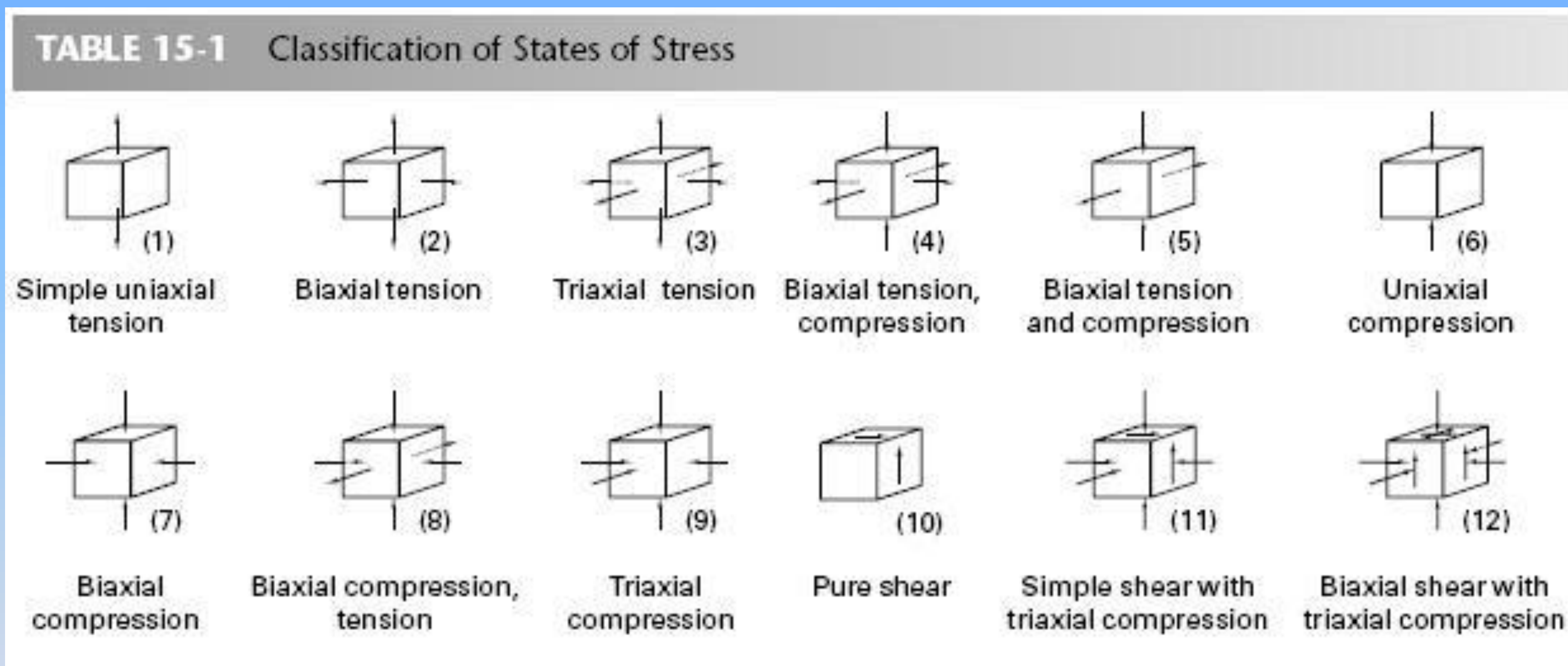
Fundamentals of Metal Forming

Chapter 15

15.1 Introduction

- Deformation processes have been designed to exploit the plasticity of engineering materials
- Plasticity is the ability of a material to flow as a solid without deterioration of properties
- Deformation processes require a large amount of force
- Processes include bulk flow, simple shearing, or compound bending

States of Stress

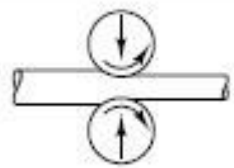
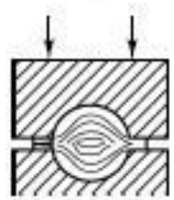
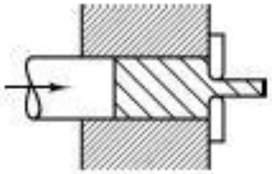


15.2 Forming Processes: Independent Variables

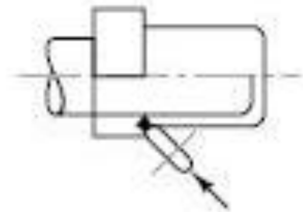
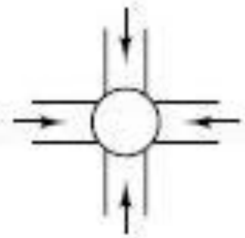
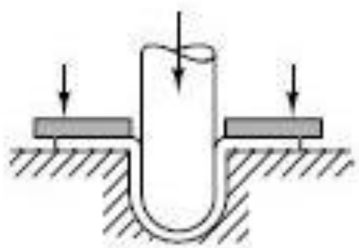
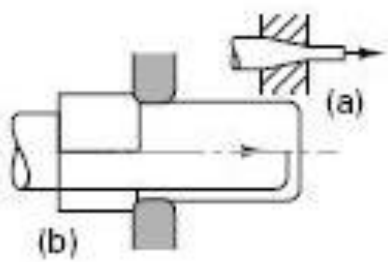
- Forming processes consist of independent and dependent variables
- Independent variables are the aspects of the processes that the engineer or operator has direct control
  - Starting material
  - Starting geometry of the workpiece
  - Tool or die geometry
  - Lubrication
  - Starting temperature
  - Speed of operation
  - Amount of deformation

Forming Operations

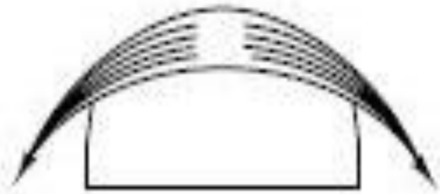
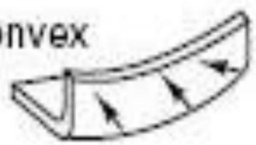
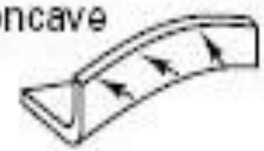
TABLE 15-2 Classification of Some Forming Operations

Process	Schematic Diagram	State of Stress in Main Part During Forming[a]
Rolling		7
Forging		9
Extrusion		9
Shear spinning		12

Forming Operations

Tube spinning		9
Swaging or kneading		7
Deep drawing		In flange of blank, 5 In wall of cup, 1
Wire and tube drawing		8

Forming Operations

Stretching		2
Straight bending		At bend, 2 and 7
Contoured flanging	(a) Convex 	At outer flange, 6 At bend, 2 and 7
	(a) Concave 	At outer flange, 1 At bend, 2 and 7

[a] Numbers correspond to those in parentheses in Table 15-1.

15.3 Dependent Variables

- Dependent variables are those that are determined by the independent variable selection
  - Force or power requirements
  - Material properties of the product
  - Exit or final temperature
  - Surface finish and precision
  - Nature of the material flow

15.4 Independent-Dependent Relationships

- Independent variables- control is direct and immediate
- Dependent variables- control is entirely indirect
  - Determined by the process
  - If a dependent variable needs to be controlled, the designer must select the proper independent variable that changes the dependent variable

Independent-Dependent Relationships

- Information on the interdependence of independent and dependent variables can be learned in three ways
  - Experience
  - Experiment
  - Process modeling

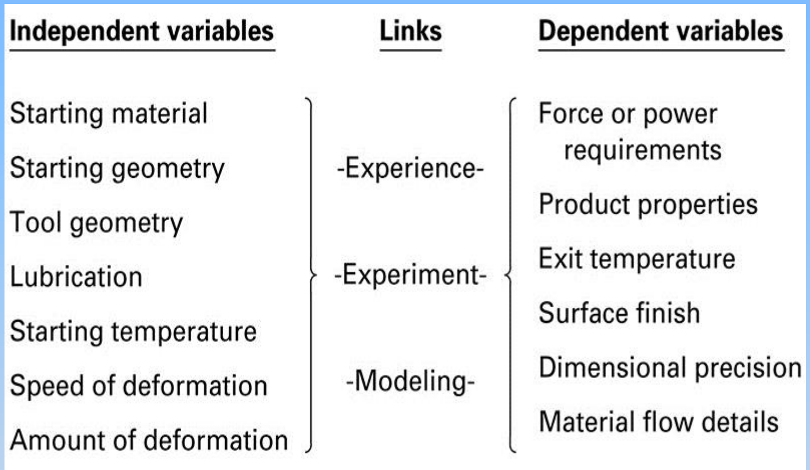


Figure 15-1 Schematic representation of a metalforming system showing independent variables, dependent variables, and the various means of linking the two.

15.5 Process Modeling

- Simulations are created using finite element modeling
- Models can predict how a material will respond to a rolling process, fill a forging die, flow through an extrusion die, or solidify in a casting
- Heat treatments can be simulated
- Costly trial and error development cycles can be eliminated

15.6 General Parameters

- Material being deformed must be characterized
  - Strength or resistance for deformation
  - Conditions at different temperatures
  - Formability limits
  - Reaction to lubricants
- Speed of deformation and its effects
- Speed-sensitive materials- more energy is required to produce the same results

15.7 Friction and Lubrication Under Metalworking Conditions

- High forces and pressures are required to deform a material
- For some processes, 50% of the energy is spent in overcoming friction
- Changes in lubrication can alter material flow, create or eliminate defects, alter surface finish and dimensional precision, and modify product properties
- Production rates, tool design, tool wear, and process optimization depend on the ability to determine and control friction

Friction Conditions

- Metalforming friction differs from the friction encountered in mechanical devices
- For light, elastic loads, friction is proportional to the applied pressure
  – μ is the coefficient of friction
- At high pressures, friction is related to the strength of the weaker material

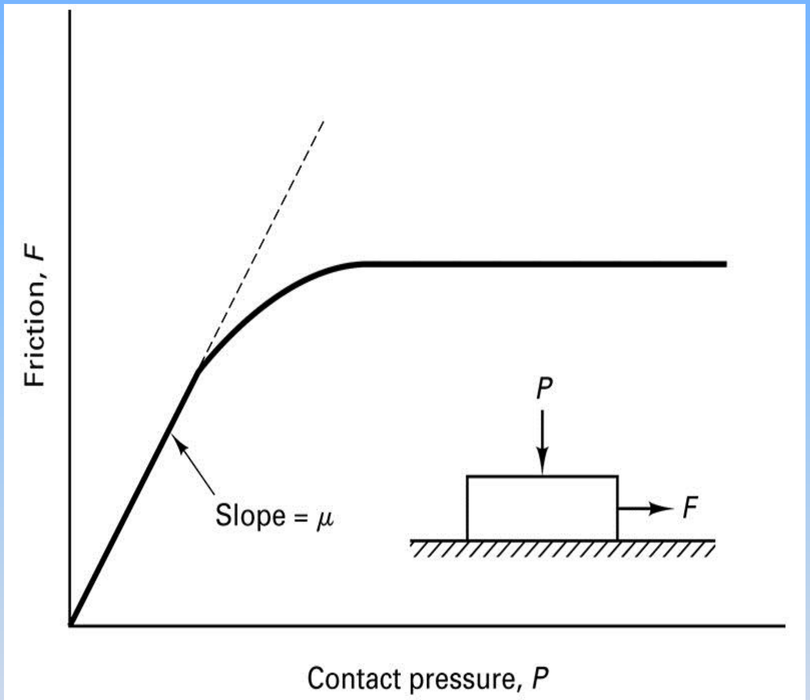


Figure 15-2 The effect of contact pressure on the frictional resistance between two surfaces.

Friction

- Friction is resistance to sliding along an interface
- Resistance can be attributed to:
  - Abrasion
  - Adhesion
- Resistance is proportional to the strength of the weaker material and the contact area

Surface Deterioration

- Surface wear is related to friction
- Wear on the workpiece is not objectionable, but wear on the tooling is
- Tooling wear is economically costly and can impact dimensional precision
- Tolerance control can be lost
- Tool wear can impact the surface finish

Lubrication

- Key to success in many metalforming operations
- Primarily selected to reduce friction and tool wear, but may be used as a thermal barrier, coolant, or corrosion retardant
- Other factors
  - Ease of removal, lack of toxicity, odor, flammability, reactivity, temperature, velocity, wetting characteristics

15.8 Temperature Concerns

- Workpiece temperature can be one of the most important process variables
- In general, an increase in temperature is related to a decrease in strength, increase in ductility, and decrease in the rate of strain hardening
- Hot working
- Cold working
- Warm working

Hot Working

- Plastic deformation of metals at a temperature above the recrystallization temperature
- Temperature varies greatly with material
- Recrystallization removes the effects of strain hardening
- Hot working may produce undesirable reactions from the metal and its surroundings

Structure and Property Modification by Hot Working

- The size of grains upon cooling is not typically uniform
- Undesirable grain shapes can be common (such as columnar grains)
- Recrystallization is followed by:
  - grain growth
  - additional deformation and recrystallization
  - drop in temperature that will terminate diffusion and freeze the recrystallized structure

Hot Working

- Engineering properties can be improved through reorienting inclusion or impurities
- During plastic deformation, impurities tend to flow along with the base metal or fraction into rows of fragments

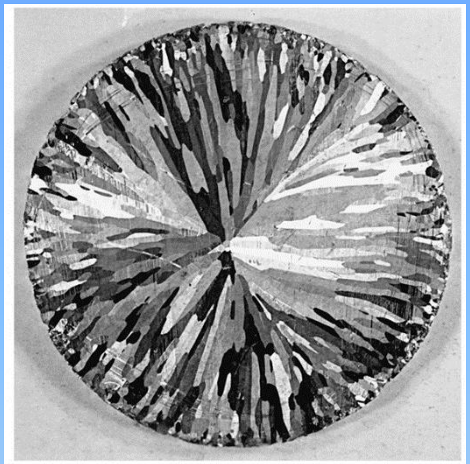


Figure 15-3 Cross section of a 4-in.-diameter case copper bar polished and etched to show the as-cast grain structure.

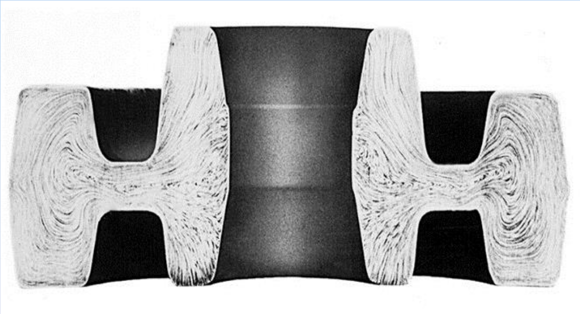


Figure 15-4 Flow structure of a hot-forged gear blank. Note how flow is parallel to all critical surfaces. (*Courtesy of Bethlehem Steel Corporation, Bethlehem, PA.)*

Temperature Variations in Hot Working

- Success or failure of a hot deformation process often depends on the ability to control temperatures
- Over 90% of the energy imparted to a deforming workpiece is converted to heat
- Nonuniform temperatures may be produced and may result in cracking
- Thin sections cool faster than thick sections

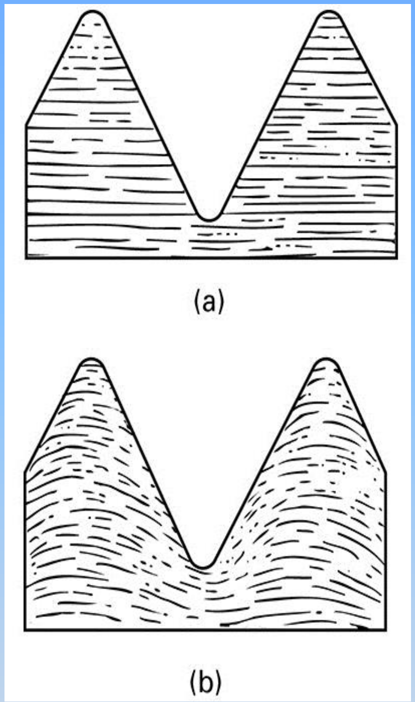


Figure 15-5 Schematic comparison of the grain flow in a machined thread (a) and a rolled thread (b). The rolling operation further deforms the axial structure produced by the previous wire- or rod-forming operations, while machining simply cuts through it.

Cold Working

- Plastic deformation below the recrystallization temperature
- Advantages as compared to hot working
  - No heating required
  - Better surface finish
  - Superior dimensional control
  - Better reproducibility
  - Strength, fatigue, and wear are improved
  - Directional properties can be imparted
  - Contamination is minimized

Disadvantages of Cold Working

- Higher forces are required to initiate and complete the deformation
- Heavier and more powerful equipment and stronger tooling are required
- Less ductility is available
- Metal surfaces must be clean and scale-free
- Intermediate anneals may be required
- Imparted directional properties can be detrimental
- Undesirable residual stresses may be produced

Metal Properties and Cold Working

- Two features that are significant in selecting a material for cold working are
  - Magnitude of the yield-point stress
  - Extent of the strain region from yield stress to fracture
- Springback should also be considered when selecting a material

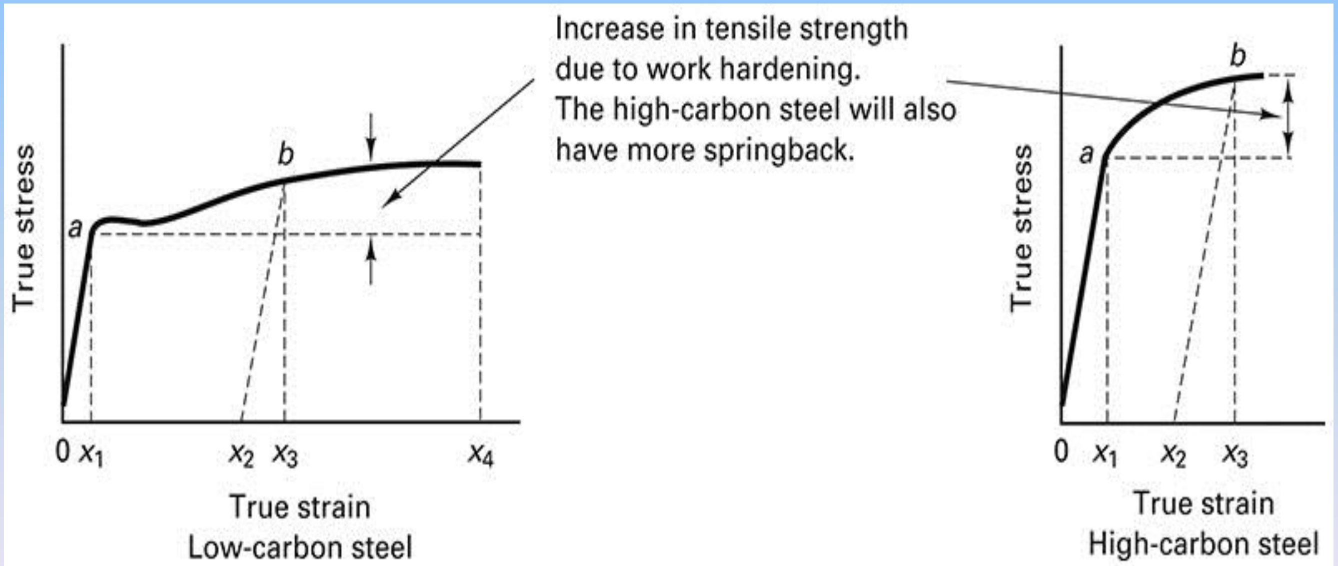
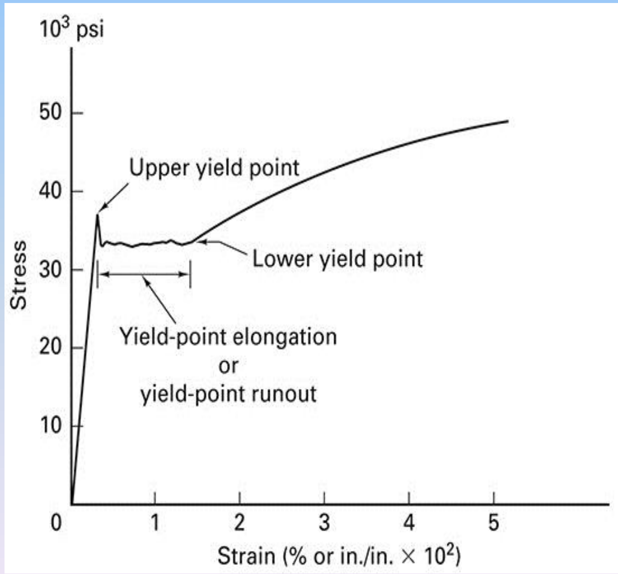


Figure 15-6 Use of true stress-true strain diagram to assess the suitability of two metals for cold working.

Initial and Final Properties in a Cold-Working Process

- Quality of the starting material is important to the success or failure of the cold-working process
- The starting material should be clean and free of oxide or scale that might cause abrasion to the dies or rolls

Figure 15-7 (Below) Stress-strain curve for a low-carbon steel showing the commonly observed yield-point runout; (Right) Luders bands or stretcher strains that form when this material is stretched to an amount less than the yield-point runout.



Additional Effects of Cold Working

- Annealing heat treatments may be performed prior or at intermediate intervals to cold working
- Heat treatments allow additional cold working and deformation processes
- Cold working produces a structure where properties vary with direction, anisotropy

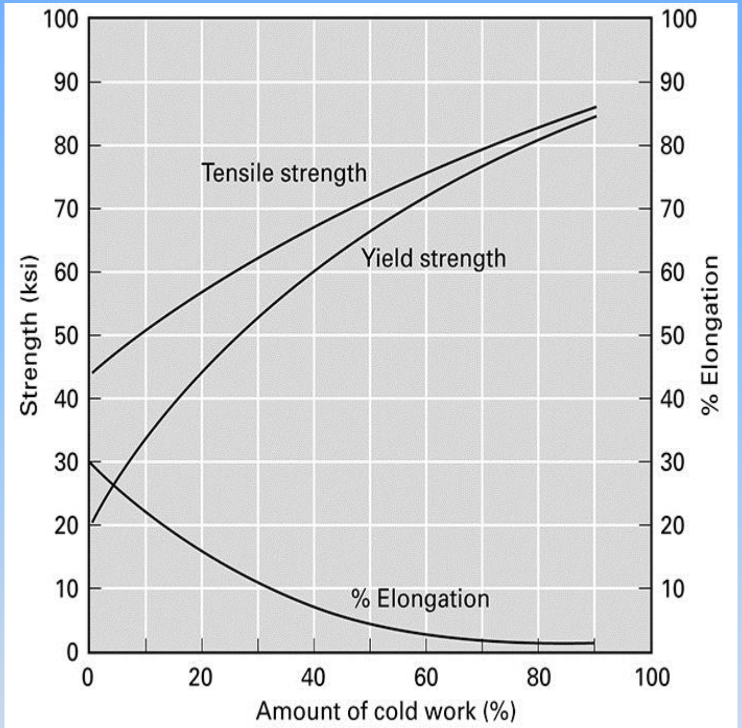


Figure 15-8 Mechanical properties of pure copper as a function of the amount of cold work (expressed in percent).

Warm Forming

- Deformations produced at temperatures intermediate to cold and hot working
- Advantages
  - Reduced loads on the tooling and equipment
  - Increased material ductility
  - Possible reduction in the number of anneals
  - Less scaling and decarburization
  - Better dimensional precision and smoother surfaces than hot working
  - Used for processes such as forging and extrusion

Isothermal Forming

- Deformation that occurs under constant temperature
- Dies and tooling are heated to the same temperature as the workpiece
- Eliminates cracking from nonuniform surface temperatures
- Inert atmospheres may be used

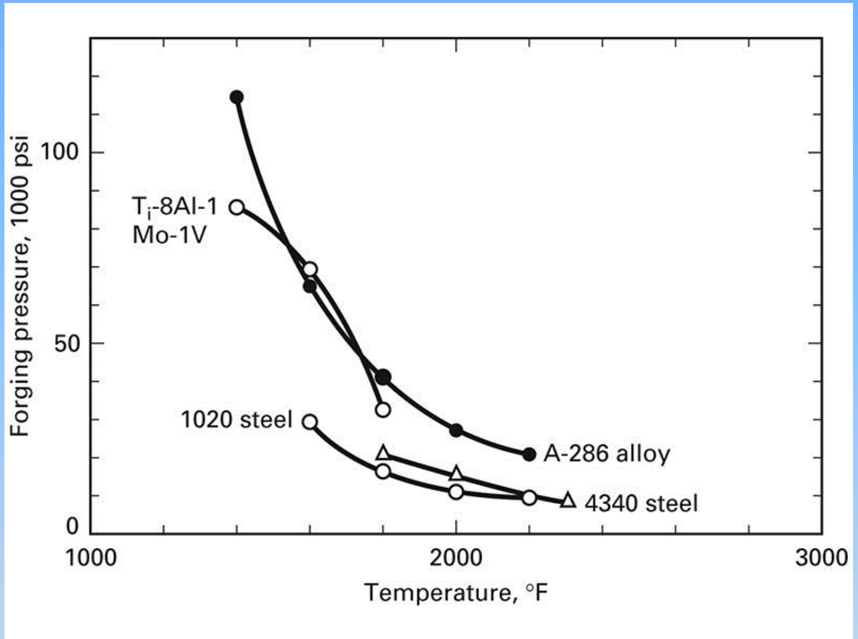


Figure 15-10 Yield strength of various materials (as indicated by pressure required to forge a standard specimen) as a function of temperature. Materials with steep curves may require isothermal forming. (*From "A Study of Forging Variables," ML-TDR-64-95, March 1964; courtesy of Battelle Columbus Laboratories, Columbus, OH.)*