14
Design for Hot Forging

14.1 INTRODUCTION

Hot forging, also referred to as drop forging, is a process that can be used to produce a wide variety of parts in most metals. Forgings are produced in sizes ranging from a few millimeters maximum dimension up to 3 m or more in some cases. The principles and practices of hot forging have been established since the last century, but improvements have obviously been made in equipment, lubricants, and the ability to process the more difficult to forge materials since that time. The basic procedure for hot forging is relatively straightforward. Metal stock in the form of either a bar or a billet is first heated into the hot working temperature range to improve ductility. Then the material is squeezed or hammered in a series of tool steel dies to convert the stock into the finished shape. Excess material in the form of flash is produced as a necessary part of forging, and the final processing stage is to remove the flash to yield the finish forged part. Hot forging is a near net shape process, but all forgings require some subsequent machining, in particular for surfaces that must locate with other surfaces during the final assembly of a product.

14.2 CHARACTERISTICS OF THE FORGING PROCESS

Most forgings require a series of forming stages, called preforms, to convert the initial stock material into the finish-forged shape. The number of preforms required depends on several factors, including the overall shape, shape complexity, and material of the part. Forging complexity is increased by several features, including:

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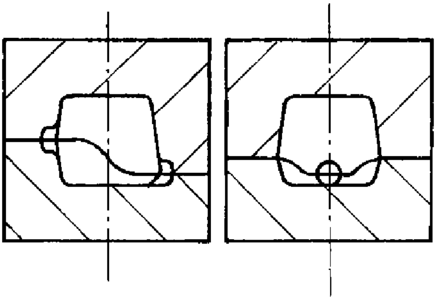

FIG. 14.1 Forging requiring a cranked parting line.

The presence of thin sections in the part
Large changes in cross-sectional area of the part
Part shapes that require the die parting line to be cranked (Fig. 14.1)

14.2.1 Types of Forging Processes

The main types of basic forging processes are referred to as open-die and closed-die forging. In open-die forging a series of relatively simple dies is used to form the final forging incrementally with a large number of blows. This process is largely a more automated version of the old blacksmith-type operations that have been used for centuries. The discussion in this chapter will not include open-die forging, since the process is used to form relatively crude final shapes, but discussion will be devoted to closed-die forging, which is used for the manufacture of a wide range of part shapes.

In closed-die forging a series of shaped dies is used to convert the initial stock into the finish-forged shape. The term "closed-die" forging is something of a misnomer, as the die cavities are not completely closed and material in the form of flash flows out at the die parting line during the final stages of forging. This flash is a critical part of the forging process, and proper control of the flash is essential to ensure die filling. Within closed-die forging two other terms are used: blocker forgings and precision forgings. Blocker forgings, compared to conventional forgings, have thicker sections and more generous radii. They are termed blocker forgings because the performing shape prior to the finishing impression is traditionally called a blocker.

Blocker forgings are easier to form than equivalent conventional forgings, requiring fewer forming stages and lower loads. They are used sometimes when small quantities of parts are required, to reduce die costs, or in difficult-to-form materials, when it is hard to obtain thin sections or there are other problems.

Blocker forgings require more subsequent machining to reach the final part shape than conventional forgings.

Precision forgings are parts formed with thinner sections and closer tolerances than equivalent conventional forgings, i.e., nearer to net shape. Such forgings require careful processing, and peak loads during the final forming stages are 2.5 to 3 times higher than those experienced for equivalent conventional forging (see Sec. 14.7). Thus larger equipment and more precise die-to-die positioning is required. Although the term precision forging implies closer precision than is normally obtained for any material, in practice precision forgings are more often produced in light alloys (aluminum alloys, magnesium alloys, etc.) than in other materials.

14.3 THE ROLE OF FLASH IN FORGING

The flash produced during closed-die forging is scrap material and may in many cases have a volume that is more than 50% of the final part volume. The amount of flash produced increases with the complexity of the part. However, the production of flash is a necessary part of the process, and its control is essential to ensure good die filling, particularly for tall, thin shape features. Figure 14.2 shows the deformation that takes place during the forging of a relatively simple axisymmetrical forging. At the start of deformation the initial stock material

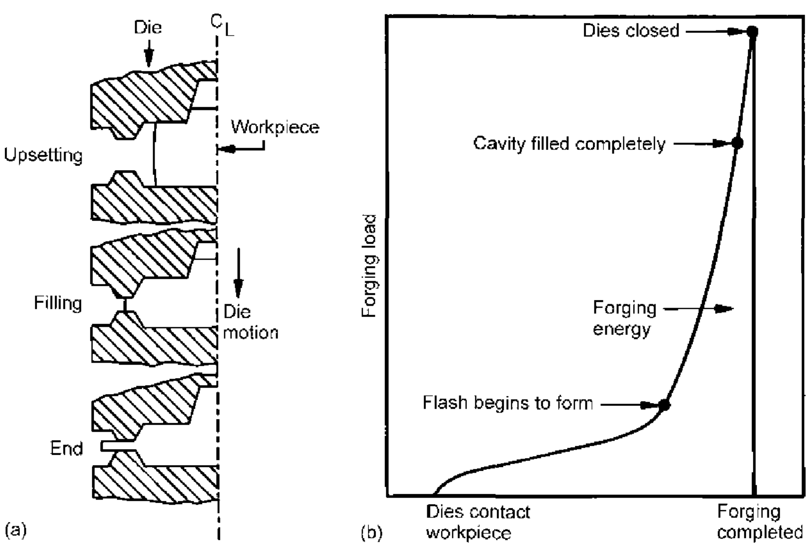

FIG. 14.2 (a) Forging of a simple axisymmetric part. (b) Load variation during the stroke for forging the part. (From Ref. 1.)

(billet) is being upset, and the corresponding forging load is relatively low. Upsetting-type deformation is the most natural form of deformation between dies and the material flows sideways, to form a flattened shape. However, if material is to be forced to move into the extremities of the die cavity, this sideways material flow must be restricted. This is the role of flash formation. A narrow flash land around the split line of the dies restricts the sideways flow of the material. In the final stages of die closure material is extruded through the flash land into the flash gutter around the forging cavity. As the deformation proceeds, the narrowing gap between the flash lands begins to restrict the sideways flow of material, through increased friction and other forces. The forging load begins to rise and the pressure inside the die increases. This increased pressure causes material to flow backwards in the direction of die closure and into the extremities of the die cavity. At the final stage of die closure, the forging load reaches its peak and this corresponds to complete die filling. At this point the last part of the flash is being squeezed through the flash land. The selection of appropriate values for the flash land geometry (gap and width) is critical to good die filling during forging, without excessive forging loads and cavity pressures.

14.3.1 Determination of the Flash Land Geometry

Figure 14.3 shows a typical arrangement for the flash land and the flash gutter on a forging. The gutter must be large enough to accommodate the flash produced. The choice of the appropriate width and thickness of the flash land is an important part of the forging process design. If the geometry is wrong, the dies may not fill completely or the forging loads may become excessive. In addition, the projected area of the flash in the flash lands is usually included in the total projected area of the part for estimation of the forging loads required and

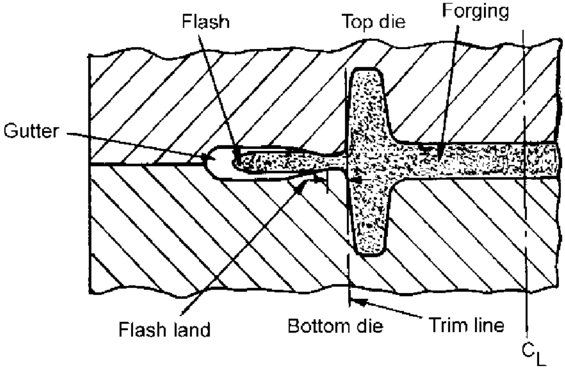

FIG. 14.3 Flash land and flash gutter configuration.

TABLE 14.1 Selected Empirical Formulas for Flash Land Geometry

Reference	Flash thickness, T_f (mm)	Flash land ratio, W_f/T_f
Brachanov and Rebelskii [3]	$0.015A_p^{0.5}$	—
Voiglander [4]	$0.016D + 0.018A_p^{0.5}$	$63D^{0.5}$
Vierrege [5]	$0.017D + 1/(D+5)^{0.5}$	$30/[D\{1 + 2D^2/(h(2r + D))\}]^{0.33}$
Neuberger and Mockel [6]	$1.13 + 0.89W^{0.5} - 0.017W$	$3 + 1.2e^{-1.09W}$
Teterein and Tarnovski [7]	$2W^{0.33} - 0.01W - 0.09$	$0.0038ZD/T_f + 4.93/W^{0.2} - 0.2$

A_p, forging projected area (mm^2); W, forging weight (kg); D, forging diameter (mm); Z, forging complexity factor.

therefore is a determining factor in equipment selection for processing. Determination of the flash land dimensions has been based on experience with forgings of a similar type. As a result there are a number of empirical formulas available for the flash land geometry, and a selection of these is given in Table 14.1 [2].

The first two formulas take no account of the forging complexity and the third formula is based on a limited number of axisymmetric forgings. The fourth and fifth formulas are based on statistical analysis for a large number of forgings and have been shown to be reliable [2, 8], each giving similar results. The fourth formula is used here for the cost estimation procedures described below, because it is simpler to evaluate. This formula is based on data for steel forgings, but it is assumed to be applicable to all materials and is used in the following form in which the main input variable is part volume, V, as opposed to part weight.

$$\text{Flash thickness, } T_f = 1.13 + 0.0789\, V^{0.5} - 0.000134V \quad (14.1)$$

$$\text{Flash land ratio, } W_f/T_f = 3 + 1.2e^{-0.00857V} \quad (14.2)$$

This formula is used to determine the area of the flash during forging. The land width, W_f is multiplied by the length of the flash line of the finish forging die (perimeter of the part, P_r).

Example

Figure 14.4 shows a simple steel forging that will be used to illustrate the subsequent calculations in this Chapter. The basic data for this part are as follows:

Part volume $V = 49.9\ cm^3$
Projected area $A_p = 78.6\ cm^2$
Perimeter $P_r = 31.4$ cm

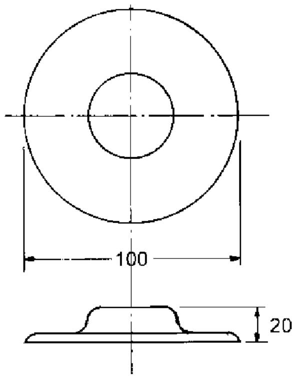

FIG. 14.4 Steel forging for sample calculations.

For this part the flash parameters can be obtained from Eqs, 14.1 and 14.2.

$$T_f = 1.13 + 0.0789\,(49.9)^{0.5} - 0.000134\,(49.9) = 1.68\text{ mm}$$

$$W_f/T_f = 3 + 1.2e^{-0.00857(49.9)} = 3.78$$

From this W_f is $3.78 \times 1.68 = 6.35$ mm, and the projected area of the flash land is $0.635 \times 31.4 = 19.9\text{ cm}^2$.

14.3.2 Amount of Flash

Costs for the material in forging are determined by the weight of the finished forging and any material wasted in processing the part. Material losses result mainly from the flash produced during forging, but further losses may occur due to scale formation for those materials that oxidize significantly during heating and, for hammer forgings, due to bar ends, and so on. Estimation of the flash for a particular forging is difficult and is usually based upon experience with the manufacture of forgings of a similar type. The amount of flash produced varies with the shape of the part, and there are two basic systematic approaches to estimating the amount of flash that have been utilized.

1. Statistical data giving average ratios of the gross to net weight of forgings for different classes of part and weight are used. This approach has been utilized in different forms by Morgeroth [9], Kruse [10], and the FIA [11] for steel forgings.
2. The use of average values of the flash amount per unit length of the flash line for different weights of forging (e.g., Refs. 8 and 12).

For the estimating procedures described in this chapter, the second of these approaches has been used. Table 14.2 shows data relating the flash weight per unit length of flash line for different weights of forging. This data has been

TABLE 14.2 Flash Weight per Unit Length of Flash Line for Steel Forgings

Forging weight (kg)	Flash weight (kg/cm of periphery)
Less than 0.450	0.0047
0.450–2.273	0.0063
2.273–4.545	0.0098
4.545–6.818	0.013
6.818–11.364	0.0168
11.364–22.727	0.0223
22.727–45.455	0.0324
Above 45.455	0.0477

Source: Ref. 8.

recommended by the United Kingdom National Association of Drop Forgers and Stampers (NADFS) and has been found to be reliable by companies who use it for flash estimation [7]. This data is for the forging of steel and it has been assumed that the equivalent volume is produced in other materials. This equivalent volume of flash can be obtained by dividing by the density of steel. An expression has been fitted to this data to enable the volume of flash per unit length of flash line to be estimated, and this relationship is as follows:

The volume of flash per unit length of flash line, V_{fl}, is given by

$$V_{fl} = 0.1234V^{0.5} \text{ cm}^3/\text{cm} \qquad (14.3)$$

Example

For the part shown in Fig. 14.4 the volume of flash per centimetre of flash line from Eq. 14.3 is $V_{fl} = 0.1234\ (49.9)^{0.5} = 0.87 \text{ cm}^3/\text{cm}$ or the total volume of flash generated is $0.87 \times 31.4 = 27.3 \text{ cm}^3$.

14.3.3 Webs in Forgings

Webs are thin sections with a large projected area in the direction of die closure. Webs are often designed into the parts for strength and other reasons, often accompanied by peripheral ribs. These webs add considerably to the load requirements during forging operations because of the large die contact areas, which increase cooling rates, friction, and so on. If the finished part has through holes to be forged in, then these must be filled with webs at the die parting line and then these webs are removed by shearing (piercing) during the flash removal process. The material in these webs is additional waste material and add to the material cost per part.

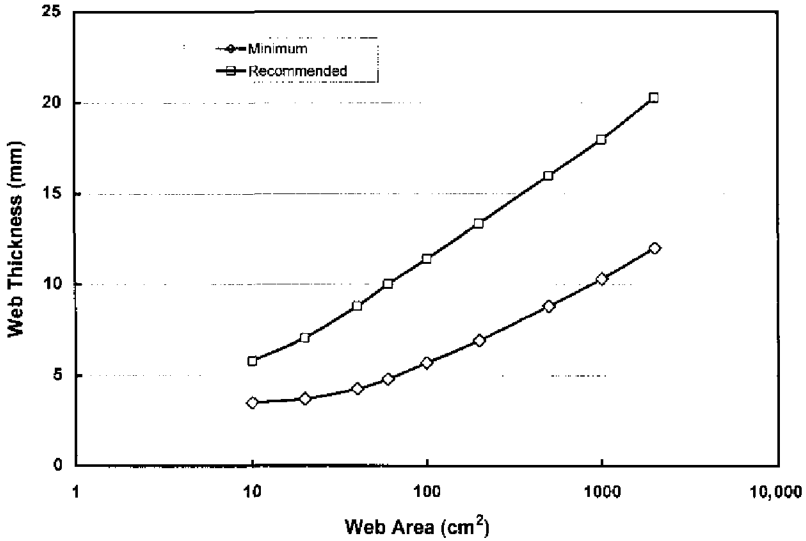

FIG. 14.5 Web thickness related to projected area. (From Ref. 2.)

The appropriate thickness of the webs is dependent on the projected area of the holes to be filled, as shown in Fig. 14.5, from which the following relationship is obtained:

$$\text{Web thickness } T_W \text{ (mm)} = 3.54\, A_H^{0.227}, \tag{14.4}$$

where A_H is the area of the holes in square centimeters.

14.4 FORGING ALLOWANCES

Parts produced by hot forging require machining on surfaces that will locate with other parts in a final product. Thus the detailed shape features of a forging are developed from the required-machined part by adding various allowances to the machined surfaces, although some of these allowances also form part of the forging design for surfaces that will not be machined. Figure 14.6 shows the cross section of a simple forging, which is assumed machined all over. The first allowance added to the machined surface is a finish or machining allowance. This amount is in addition to any dimensional tolerances and must be sufficient to result in a clean surface after finish machining. The allowance for machining is dependent on several factors, but particularly on the amount of oxidation that will result from heating the part up to the forging temperature. The level of oxidation will be dependent on the material type and on the overall size of the forging. Figure 14.7 shows typical finish allowances for different materials [13].

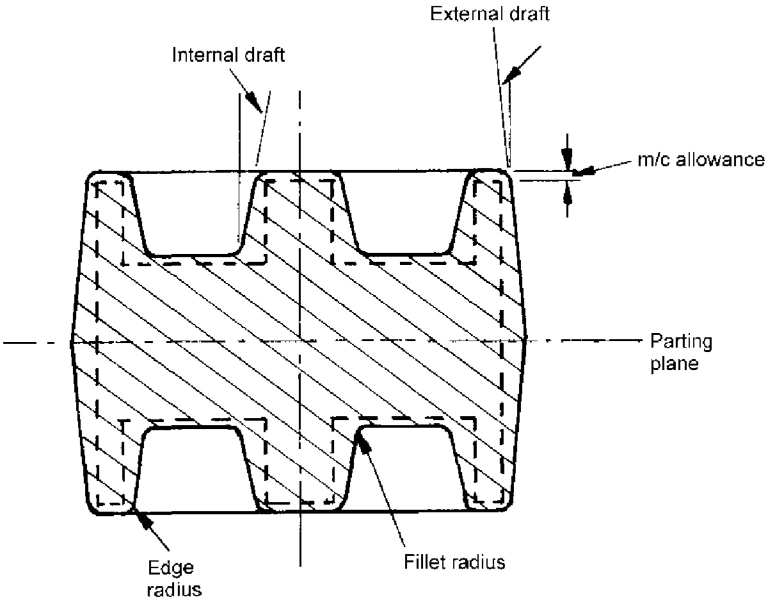

FIG. 14.6 Forging allowances for finish machining and draft.

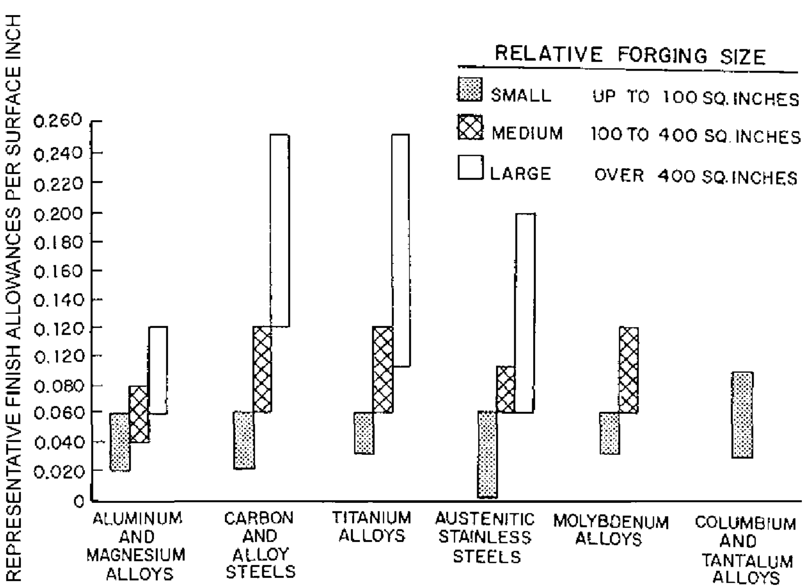

FIG. 14.7 Finish machining allowances for different materials. (From Ref. 13.)

TABLE 14.3 Draft Allowances for Forgings

	Hammer dies		Press dies	
Materials	External	Internal	External	Internal
Steels				
Aluminum alloys	5–7°	7–10°	3–5°	5–7°
Titanium alloys				
Ni-based alloys				
Tolerances in all cases	±1°	±1°	±1°	±1°

Source: Ref. 2.

Draft is an angle allowance added to surfaces parallel to the direction of die closure to facilitate release of the part from the die after forging. In general, draft allowances on inside surfaces are greater than those on outside surfaces, because of the tendency of the part to shrink onto projections in the die as cooling takes place. Table 14.3 gives recommended values of draft angles for both presses and hammers [2].

Finally, all edges and corners in the part must have radii added. These radii are necessary to aid material flow and ensure good die filling. In addition, sharp corners in dies can lead to premature die failure due to fracture as a result of associated stress concentrations, high stresses and so on. Table 14.4 shows typical recommendations for edge and fillet radii for different materials. In general, larger radii are recommended for the more difficult-to-forge materials.

TABLE 14.4 Typical Minimum Edge and Fillet Radii for Rib/Web Type Forgings

Material	Corner radius (mm)	Fillet radius (mm)
Aluminum alloys	2.3	9.7
Low alloy steels	3.0	6.4
Titanium alloys	4.8	12.7
Nickel-based superalloys	6.4	19.0
Iron-based superalloys	4.8	17.0
Molybdenum	4.8	12.7

Source: Adapted from Ref. 13.

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14.5 PREFORMING DURING FORGING

In practice very few forgings are produced in the one stage indicated in Fig. 14.2. This will usually result in excessive amounts of flash to ensure die filling and/or large die loads. Thus in most cases a series of preforming operations are necessary to gradually bring the stock material closer to the finished shape before the last forming stage in the finishing die cavity (finisher). The number and type of preforming operations depend largely on the finished forging shape. Figure 14.8 shows a typical sequence for a simple connecting-rod forging [1].

In most cases the starting point of forging is a simple shape—either a length of round or square section bar or a billet cut off from bar stock. The object of

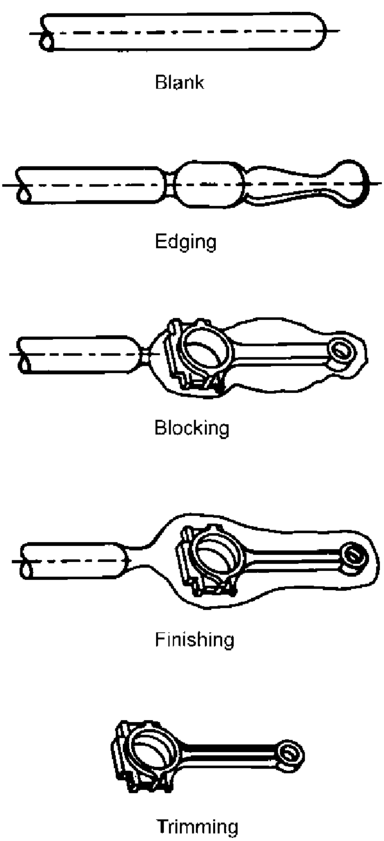

FIG. 14.8 Typical forging sequence for a connecting rod. (From Ref. 1.)

preforming is to redistribute the stock material to correspond more closely to the finished shape. The design of preforms is still something of a “black art,” relying heavily on the skills of experienced personnel. Progress has been made in the application of finite element and upper-bound plasticity analyses to the design of preforms, but this is still the subject of some research [14, 15].

Most flat or compact forgings start from billets and can usually be produced in two to four forming stages. The first forging stage is usually a simple die, which may just be flat faces, called a buster or scale-breaking die. The purpose of this die is to do some initial flattening of the billet, largely to remove the scale produced by oxidation during heating. For simple shapes the material may then be forged in the finishing die. However, for most parts one or two more preforming stages will be necessary. The preform prior to finishing is called a blocker (sometimes called a semifinisher or in the United Kingdom a molding impression). The blocker is essentially a smoothed-out version of the finisher with thicker sections and larger radii. There are some well-accepted design rules for blocker cross sections [16]. Figure 14.9 shows some typical blocker sections relative to finisher cross sections. If the final part has thin and/or tall features (thin ribs and webs), then a preblocker may also be required and this will have thicker sections and larger radii than the blocker.

For long parts, the starting point is usually the heated end of a bar of material of constant cross section. The initial preforming stages are relatively simple open-die forging operations, the purpose of which is to distribute the material along the length of the forging to correspond more closely to the mass distribution of the finished part. This is achieved by using relatively simple dies called fullers, followed by a die called an edger (or in the United Kingdom a roller die). Figure 14.10 shows a typical sequence for forging a connecting rod. Fullers are used to elongate and draw down the bar stock as appropriate. Fullers have crowned faces and the stock is placed between the dies, with one or two blows taking place. The stock is then rotated through 90 degrees and the process is repeated. Usually only one fuller stage is used, but if there are two or more major changes in cross-sectional area along the length of the part, more than one fuller may be used. After fullering, the edger or roller die is used to smooth out the stock material and to further elongate it somewhat.

For the connecting-rod example in Figure 14.10, after two fullering stages and one edger die, the result is a dumbbell shape, with approximately round cross sections and with an axial mass distribution similar to the finished shape. These initial mass-distribution-preforming stages can be done on reducer rolls, which use a series of shaped rolls to elongate and draw down the bar stock. Reducer rolls are sometimes used in conjunction with mechanical presses for higher productivity.

Following these initial mass-distribution-preforming stages, the cross sections of the part are then formed to correspond to the finished shape. For simple shapes this may be done directly in the finishing cavity, but usually a blocker die is used,

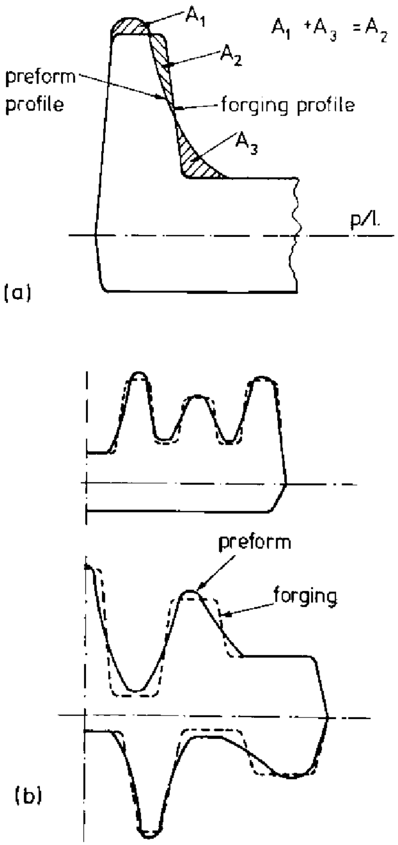

FIG. 14.9 Typical blocker cross sections compared to the finish forging cross sections. (a) General design procedure. (b) Sample cross sections. (From Ref. 17.)

and for forgings with very thin sections a preblocker may also be required. The usual reason to include a blocker forging stage is to increase the life of the finishing-die impression before resinking is necessary. Whether a blocker die is required is usually decided based on experience with similar parts and on the total quantity of forgings required. For simple forgings no blocker impression may be needed. Chamouard [16] gives recommendations for the use of blocker impressions for rib/web type forgings, based on the rib height to rib thickness ratio. A blocker impression is recommended when this ratio exceeds 2.5.

Blocker forging cross sections are essentially smoothed-out versions of corresponding sections in the finished forging, with thicker sections and larger radii. The

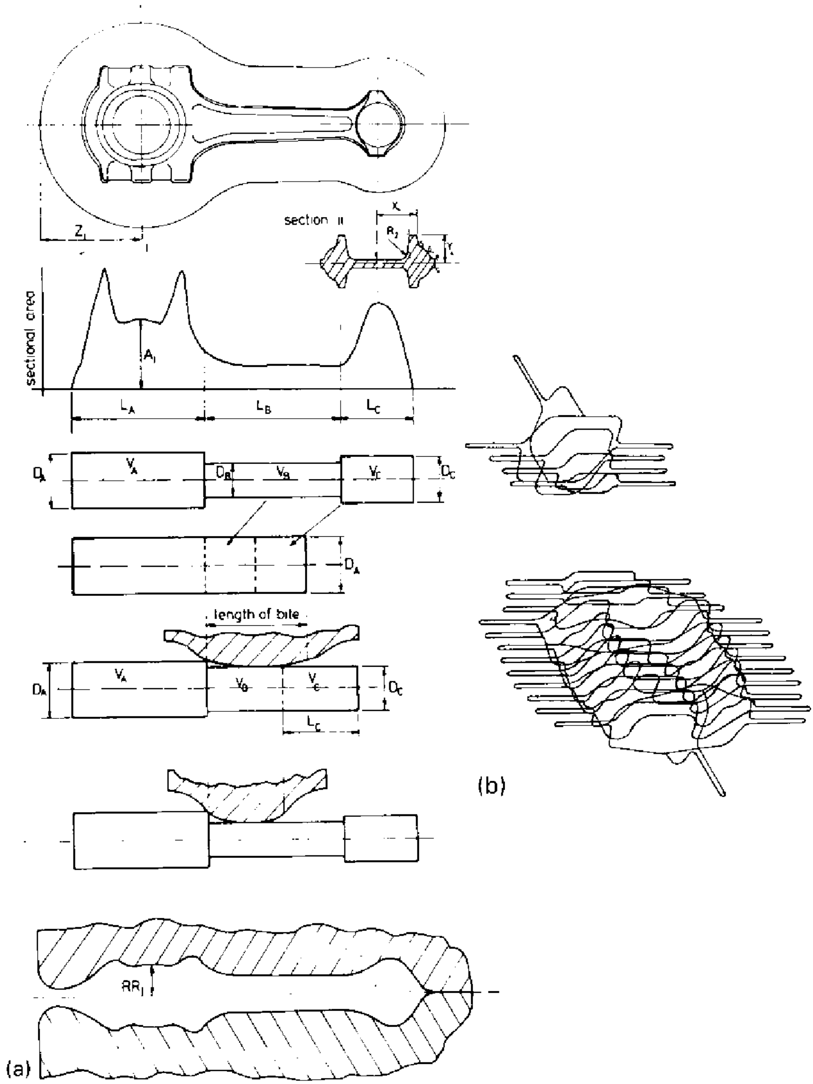

FIG. 14.10 Forging sequence design for a connecting rod. (a) Mass distribution stages. (b) Blocker cross sections. (From Ref. 17.)

blocker sections are designed by modifying the corresponding finished sections, using empirically established design rules. For a connecting-rod forging several transverse sections along the length of the part would be selected, together with radial sections at the ends (Fig. 14.10). From these sections corresponding blocker sections are developed, and these define the shape of the blocker die impression. For rib/web-type cross sections, blocker sections have been developed using logarithmic curves, based on the recommendations of Chamouard [16].

If the final forging has bends in the longitudinal axis, a bending operation will be added to the sequence. In this case the mass-distribution-preforming stages (fullers and edgers) will be developed with the axis of the part straightened out, followed by the bending impression. Any blocker stages will be carried out on the bent stock, and again the corresponding die will be developed from cross sections of the finishing impression.

14.5.1 Die Layout

As seen above, several die impressions will be needed to process a hot forging completely. For small and medium-sized hammer forgings these impressions will be laid out on a single die block. Figure 14.11 shows two typical examples [18].

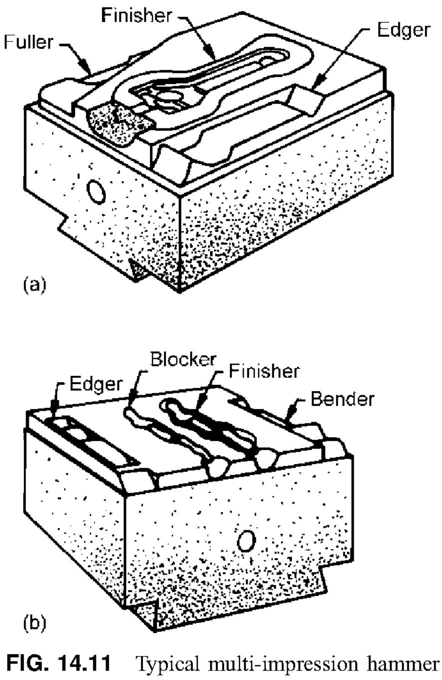

FIG. 14.11 Typical multi-impression hammer forging dies. (From Ref. 18.)

For larger forgings the various stages may be carried out on separate machines with reheating of the forging stock between stages. For press forgings the various die impressions may be machined into one die block or into separate die inserts attached to the machine bed.

For multiple impression dies the various impressions must be laid out on the die surface to enable successful forging with a minimum-sized die block. The die block depth should be sufficient to enable several resinks of the cavities as wear occurs. A number of factors must be taken into account in the layout of die impressions, including the minimum spacing between cavities, which depends among other things on the cavity depth. In general, the finisher and blocker impressions are placed in the center of the die block, with the fullers to one side and the edger and/or bending die to the other (Fig. 14.12). The finisher is positioned such that the center of loading corresponds to the dowel pin that is used to position the dovetails on the back of the die on the hammer bed. If more than one forging is to be made at once, the finisher and blocker impressions can sometimes be nested to conserve space. The fuller dies are usually inclined at 10 to 15 degrees across the left-hand corner of the die block, again to conserve space. For the purposes of estimating die block size the following cavity-spacing rules, derived from data provided by Thomas [2], can be used.

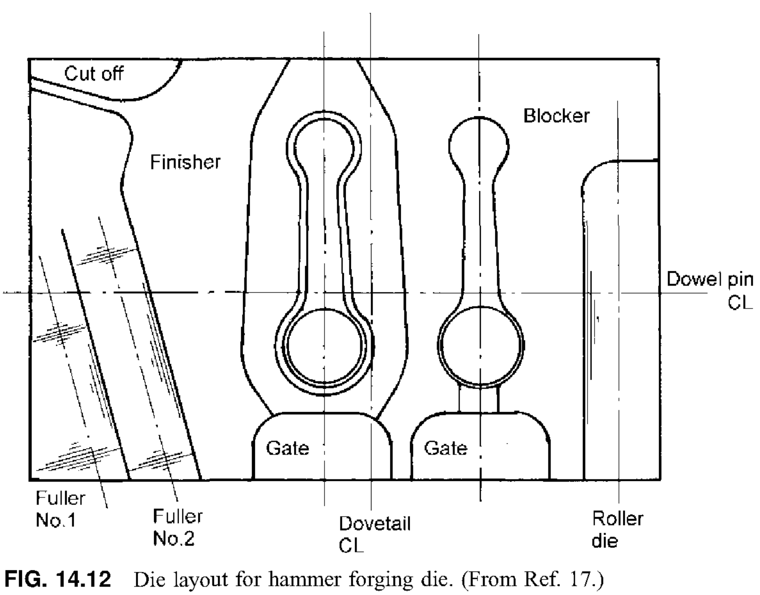

FIG. 14.12 Die layout for hammer forging die. (From Ref. 17.)

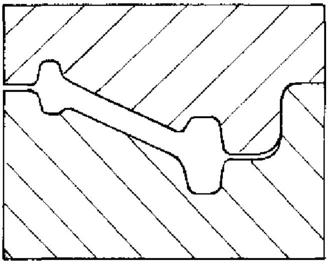

FIG. 14.13 Typical die lock configuration. (From Ref. 2.)

Cavity depth $d_c = 0.5\ T$, where T is the part thickness
Cavity spacing $S_d = 3.1(d_c)^{0.7}$
Cavity edge distance $S_e = 3.4(d_c)^{0.76}$
Die block depth $= 5\ d_c$

Die locks or registers are provided on some dies to prevent mismatch during forging for parts with cranked parting lines. Die locks absorb the side loads produced, but add to the size of the die block and increase the machining costs of the die blocks. Figure 14.13 shows a typical die lock configuration. To be effective the die lock must engage just before the top die comes into contact with the forging stock. An overlap of 10 to 12 mm is recommended, and to allow adequate strength the width of the lock should be at least 1.5 times the depth [1]. If the die parting line is only marginally cranked, a die lock may not be required, but for the purposes of the classification of forgings below it will be assumed that locked dies will be necessary for forgings with cranked parting lines.

14.6 FLASH REMOVAL

The final stage in hot forging is the removal of the flash to yield the finish forging. The flash removed is scrap material and can be more than 50% of the material used for some forgings. The flash is usually removed with a trimming die, which shears the flash off at the parting line of the forging. The webs in any through holes will also be pierced out at the same time. Flash trimming will usually be done on a mechanical press adjacent to the main forging machine, with the forging still hot. In some cases flash trimming may be done later when the part is cold. The operation and the dies used are similar for both hot and cold flash trimming, but the press loads are higher for cold flash trimming. The flash may also be removed by a machining operation, such as band sawing, but this is slow and relatively expensive. Consequently, band sawing should only be considered for small quantities of parts or for some larger forgings.

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Trimming and piercing dies have a shearing edge corresponding to the parting line of the forging. The complexity is therefore increased by the need for a cranked parting line. The corresponding punch forces the forging through the trimming die to remove the flash, and the design of the punch must be such that this can be achieved without distortion or damage to the forged part.

14.7 CLASSIFICATION OF FORGINGS

A number of classification schemes for forgings have been developed over the years [19]. These range from relatively simple pictorial systems to quite complex numerical coding schemes. The general objective has been to indicate forging complexity in some way in order to relate this difficulty to different aspects of the forging process design. Several early systems were proposed to systematically provide data on typical gross to net weights for different forging types for estimating purposes [9–11].

A relatively complex classification and coding scheme was used in a *Design for Forging Handbook* [20] in order to indicate general forging costs [21]. This classification scheme covered the presence of individual shape features of the forging such as holes, depressions, bosses, ribs, and so on. Parts were allocated to different classes dependent on the presence of these features. For the purposes of the current procedure a more simplified approach based not on the presence of specific features, but on numerical evaluations of complexity, is used [12]. Parts are first divided into main classes determined by the overall dimensions of the rectangular envelope that encloses the part (Fig. 14.14). For long forgings with a bent axis this envelope is determined after the part has been straightened out. This

First Digit	Description	
0	Compact Parts, L/W <= 2, L/T <= 2	
1	Flat Parts, L/W <= 2, L/T > 2	
2	Long Parts, L/W > 2	Main Axis Straight
3		Main Axis Bent

L = Envelope Length
W = Envelope Width
T = Envelope Thickness
L >= W >= T

FIG. 14.14 Forging classification, allocation of first digit.

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initial broad classification divides parts according to the basic sequence of operations required for processing.

Class 0: Compact Parts ($L/W \leq 2.0$, $L/T \leq 2.0$)

The basic sequence of operations for this class is

Scale break (buster)
Blockers (one or two)
Finisher
Clip and pierce to remove flash and webs for through holes

The forging complexity for this class is increased by the presence of

Thin sections
Cranked die split lines
Forged in side depressions

Class 1: Flat Parts ($L/W \leq 2.0$, $L/T > 2.0$)

The basic sequence of operations for this class is

Scale break (buster)
Blockers (one or two)
Finisher
Clip and pierce to remove flash and webs in through holes

The forging complexity for this class is increased by the presence of

Thin sections
Ribs and webs
Cranked die split lines
Forged in side depressions

Second Digit	Description	
0	Parting Line Flat	No Side Depressions
1	Parting Line Not Flat	
2	Parting Line Flat	Side Depressions
3	Parting Line Not Flat	

FIG. 14.15 Allocation of second digit for compact and flat parts.

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Second Digit	Description
0	Parting Line Flat
1	Parting Line Not Flat

FIG. 14.16 Allocation of second digit for long parts.

Classes 2 and 3: Long Parts ($L/W > 2.0$)

The basic sequence of operations for these classes is

Fullers (one or two)
Edger (roller)
Bender (for bent parts)
Blockers (one or two)
Finisher
Clip and pierce to remove flash

In some cases, passes through reducer rolls may replace the first two stages.

The forging complexity for these classes is increased by the presence of

Large changes in cross-sectional area
Thin sections
Ribs and webs
Cranked die split lines

Example

For the part shown in Fig. 14.4, $L = W = 100$ mm and $T = 20$ mm. Thus $L/W = 1$ and $L/T = 5$. The first digit is 1 (flat part). There are no side depressions and the parting line is flat, so the second digit is zero.

14.7.1 Forging Complexity

Two numerical indications of forging complexity are used: the shape complexity factor and the number of surface patches in the part.

Shape Complexity Factor

This factor is a modification of that used in the European tolerancing standards for forgings to indicate complexity [23], i.e.

$$\text{Complexity factor } F_{\text{fc}} = \frac{\text{volume of rectangular envelope for part}}{\text{part volume}} = \frac{\text{LWT}}{V}$$

For bent parts, the axis is straightened before this complexity factor is calculated. This factor indicates in a general way the amount of deformation necessary within specific classes of forging, as the presence of thin sections and large changes in cross-sectional area result in increased values of this complexity rating. For the example part shown in Fig. 14.4, $F_{fc} = 4.00$.

Number of Surface Patches in the Part

This rating is similar to the counting procedure for surface patches used for cost estimation for injection molded parts as outlined in Chapter 8. The number of surface patches that make up the shape in the upper and lower cavities are counted up. All standard surface elements, such as planes, cylinders, cones, and so on, are given equal rating, but free form or sculptured surface elements are counted equal to four standard surface patches. This number is a measure of the forging complexity that indicates the presence of more complex shape features. For example, a multiribbed part will have increased numbers of surface elements present relative to a simpler forging.

14.8 FORGING EQUIPMENT

Hot forgings can be produced on a variety of equipment, including mechanical and hydraulic presses, friction screw presses, and hammers. This forging equipment can be divided into two basic types: work-restricted and stroke-restricted machines. In work-restricted machines the amount of deformation that can be achieved during each stroke or blow of the machine is limited by the energy or maximum force available. If the energy or force capacity is less than is required to deform the part, then more than one stroke or blow is needed. Machines that fall into this category are hammers, friction screw presses, and hydraulic presses. In stroke-restricted machines the amount of deformation that can be done is fixed by the stroke of the machine. If sufficient force or energy to carry out the operation is not available, then the machine will stall and a larger machine should be used. Mechanical presses fall into this category, as a crank or eccentric determines the amount of ram movement.

Hammers are the most common types of machine used [23], and the basic technology of forging hammers was developed in the last century. The choice of forging equipment depends on a number of factors, including part size and complexity, material, and the quality of the parts to be produced. Hammers are often preferred for small to medium batches because of quicker tool setups and lower overheads. They are also used for elongated and branch-type forgings because die areas can be provided for the larger number of preform dies required for such shapes. Additionally, mechanical presses are not available in very large load capacities, so, for large forgings, hammers or large hydraulic presses must be used.

14.8.1 Gravity Drop Hammers

Gravity drop hammers [18] are the oldest type of forging equipment available. The principle of operation is that the moving die block (tup) is raised by a lifting mechanism and then released, so that it falls onto the fixed die attached to the anvil. The amount of deformation that can be carried out is determined by the potential energy of the moving die block at its maximum height. This potential energy is converted into kinetic energy as the die block falls and is then dissipated in deformation of the workpiece. Various lifting mechanisms are used, including frictional means with boards, band brakes or belts, or a lifting cylinder employing steam, compressed air, or hydraulic fluid (Fig. 14.17). These machines are available in a range of blow energies from 0.6 kNm (60 kg-m) to 400 kNm (40,000 kg-m).

14.8.2 Double Acting or Power Hammers

These machines [18] are similar to gravity hammers in that a lifting cylinder raises the moving tup, but power is also applied to the downward-moving tup to increase the energy capacity. Energy ratings for similar tup weights are considerably more than for gravity hammers, and the die closing speeds are higher also. Power comes from double-acting steam, compressed air, or hydraulic cylinders. Double-acting hammers are manufactured in a range of energy ratings from 3 kNm (300 kg-m) to 825 kNm (82,500 kg-m).

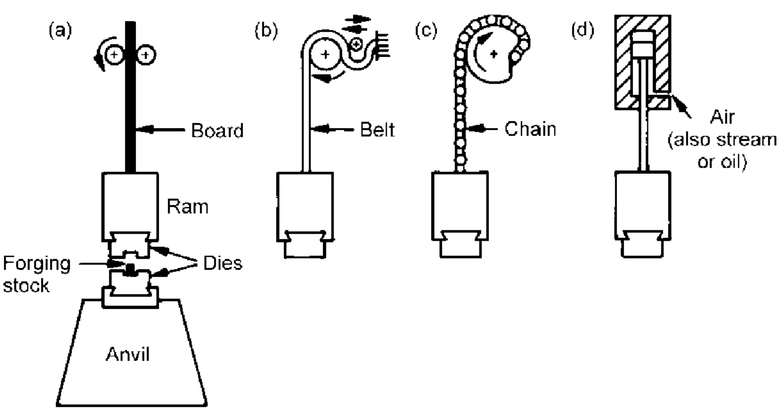

FIG. 14.17 Schematic of various types of drop hammer. (a) Board hammer. (b) Belt hammer. (c) Chain hammer. (d) Airlift hammer. (From Ref. 1.)

14.8.3 Vertical Counterblow Hammers

In these machines two tups with nearly equal masses are driven by double-acting cylinders toward each other and impact in the center of the machine. More energy is dissipated in the workpiece than in the foundations and subsoil compared to single-acting hammers. Very high energy capacities are available in the largest machines, with ranges from 30 kNm (30,000 kg-m) to 2000 kNm (200,000 kg-m).

14.8.4 Horizontal Counterblow Hammers

These machines are also called impacters and two rams are actuated by double-acting cylinders. Heated stock is positioned vertically between the dies by an automatic transfer mechanism. Energy ranges from 4 kNm (400 kg-m) to 54 kNm (5400 kg-m) are typical.

14.8.5 Mechanical Presses

In mechanical presses [18] a crank, knuckle joint, scotch yoke, or moving-wedge mechanism is used to apply a vertical squeezing motion between the upper moving die and a lower fixed die. Figures 14.18a and b show typical mechanical

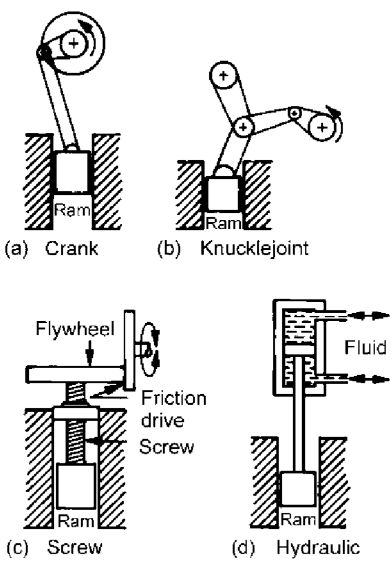

FIG. 14.18 Schematic of various types of forging press mechanisms. (a) Crank press. (b) Knuckle joint press. (c) Friction screw press. (d) Hydraulic press. (From Ref. 1.)

press mechanisms. In general, guidance of the two dies is better than in hammers, so improved die matching is possible. Press ratings from 3 MN to 140 MN (300–14,000 tons) are available. Thus, mechanical presses are not available for the largest of parts processed by forging.

14.8.6 Screw Presses

In screw presses [18] the upper ram and die are connected to a large vertical screw that can be rotated by a flywheel, so that the ram can move up and down relative to the fixed die in the bed of the machine (Fig. 14.18c). The ram has a limited amount of energy for each stroke; thus multiple blows are usually employed similar to hammers. Screw presses are available in ratings from 0.63 MN to 63 MN (63–6300 tons).

14.8.7 Hydraulic Presses

Hydraulic presses [18] are available in a wide range of sizes up to the largest at 50,000 tons or more capacity. The moving die is attached to a ram actuated by a large hydraulic cylinder (Fig. 14.18d). Various strokes, forces, and closing speeds can be obtained on hydraulic presses. In some cases hydraulic presses are fitted with auxiliary horizontally moving rams, and these enable side depressions to be forged into some parts, although this is not done to a great extent.

14.8.8 Choice of Forging Machine Type

In general, whether to use hammers or presses depends on a number of factors, but some guidelines exist [23].

Circular or ring forgings in steels are particularly suited to crank presses until the dimensions of the forgings result in loads in excess of the range of mechanical presses, when power or counterblow hammers become necessary.

TABLE 14.5 Some Comparative Data for Forging Equipment

Hammers	Maximum blow energy (kJ)	Die closing speed (m/s)
Gravity drop	47–120	3–5
Power drop	1150	4.6–9
Counterblow	1220	4.6–9
Impacter	34	10–17
Presses	Force (MN)	—
Mechanical	2.2–143	0.06–1.5
Screw	1.3–280	0.5–1.2
Hydraulic	2.2–623	0.03–0.8

Source: Ref. 24.

Asymmetrical and branched forgings tend to be produced on hammers, as more total die area is required than is available on mechanical presses of appropriate load capacity.
Large circular forgings are manufactured using hammers because of the large force requirements.
Close-to-form blade-type forgings tend to be made using screw presses or with wider tolerances on hammers.
Thin-plate-type forgings with edge ribs, together with light alloy precision forgings are usually produced on hydraulic presses.
Smaller batch sizes tend to be made on hammers rather than presses.

14.8.9 Comparisons of Forging Equipment

Table 14.5 [24] shows some comparative data for the different types of forging equipment. As can be seen, die-closing speeds are significantly higher for hammers compared to presses. This has relevance for the forging of strain rate sensitive materials. Table 14.6 shows the ranges of the different types of forging equipment available. The different machines are compared based on their maximum deformation energy capacity. However, this comparison is not related to the energy available per blow or stroke of the machine, but is based on the energy requirements for parts typically processed on the size of machine indicated. The relative comparisons between machines are derived from ratios presented in Dallas [24] and other reports. The ratings at the top of each column are those normally used in industry, with hammers usually rated by the weight of the tup and presses by the load capacity in tons. As can be seen, mechanical presses are not usually available above 14,000 tons capacity; thus large forgings must be produced on either hammers or hydraulic presses, with the very largest restricted to counterblow hammers or large hydraulic presses.

Figure 14.19 shows typical average usable blow or stroke rates for forging equipment. This data is largely based on data from Scott and Wilson [23], with some supplementary calculations from Dallas [24]. These blow rates are not the maximum obtainable from the equipment, but are typical usable blow rates, which reflect such factors as the time taken to manipulate the part between impressions. As can be seen, mechanical presses are capable of the highest usable blow rates for smaller parts, which is why they are preferred for higher productivity situations for parts that are appropriate. For large parts the usable blow rates become comparable for the various types of equipment, because the time taken to manipulate the forgings between blows becomes dominant rather than the blow rate capabilities of the machines. These curves enable estimates of the forging cycle times to be made once an appropriate machine has been chosen.

TABLE 14.6 Equivalent Capacities of Presses and Hammers

Maximum energy ft-lb	Maximum energy kg-m	Hydraulic presses, rating (tons)	Counterblow hammers, rating (kg-m)	Power hammers, rating (lb)	Mechanical presses, rating (tons)	Gravity drop hammers, rating (lb)	Friction screw presses, rating (tons)
3,850	533	170	450	455	210	1,000	170
5,870	812	260	650	680	320	1,500	250
8,830	1,200	400	1,000	910	475	2,000	390
11,000	1,540	400		1,000	600	2,200	490
11,320	1,570	550		1,130	660	2,500	500
14,200	1,960	680		1,360	820	3,000	620
16,700	2,310	750	2,000	1,500	900	3,300	730
19,400	2,690	900		1,800	1,080	4,000	850
21,700	3,000	935	2,500	1,870	1,120	4,100	950
22,500	3,120	1,000		2,000	1,200	4,400	990
24,700	3,420	1,125		2,250	1,350	5,000	1,050
26,200	3,630		3,000				1,150
28,500	3,950	1,250		2,500	1,500	5,550	1,250
30,000	4,160	1,350	3,500	2,700	1,620	6,000	1,520
34,400	4,770	1,500	4,000	3,000	1,800	6,600	1,600
41,600	5,770	1,800		3,600	2,160	8,000	1,830
46,000	6,370	2,000	5,500	4,000	2,400	8,800	2,020
52,000	7,200	2,250	6,000	4,500	2,700	10,000	2,290
58,000	8,030	2,500		5,000	3,000		2,590
70,000	9,700	3,000	8,000	6,000	3,600		3,080
86,800	12,000	3,700	10,000	7,400	4,400		3,800
94,000	13,000	4,000		8,000	4,800		4,180
118,000	16,000	5,000	13,000	10,000	6,000		5,000
138,000	19,100	5,850	16,000	11,700	7,000		6,060
142,000	19,600	6,000		12,000	7,200		6,220
173,000	23,900	7,300	20,000	14,600	8,700		7,590
220,000	27,120	8,300	25,000	16,600	10,000		9,650
240,000	32,200	10,000	32,000	20,000	10,600		10,220
300,000	41,500	12,500	13,650	25,000	13,650		
361,500	50,070	15,000	40,000	30,000			
425,000	59,000	17,500		35,000			
	60,330	18,000		36,000			
484,000	67,036	20,000	50,000	40,000			
546,800	75,500		63,000				
610,000	84,500	25,000		50,000			
694,400	95,800		80,000				
738,000	102, 00	30,000					
868,000	120,200	35,000	100,000				
1,280,000	172,000	50,000	144,000				

From Ref. 20, with data from several sources (Refs. 24, 25).

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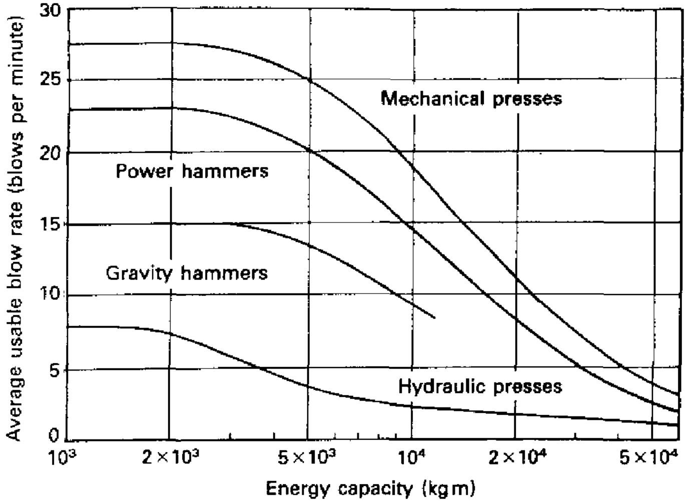

FIG. 14.19 Average usable blow rates for forging equipment. (From Ref. 12.)

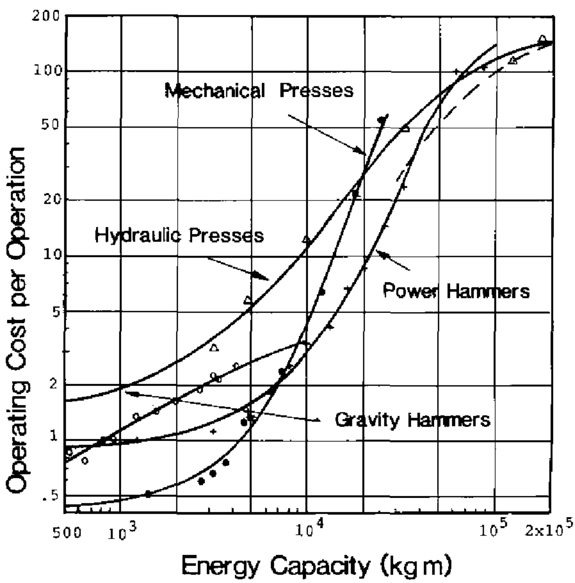

FIG. 14.20 Operating cost per operation relative to 1000-lb power hammer. (From Ref. 25.)

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Figure 14.20 shows data on the cost per operation for different types of forging equipment relative to the cost of a 1000 lb power hammer [25]. In this context, operation means forging stage (i.e. blocker, finisher, etc.). The data have been collected from a variety of industry sources and also reflect the fact that on average hammers utilize two or three times the number of blows per forming stage as is used on presses, for which only one per operation is assumed. Figure 14.21 [26] shows some combined curves for the data in Fig. 14.20. The curve for hammers is a combination of the data for all types of hammers. In the upper range of energy capacities the curve corresponds to counterblow hammers and at the

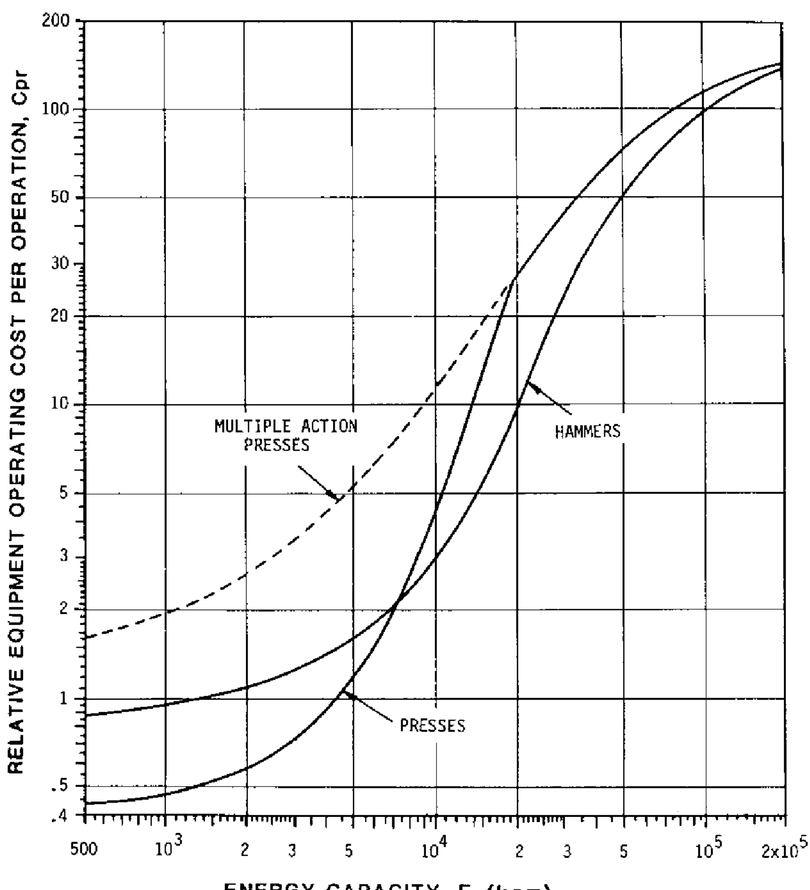

FIG. 14.21 Relative operating cost per operation for forging equipment. (From Ref. 26.)

lower ranges to power hammers. The curve for mechanical presses ends at the point of intersection with the curve for hydraulic presses. These curves can be used to estimate forging processing costs once the number of forging stages has been established.

TABLE 14.7 Classification of Forging Materials

Class	Materials	Load factor, α_m(kg-m/mm^2)	Die life factor, β_m
0	Aluminum alloys		
	Group A	0.054	1.0
	Group B	0.087	1.0
	Magnesium alloys	0.065	1.0
1	Copper and copper alloys	0.065	1.0
2	Carbon and alloy steels		
	Group A	0.065	1.0
	Group B	0.076	0.8
	Group C	0.087	0.7
	Group D	0.098	0.6
3	Ferritic and martensitic stainless steels	0.109	0.3
	Tool steels	0.109	0.3
	Maraging steels	0.109	0.3
4	Austenitic stainless steels	0.130	0.3
	PH stainless steels	0.141	0.3
	Nickel alloys of iron	0.130	0.3
5	Titanium and titanium alloys		
	α and α/β alloys	0.163	0.2
	β alloys	0.195	0.2
6	Iron-based superalloys	0.152	0.2
7	Cobalt-based superalloys	0.195	0.2
8	Nickel-based superalloys	0.220	0.1
9	Niobium (Columbium) alloys	0.195	0.1
	Molybdenum alloys	0.217	0.1
	Tantalum alloys	0.124	0.1
	Tungsten alloys	0.260	0.1
	Beryllium	0.065	0.5

Source: Ref. 20.

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14.9 CLASSIFICATION OF MATERIALS

A wide variety of materials can be used for forging, but by far the largest proportion of parts produced is from carbon and alloy steels, with a significant number also made from light alloys. Table 14.7 shows a general classification of materials used in hot forging [11, 20]. These material classes are arranged roughly in increasing order of forging difficulty. However, there is considerable overlap in these class. For example, many high-strength aluminum alloys are more difficult to process than steels. Increase in forging difficulty is represented by increased forging load requirements and usually reduced die life. In addition, for the more difficult to deform materials it may be impossible to obtain very thin sections (ribs and webs), and consequently the end product must be less close to net shape than for the easier to forge materials. Thus so-called precision forgings are usually associated only with light alloy materials.

Table 14.7 contains two factors that are used in cost estimating procedures described later. The first of these is a load factor α_m that gives the approximate deformation energy per unit area required for a relatively simple shape in the specific material. The second factor is a material die life factor β_m, which represents the approximate reduction in die life for the forging of similar shapes in different materials.

14.10 FORGING COSTS

Figure 14.22 shows the breakdown of the average forging costs for hot forgings found in industry [27]. Material costs usually make up around 50% of forging costs, and of this material, a significant proportion is waste material in the form of flash, scale losses, and so on. Die costs represent about 10% of forging costs and the remainder includes direct labor, equipment operating costs and overhead costs. For the purposes of early cost estimating, three main cost elements are considered.

1. Material costs, including flash and scale losses
2. Equipment operating costs, including labor, heating costs, ancillary equipment, and overhead
3. Die costs, including initial tooling costs and maintenance and resinking costs

Each of these will be considered in more detail in the following discussion. The early costing procedure described for hot forging is currently restricted to parts produced on hammers and forging presses using conventional dies. Preforming carried out on forging rolls is not considered, nor are such processes as ring rolling and hot upset forging.

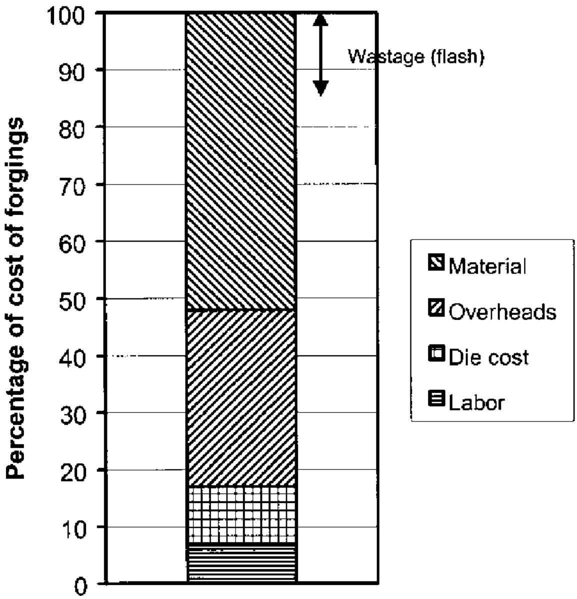

FIG. 14.22 Breakdown of average costs for hot forging. (From Ref. 27.)

14.10.1 Material Costs

The material costs for a forged part are determined as follows:

$$\text{Material cost } C_{mat} = C_m \rho [(V + P_r V_{fl} + A_H T_w)(1 + S_{sl}/100)], \qquad (14.5)$$

where

C_m = cost per unit weight of material
ρ = part density
V = the part volume
P_r = length of the flash line (perimeter of part)
V_{fl} = flash volume per unit length of flash line (Eq. 14.3)
A_H = area of through holes
T_w = web thickness recommended (Eq. 14.4)
S_{sl} = scale loss for material, %

Example

For the part shown in Fig. 14.4 the following data are available:

Part volume $V = 49.9$ cc

Flash volume per length of flash line $V_{fl} = 0.87$ cc/cm
Length of flash line $P_r = 31.4$ cm
There are no through holes

Assuming that $C_m = 1.1\$/\text{kg}$, $\rho = 7.86$ gm/cc, and $S_{sl} = 5\%$, then

$$C_{mat} = 1.1 \times 7.86[(49.9 + 31.4 \times 0.87)1.05]/1000 = \$0.43 \text{ per forging}$$

14.10.2 Equipment Operating Costs

The production cost per piece is basically expressed as

$$C_{pr} = M/R_p \tag{14.6}$$

where M is the operating cost per unit time of the equipment and R_p is the production rate (pieces per unit time). The operating cost per unit time, M, includes direct labor, ancillary equipment for handling and heating, and not just the operating cost of the main press or hammer used for the forging. It is usual for a separate press to be used for the trimming of the flash and piercing, and this is usually a mechanical press. The costs for this are determined separately. Thus the operating cost of the equipment used is given by

$$C_{pr} = MN_b/B_r \tag{14.7}$$

where N_b is the number of blows or strokes required to form the part and B_r is the effective blow or stroke rate of the press or hammer used. It should be noted that the number of strokes is usually equal to the number of operations if a mechanical or hydraulic press is used. For work-restricted machines such as hammers, several blows per operation are usually used, the average being between two and three blows per operation in general. This assumption has been used for generating the data in Fig. 14.21.

Thus, the operating costs of the equipment are dependent on the equipment selected for the forging and its effective stroke or blow rate. The required equipment must be selected based on the load or energy required for shaping the part. A variety of methods are available for estimating the load needed for a specific forging [18, 24, 28–32], including some relatively complex plasticity analyses. For the purposes of early cost estimation, it has been decided to modify the procedure outlined in the ASM handbook [18]. The plan area of the forging (including area of the flash in the flash lands) is multiplied by a material factor to give the energy capacity of the hammer required to forge the part. Variations of this approach are generally used by estimators in industry to determine the appropriate equipment to be used. However, the load or energy required for a forging is influenced by the shape complexity of the part in addition to the

Forging Data:

	Forging Shape Complexity Factor, F_{fc}							
Second Digit	**<= 1.5**		**>1.5 and <= 2.5**		**> 2.5 and <= 5.0**		**>5.0**	
0	1.6	0.95	1.7	0.9	1.9	0.75	2.2	0.55
	2		3		3		4	
1	1.6	0.7	1.7	0.6	1.9	0.5	2.2	0.3
	2		3		3		4	
2	1.6	2	1.7	0.6	1.9	0.5	2.2	0.3
	2		3		3		4	
3	1.6	0.65	1.7	0.5	1.9	0.45	2.2	0.25
	2		3		3		4	

Key: Shape Load Factor, α_s, upper left
Shape Die Life Factor, β_s, upper right
Number of Forging Operations, N_{op}, lower left

Forging Operations Required:

	Number of Forging Operations, N_{op}		
	2	**3**	**4**
Scale break, n_{sb}	1	1	1
Blocker, n_{bk}	0	1	1
Semifinisher, n_{sf}	0	0	1
Finisher, n_{fn}	1	1	1

Bender, $n_{bnd} = 0$; Edger, $n_{edg} = 0$; Fuller stage 1, $n_{fl} = 0$; Fuller stage 2, $n_{f2} = 0$

FIG. 14.23 Data for compact forgings, Shape Class 0.

material being forged. Thus, for the purpose of this early cost-estimating system, the following is used:

$$\text{Energy capacity } E_f = A_p \alpha_m \alpha_s \tag{14.8}$$

where

A_p = the projected part area including flash
α_m = material load factor (Fig. 14.7)
α_s = shape load factor

Once the energy capacity of the required equipment is known, a specific piece of equipment can be selected from Table 14.6 and the relative operating cost per operation determined from Fig. 14.21.

Forging Data:

Second Digit	Forging Shape Complexity Factor, F_{fc} <= 1.5	>1.5 and <= 3.0	> 3.0 and <= 6.0	>6.0
0	1.0 1.0 2	1.25 0.75 3	1.4 0.45 3	1.6 0.3 4
1	1.05 0.9 2	1.3 0.7 3	1.45 0.4 3	1.65 0.3 4
2	1.0 1.0 2	1.25 0.75 3	1.4 0.45 3	1.6 0.3 4
3	1.05 0.9 2	1.3 0.7 3	1.45 0.4 3	1.65 0.3 4

Key: Shape Load Factor, α_s, upper left
Shape Die Life Factor, β_s, upper right
Number of Forging Operations, N_{op}, lower left

Forging Operations Required:

	Number of Forging Operations, N_{op} 2	3	4
Scale break, n_{sb}	1	1	1
Blocker, n_{bk}	0	1	1
Semifinisher, n_{sf}	0	0	1
Finisher, n_{fn}	1	1	1

Bender, $n_{bnd} = 0$; Edger, $n_{edg} = 0$; Fuller stage 1, $n_{f1} = 0$; Fuller stage 2, $n_{f2} = 0$

FIG. 14.24 Data for flat forgings, Shape Class 1.

The material load factor is obtained from the material classification given in Table 14.7. The shape load factor reflects the increased load required to finish-forge more complex shapes. This factor is obtained from the classification scheme described above (Figs. 14.14 to 14.16). Figures 14.22 to 14.26 show the data associated with the classification. The appropriate shape load factor, α_s, is given in the upper left of each classification block. The other data include the shape die life factor, α_s (upper right), and the number of forging operations required, N_{op} (lower left). Shown in the lower part of these figures are the specific operations required for each value of N_{op}.

Forging Data:

	Forging Shape Complexity Factor, F_{fc}							
Second Digit	<= 2.0		>2.0 and <= 5.0		> 5.0 and <= 10		>10	
0	1.0 3	0.9	1.1 4	0.85	1.2 5	0.75	1.3 6	0.6
1	1.2 2	0.65	1.3 3	0.6	1.45 3	0.5	1.7 4	0.35

Key: Shape Load Factor, α_s, upper left
Shape Die Life Factor, β_s, upper right
Number of Forging Operations, N_{op}, lower left

Forging Operations Required:

	Number of Forging Operations, N_{op}			
	3	**4**	**5**	**6**
Fuller stage 1, n_{f1}	0	1	1	1
Fuller stage 2, n_{f2}	0	0	1	1
Edger, n_{edg}	1	1	1	1
Blocker, n_{bk}	1	1	1	1
Semifinisher, n_{sf}	0	0	0	1
Finisher, n_{fn}	1	1	1	1

Bender, $n_{bnd} = 0$; Scale break, $n_{sb} = 0$

FIG. 14.25 Data for long straight forgings, Shape Class 2.

14.10.3 Examples of Equipment Selection

Figures 14.27, 14.28, and 14.29 [12] show comparisons of the forging equipment capacities determined by this procedure, compared to the actual equipment used for a range of forgings in different classes. As can be seen, the correlation is generally good, except for the case of precision forgings in light alloy materials, where a factor of 2 to 2.5 is necessary to give the required result (parts F and M in Fig. 14.27) . Thus, for the purposes of early cost estimating, the basic calculation is applied to conventional forgings and this value increased by 2.5 for precision forging and multiplied by a factor of 0.9 for blocker-type forgings, to reflect the lower loads required in this case.

Forging Data:

	Forging Shape Complexity Factor, F_{fc}							
Second Digit	**<= 2.0**		**>2.0 and <= 5.0**		**> 5.0 and <= 10**		**>10**	
0	1.05	0.9	1.15	0.85	1.25	0.75	1.4	0.5
	4		5		6		7	
1	1.25	0.65	1.35	0.6	1.5	0.5	1.7	0.35
	4		5		6		7	

Key: Shape Load Factor, α_s, upper left
Shape Die Life Factor, β_s, upper right
Number of Forging Operations, N_{op}, lower left

Forging Operations Required:

	Number of Forging Operations, N_{op}			
	4	**5**	**6**	**7**
Fuller stage 1, n_{fl}	0	1	1	1
Fuller stage 2, n_{f2}	0	0	1	1
Bender, n_{bnd}	1	1	1	1
Edger, n_{edg}	1	1	1	1
Blocker, n_{bk}	1	1	1	1
Semifinisher, n_{sf}	0	0	0	1
Finisher, n_{fn}	1	1	1	1

Scale break, $n_{sb} = 0$

FIG. 14.26 Data for long bent forgings, Shape Class 3.

14.10.4 Forging Processing Costs

Once the appropriate forging equipment type and size and the forging complexity have been determined, the processing cost for the forging can be estimated. Equation 14.7 can be modified to the form:

$$C_{pr} = C_{op} N_{op} / N_c \tag{14.9}$$

where
C_{op} = the forging equipment cost per operation
N_{op} = the number of operations required
N_c = the number of identical forgings per cycle

The forging equipment operating cost per operation, C_{op}, is obtained from

$$C_{op} = C_{ro} C_{1000} \tag{14.10}$$

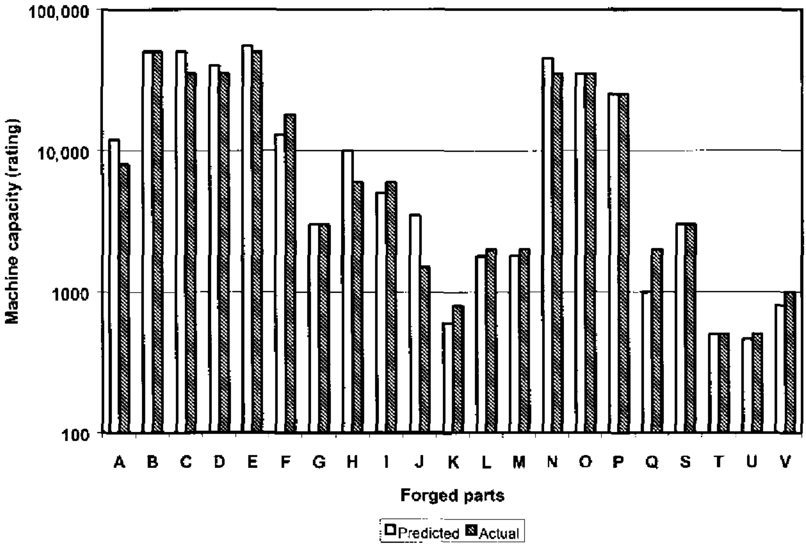

FIG. 14.27 Comparison between predicted and actual forging equipment capacities for flat, round forgings. (From Ref. 12.)

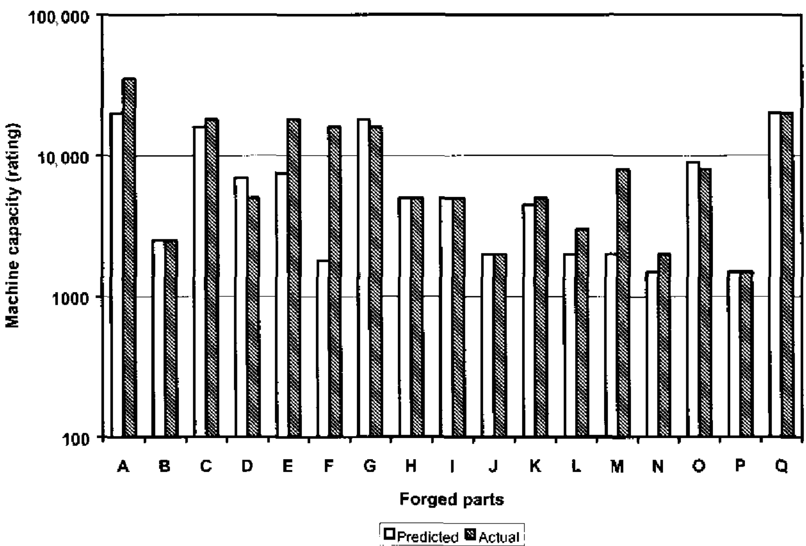

FIG. 14.28 Comparison between predicted and actual forging equipment capacities for flat, nonround forging. (Forgings F and M are precision forgings in aluminum alloy.) (From Ref. 12.)

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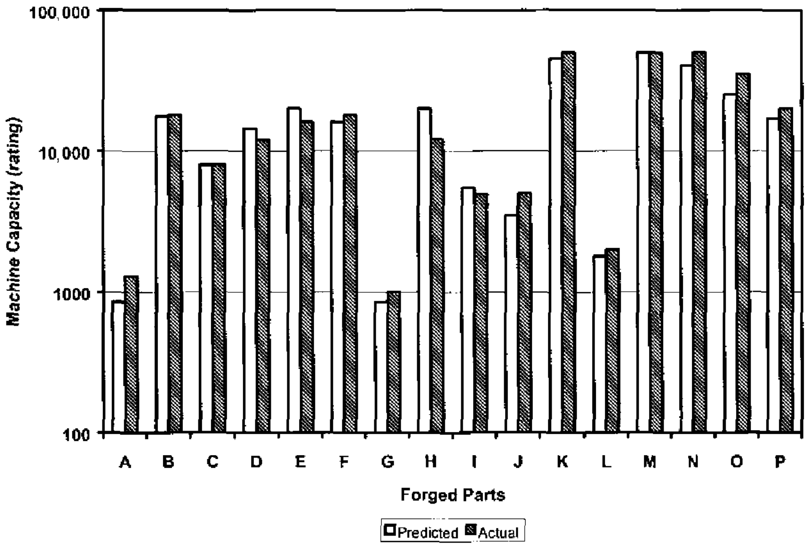

FIG. 14.29 Comparison between predicted and actual forging equipment capacities for long forging. (From Ref. 12.)

where C_{ro} is the relative cost per operation compared to a 1000 lb power hammer, obtained from Fig. 14.21, and C_{1000} is the operating cost per operation of a 1000 lb power hammer.

Example

For the sample part shown in Fig. 14.4 the following data are available:

Projected area = 78.6 cm^2
Projected area of flash land = 19.9 cm^2
Material load factor = 0.065 kg-m/mm^2 (Table 14.7)
Shape classification number = 10
Forging complexity factor = 4
Shape load factor = 1.4 (Fig. 14.23)
Number of operations = 3 (Fig. 14.23)

The equipment energy capacity required, E_f, is given by Eq. 14.8:

$$E_f = (78.6 + 19.9) \times 100 \times 0.065 \times 1.4 = 896 \text{ kg-m}$$

From Table 14.6 this part will require a power hammer rated at just below 1000 lb or a mechanical press of about 450 tons. From Fig. 14.21, the relative operating cost per operation for a hammer of this size is 0.95. Thus, assuming the processing cost per operation for a 1000 lb power hammer is \$0.15, then the processing cost per forging will be

$$C_{pr} = 0.95 \times 0.15 \times 3 = \$0.42 \text{ per forging}$$

14.10.5 Forging Machine Setup Costs

The forging press or hammer must be set up prior to each batch of forgings produced. The setup cost per forging is given by

$$C_{set} = T_{set} M / B_s \tag{14.11}$$

where T_{set} is the setup time and B_s is the batch size. Based on data available for average setup times for forging equipment [31] , a relationship between setup time and forging equipment capacity of the following form can be found:

$$T_{set} = 0.3925(E_f)^{0.28} \text{ h} \tag{14.12}$$

where E_f is the energy capacity in kg-in determined from Eq. (14.8).

Example

For the sample part in Fig. 14.4 the required energy capacity has been determined to be 896 kg-m. Thus the corresponding setup time from Eq. (14.12) is $0.3925(896)^{0.28} = 2.6$ h. Assuming an operating cost rate, M, of \$85/hr and a batch size of 10,000 forgings, the setup cost per forging becomes $85 \times 2.6/10000$, which gives \$0.02. This is small, but will increase significantly for small batch quantities.

14.11 FORGING DIE COSTS

Several factors contribute to the die cost per piece, including:

1. The initial tooling costs
2. The total number of forgings to be produced or the expected life of the tools
3. The costs of tool refurbishing and/or resinking, together with the number of resinks possible.

These factors are influenced by the complexity of the forging and the material used.

14.11.1 Initial Die Costs

The approach adopted for estimating the initial die cost is as follows:

1. Determine the die material costs.
2. Estimate the number of hours required for machining the tooling and dies, including all hand finishing and other factors.

There is one die cavity for each operation in the forging sequence, but some of the initial dies are relatively simple in form. There is a difference in practice between the use of presses and hammers in forging. For hammer forgings it is most usual to utilize multi-impression die blocks manufactured as one piece. In some circumstances the finishing cavity may be inserted into the die block, but this is often a result of resinking after the initial cavity becomes worn. Hammer forging preforming operations include fullering, edging, bending, etc. On presses, it is more normal to use separate die inserts for each operation, which are mounted into standard die containers on the press bed. The preforming stages are busters, preblockers, etc. Thus, the tool material requirements are different for presses and hammers, but the complexity considerations for machining the main cavities are similar.

14.11.2 Estimation of Costs for Multi-Impression Forging Dies

The procedure adopted for determining the initial die costs is a modification of that given by the Forging Industry Association (FIA) for forging estimating [11]. Based on the plan area of the forging, the type of forging, and complexity as expressed as the number of surface patches in the cavity shape, the number of hours to machine each die type required is determined. The size of the die blocks can be estimated based upon the guidelines used in industry.

Die Material Costs

The die material costs are determined from the number of die cavities required and the dimensions of the part, using industry guidelines for such factors as the spacing between die impressions [2]. The number of forging impressions N_{imp} is given by

$$N_{imp} = n_{bd} + n_{bk} + n_{sf} + n_{fin} + n_{sb} \tag{14.13}$$

where the appropriate values are obtained from the forging classification data given in Fig. 14.23 to 14.26.

Similarly, the number of fuller dies

$$N_{fl} = n_{fl} + n_{f2}. \tag{14.14}$$

The equivalent bar diameter for long parts or for other types of part when more than one forging per cycle are produced, D_{bar}, is given by

$$D_{bar} = (4d_{ave}W_{plt}/\pi)^{0.5} \tag{14.15}$$

where d_{ave} is the average cavity depth and W_{plt} is the platter width. The average cavity depth, d_{ave}, is given by $d_{ave} = V/A_p$. The platter width is equal to the width of the part if only one forging per cycle is to be produced. Otherwise, the platter width and length need to be determined taking into account any nesting of the part shapes that may be possible.

The width of the die block, W_{blk}, is given by

$$W_{blk} = n_{edg}(D_{bar} + 19) + (N_{imp} - 1)S_d + N_{imp}W_{plt} + 2S_e + N_{fl}(D_{bar} + 19)\cos\psi_{fl} \quad (14.16)$$

where W_{plt} is the platter width and ψ_{fl} is the angle of the fullers to the die face, usually 15°. The length of the die block, L_{blk}, is given by

$$L_{blk} = L_{plt} + 2S_e \quad (14.17)$$

but if locked dies are required to counteract lateral forces from cranked parting lines, then a further S_e is added to the die block length to accommodate the counter lock. The length and width of the platter, L_{plt} and W_{plt} are equal to the part length, L, and the part width, W, respectively, if only one part per cycle is produced. However, if more than one part per cycle is produced, then appropriate values of L_{plt} and W_{plt} should be assigned, taking into account any nesting of the part profiles that may be possible.

The die block depth, T_{blk}, is assumed equal to 5 times the cavity depth, d_c. Then the cost of the die block material, C_{dmat}, is given by

$$C_{dmat} = 2C_t L_{blk} W_{blk} T_{blk} \rho_t \quad (14.18)$$

where C_t is the cost of tool steel per unit weight and ρ_t is the density of tool steel.

Example

For the part shown in Fig. 14.4, the calculations of die material costs are as follows. For this part, $n_{bd} = 0$, $n_{bl} = 1$, $n_{sf} = 0$, $n_{fin} = 1$, $n_{edg} = 0$, $n_{sb} = 1$, and $n_{fl1} = n_{nfl2} = 0$ (Fig. 14.24). Therefore, $N_{imp} = 3$ and $N_{fl} = 0$. The width of the platter is equal to the width of the part = 100 mm, if only one part per cycle is produced. For the part, the cavity spacing $S_d = 3.1(10)^{0.7} = 15.5$ mm and the cavity edge distance, $S_e = 3.4(10)^{0.76} = 19.6$ mm (Sec. 14.5). Consequently, the width of the die block is given by Eq. (14.16) as

$$W_{blk} = 2 \times 15.5 + 3 \times 100 + 2 \times 19.6 = 370 \text{ mm}$$

The length of the die block is $L_{blk} = 100 + 2 \times 19.6 = 140$ mm and the block thickness $T_{blk} = 100$ mm. Assuming the cost of tool steel is \$20 per kilogram and the density of tool steel is 7.9 gm/cc, then the die material cost for this part is

$$C_{dmat} = 2 \times 20 \times 7.9(5 \times 14 \times 37)/1000 = \$818.$$

Multi-Impression Die Manufacturing Costs

The cost of manufacturing multi-impression dies is determined by estimating the number of hours required to manufacture the dies and then multiplying this by a die manufacturing hourly rate. The procedure used is modification of the FIA estimating procedure [11]. The total time to manufacture the die set is the sum of the times corresponding to the various steps in the procedure.

i. Block Preparation Time. The time for initial preparation of the die block is given by

$$T_{\text{prep}} = T_{\text{bt}} + 0.0078 W_{\text{blk}} L_{\text{blk}} \text{ h} \qquad (14.19)$$

where T_{bt} is the base time, which is equal to 4 h if the forging complexity factor F_{fc} is less than 2.0, 5 h for F_{fc} between 2.0 and 6.0, and 6 h for F_{fc} greater than 6.0. The die block width and length are given in centimeters.

Example: For the sample part in Fig. 14.4 $T_{\text{bt}} = 5$ h as $F_{\text{fc}} = 4$. Then T_{prep} is determined as $5 + 0.0078 \times 37 \times 14 = 9$ h.

ii. Layout Time. The time for laying out the die block is given by

$$T_{\text{lay}} = 0.008 N_{\text{c}}^{\text{m}} A_{\text{p}} F_{\text{fc}} S_{\text{c}} S_{\text{lk}} \text{ h} \qquad (14.20)$$

where N_{c} is the number of forgings per cycle, S_{c} is the cavity standard, S_{lk} is the lock standard, and m is the multicavity index—usually taken as 0.7. The lock standard, S_{lk}, is 1.0 for parts for which the die split line is in one plane and 1.5 if the split line is not in one plane. The cavity standard, S_{c}, is

$$S_{\text{c}} = 0.6(n_{\text{fn}} + n_{\text{sf}}) + 0.4(n_{\text{sb}} + n_{\text{blk}} + n_{\text{bnd}} + n_{\text{edg}} + n_{\text{f1}} + n_{\text{f2}}) \qquad (14.21)$$

Example: For the sample part $S_{\text{lk}} = 1$, as the split line will be flat. In Eq. (14.21), $n_{\text{fn}} = n_{\text{sb}} = n_{\text{blk}} = 1$ and all other terms are zero; thus S_{c} becomes 1.4. The projected area of the part is 78.6 cm^2. Therefore, the layout time is given as

$$T_{\text{lay}} = 0.008 \times 78.6 \times 4 \times 1.4 = 3.52 \text{ h}$$

iii. Milling Time. The time for milling the die cavities is obtained from

$$T_{\text{mill}} = 0.155 N_{\text{c}}^{\text{m}} A_{\text{p}} S_{\text{ml}} S_{\text{c}} S_{\text{lk}} \qquad (14.22)$$

where S_{ml} is the milling standard given by

$$S_{\text{ml}} = K(6.45 M_{\text{s}})^{\text{b}} \quad \text{or } 0.2, \quad \text{whichever is greater} \qquad (14.23)$$

Here M_{s} is the number of surface patches per unit projected area, $N_{\text{sp}}/A_{\text{p}}$ and

$$K = 0.9(1 - \exp(-0.0098 d_{\text{ave}}))$$
$$b = 0.4 + 0.7 \exp(-0.0039 d_{\text{ave}})$$

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Example: For the sample part the following data are available: Number of surface patches, N_s, is 7 and therefore $M_s = 7/78.6 = 0.089$. The average depth, d_{ave}, is given by V/A_p and equals 49.9/78.6 or 6.35 mm. Thus $K = 0.9[1 - \exp(-0.0098 \times 6.35)] = 0.0543$ and $b = 0.4 + 0.7\exp(-0.0039 \times 6.35) = 1.083$. These give a milling standard of 0.03, which is less than 0.2; thus $S_{ml} = 0.2$. Thus, the milling time $T_{mill} = 0.155 \times 78.6 \times 0.2 \times 1.4 = 3.41$ h.

iv. Bench Work Time. The bench work time, t_{bw}, on the dies is given by

$$T_{bw} = N_c^m S_{bn} S_c S_{lk}, \tag{14.24}$$

where S_{bn} is the bench standard, which depends on the forging complexity and average cavity depth. The benchwork factor, $F_{ins} = (A_p/6.54 + 0.5N_s)$ and $S_{bn} = B_0 + 0.26(F_{ins} - 15)$. The constant B_0 depends on the average depth, d_{ave}, as follows:

$d_{ave} \leq 12.7$ mm	$B_0 = 0.056 d_{ave}$
$d_{ave} > 22.86$ mm	$B_0 = 4.5 + (0.04 d_{ave} - 0.9)2.19$
$d_{ave} > 12.7$ and ≤ 22.86	$B_0 = 0.5 + (0.04 d_{ave} - 0.35)7.27$

Example: For the example part $d_{ave} = 6.35$ mm. Thus $B_0 = 0.056 \times 6.35 = 0.356$. Also, $A_p = 78.6\ \text{cm}^2$ and $N_s = 7$. From this $F_{ins} = (78.6/6.6.54 + 0.5 \times 7) = 15.52$ and $S_{bn} = 0.356 + 0.26(15.52 - 15) = 0.49$. Thus the benchmark time is $0.49 \times 1.4 = 0.69$ hours.

v. Planing Time. The block planning time

$$T_{pl} = 0.008 T_{cav}^{1.5} \tag{14.25}$$

where the cavity time $T_{cav} = T_{lay} + T_{mill} + T_{bw}$.

Example: The block planing time for the example part $T_{pl} = 0.008(5.3 + 3.41 + 0.69)^{1.5}$, or 0.23 h.

vi. Dowel Time. The dowel time, T_{dl}, is 3 h if the die material volume is less than 4260 cm^2, or else is 4 h.

Example: For the example part the total volume of the die material is 10,350 cm^3, thus $T_{dl} = 4$ h.

vii. Flash Gutter Time. The time to machine flash gutters on the die cavities,

$$T_{fl}, = N_c P_r/635 \quad \text{or } 0.8 \text{ h} \quad \text{whichever is the larger} \tag{14.26}$$

In this expression P_r is the forging outside perimeter in millimeters.

Example: For the example part, $T_{fl} = 314/635 = 0.49$ h and therefore T_{fl} is 0.8 h.

viii. Edger Time. If an edger die is required, the time for manufacture is T_{edg} and is given by

$$T_{edg} = n_{edg}L(D_{bar}/25.4 + 1)0.005 \tag{14.27}$$

No edger is required for the example part.

ix. Finish-Polish Time. The time to finish-polish the dies cavities, T_{pol}, is given by

$$T_{pol} = N_c[1 + (F_{fc} - 1)0.6] \tag{14.28}$$

Example: For the example part $F_c = 4$, and therefore $T_{pol} = (1 + (4 - 1)0.6) = 2.8$ h.

The total die manufacturing time is the sum of the above times and consequently the die manufacturing cost is

$$C_{dman} = C_{man}(T_{prep} + T_{lay} + T_{mill} + T_{bw} + T_{pl} + T_{dl} + T_{fl} + T_{edg} + T_{pol}) \tag{14.29}$$

The total initial die manufacturing costs are thus

$$C_{DIE} = C_{dmat} + C_{dman} \tag{14.30}$$

Example: Assuming a die manufacturing cost rate of \$45 per hour, then for the example part $C_{dman} = 45(9 + 3.51 + 3.41 + 0.69 + 0.23 + 4 + 0.8 + 0 + 2.8) = \$1100$.

Thus the total initial die cost is $C_{DIE} = \$1100 = \$1918$.

14.12 DIE LIFE AND TOOL REPLACEMENT COSTS

The life of hot forging dies is relatively short, and therefore it is necessary to include in the estimating procedure a consideration of the expected tool life and a general strategy for tool replacement and refurbishing. The life of the finishing cavity particularly is determined by the complexity of the forging and the material being forged. For example, the same shape produced by different materials will result in different die lives. This can be accommodated by the use of the material die life factor, β_m, and typical values for these are given by the FIA [12], as shown in Table 14.7.

Similarly, the life of the tools is reduced as the complexity of the forging (thinner sections, ribs, etc.) is increased. This reduction is accommodated by the shape die life factor, β_s, which is obtained from the classification of forgings described above. Using these factors, die costs are determined by specifying a typical die replacement and refurbishing strategy for a relatively simple forging in low carbon steel. For such a part, the die life would be, say, 40,000 pieces, with up to five resinks of the main die cavity possible. Subsequent to this, a new tool set is assumed necessary. For other parts it is assumed that this basic tool life and the periods before refurbishing will be reduced by the die life factors for material and shape complexity. The die resink quantity, Q_{rs}, is determined by

$$Q_{rs} = Q_{rb}\beta_s\beta_m \tag{14.31}$$

where Q_{rb} is the basic resink quantity (say 40,000), β_s is the shape die life factor, and β_m is the material die life factor. Thus the total die life, L_D, is given by

$$L_D = (N_{rs} + 1)Q_{rs}N_c, \tag{14.32}$$

where N_{rs} is the number of resinks possible, say 5.

The cost of each resink, C_{rs}, is assumed to be equal to

$$C_{man}[0.9(T_{mill} + T_{bw} + T_{fl}) + T_{pol}] \tag{14.33}$$

If the total number of forgings required (life volume), Q_{lv}, is greater than the total die life, then the forging die cost per part, C_D, is given by

$$C_D = (C_{DIE} + (N_{rs} + 1)C_{rs})/\mathrm{L}_D \tag{14.34}$$

However, if the life volume is less than the total die life, then the number of resinks required, n_{rs}, will be $Q_{lv}/(Q_{rs}N_c)$ and then the forging die cost per part will be

$$C_D = (C_{DIE} + n_{rs}C_{rs})/Q_{lv} \tag{14.35}$$

Example

For the part $\beta_s = 0.45$ (Fig. 14.24) and $\beta_m = 1.0$ (Table 14.7). The resink quantity, $Q_{rs} = 40{,}000 \times 0.45 \times 1.0 = 18{,}000$. From this the total die life will be, from Eq. (14.32), $L_D = (5 + 1)\ 18{,}000 = 108{,}000$ parts. The cost of each resink is $C_{rs} = 45[0.9(3.41 + 0.69 + 0.23) + 0.2.8] = \$301$. Thus, assuming a total required quantity of 25,000 forgings, then from Eq. (14.35), the die cost per part is $(1918 + 301 \times 25{,}000/18{,}000)/25{,}000 = \$0.09$ per forging.

14.13 COSTS OF FLASH REMOVAL

14.13.1 Flash Removal Processing Costs

After the main forging processes the flash must be removed to yield the finished forging. This is usually carried out on a mechanical press, with a purpose-built trimming die and punch. If possible, any webs in through holes are pierced out at the same time. For small quantities of parts and for large forgings the flash may be removed by a bandsaw or a similar machining method, but this is generally time-

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consuming and more expensive. In order to determine the processing costs for flash trimming, the required size of the trimming press must be estimated, and this is determined from the load needed to shear the flash at the parting line. The trimming load, F_{trm}, is given by

$$F_{trm} = (T_f P_r + T_w P_w) Y_s N_c 1.15 \quad (14.36)$$

where P_w is the perimeter of the through holes and Y_s is the equivalent shear stress of the material of the forging. The constant of 1.15 is used to give a factor of safety of 15%. The equivalent yield stress is usually taken to be 70% of the UTS of the material. For cold trimming the room temperature UTS should be used and for hot forming the UTS should be assumed to be the material flow stress at an appropriate strain rate.

Once the trimming load is known, the energy equivalent for the mechanical press can be determined as

$$E_f = 0.096 F_{trm}^{0.98} \text{ kg-m} \quad (14.37)$$

From this the relative cost per operation can be determined from Fig. 14.20, and multiplying this by the operating cost per operation for a 1000 lb hammer gives the trimming cost, which should be divided by the number of forgings per cycle to result in the trimming cost per part.

There is a small setup cost for flash trimming. This can be determined in the same manner as for the main forging equipment, following the procedure outlined in Sec. 14.10.5.

Example

For the example part the perimeter of the part is 31.4 cm and the flash thickness is 1.68 mm. For hot trimming of mild steel the material flow stress is approximately 97 MPa. Thus from (14.36) the trimming load, F_{trm}, is given by

$$F_{trm} = 314 \times 1.68 \times 0.7 \times 97 \times 1.15 = 41{,}191 \text{ N}$$

From this equation, (14.37) gives $E_f = 3197$ kg-m, which from Fig. 14.21 results in a trimming cost relative to the cost per operation of a 1000 lb hammer of 0.73. Thus, assuming that the cost per operation of a 1000 lb hammer is \$0.15, then the trimming cost per part is $0.73 \times 0.15 = \$0.11$.

14.3.2 Tooling Costs for Flash Removal

The procedure for determining the tooling costs for trimming is modified from the FIA estimating procedure [11]. First, the material required for the tools is estimated. The trimming die material volume, V_{trd}, is given by

$$V_{trd} = 1.2 L_{plt} W_{plt} T/2 \quad (14.38)$$

The trimming punch material volume, V_{trp}, is given by

$$V_{trp} = L_{plt} W_{plt} T \tag{14.39}$$

From these the trimming tool material cost, C_{trm}, is determined as

$$C_{trm} = (V_{trd} + V_{trp})\rho_t C_t \tag{14.40}$$

Example

For the example part $L_{plt} = W_{plt} = 10$ cm and the part thickness is 2 cm. From these $V_{trd} = 120\ \text{cm}^3$ and $V_{trp} = 200\ \text{cm}^3$. Assuming the cost of tool steel is \$20/kg and the density is 7.9 gm/cc, then the material cost of the trimming tools is

$$C_{trm} = 20 \times 7.9 \times 320/1000 = \$50.6$$

The time to manufacture the trimming die, T_{td}, is given by

$$T_{trd} = T_{int} + (A_0 + M_p A_{tb} + T_{lk}) N_c \ \text{h} \tag{14.41}$$

where
T_{int} = initial time allowance hours (4 for cold trim and 5 for hot trim)
A_0 = base time, h
M_p = block area factor, cm^2
A_{tb} = die block area, cm^2
T_{lk} = addition for locked forging dies, h

The values of A_0, M_p, and T_{lk} are obtained from Table 14.8, for different values of the parting line profile complexity factor, F_c, where this is determined by

$$F_c = P_r/2(\pi A_p)^{0.5} \tag{14.42}$$

The number of hours required for the trim punch manufacture is estimated from

$$\begin{aligned} T_{tp} = {} & (0.004A_{pb} + 0.33) + 0.05 + [(A_{pb} - A_p N_c)/6.56] \\ & + [(P_r - P_w)/2.54 + 14F_c - 13] N_c F_{lck} + 0.005 N_c A_p F_{fc} \end{aligned} \tag{14.43}$$

TABLE 14.8 Data for Estimating Trim Die Manufacturing Times

Profile complexity, F_c	Base time, A_0 (h)	Block area factor, M_p (h/cm^2)	Locked die addition, T_{lck} (h)
1.0 to 1.5	0.62	0.0143	2
1.5 to 1.8	2.52	0.0146	3
>1.8	5.08	0.0168	0
>1.8 + die lock	8.86	0.0203	0

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where A_{pb} is the punch block area, given by L_{plt} W_{plt}, and F_{lck} is a lock factor equal to 0.06 unless the die split line is cranked, in which case the factor is 0.065.

The total initial trim tooling cost is

$$C_{trim} = (T_{td} + T_{tp})C_{man} + C_{trm} \tag{14.44}$$

The trim die life, L_{trm}, is given by $L_{trm} = L_{tbas}\beta_m N_c$, and from this the trim tool cost per part is C_{trim}/L_{trm} or C_{trim}/Q_{lv} if the life volume required, Q_{lv}, is less than L_{trm}.

Example

For the example part the profile complexity factor, F_c, is 1.0 as the forging profile is circular. Thus, from Table 14.8, $A_0 = 0.62$ h, $M_p = 0.0143$ h square centimeters and the forgoing dies are not locked so $T_{lck} = 0$. From these, assuming hot trimming, the manufacturing time for the trimming die is

$$T_{td} = 5 + (0.62 + 0.0143 \times 78.6) = 6.74 \text{ h}$$

The value of F_{lck} is 0.06 and hence the time for manufacturing the trimming punch becomes

$$T_{tp} = (0.004 \times 100 + 0.33) + 0.05 + [(100 - 78.6)/6.56 + 14 - 13]0.06 + 0.005 \times 78.6 \times 4 = 2.61 \text{ h}$$

Thus the total cost of the flash trimming tools is

$$C_{trim} = 45[6.74 + 2.61] + 50.6 = \$472$$

Assuming a lifetime production quantity of forgings, Q_{lv}, of 25,000, then the trimming tool cost per part \$472/25,000 = \$0.02 per part.

14.14 OTHER FORGING COSTS

There are some additional small costs associated with forging.

14.14.1 Billet Preparation

For most forging operations there will be a small additional cost for billet preparation. For long parts the forging may be made directly from the heated end of an appropriate length of bar stock. For other types an appropriate billet must be cut off from bar stock. This can be achieved by several methods, including sawing, abrasive cutoff, and cold shearing, which involves the least waste material. Cold shearing will usually be carried out on a mechanical press, and the cost of processing can be calculated following a procedure similar to that for flash trimming described in Sec. 14.13.1. Since standard tools will be used the tool cost per part is very small.

14.14.2 Billet Heating Costs

The costs for heating the billet or bar end to the appropriate forging temperature can be estimated by determining the energy costs for heating. These can be obtained by multiplying the billet weight by the material specific heat and the required temperature rise. For small forgings this cost will be relatively small, but for large forgings that may require several reheats between operations the heating costs may become significant.

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