FROM STEEL INGOTS TO FINISHED PRODUCTS

Selected Examples

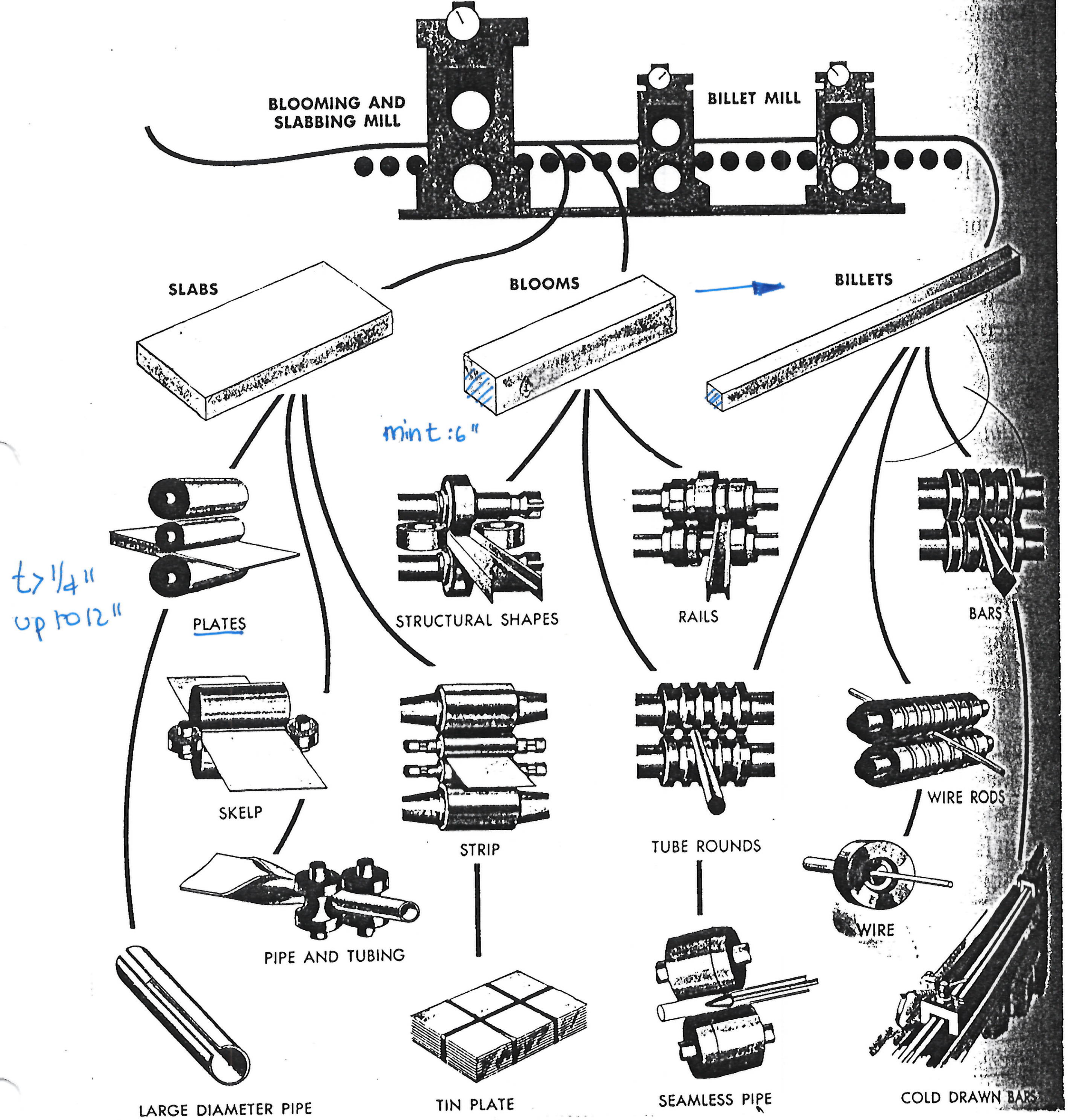
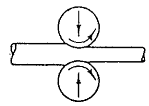
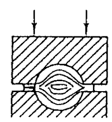
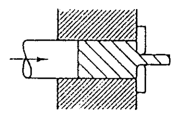
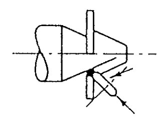
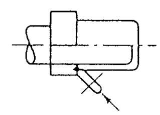
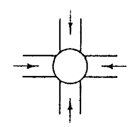
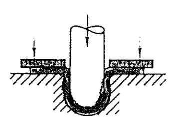
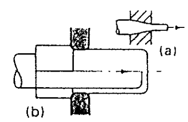
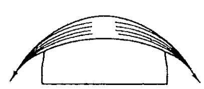
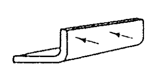
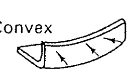
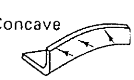
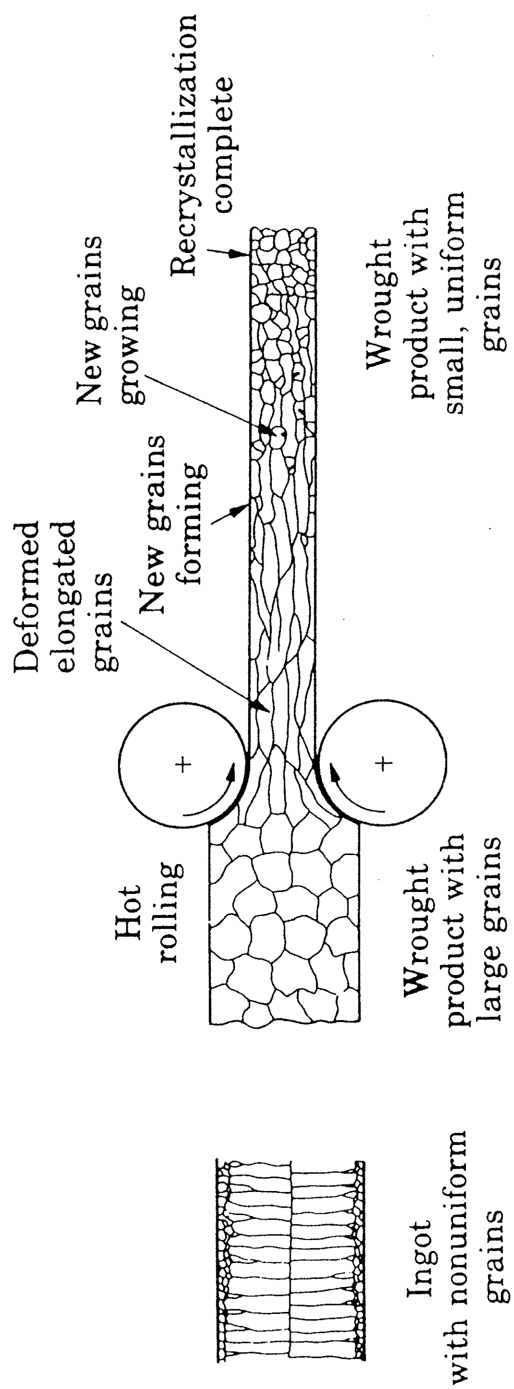


TABLE 17-2. Classification of Some Forming Operations

Number	Process	Schematic Diagram	State of Stress in Main Part During Forming[a]
1	Rolling		7
2	Forging		9
3	Extrusion		9
4	Shear spinning		12
5	Tube spinning		9
6	Swaging or kneading		7
7	Deep drawing		In flange of blank, 5 In wall of cup, 1
8	Wire and tube drawing		8
9	Stretching		2
10	Straight bending		At bend, 2 and 7
11	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] See Table 17-1 for key.

Figure 13.6 (page 364) **Changes in the grain structure of cast or large-grain wrought metals during hot rolling** **Master 29**



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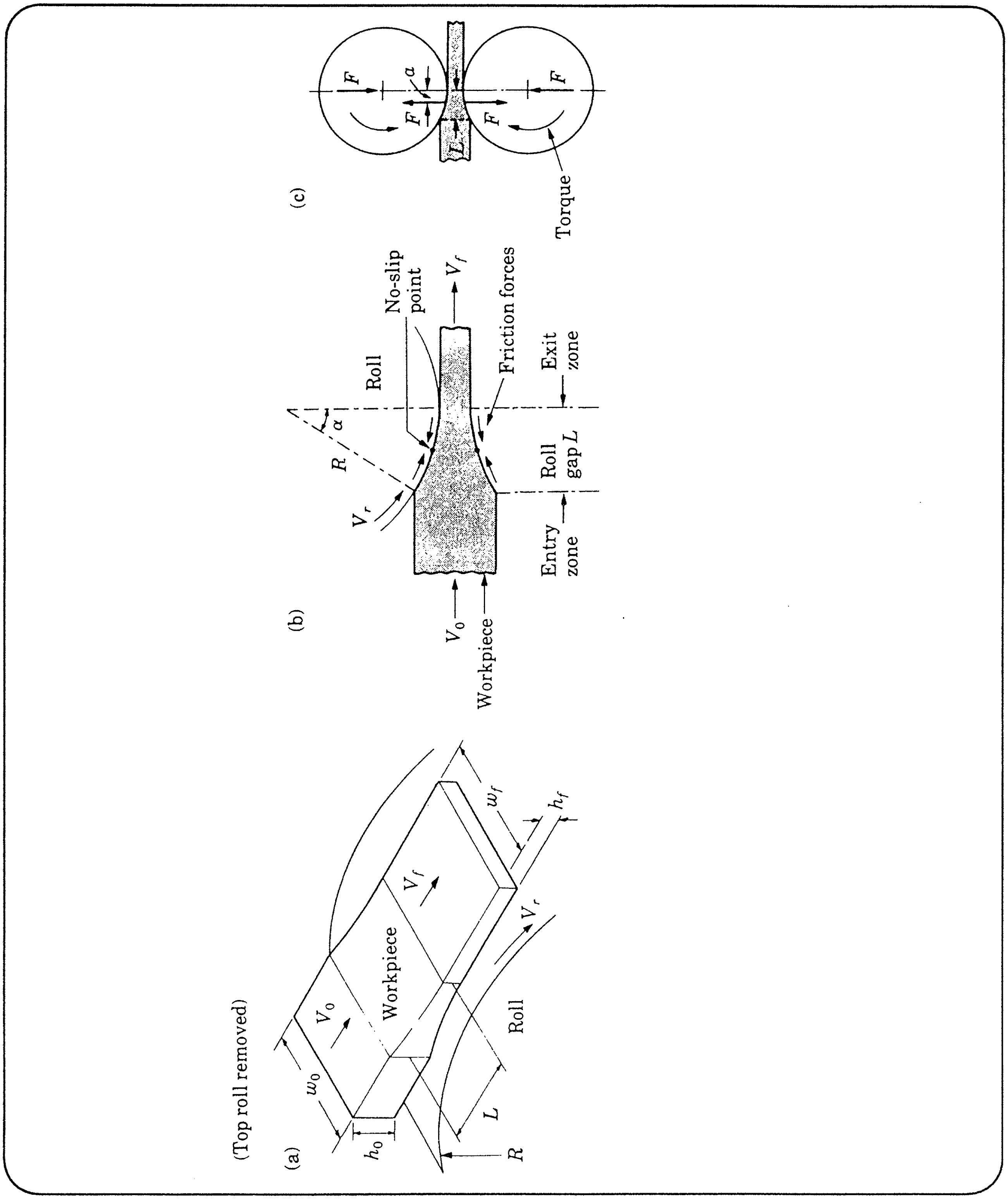

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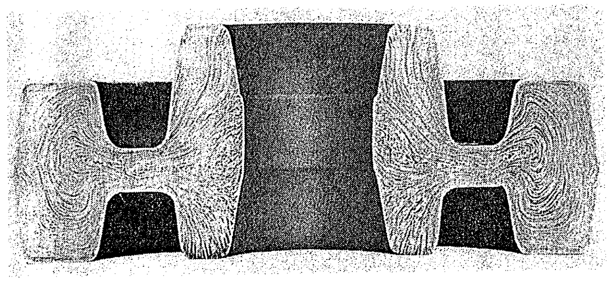
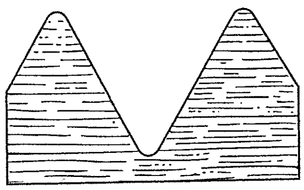


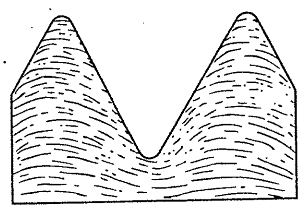
FIGURE 17-4 Flow structure of a hot-formed (forged) transmission gear blank. *(Courtesy of Bethlehem Steel Corporation.)*

If a cast metal is reheated without prior deformation, it will simply experience grain growth and the accompanying deterioration in engineering properties. However, if the metal has experienced a sufficient amount of deformation, the distorted structure will be rapidly replaced by new strain-free grains. This *recrystallization* is then followed by either (1) grain growth, (2) additional deformation and recrystallization, or (3) a drop in temperature that will terminate diffusion and "freeze in" the recrystallized structure. The structure in the final product is that formed by the last recrystallization and the thermal history that followed. By replacing the starting structure with one of fine, spherical-shaped grains, it is possible to produce an increase not only in strength but also in ductility and toughness—a somewhat universal enhancement of properties.

Engineering properties can also be improved through the reorientation of inclusions or impurity particles that are present in the metal. With normal melting and cooling, many impurities tend to locate along grain boundary interfaces. If these are unfavorably oriented or intersect surfaces, they can initiate a crack or assist its propagation through a metal. When a metal is plastically deformed, the impurities tend to flow along with the base metal, or fracture into rows of fragments (*stringers*) that are aligned in the direction of working. These nonmetallic impurities do not recrystallize with the base metal but retain their distorted shape and orientation. The product exhibits a *flow structure*, like the one shown in Figure 17-4, and properties tend to vary in different directions. Through proper design of the deformation, the impurities can often be reoriented into a "crack-arrestor" configuration where they are perpendicular to the direction of crack propagation. For example, the outer lobe of the forging in Figure 17-4 has excellent fracture resistance since all flow lines are parallel to the external surface. The impurities appear as crack initiators or crack propagators only at the top and bottom of the inner lobe, which hopefully is a low-stress or noncritical location.



(a)



(b)

FIGURE 17-5 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.

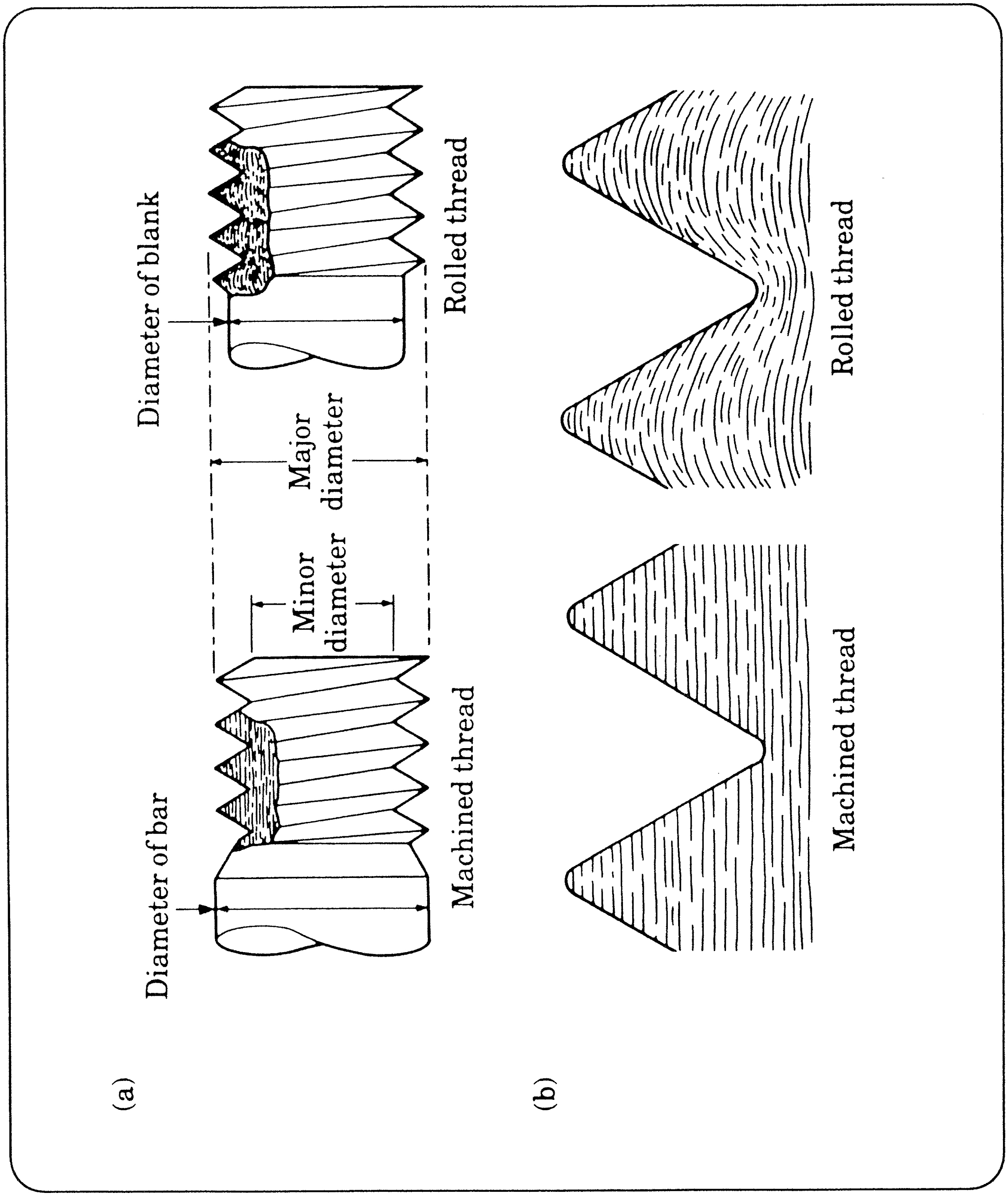
Figure 17-5 schematically compares a machined thread and a rolled thread in a threaded fastener. By reorienting the axial defects in the starting wire or rod to be parallel to the thread surfaces, the rolled thread offers improved strength and fracture resistance.

Temperature Variations. The success or failure of a hot deformation process often depends on the ability to control the temperatures within the workpiece. Over 90% of the energy imparted to a deforming workpiece will be converted into heat. If the deformation process is sufficiently rapid, the temperature of the workpiece may actually increase. More common, however, is the cooling of the workpiece in its lower-temperature environment. Heat is lost through the workpiece surfaces, with the majority of the loss occurring where the workpiece is in direct contact with lower-temperature tooling. Nonuniform temperatures are produced, and flow of the hotter, weaker, interior may well result in cracking of the colder, less ductile, surfaces. Thin sections cool faster than thick sections, and this may further complicate the flow behavior.

To minimize problems, it is desirable to keep the workpiece temperatures as uniform as possible. Heated dies can reduce the rate of heat transfer, but die life tends to be compromised. For example, dies are frequently heated to 325 to 450°C (600 to 850°F) when used in the hot forming of steel. Tolerances could be improved and contact times could be increased if the tool temperatures could be raised to 550 to 650°C (1000 to 1200°F), but tool life drops so rapidly that these conditions become quite unattractive.

A final concern is the cool-down from the temperatures of hot working. Nonuniform cooling can introduce significant amounts of *residual stress* in hot-worked products. Associated with these stresses may be warping or distortion, and possible cracking.

Figure 13.17 (page 374) (a) Differences in the diameters of machined and rolled threads. (b) Grain flow in machined and rolled threads



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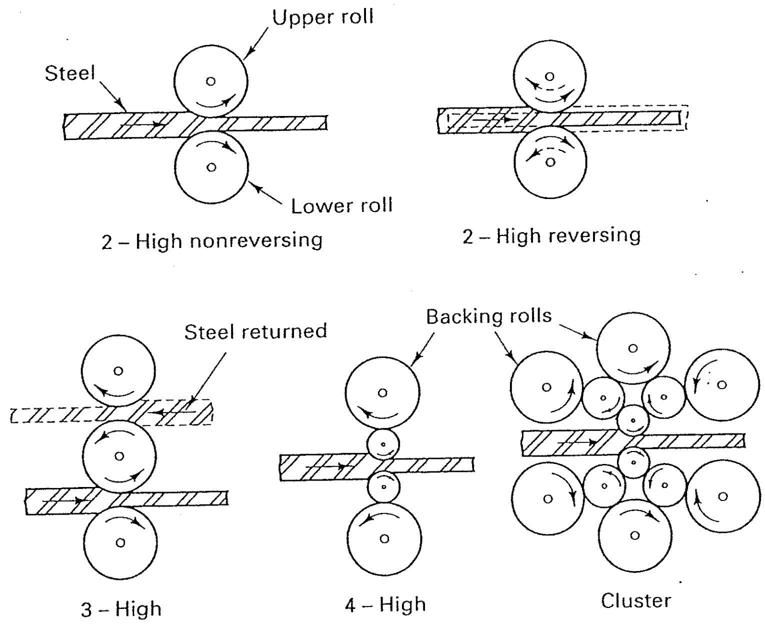
F3



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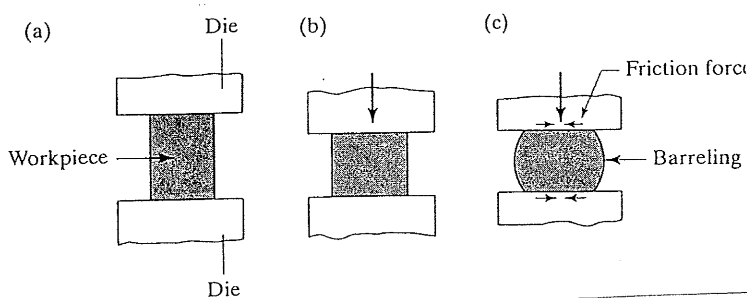

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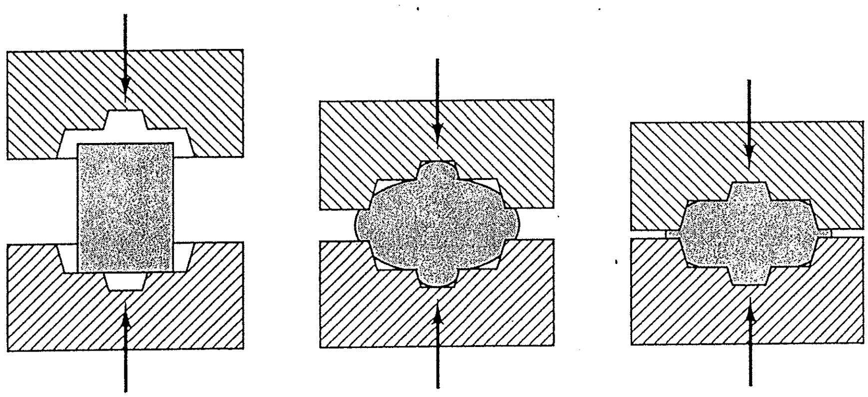

FIGURE 18-9 Schematic of the impression-die forging process showing partial die filling and the beginning of flash formation in the center sketch, and the final shape with flash in the right-hand sketch.