Shape factor
  - Pressure
  - Punch Force

- Starting material
  - K=200 Mpa
  - n=0.2



Knowledge Check

Extrusion processes are characterized by forcing the material between two pressurized rollers to reduce its thickness

A. True
B. False

Knowledge Check

Extrusion processes are characterized by forcing the material between two pressurized rollers to reduce its thickness

A. True

B. **False**

Knowledge Check

In extrusion we lose approximately XX% of the material volume

A. 80
B. 60
C. 40
D. 20
E. 0

Knowledge Check

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A. 80
B. 60
C. 40
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Rolling

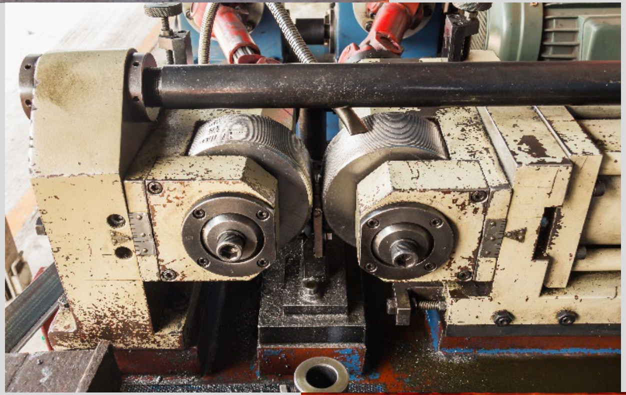
Section III

[1] https://cen.acs.org/materials/inorganic-chemistry/s-fiberglass-does-delicate-material/96/i38

ability-in-manufacturing-industry-4-0-a-path-towards-a-greener-future-4b511053137f

III.A | Theoretical Concept: What is Rolling?

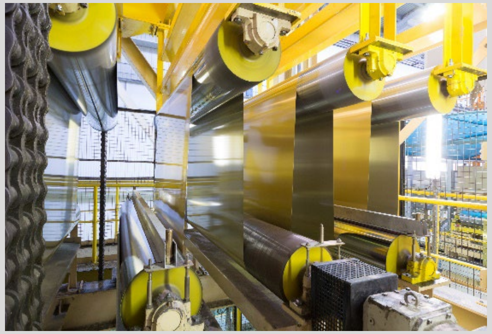
- Rolling is a deformation process where shape of a (continuous) work piece is transformed using (one or multiple) pairs of rolls without changing the volume
- Generally, rolling processes produces constant cross-sectional shapes (exception: thread rolling)
- Hot-Rolling (e.g., ring, regular) and Cold-Rolling (e.g., thread) can be used in rolling processes
- Multi-stage processes are very common due to max. deformation in one step
- Bearings (e.g., force) and surfaces of rolls (e.g., temperature) are highly stressed



III.A | Theoretical Concept: Geometry and Products

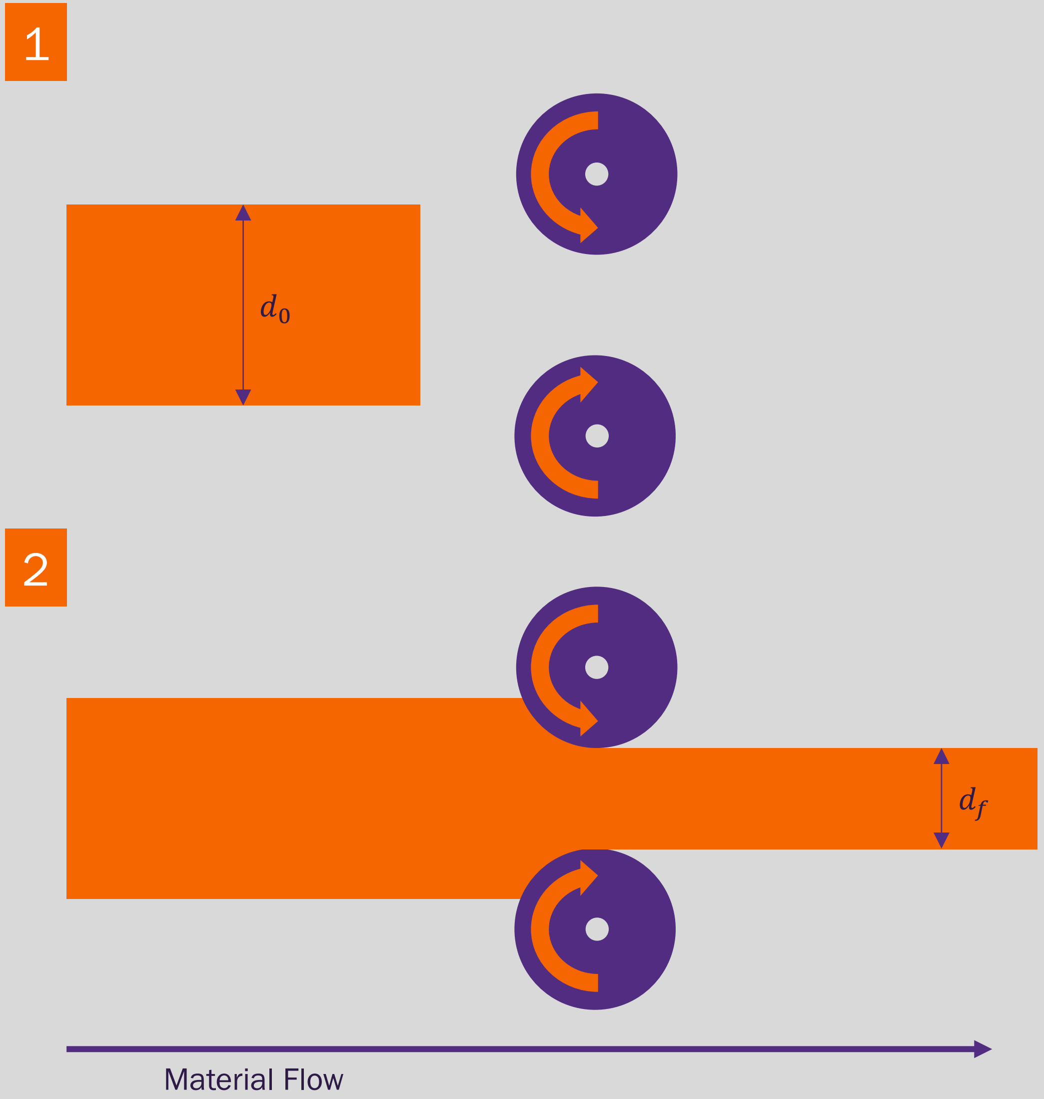
- Rolling is a **multi-stage process** that can produce a large variety of different products
- Succession is reflected in work piece **terminology**
  1. Ingots
  2. Bloom (square cross-section)
  3. Slab (rectangular cross section)
  4. Billet (Bar w/ cross-section smaller than 6in x 6in)
- Typical products stemming from the various rolling processes are
  - **Sheet metal products** (e.g., Plates, Sheets, Large diameter pipes)
  - **Constant cross-sectional products** (e.g., Seamless pipes, Train rails, various profiles (e.g., H, T), Wires, Bars)
  - **Misc. products** (e.g., Rings, Bolts, Train wheels)



III.B | Categorization: Rolling Mills

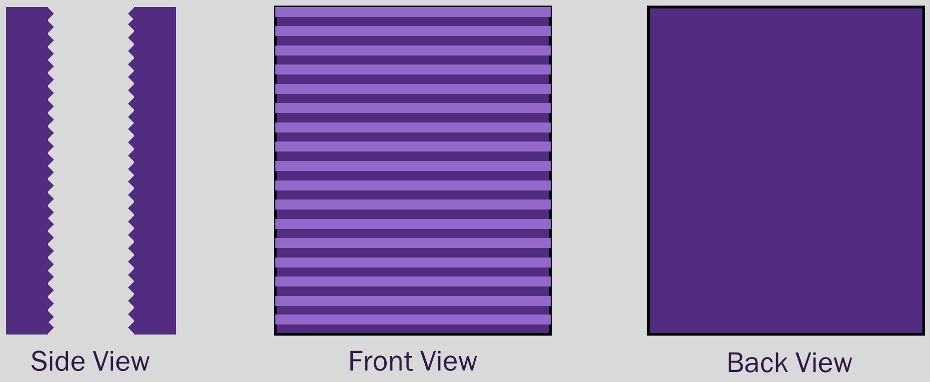
- Shaping material by forcing it through two **rotating rolls** on both sides of the workpiece
- Parts of **uniform cross-sectional areas** can be produced
- Parts are generally **longer** than those produced by extrusion and **larger** than those produced by wire drawing
- Structural shapes, such as I-beams, and railroad rails are produced by rolling

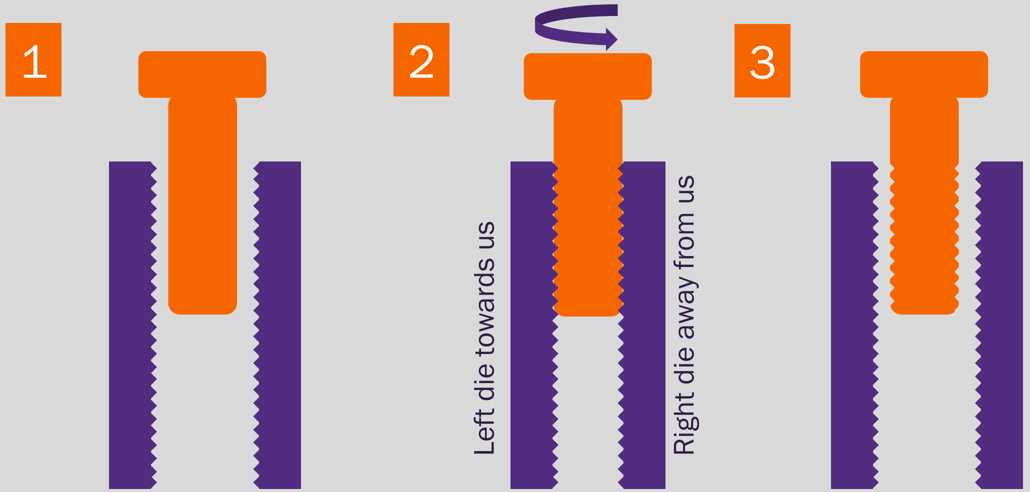


III.B | Categorization: Thread Rolling

- Thread rolling deforms the material by rolling it between **two threaded dies** to imprint external threading on a round bar/wire material
- The threaded dies can be **plane or round** depending on the process
- Thread rolling is a cold forming process
- Produces external threads with **desirable properties** like
  - Strong
  - Precise
  - Uniform
  - Smooth

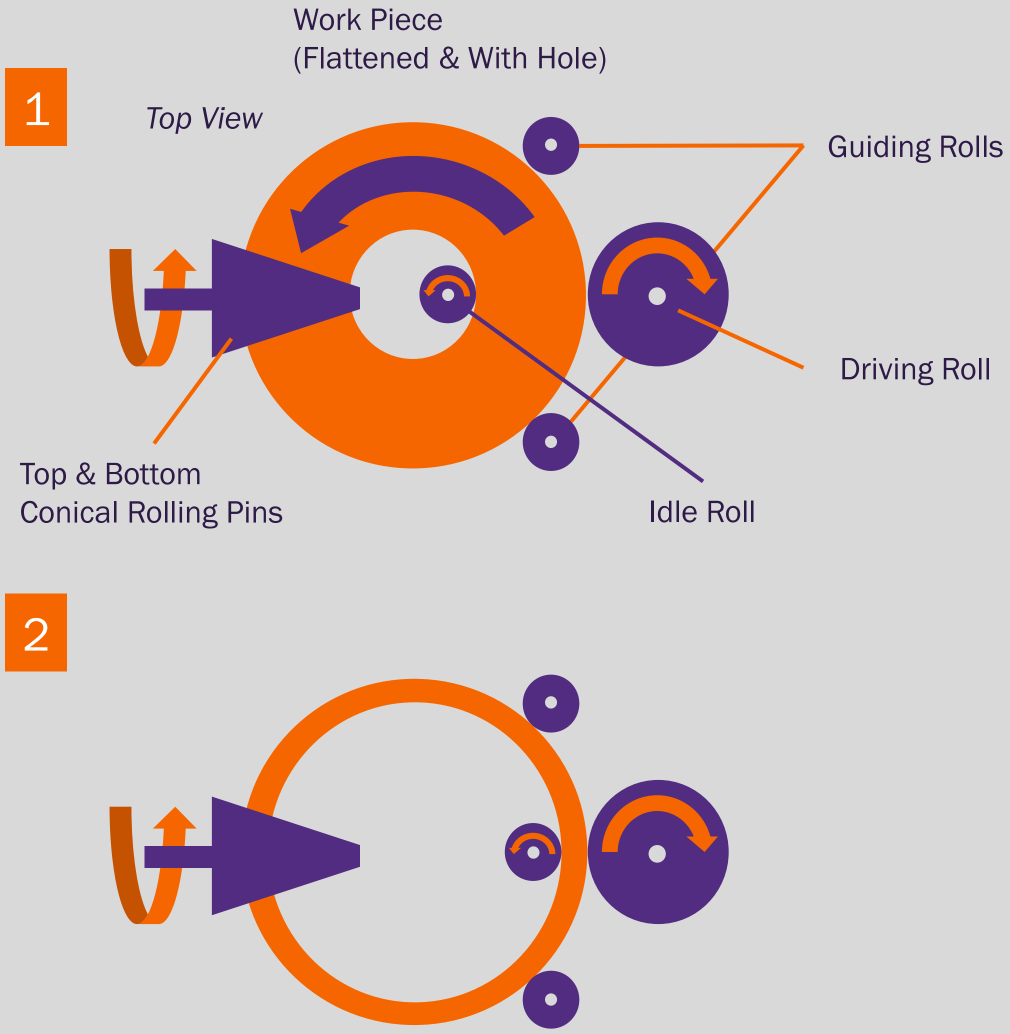
Thread Rolling Die:





III.B | Categorization: Ring Rolling

- Ring rolling is a deformation process which increases diameters of rings by reducing the radial thickness of the work piece between a set of rollers
- Work piece volume is maintained which leads to diameter increase and requires rollers to adjust with work piece throughout the ring rolling process
- Driver roll is fixed in most cases while idle roll, rolling pins and guiding rolls adjust to the changing dimensions of the work piece
- Two, often conical shaped rollers maintain the upper and lower boundary of work piece (= height)
- Ring rolling is generally a hot working process
- Ring rolling results in desirable circumferential grain structure achieving better mechanical properties



III.B | Rolling Process Parameters (Flat Rolling)

- Draft
  - d = $t_0 - t_f$

  Where d = draft, t_0 = starting thickness, t_f = final thickness

- Reduction
  - r = $^{d}/_{t_0}$

  Where r = reduction, d = draft, t0 = starting thickness

- Width to thickness ratio
  - $t_0\, w_0\, L_0 = t_f\, w_f\, L_f$

  Where t_0 = starting thickness, w_0 = starting width, L_0 = starting length

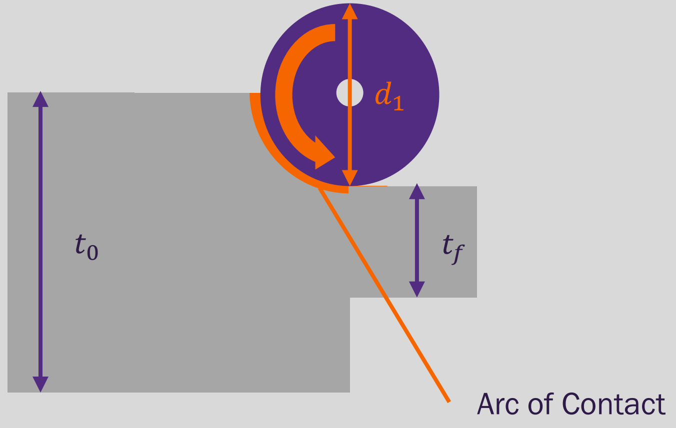
- Velocities
  - $t_0\, w_0\, v_0 = t_f\, w_f\, v_f$

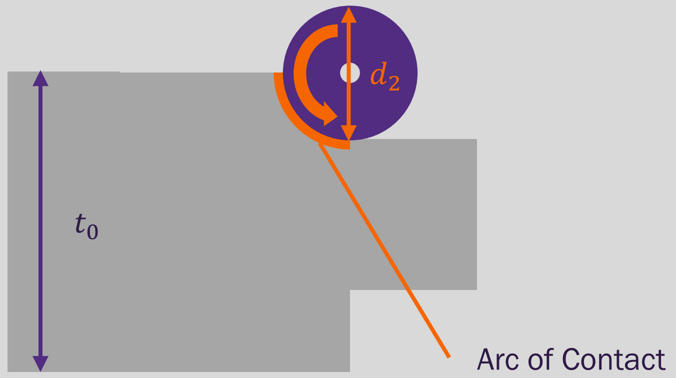
  Where t0 = starting thickness, w0 = starting width, v0 = starting velocity

- True strain
  - ε = ln(t_0 / t_f)

- Maximum possible draft
  - dmax = μ2 R

  Where μ = coefficient of friction, R = roll radius





Rolling Load & Length of Arc of Contact Increase With Roll Radius

Knowledge Check

Ring rolling involves a variety of different rolls and typically the following roll(s) are fixed

A. Idle Roll(s)
B. Rolling Pin(s)
C. Driver Roll(s)
D. Guiding Roll(s)
E. None of the above (A-D)
F. All of the above (A-D)

Knowledge Check

Ring rolling involves a variety of different rolls and typically the following roll(s) are fixed

A. Idle Roll(s)
B. Rolling Pin(s)
C. **Driver Roll(s)**
D. Guiding Roll(s)
E. None of the above (A-D)
F. All of the above (A-D)

Knowledge Check

Rolling is commonly used as a multistage process due to a maximum deformation allowed for certain materials without tampering with material properties

A. True

B. False

Knowledge Check

Rolling is commonly used as a multistage process due to a maximum deformation allowed for certain materials without tampering with material properties

A. True

B. False

Casting

Section IV

IV.A | Introduction

- Casting is a **prehistoric technology** enabled by the fire-using technologies
  - According to the ASM Handbook
  - 9000 BC: Earliest metal objects of wrought native copper
  - 6500 BC: Earliest life-size statues of plaster
  - 3000 BC: Lost wax casting of small objects
  - 2000 BC: Bronze Age
  - 1500 BC: Iron Age
  - …
- Early molds were made of stone, using stone carving. It was until the 16th century that sand was used as mold material (in France)

IV.A | Theoretical Concept: Process

- Casting is a primary manufacturing processes that transforms shape of a material by changing its state to allow it to fill a mold cavity and take the shape represented without changing its volume
- Casting is applicable for all material groups: Metals, Ceramics and Polymers
- Polymers most famous casting processes are Injection and Blow molding. They are presented in Chapter 5.
- Metal casting, which we present in this section, is classified based on the mold material:
    - If the mold material is a solid material (e.g., stone, metal, ceramic) and is reused in the casting process, we refer to permanent mold processes
    - If the mold material is sacrificed to obtain the final shape of the work piece (e.g., sand, wax) and we have to create a new mold every time we manufacture a new part, we refer to expendable mold processes
- The fundamental concept of casting is by (1) melting the material into a highly plastic (polymers) or liquid (metals) state, (2) designing a mold (and cores if applicable) to contain the molten material, (3) pouring the material into the designed mold, and, finally (4) waiting for the material to solidify/cool.

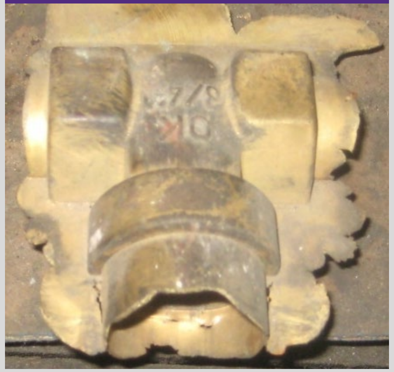
IV.A | Theoretical Concept: Process

Metal Melting

Mold Preparation

Metal Pouring

Solidification



For More Check

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IV.A | Theoretical Concept: Advantages & Disadvantages

Advantages

- Suitable for mass production (selected processes)
- Ability to create complex components
- Ability to create small to large components (such as nuclear reactor pressure heads of 60+ tons)
- Versatile process
- Ability to design both internal and external contours
- Variety of materials can be manufactures (incl. special alloys)

Disadvantages

- Limited mechanical strength and lifecycle fatigue
- Often requires a ‘next’ process due to poor dimensional accuracy and surface finish
- Ergonomics of the process are challenging especially with respect to safety of operators

Knowledge Check

Casting is applicable on …

A. Non-Ferrous Metals
B. Ferrous Metals
C. Polymers
D. Ceramics
E. All of the above

Knowledge Check

Casting is applicable on …

A. Non-Ferrous Metals
B. Ferrous Metals
C. Polymers
D. Ceramics
E. **All of the above**

IV.A | Theoretical Concept: Mold | Parting Line

COPE

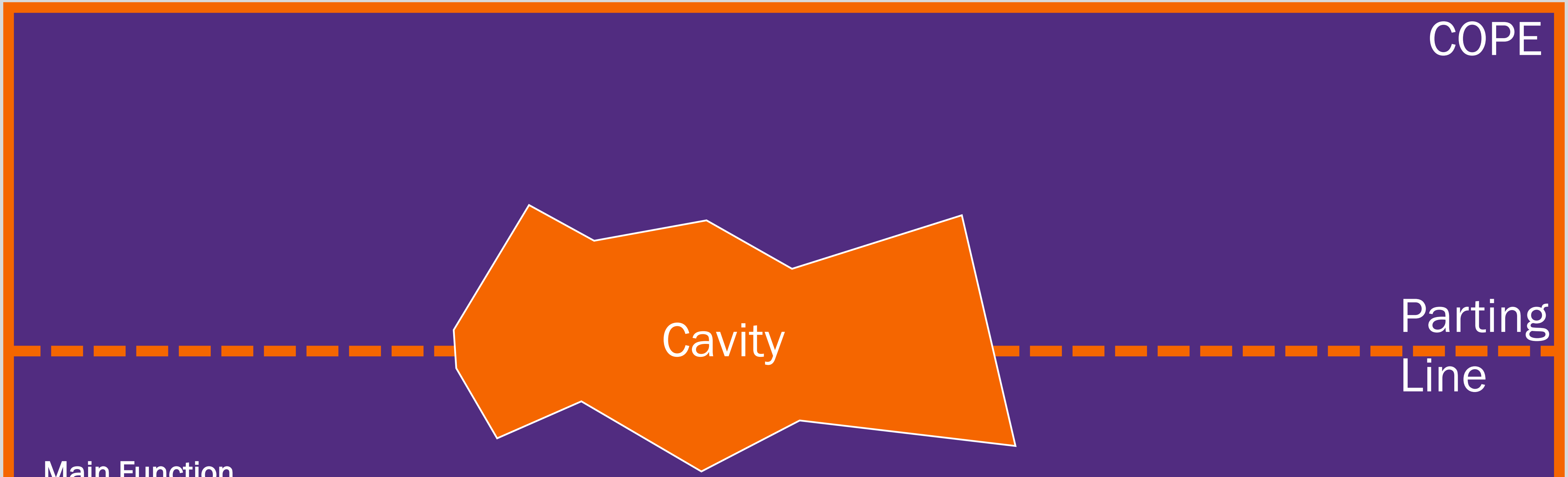
Parting Line

Main Function

- Drag is the bottom half of the mold
- Cope is the upper half of the mold
- They are split along the parting lines
- Molds have multiple internal cores

DRAG

IV.A | Theoretical Concept: Mold | Cavity

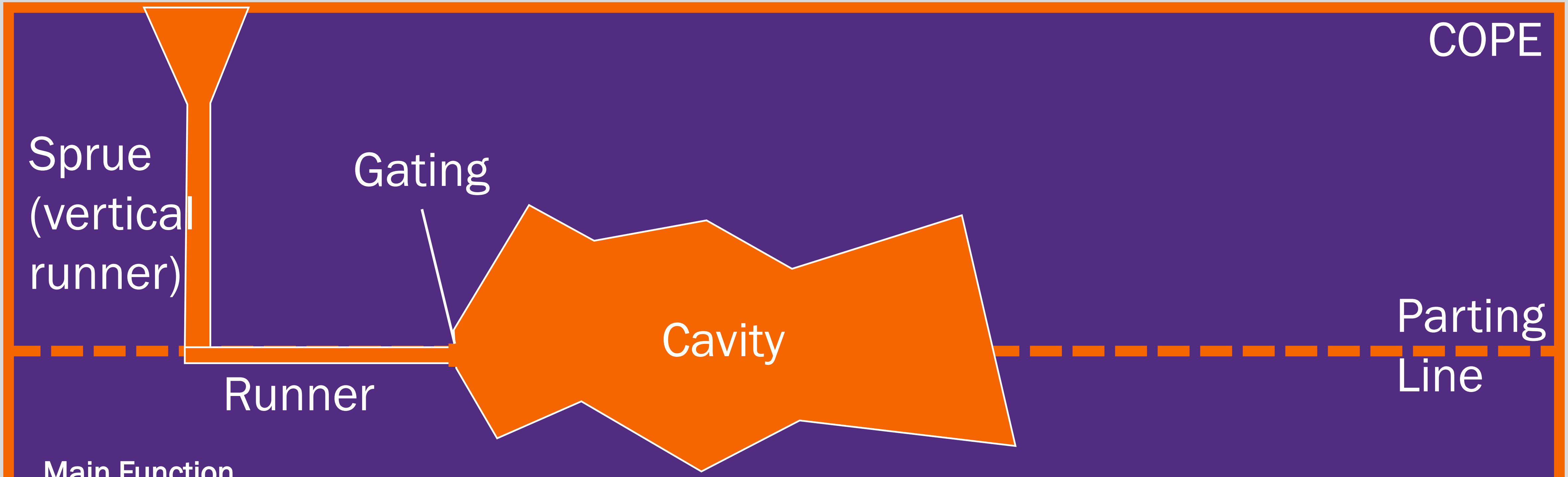


Main Function

- Cavity is the void in the mold
- This will be filled to create the final shape
- Often it includes cores to create internal shapes

DRAG

IV.A | Theoretical Concept: Mold | Gating and Runner



<u>Main Function</u>

- Gating includes the pouring location and the downsprue
- The main function is to regulate the flow into a laminar flow so that the mold is not eroded
- The runner has the function to transfer the poured metal to the cavity

IV.A | Theoretical Concept: Mold | Riser

<u>Main Function</u>

- Metals exhibit shrinkage during solidification
- The riser main function is to act as a reservoir to supply molten metal and fill the shrinkage voids
- A rule of thumb: Risers should never solidify, by design, before the cavity
- A common practice is to use riser solidification times of 1.2 to 1.3 the cavity solidification time

DRAG

IV.A | Theoretical Concept: Process Parameters

Heat ?

Metal Melting

Mold Preparation

Design?

Metal Pouring

Flow ?

Solidification

Time ?

IV.A | Theoretical Concept: Process Parameters

- Computing the amount of heat needed to pour the metal at *? WHAT ;-) ??????*
- A conventional pouring temperature is 100 degrees Celsius above the melting temperature

$$H = \rho * V * [\underbrace{C_s * (T_m - T_0)}_{\text{Solid} \rightarrow \text{Melting}} + \underbrace{H_f}_{\text{Fusion}} + \underbrace{C_L * (T_p - T_m)}_{\text{Melting} \rightarrow \text{Pouring}}]$$

where: *H* = total required heat, ρ = density, V = Volume of to be heated metal, C_s = weight specific heat for solid material, T_m = metal melting temp., T_0 = starting temp – surrounding temp., H_f = heat of fusion, C_L = weight specific heat for liquid material, T_p = pouring temp.

IV.A | Theoretical Concept: Process Parameters

- After the metal is poured into the mold cavity, it requires a certain amount of time to solidify t_{ST}
- Observation: If you spread out the same quantity of a soup in a flat plate vs a bowl, which one cools fasters?
- Having a bigger contact area for the same volume enables faster solidification.
- Chvorinov developed a rule that is dependent on:
    - Mold Material
    - Molten Material
    - Volume/Area ratio of the cavity
- The area represents the contact area from all sides
- Mold constant C_m and mold exponent n are experimentally derived
- Volume V and Area A are computed based on the geometry

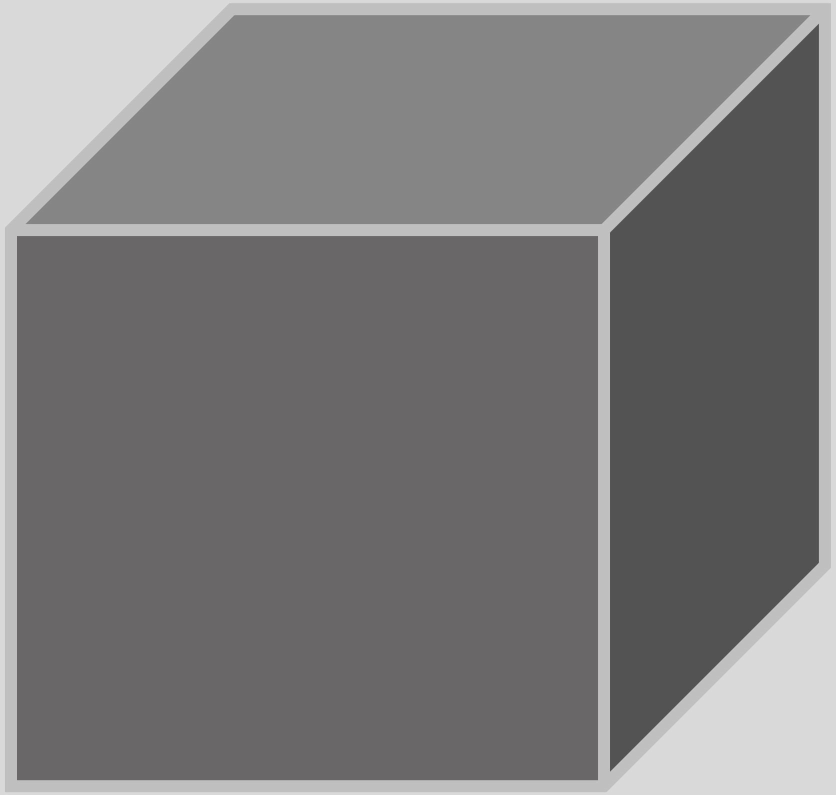
$$t_{ST} = C_m \, (V/A)^n$$

where: t_{ST} = solidification time, V = volume of casting, A = surface area, C_m mold constant, , constant usually =2

IV.A | Solidification Class Exercise 1

Solidification

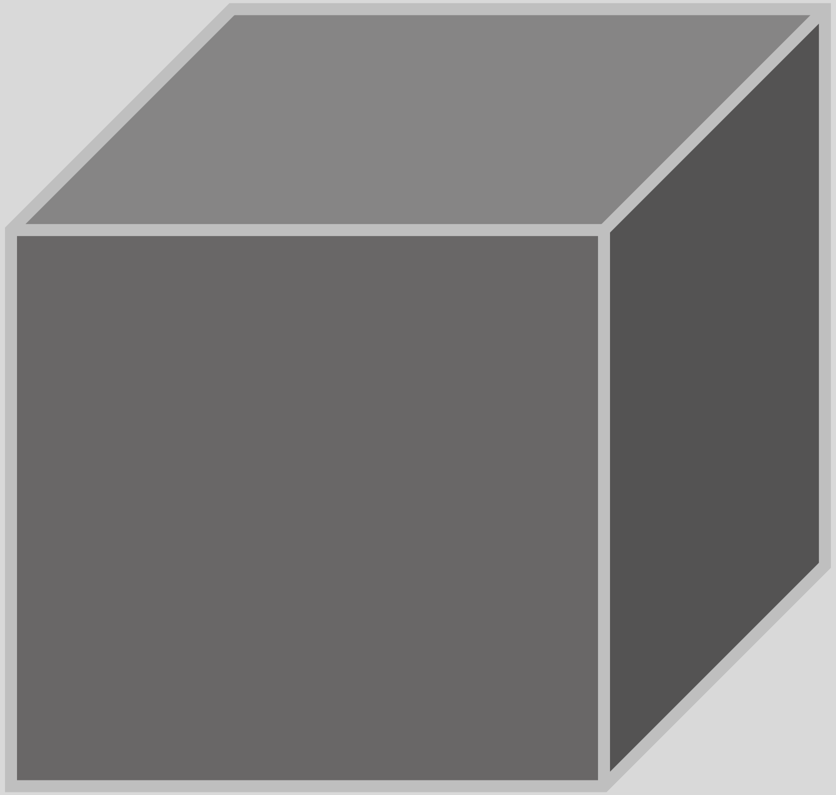
What is the solidification time of a cube having a 6 cm side, if the mold constant is 1 min/cm2 ?



IV.A | Solidification Class Exercise 1

Solidification

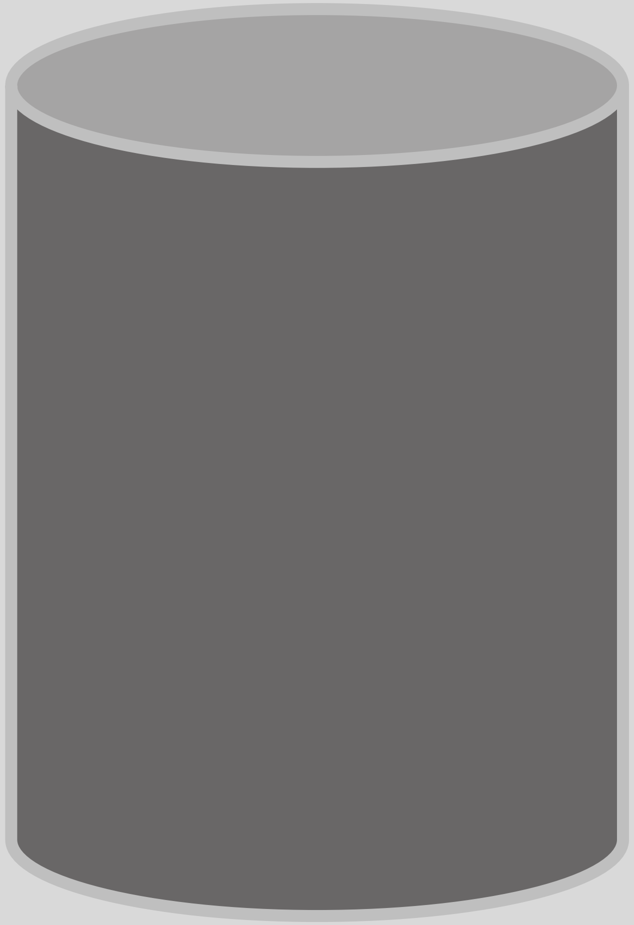
- What is the solidification time of a cube having a 6 cm side, if the mold constant is 1 min/ cm^2 ?
- Volume of the cube is a^3 = 6^3 = 216 cm^3
- Contact area of the cube is 6 * a^2 =216 cm^2
- t_{ST} = C_m $(\frac{V}{A})^n$ = 1 minute



IV.A | Solidification Class Exercise 2

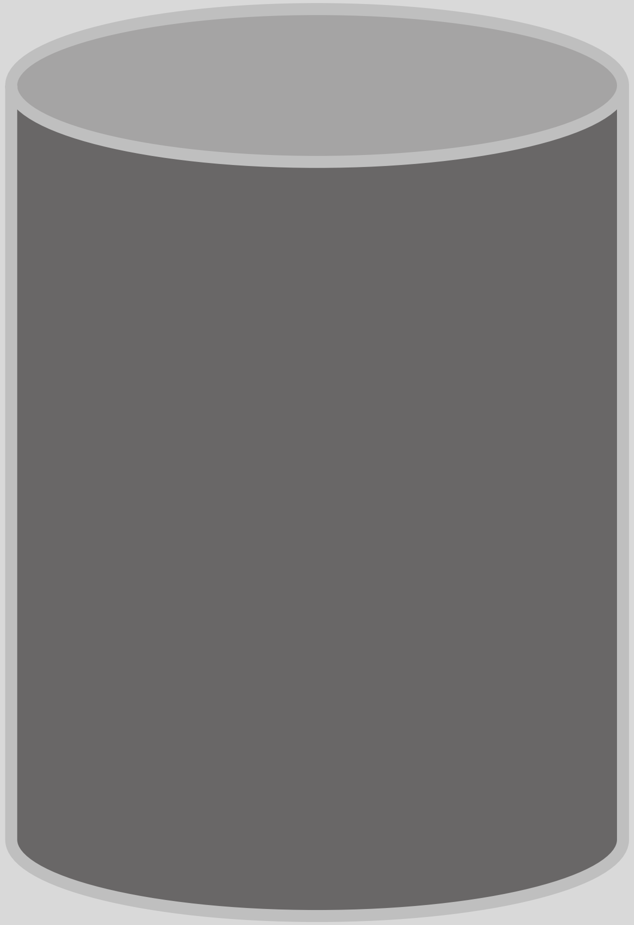
Solidification

Design a cylindrical riser to solidify 30 seconds after the cube? The height of the cylinder is equal to its diameter.



IV.A | Solidification Class Exercise 2

- Design a cylindrical riser to solidify 30 seconds after the cube? The height of the cylinder is equal to its diameter.
- **Volume of the cylinder is**
  - V = Pi *(d/2)2 * d = Pi * d3 / 4
- **Contact area of the cylinder is**
  - A = 2 * (Pi * $(\frac{d}{2})^2$) + 2 * Pi * (d/2) * d
  - = 2 * Pi (d^2/4 + 2* d^2/4) = Pi * 3 * d^2/ 2
  - **t_{ST} = Cm $(\frac{V}{A})^n$ = 1.5 minute**
  - 1.5 min = 1 min/cm^2 [(Pi * d^3 / 4) / (Pi * 3 * d^2/ 2)]^n = [d/6]^2
  - **d = 7.35 cm**



Knowledge Check

What’s the logical sequence for casting ?

A. Freeze, Melt, Pour
B. Pour, Melt, Freeze
C. Melt, Freeze, Pour
D. Melt, Pour, Freeze

Knowledge Check

What’s the logical sequence for casting ?

A. Freeze, Melt, Pour
B. Pour, Melt, Freeze
C. Melt, Freeze, Pour
D. **Melt, Pour, Freeze**

Knowledge Check

What is the function of the riser?

A. To feed the toughening agent
B. To help cooling
C. To compensate for shrinkage
D. To create a core

Knowledge Check

What is the function of the riser?

A. To feed the toughening agent
B. To help cooling
C. **To compensate for shrinkage**
D. To create a core

Knowledge Check

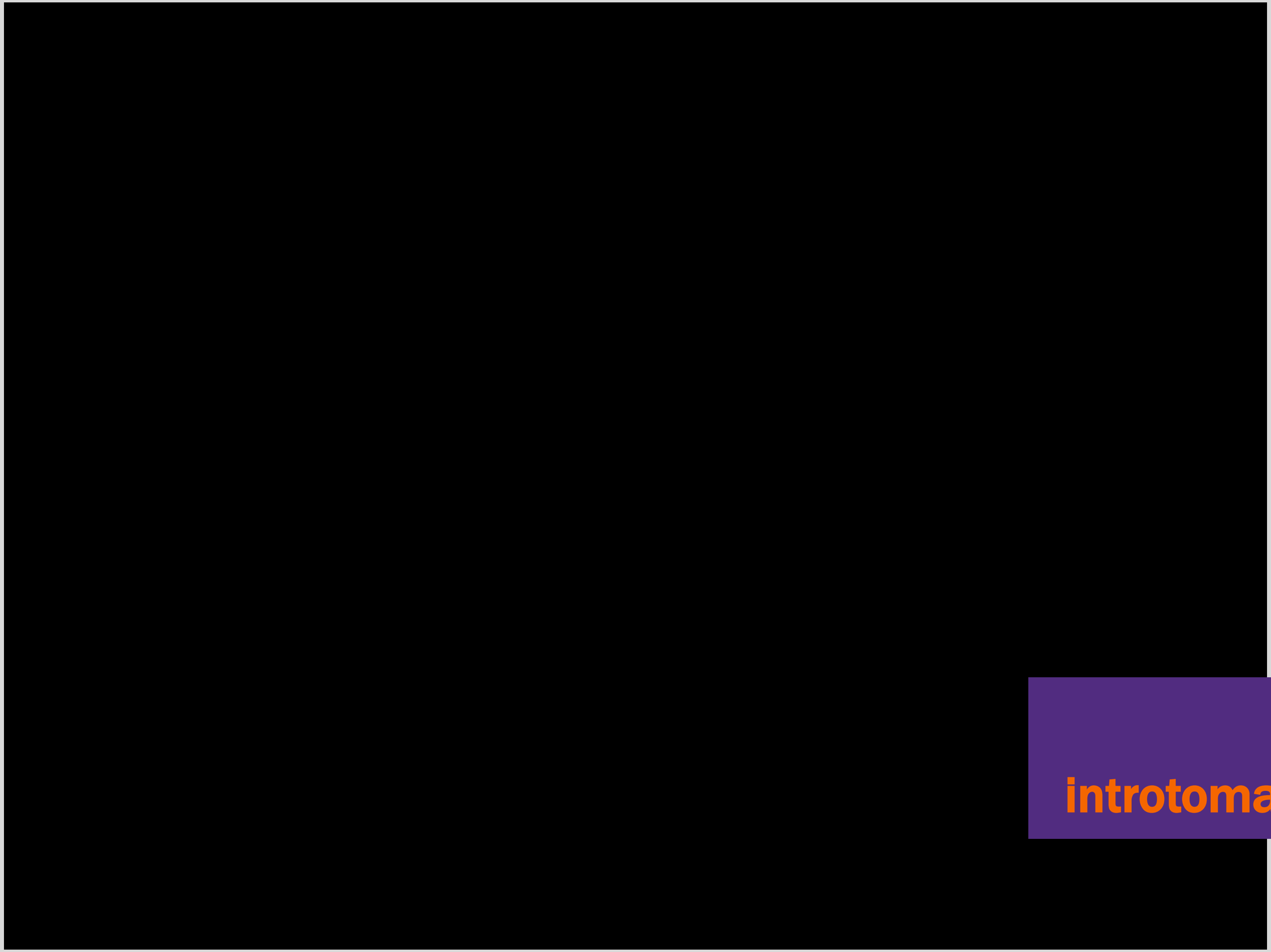
Aluminum has a melting temperature of 660C, what would be the pouring temperature ?

A. 660
B. 560
C. 100
D. 760
E. 360

Knowledge Check

Aluminum has a melting temperature of 660C, what would be the pouring temperature ?

A. 660
B. 560
C. 100
D. 760
E. 360



For More Check

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IV.B | Categorization: Expendable Mold

- The fundamental difference in expendable mold processes is that the mold is sacrificed for the creation of each part
- This provides a great advantage: The creation of internal shapes.
- There are plenty of expendable mold processes:
  - Sand Casting where the mold is made of Sand
  - Lost Wax Process where the pattern is made of Wax
  - Lost Foam Process where the pattern is made of polystyrene

Sand Casting

IV.B | Categorization: Expendable Mold

- Lost wax process is primarily used in the jewelry manufacturing industry
- The process is as follows:
  - Making patterns of wax
  - Assembling the patterns in a tree
  - Placing the assembly in a plaster mold
  - Heating the mold with pattern to lose the wax
  - Filling the void with molten metal
  - Breaking the mold
- Do it at home kits are available for Lost Wax Process !

Lost Wax Process

IV.D | Class Exercise

- What is the relationship between the diameter of a sphere D and the length of a cube side a if they have the solidification time of the sphere is half the one of the cube.

IV.D | Class Exercise Solution

- What is the relationship between the diameter of a sphere D and the length of a cube side a if they have the solidification time of the sphere is half the one of the cube.

$$T_{solidification} = C_m \left(\frac{V}{A}\right)^2$$

$$T_{sphere} = \frac{T_{cube}}{2}$$

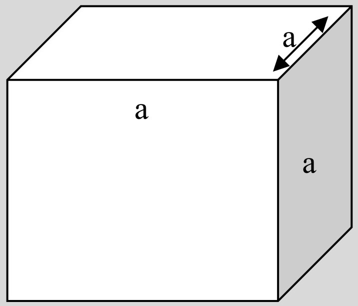
$$2\left[C_m \left(\frac{V}{A}\right)^2\right]_{sphere} = \left[C_m \left(\frac{V}{A}\right)^2\right]_{cube}$$

$$\left(\frac{V}{A}\right)_{sphere} = \frac{1}{\sqrt{2}}\left(\frac{V}{A}\right)_{cube}$$

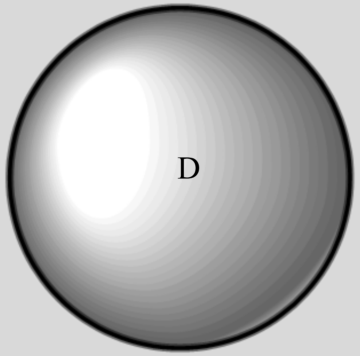
$$\left(\frac{V}{A}\right)_{sphere} = \frac{\frac{\pi D^3}{6}}{\pi D^2} = \frac{D}{6}$$

$$\left(\frac{V}{A}\right)_{cube} = \frac{a^3}{6a^2} = \frac{a}{6}$$

$$\frac{D}{a} = \frac{1}{\sqrt{2}}$$



$V = a^3$
$A = 6a^2$



$V = (4/3)\,\pi\, r^3 = (\pi D^3)/6$
$A = 4\,\pi\, r^2 = \pi D^2$

CLEMSON COMPOSITES CENTER

For More Check

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Knowledge Check

What is another name for investment casting?

A. Shell Molding
B. Pyrex Making
C. Expandable Polystyrene Process
D. Lost-Wax Process
E. Money Casting

Knowledge Check

What is another name for investment casting?

A. Shell Molding
B. Pyrex Making
C. Expandable Polystyrene Process
D. **Lost-Wax Process**
E. Money Casting

Knowledge Check

In some casting techniques, the mold is used once to create only one part.

A. True
B. False

Knowledge Check

In some casting techniques, the mold is used once to create only one part.

A. True

B. False

Sheetmetals

Section V

[1] https://cen.acs.org/materials/inorganic-chemistry/s-fiberglass-does-delicate-material/96/i38

ability-in-manufacturing-industry-4-0-a-path-towards-a-greener-future-4b511053137f

V.A | Theoretical Concept: What is a Sheetmetal?

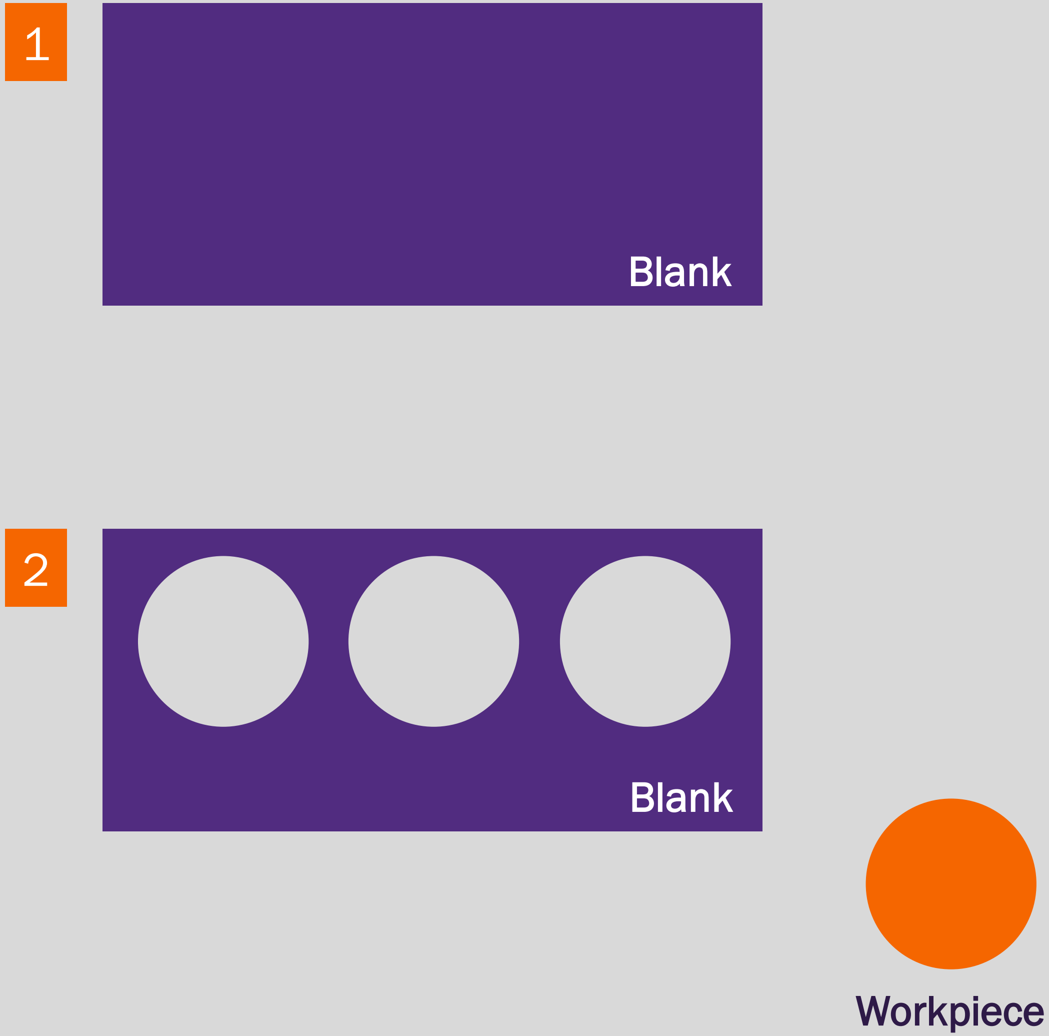
- **Sheetmetal deformation** describes the change of shape of a material in sheet form with no or little change in thickness
- Generally, the deformation is **two-dimensional** (2D)
- In Sheetmetal processing, the modulus value of the material does not change
- The **elastic recovery** of the material has to be considered as it is usually larger than in other deformation processes
- Sheetmetal processes blanking and punching are **removing material** from the blank

Sheet Metal Versus Plate

- Definition according to ASTM A 480/A 480M
- Plate: material 3⁄16 in. [5.00 mm] and over in thickness and over 10 in. [250 mm] in width
- Sheet: material under 3⁄16 in. [5.00 mm] in thickness and 24 in. [600 mm] and over in width

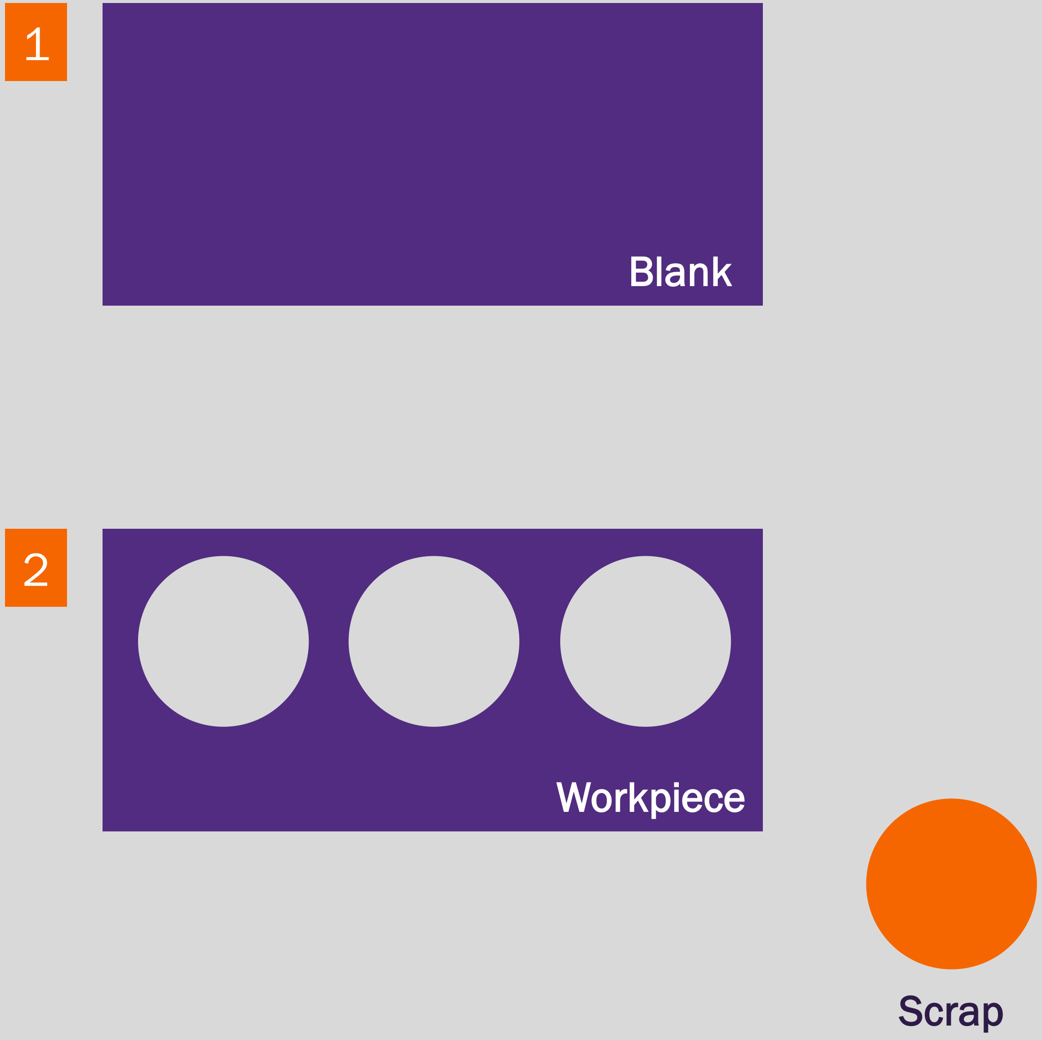
V.B | Categorization: Blanking

The Sheetmetal blanking process describes the process of **remove the work piece** from the blank by forcing a shaped punch through the sheet into a shaped die



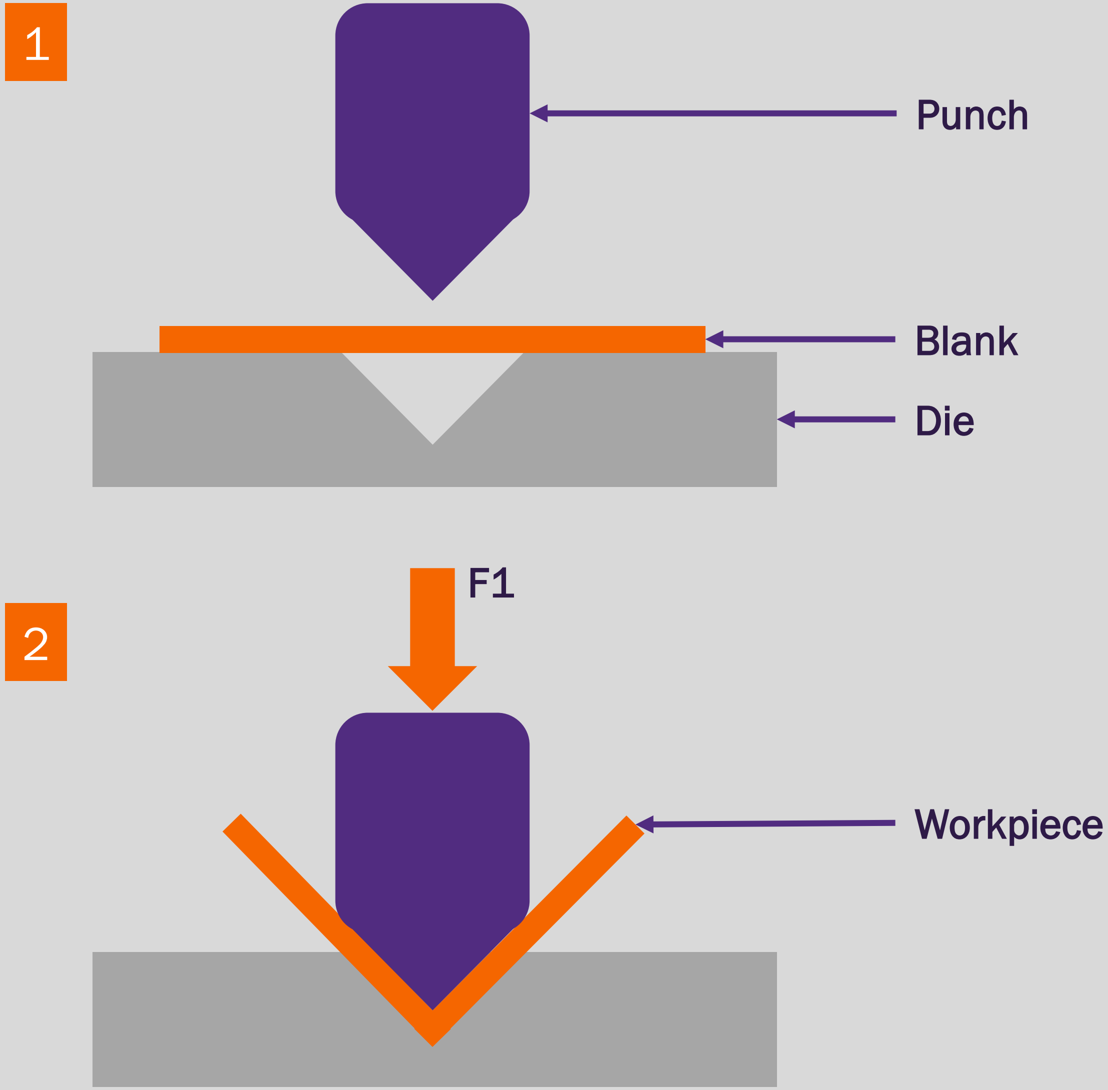
V.B | Categorization: Punching

The Sheetmetal punching process describes the process of removing material from the blank which is the desired work piece



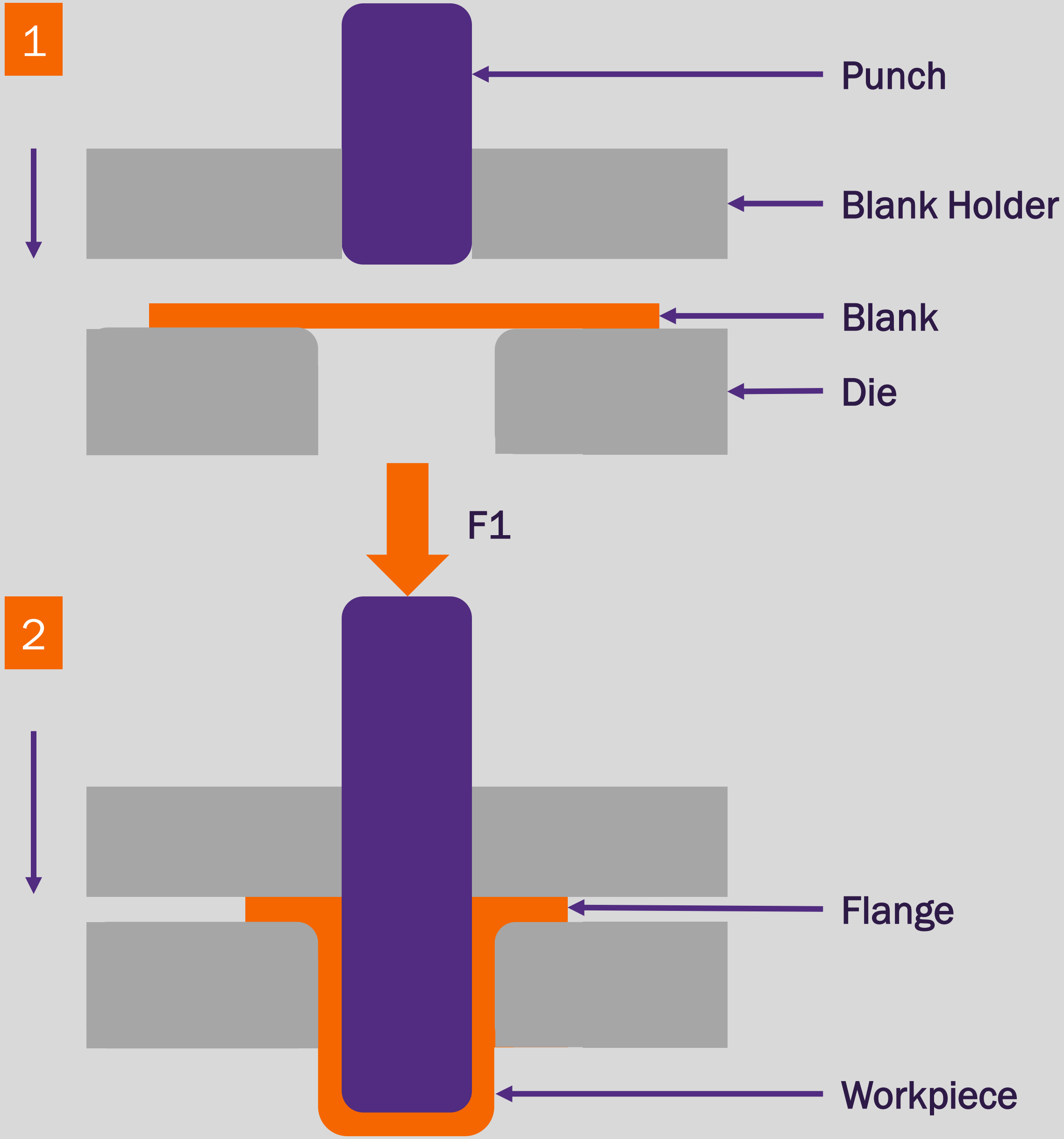
V.B | Categorization: Bending

- Sheetmetal bending processes are **plastic deformation processes** around a linear axis while not (or only slightly) changing the surface area
- Bending processes entail a certain **elastic recovery** from the combined tension and compression that needs to be accounted for
- Parameters influencing the elastic recovery include material type and thickness



V.B | Categorization: Drawing

- Sheetmetal (deep) drawing describes a process of forming a material through plastic deformation using a punch and die, typically creating cylindrical or rectangular containers
- There are two common types of Sheetmetal drawing processes, deep drawing (depth > diameter) and shallow drawing (depth < diameter)



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Knowledge Check

Blanking separates the part from the original sheet metal strip which is later used as scrap

A. True
B. False

Knowledge Check

Blanking separates the part from the original sheet metal strip which is later used as scrap

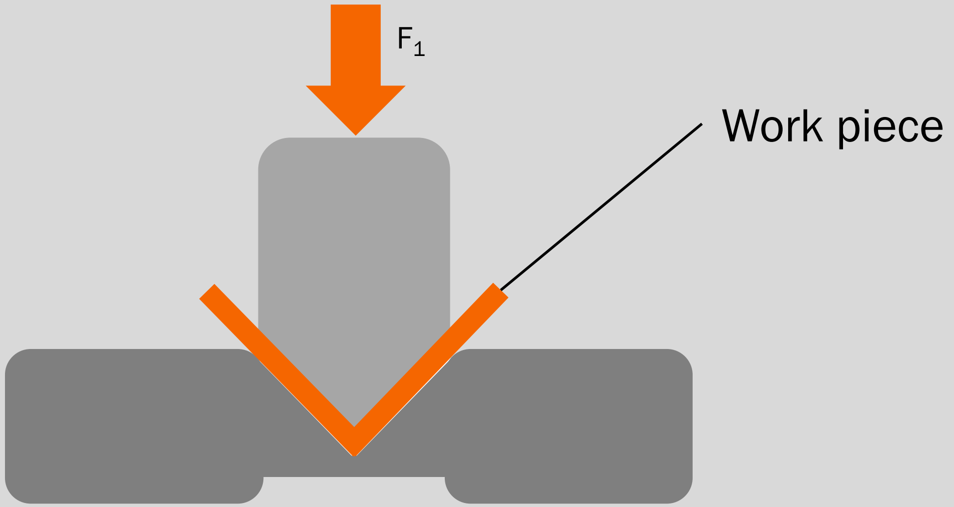
A. True

B. False

Knowledge Check

What is the manufacturing process below ?

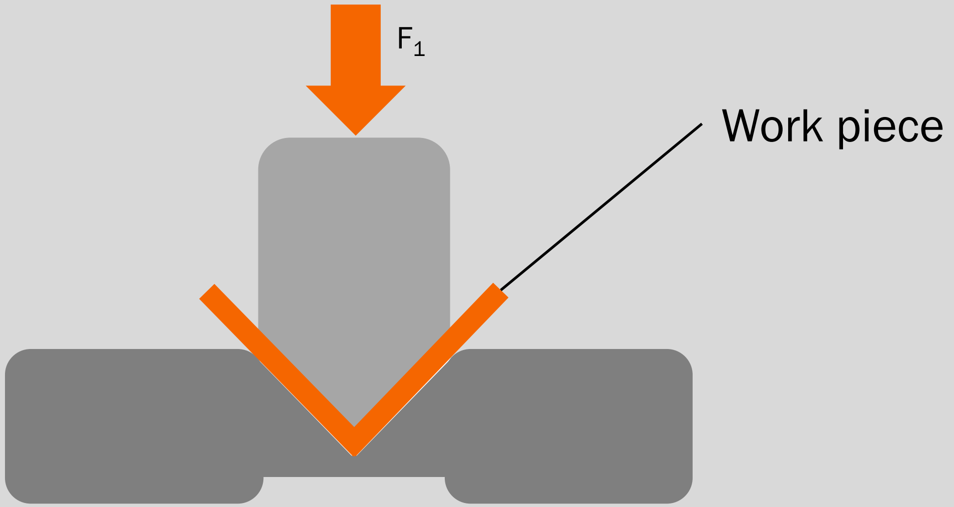
A. V Bending
B. Deep Drawing
C. Shearing
D. Blanking



Knowledge Check

What is the manufacturing process below ?

A. V Bending
B. Deep Drawing
C. Shearing
D. Blanking



THANK YOU

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