

Influence of Fabrication Processes on the Strength of Metals

Lecture 2



**Engineering 473
Machine Design**



Things that Affect Metal Strength

The strength of ductile metallic materials is dependent on several parameters.

1. Load Direction (Tensile or Compressive)
2. Strain Rate (Slow or Fast)
3. Temperature (Hot or Cold)
4. Load History (Monotonic or Cyclic)
5. Fabrication Process

Common Fabrication Processes

Casting

Sand Casting
Investment Casting
Shell Molding

Powder-Metallurgy

Hot-working

Hot rolling
Extrusion
Forging

Cold-working

Heading
Roll threading
Spinning
Stamping

Heat Treatment

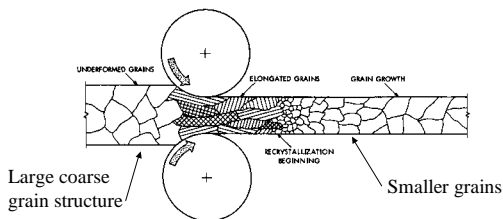
Annealing
Quenching
Tempering
Case Hardening

Hot Working

Hot working of metals is done for two reasons

1. Plastically mold the metal into the desired shape
2. Improve the properties of the metal as compared to the as-cast condition

Microstructure Changes due to Hot Rolling



The granular structure of the material is changed during hot rolling.

Allen, Fig. 16-14

Hot Working Temperatures

Material	Temperature Range (°F)
Aluminum	650-900
Aluminum Alloys	750-900
Beryllium	700-1300
Brass	1200-1475
Copper	1200-1650
High Speed Steels	1900-2200
Inconel	1850-2350
Magnesium Alloys	400-750
Monel	1850-2150
Nickel	1600-2300
Refractory Metals & Alloys	1800-3000
Steel: Carbon	1900-2400
Low Alloy	1800-2300
Stainless	1900-2200
Titanium	1400-1800
Zinc Alloys	425-550

Allen, Table 16-1

Example of Microstructure Changes

Low carbon cast steel

- (A) As cast (dendritic structure)
- (B) After hot rolling (reduced grain size)
- (C) After temper rolling (elongated grains) Directional Properties



Allen, Fig. 16-18.

Beneficial Effects of Hot Rolling

Typical defects in cast metals which are minimized in hot worked metals

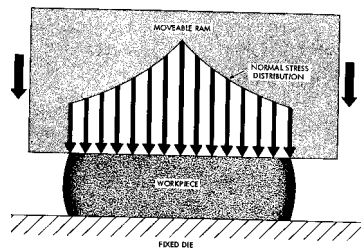
1. Large grain size (due to slow cooling)
2. Porosity (voids due to shrinkage)
3. Blow holes (due to gas evolution during solidification)
4. Segregation (due to limited solubility in the solid state)
5. Dirt and slag inclusions
6. Poor surface condition (due to oxides and scale)

The strength of hot rolled metals is higher than cast metals.

Allen, pg 508.

Forging

- A hot working process
- Metal flows under high compressive stresses
- May be used with or without die cavity to obtain a specific shape



A blacksmith uses a hammer and an anvil to forge metallic parts.

Forged Workpiece



The curvature on the sides of a forged product is due to friction between the ram and the workpiece.

Allen, Fig. 16-19

Directional Nature of Forged Material Properties



Flow lines in upset forging of 1.5" dia. AISI 1045 steel specimen at 1800 °F.

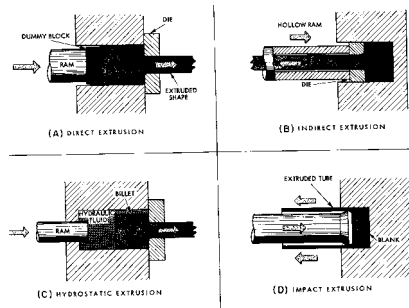
Flow lines are caused by the elongation of slag particles or non-metallic inclusions.

Allen, Fig. 16-23

Strength of Forged Materials

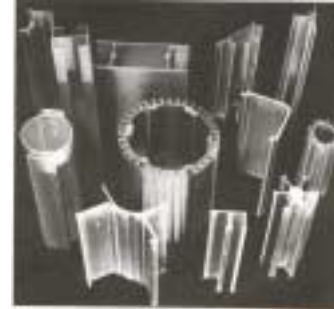
- Forged products generally have substantially higher strength properties than cast products.
- Cast products have material properties that are approximately the same in all directions (isotropic).
- Forged products have material properties that are different in each direction. Transverse properties are significantly less than the longitudinal direction (orthotropic or anisotropic)

Extrusion



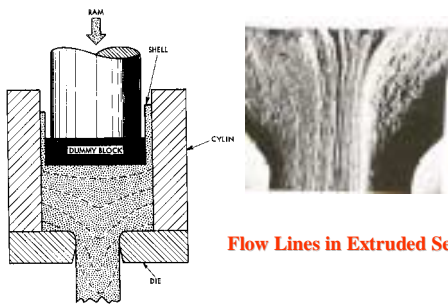
Allen, Fig. 16-25

Example of Extruded Aluminum Cross Sections



Allen, Fig. 16-24

Directional Nature of Extrusion Material Properties



Allen, Fig's 16-26 and 16-27

Extrusion Conditions for Typical Metals

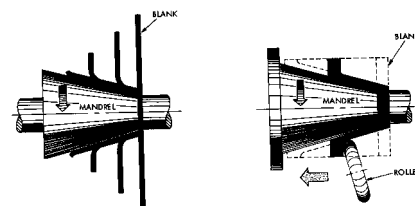
METAL	PRESSURE TONS/SQ-IN	TEMPERATURE, DEG. F.	EXTRUSION SPEED FEET/MIN.
ALUMINUM (EXTRUSION GRADE)	40	700-900	1 1/2-300
BRASS (SOFT)	30	1200-1400	NOT CRITICAL
COPPER (SOFT)	25	1500-1600	NOT CRITICAL
LEAD	20	400-500	---
MAGNESIUM, M1	6-10	780-820	20-100
NICKEL	50-60	2000-2300	400-750
STEEL (C1010 EXTRUSION GRADE)	50	2000-2300	400-750
STEEL (C1020 SPHEROIDIZED)	60	2000-2300	400-750
TIN	20	140-150	10-30

Allen, Table 16-2

Strength of Extruded Materials

- High degree of grain flow in the direction parallel to the axis of extrusion.
- High strength properties in the direction parallel to the axis of extrusion.
- Lower strength properties in the direction transverse to the axis of extrusion.

Spinning



Conventional Spin Forming
(No change in material thickness)

Shear Spin Forming
(Significant material thickness changes)

Used to produce rocket motor casings and missile nose cones.

Allen, Fig. 16-43

Directional Nature of Spin Formed Material Properties

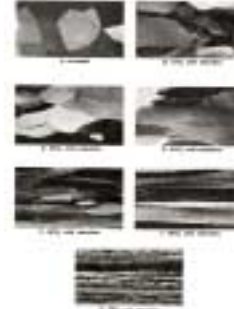


Grid Flow Lines in Shear Spun Copper Cone

Allen, Fig. 16-44

Effect of Cold Working on Microstructure

Grain boundaries in 3003 aluminum alloy.



Strength of Spin Formed Materials

- Spin formed products have increased strength in the longitudinal direction
- Strength properties in the transverse direction (through thickness) may be significantly different.

Heat Treatment

Heat Treating Processes

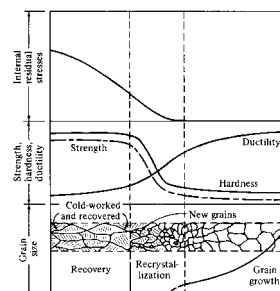
- Annealing
- Quenching
- Tempering
- Case Hardening

Annealing

Heat treating operation used to:

- 1) Refine the grain structure,
- 2) Relieve residual stresses,
- 3) Increase ductility.

Annealing Effects



Recrystallization

The growth of new stress-free equiaxed crystals in cold worked materials. Occurs after a critical (recrystallization) temperature is reached.

Equiaxed Crystals

Have equivalent dimensions in all directions (i.e. not longer in one direction)

Flinn, Fig. 3-19

Fabrication Processes Summary

- Hot and cold working fabrication processes have significant influence on the materials strength.
- Cast materials generally have uniform or isotropic material strength.
- Cold and hot worked materials generally have higher strengths. Strength properties are dependent on direction (orthotropic or anisotropic)
- Standard practice is to obtain/verify material properties from sample product in the direction of highest stress/strain.

Fabrication Processes Summary (Continued)

- Annealing may be used on hot and cold worked materials to obtain uniform properties and to relieve fabrication induced stresses.
- Heat treating may be performed to obtain strength properties and characteristics higher than the annealed state.

Summary

The strength of ductile metallic materials is dependent on several parameters.

1. Load Direction (Tensile or Compressive)
2. Strain Rate (Slow or Fast)
3. Temperature (Hot or Cold)
4. Load History (Monotonic or Cyclic)
5. Fabrication Process (Hot or cold working and/or heat treatment)

Assignment

Read pages 35-51