GLOBAL EDITION

Manufacturing Engineering and Technology

Eighth Edition in SI Units

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EIGHTH EDITION IN SI UNITS

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Thus, $r = 106$ mm. The quantity σ_f in Eq. (14.1) is the flow stress of the material, which is the stress required to continue plastic deformation of the workpiece at a particular true strain. The absolute value of the true strain that the workpiece has undergone at the end of the stroke in this operation is

$$\epsilon = \ln\left(\frac{100}{50}\right) = 0.69.$$

The flow stress can be determined using by referring to Eq. (2.8) and noting from Table 2.3 that, for 304 stainless steel, $K = 1275$ MPa and $n = 0.45$. Thus, for a true strain of 0.69, the flow stress is calculated to be 1100 MPa. Another calculation method is to refer to Fig. 2.5 and note that the flow stress for 304 stainless steel at a true strain of 0.69 is about 1000 MPa. The small difference between the two values is due to the fact that the data in Table 2.3 and Fig. 2.5 are from different sources. Taking the latter value for flow stress, the forging force can now be calculated, noting that in this problem the units in Eq. (14.1) must be in N and m. Thus,

$$\begin{aligned} F &= \left(1000 \times 10^6\right)(\pi)(0.106)^2(1) + \frac{(2)(0.2)(0.106)}{(3)(0.050)} \\ &= 4.5 \times 10^7 \text{ N} = 45 \text{ MN} = 4500 \text{ metric tons.} \end{aligned}$$

14.3 Impression-die and Closed-die Forging

In *impression-die forging*, the workpiece takes the shape of the die cavity while being forged between two shaped dies (Figs. 14.6a through c). This process is usually carried out at elevated temperatures in order to lower the forging forces and to develop enhanced ductility of the workpiece. Note in Fig. 14.6c that, during deformation, some of the material flows outward and forms a **flash**.

The flash has an important role in impression-die forging: The high pressure and the resulting high frictional resistance in the flash present a major constraint on the radially outward flow of the material in the die; this is due to the friction hill effect, described in Sec. 14.2. Thus, based on the principle that the material flows in the direction of least resistance (because it requires less energy), the material flows preferentially *into* the die cavity, eventually filling it completely.

Instead of being made as one piece, forging dies may be made of two or more pieces (*segmented*), including *die inserts* (Fig. 14.7) and particularly for complex part shapes. The inserts can easily be replaced in case of wear or failure in a particular region of the die; they are usually made of stronger and harder wear-resistant materials (see Section 33.5).

The blank to be forged can be prepared by (a) *cropping* (shearing, Section 16.2) from an extruded or drawn bar stock; (b) *powder metallurgy* or *casting*; or (c) it is a preformed blank from a prior forging operation. The blank is placed on the lower die, and as the upper die begins to descend, its shape gradually changes, as shown in Fig. 14.8a.

Preforming operations (Figs.14.8b and c) are typically made to enhance the distribution of the material into various regions of the blank, using simple dies with various contours. In **fullering**, material is distributed away from a die region; in **edging**, it is gathered into a localized region. The part is then formed into a rough shape by a process called **blocking**, using *blocker dies*. The final operation consists of finishing of the forging in *impression dies*, giving the forging its final shape. The flash is later removed by a trimming operation (Fig. 14.9).

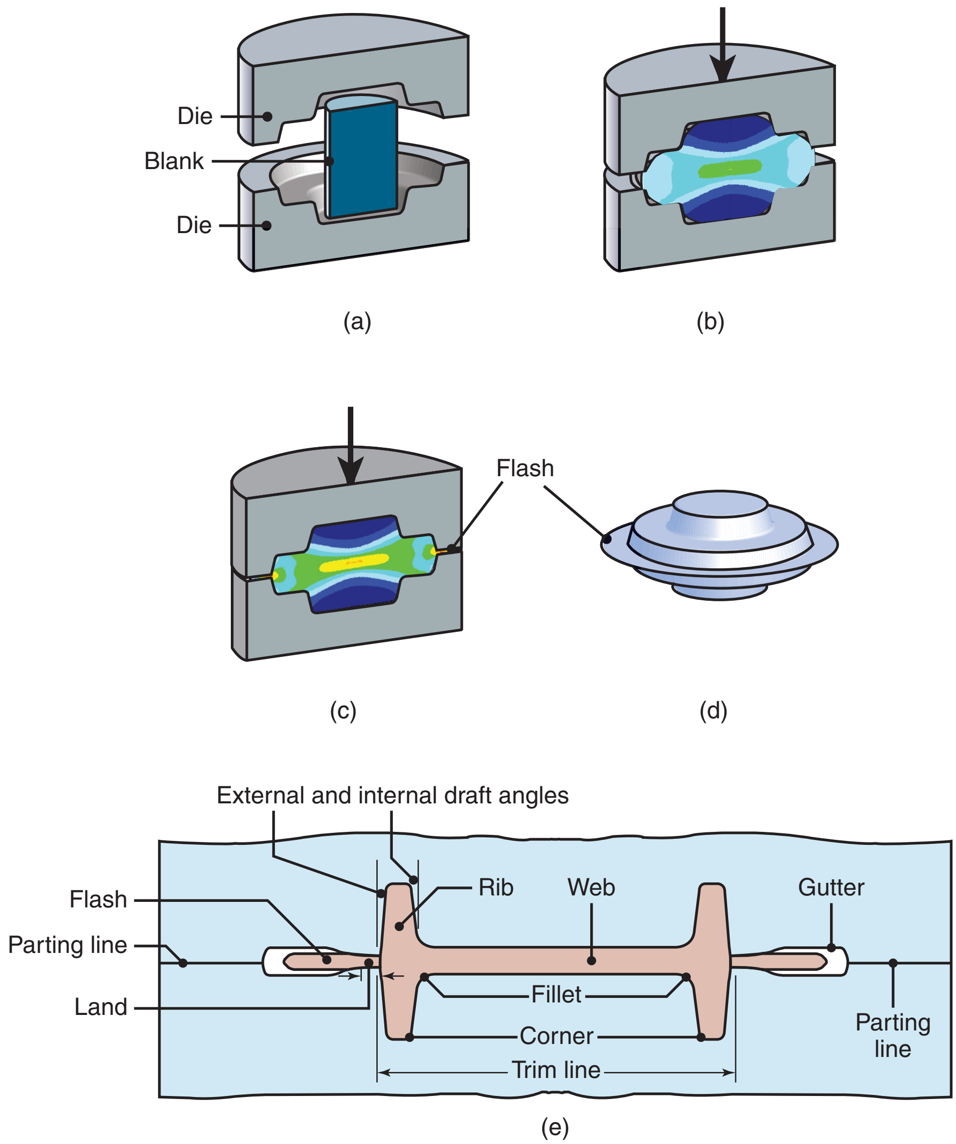

Figure 14.6: (a) through (d) Stages in impression-die forging of a solid round billet, with contours showing effective strain. Note the formation of flash, which is excess metal that is subsequently trimmed off. (e) Standard terminology for various features of a forging die.

Forging Force. The *forging force*, F, required in an *impression-die forging* operation can be estimated from the formula

$$F = k\sigma_f A, \tag{14.3}$$

where k is a multiplying factor, obtained from Table 14.2, σ_f is the flow stress of the material at the forging temperature, and A is the projected area of the forging, including the flash area. In hot-forging operations, the actual forging pressure for most metals typically ranges from 550 to 1000 MPa. As an example, assume that the flow stress of a material at the forging temperature is 300 MPa, and a part (such as that shown in Fig. 14.8a) has a projected area (with flash) of 0.05 m^2. Taking a value of $k = 10$ from Table 14.2, the forging force would be $F = (10)(300 \times 10^6)(0.05) = 150$ MN.

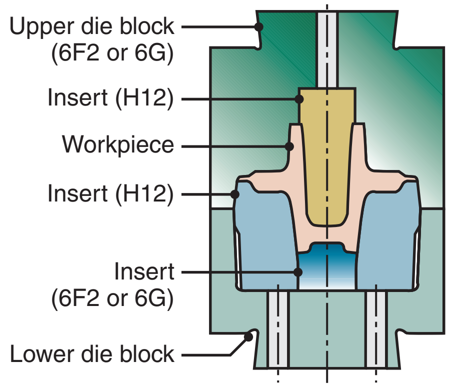

Figure 14.7: Die inserts used in forging an automotive axle housing (see Section 5.7 for die materials).

Closed-die Forging. The process shown in Fig. 14.6 is also referred to as *closed-die forging*. In true closed-die forging, however, a flash does not form (hence the term *flashless forging*), and the workpiece completely fills the die cavity (see right side of Fig. 14.10b). The accurate control of the blank volume and proper die design are essential to producing a forging with the required dimensional tolerances. Undersized blanks prevent the complete filling of the die cavity; conversely, oversized blanks generate excessive pressures and may cause dies to fail prematurely or the forging machine to jam.

Precision Forging. In order to reduce the number of additional finishing operations, hence cost, the trend has been toward greater precision in forged products (net-shape forming). Typical precision-forged products are gears, connecting rods, and turbine blades. Precision forging requires (a) special and more complex dies, (b) precise control of the blank's volume and shape, and (c) accurate positioning of the blank

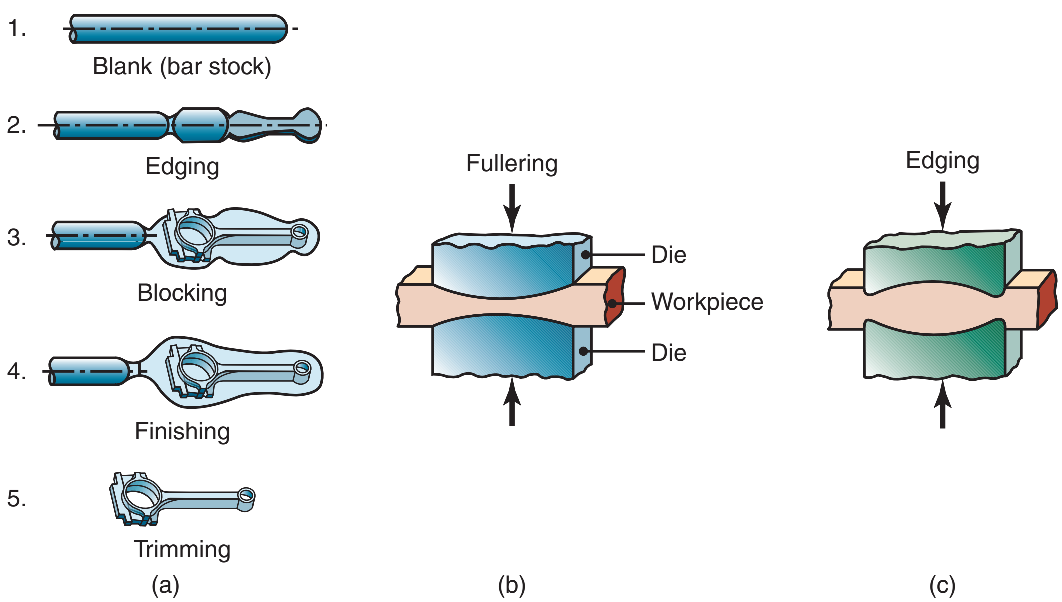

Figure 14.8: (a) Stages in forging a connecting rod for an internal combustion engine. Note the amount of flash required to ensure proper filling of the die cavities. (b) Fullering and (c) edging operations to distribute the material properly when preshaping the blank for forging.

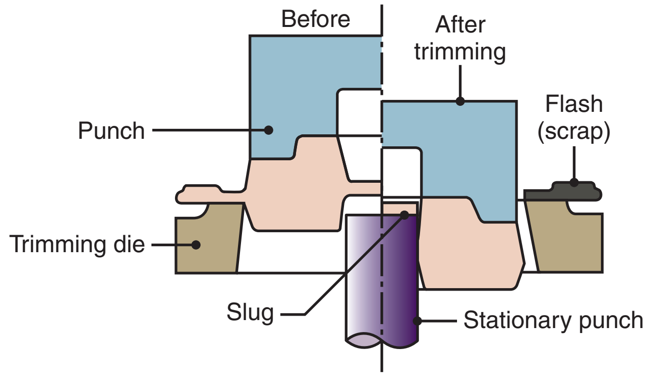

Figure 14.9: Trimming flash from a forged part. Note that the thin material at the center is removed by punching.

Table 14.2: Range of k Values for Eq. (14.3).

Shape	k
Simple shapes, without flash	3–5
Simple shapes, with flash	5–8
Complex shapes, with flash	8–12

in the die cavity. Because of the higher forces required to produce fine details on the part, precision forging requires higher capacity equipment. Aluminum and magnesium alloys are particularly suitable, because of the relatively low forging loads and forging temperatures that they require; however, steels and titanium also can be precision forged economically.

Forging Practice and Product Quality. A hot forging operation typically involves the following sequence of steps:

1. Prepare a slug, billet, or preform; if necessary, clean surfaces by such means as shot blasting (see Section 34.16).

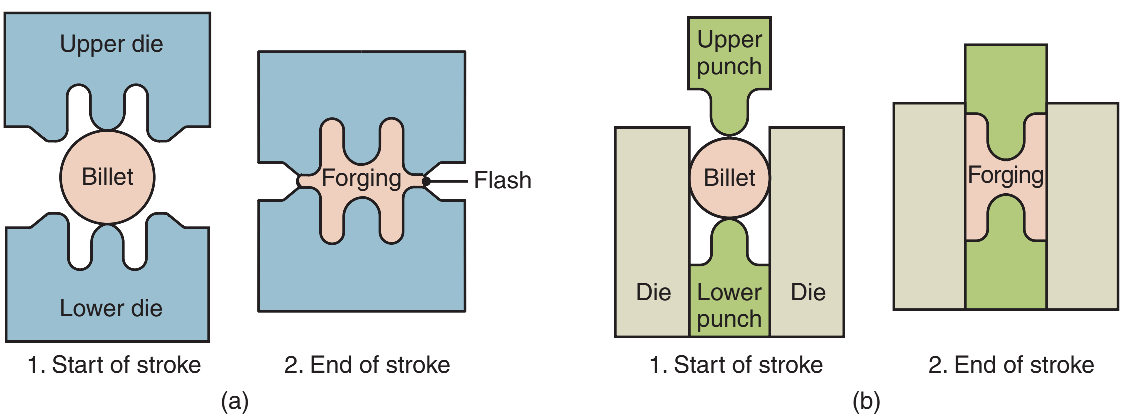

Figure 14.10: Comparison of (a) closed-die forging with flash and (b) precision or flashless forging of a round billet. *Source:* After H. Takemasu, V. Vazquez, B. Painter, and T. Altan.

2. Heat the workpiece in a suitable furnace; then, if necessary, descale it with a wire brush, water jet, steam, or by scraping. Some descaling also may occur during the initial stages of forging, when the thick, brittle scale falls off during forging.

3. Preheat, if necessary, and lubricate the dies.

4. Forge the billet in appropriate dies and in the proper sequence. If necessary, remove any excess material, especially any flash, by trimming, machining, or grinding.

5. Clean the forging, check for dimensional accuracy; if necessary, machine or grind to final dimensions and specified tolerances and surface finish.

6. Perform additional finishing operations, such as straightening and heat treating, for improving mechanical properties.

7. Inspect the forging for any external and internal defects.

The quality, dimensional tolerances, and surface finish of a forging depend on how well these operations have been performed. Generally, dimensional tolerances range between ± 0.5 and $\pm 1\%$ of the dimensions of the forging. In good practice, tolerances for hot forging of steel are usually less than ± 6 mm; in precision forging, they can be as low as ± 0.25 mm. Other factors that contribute to dimensional inaccuracies are draft angles, radii, fillets, die wear, whether the dies have closed properly, and mismatching of the dies.

14.4 Various Forging Operations

Several other operations related to the basic forging process are described below.

Coining. Essentially a closed-die forging process, coining was originally used in the minting of coins, medallions, and jewelry (Fig. 14.11). It is also used to produce a wide variety of parts with high accuracy, such as precision gears, industrial seals, and medical devices. The blank or slug is coined in a completely closed die cavity, in order to produce fine details. The pressures required can be as high as five or six

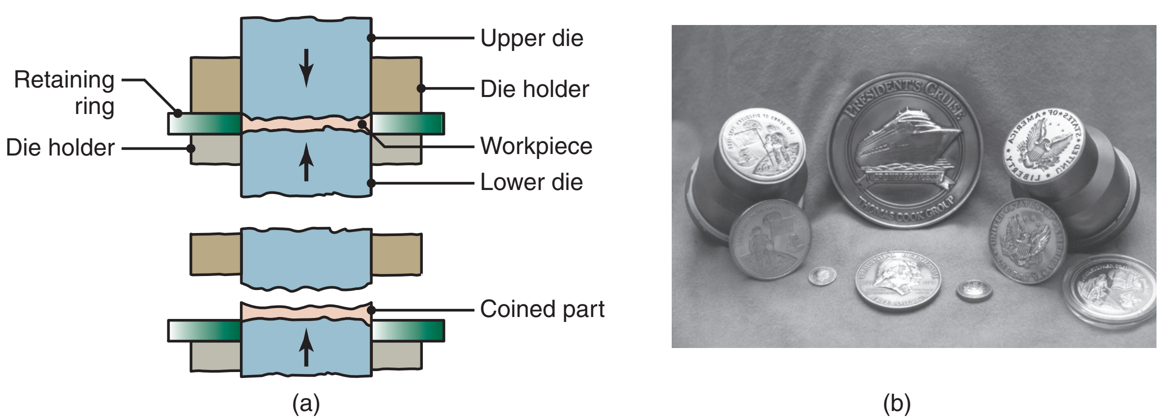

Figure 14.11: (a) Schematic illustration of the coining process. (b) An example of a modern coining operation, showing the coins and tooling. Note the detail and superior surface finish that can be achieved in this process. *Source:* Courtesy of C & W Steel Stamp Co., Inc.

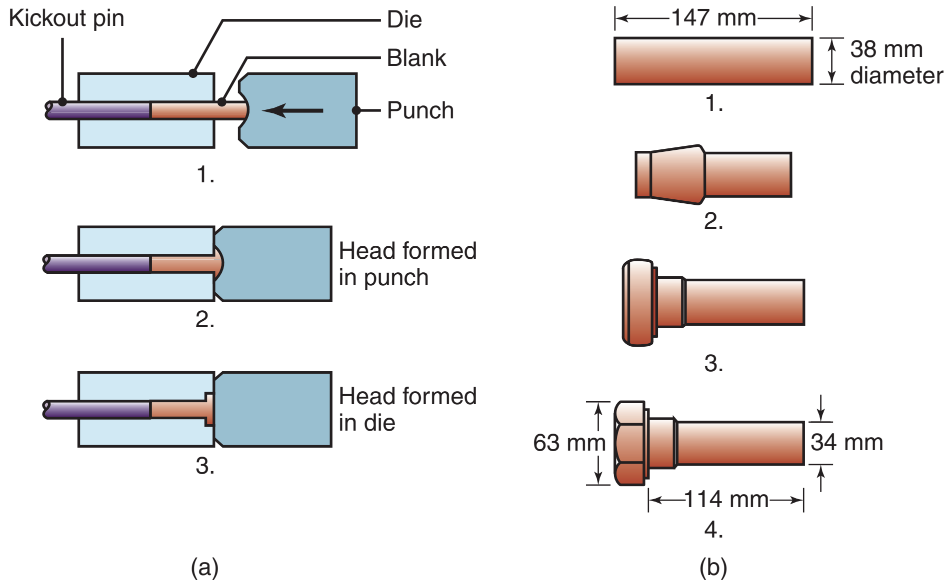

Figure 14.12: (a) Heading operation to form heads on fasteners, such as nails and rivets. (b) Sequence of operations used to produce a typical bolt head by heading.

times the strength of the material. On some parts, several coining operations may be required. Lubricants should not be used in coining because they can become entrapped in die cavities and, being incompressible, prevent the full reproduction of die-surface details and surface finish.

Marking parts with letters and numbers (for identification) also can be done rapidly through coining. **Sizing** is a process used mainly with forged or powder metal blanks (see Chapter 17) and other processes to improve surface finish and to impart the desired dimensional accuracy, with little or no change in part size.

Heading. Also called **upset forging**, *heading* is basically an upsetting operation, performed on the end of a rod or wire in order to increase the cross section. Typical products made are nails, bolt heads, screws, rivets, and fasteners (Fig. 14.12a). Heading can be carried out cold, warm, or hot, and can be combined with cold-extrusion processes to make various parts, as described in Section 15.4. Heading operations are performed on machines called **headers**; they are highly automated, with production rates of hundreds of pieces per minute for small parts. Hot heading operations on larger parts typically are performed on **horizontal upsetters**.

An important consideration in heading is the tendency for the workpiece to *buckle* if its unsupported length-to-diameter ratio is too high. This ratio is generally limited to 3:1, but with appropriate dies, it can be higher. Higher ratios can be accommodated if the diameter of the die cavity is not more than 1.5 times the diameter of a round bar.

Piercing. This is a process of indenting, but not breaking through, the surface of a workpiece with a punch, in order to produce a cavity or an impression (Fig. 14.13). The workpiece may be confined in a container, such as a die cavity, or may be unconstrained. The surface deformation of the workpiece will depend on how much it is constrained from flowing freely as the punch penetrates. Piercing may be followed by punching to produce a hole in the part; see the slug above the stationary punch in the central portion of Fig. 14.9.

The *piercing force* depends on (a) the cross-sectional area and the tip geometry of the punch, (b) the strength of the workpiece material, and (c) friction at the punch-workpiece interfaces. The pressure may range from three to five times the strength of the material, which is about the same level of stress required to make an indentation in hardness testing (see Section 2.6).