Design for Forging

Forging processes

Forging is a controlled plastic deformation process in which the work material is compressed between two dies using either impact or gradual pressure to form the part. Forging operation carried out usually at an elevated temperature. It is the oldest metal forming operation date back to perhaps 5000 B.C.

Forging can be classified in many different ways: hot forging, warm forging, and cold forging. In the forging, either impact load or gradual loads are applied. A forging machine that applies the impact load is called a forging hammer and the one that applies gradual pressure is called a forging press.

Another classification of forging is done based on the degree to which the flow of the work material is constrained in the dies. Based on this, forging is classified as:

1. Open die forging: The work is compressed in two flat dies thereby allowing the metal to flow in the lateral direction without restriction.
2. Impression-die forging: The die surfaces contain a shape or an impression that is imparted to the work during compression, thus putting constraints on the metal to a certain degree.
3. Flashless forging: In this type of operation, a portion of the work metal flows beyond the die impression to form flash. In flashless forging, the work is completely constrained within the die and no excess flash is produced.

Typical characteristics and applications

The major benefit obtained in the forging process is that a controlled grain structure can be achieved and also with proper design, grain flow can be aligned with directions of the principal stresses. The directional pattern in which metal crystals are aligned during plastic deformation is called grain flow. Various properties like strength, ductility, and impact resistance along the grains are significantly higher than in the case with randomly oriented crystals of cast metal or weld metal. Since hot working refines grain structure, physical properties are also improved across the grain as shown in Figure M4.7.1

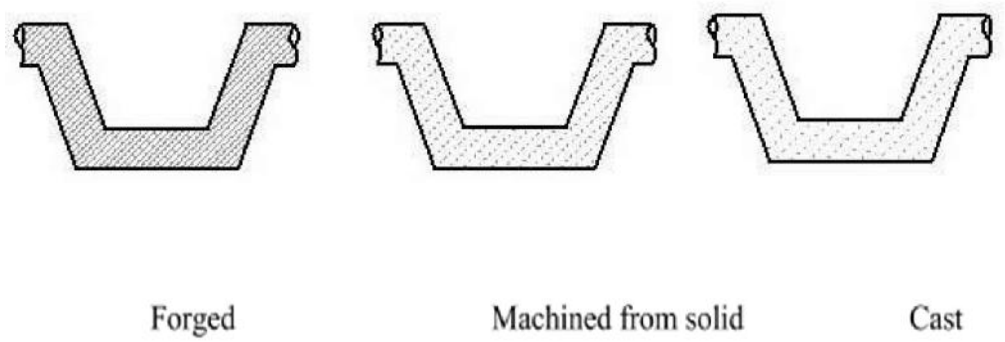

Figure M4.7.1: Forging produces parts with an unbroken grain flow

Mostly, forging parts need to be machined before use. So, an allowance is kept for this during the initial design of the part. Some typical forging applications are landing gear parts for aircraft, automotive connecting rods, universal joints, crankshafts, off-highway and farm equipment parts, plumbing valves, tees, elbows, ordinance components, railroad wheels, axles, gears, oil-field machinery components, turbine disks and blades, and bearing assemblies. A few collection of typical forging parts are shown in Figure M4.7.2.

Figure M4.7.2: A collection of typical forgings

Forging nomenclature

Various terminologies are used for geometric shapes on an impression-die forging based on the direction in which metal must flow to fill the die impressions. When a wall is filled by the flow parallel to die motion is called a rib, and the projection made by filling parallel to the die motion is called a boss. A web is formed when the wall is filled by horizontal flow, perpendicular to die motion and parallel to the parting plane. A small web area surrounded by thicker metal is called a recess. Figure M4.7.3 illustrates these terminologies.

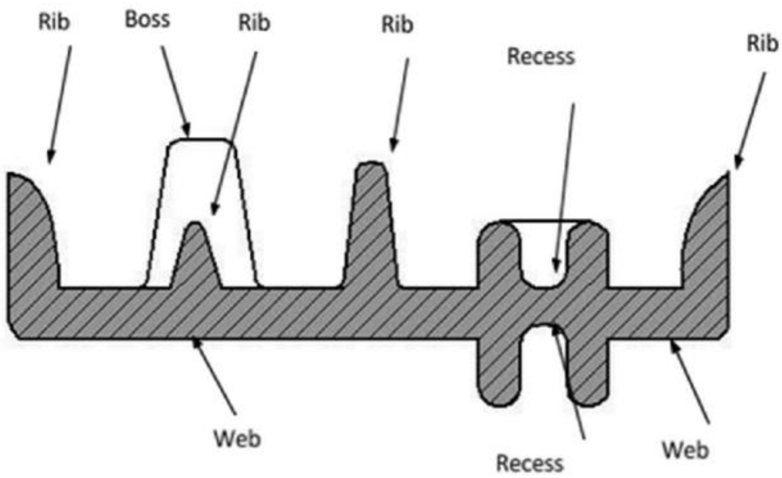

Figure M4.7.3: Forging nomenclature (All features of a part to the direction of die motion.)

Flash

When a portion of the work metal flows beyond the die impression, flash is formed. This flash is trimmed off in a separate operation.

Suitable materials for forging

Most of the metals and alloys can be forged at elevated temperatures and forge ability is the term used to measure this behaviour. Forgeability refers to the ease with which the metal deforms plastically. Table M4.7.1 summarizes the relative forge ability (in decreasing order) of metals and their alloys. Suitable mate

Table M4.7.1: Relative Forgeability (Source: Design for Manufacturability Handbook by

James G Bralla, 2nd Ed)

Base metal	Alloy
Aluminum	2104
	2024
Magnesium	AZ31B
	AZ61A
Copper, brass, and bronze	CA377
	CA464
Steel	1010–1030
	1050–1095
Martensitic stainless steel	430
	405
Austenitic stainless steel	316
	317
Nickel	Nickel 200
	Monel 400

Design recommendations

Forging drawings:

Forging drawing with a complete dimension of the parts to be forged should be prepared. Die design and processing requirements are controlled depending on the way in which the part is drawn. Grain flow must be aligned with the direction of highest principal stress. Forging design should be developed in consultation with forging user and the forging producer. It is often advisable to use metal flow simulation software to study blocker and finisher shapes for forgings.

Parting line: When the die halves join together and confine metal in their cavities, the joining line of the die halves around the edge of the forging surface is called a parting line of the forging. Under ideal condition, the parting line should lie on a plane perpendicular to the axis of the die motion, as shown in Figure M4.7.4.

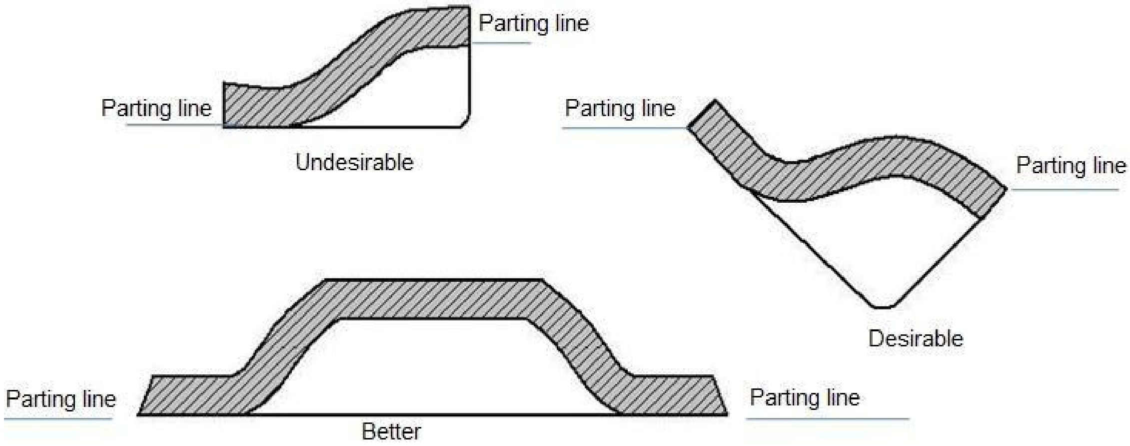

Figure M4.7.4: Parting line lies in one plane, perpendicular to the direction of die motion.

Sometimes the impression is entirely on one half and the other die half is completely flat and the line surrounds the largest projected area of the piece as shown in Figure M4.7.5.

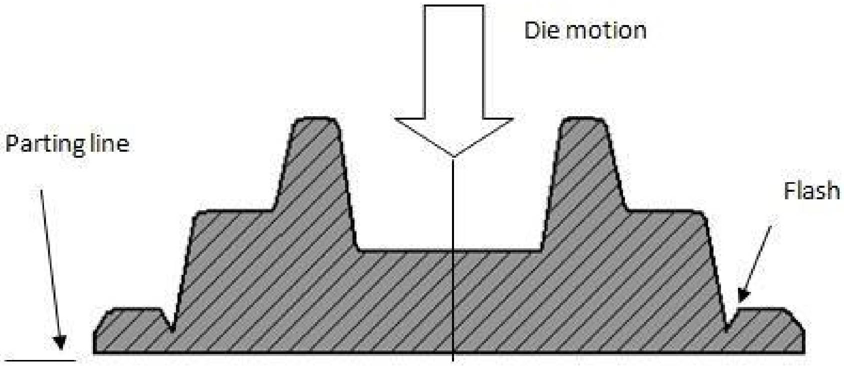

Figure M4.7.5: Parting line is in one plane perpendicular to die motion, and the complete impression is in one die half

The instances in which the parting line cannot lie in one plane, it is necessary to maintain symmetry so as to prevent high side-thrust forces on the dies and the press. When there is a choice, parting line is located in such a manner that metal will flow horizontally being parallel to the parting line.

Draft:

Die impressions are generally made tapered for easy withdrawal of the forgings from their dies. In fact, forged surfaces that generally lie parallel to die motion are correspondingly tapered. The taper provided is called draft. Table M4.7.2 shows typical standard draft angle ranges for finished forgings in the various alloy families. Often certain shapes exhibit natural draft. If the cylindrical section needs to be considered, the draft angle has to be modified slightly to provide draft in the narrow region next to the parting line as shown in Figure M4.7.6.

Table M4.7.2: Typical Draft Angles (Source: Design for Manufacturability Handbook by James G Bralla, 2nd Ed)

Alloy family	Draft angle(°)
Aluminum	0–2
Magnesium	0–2
Brass and copper	0–3
Steel	5–7
Stainless steel	5–8
Titanium	5–6

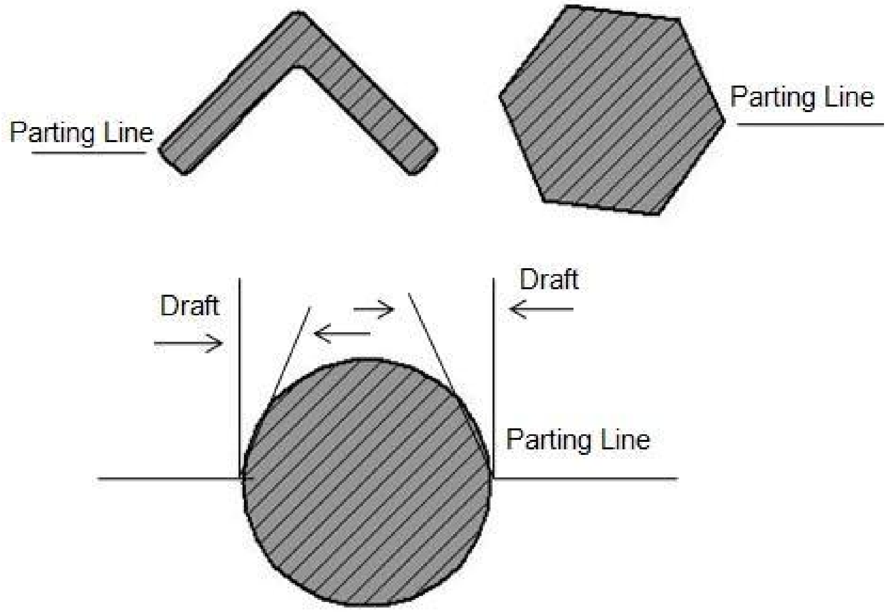

Figure M4.7.6: Natural draft for certain shapes

Ribs, Bosses, Webs, and Recesses:

It is recommended to avoid too high and narrow ribs and bosses for easy metal flow. This is shown in the Figure M4.7.7. It becomes very difficult when large amounts of metal have to be moved out of relatively thin webs into such projections as deep ribs and high bosses. Hence, it is better to taper such webs toward the ribs and bosses. In addition, deep recesses are also found to be easier to forge provided they have spherical bottoms. Further, surface textures, designs, and lettering on forged surfaces are very small ribs and recesses. These features are recommended to be located on the surfaces that are as nearly perpendicular to die motion and also need to be located them away from zones of wiping metal flow. It is difficult to achieve die projections that will form recessed symbols on the forging.

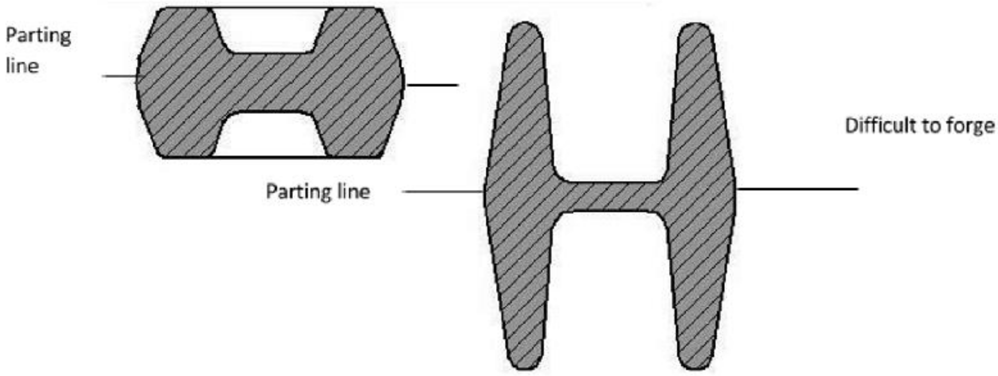

Figure M4.7.7: Too high and narrow ribs

Radii: Generous corner radii are recommended at all external sharp corners except at the parting line. The sharp corner act as stress raiser and excessive pressure is required to fill the sharp corners. A common practice is to use full radii at the edges of all ribs and to maintain the same radius on each corner of a boss, web, or another shape. Table M4.7.3 provides typical minimum radii for forging. As the depth increases both the fillet and corner radius increases.

Table M4.7.3: Typical Minimum Radii for Forgings (Source: Design for Manufacturability Handbook by James G Bralla, 2nd Ed)

	Minimum radius,	
Depth of rib or boss(	Corner	Fillet
13	1.6	5
25	3	6.3

50	5	10
100	6.3	10
200	16	25

Machining allowance:

Design features are added for easy forging. Those design features have to be machined. Ample draft angles, large radii, and generous tolerances can all have this effect. See Table M4.7.4 for typical allowances for machined surfaces.

Table M4.7.4: Typical Machining Allowances for Forging (Source: Design for Manufacturability Handbook by James G Bralla, 2nd Ed)

	Forging size: projected area at parting line(		
Alloy	To 640 cm^2	To 2600 cm^2	Over 2600 cm^2
Aluminum	0.5–1.5	1.0–2.0	1.5–3.0
Magnesium	0.5–1.5	1.0–2.0	1.5–3.0
Brass	0.5–1.5	1.0–2.0	1.5–3.0
Steel	0.5–1.5	1.5–3.0	3.0–6.0
Stainless steel	0.5–1.5	1.5–2.5	1.5–5.0
Titanium	0.8–1.5	1.5–3.0	2.0–6.0
Niobium	0.8–2.5		
Tantalum	0.8–2.5		
Molybdenum	0.8–2.0	2.0–3.0	

Tolerances

The tolerances summarized below should be considered as guidelines. However, adjustment to these absolute values of tolerance can be made for reasons of either manufacturing economy or the component's function. These are applied to impression die forgings made in two-part die sets.

Length and width tolerances: Dimensions parallel to the parting plane and perpendicular to die motion is provided with length and width tolerances. Length and width tolerances are commonly specified at +0.3 percent of each dimension, rounded off to the next higher 0.5 mm.

Die-wear tolerances: These tolerances meant only two dimensions generally parallel to the parting plane and perpendicular to die motion. The corresponding variations parallel to die motion are included in die-closure tolerances. Die-wear tolerances are generally additive to the external dimensions and subtractive to the internal dimensions. Table M4.7.5 shows typically recommended tolerances. To implement these tolerances in the design, each implement the horizontal dimension is multiplied by an appropriated factor and rounded off to the next .

Table M4.7.5: Typical Die-Wear Tolerances (Source: Design for Manufacturability

Handbook by James G Bralla, 2nd Ed)

Alloy family	**%**
Aluminum, 2014	0.4
Aluminum, 7075	0.7
Magnesium	0.6
Brass and copper	0.2
Mild steel	0.4
Alloy steel	0.5
Martensitic stainless steel	0.6

Austenitic stainless steel	0.7
Titanium	0.9
Superalloys	0.8
Refractory alloys	1.2

Die-closure tolerances:

Dimensions parallel to die motion between opposite sides of a forging are affected by the failure of the two die halves to close precisely. The plus tolerances on such dimensions are shown in Table M4.7.6. There is no minus tolerance in this category.

Table M4.7.6: Typical Die-Closure Tolerances, mm (Source: Design for Manufacturability Handbook by James G Bralla, 2nd Ed)

	Forging size: Projected area at parting line, mm						
Alloy family	To 65 cm^2	To 135cm^2	To 320cm^2	To 650cm^2	To 3200cm^2	To 6450cm^2	Over 6450cm^2
Aluminum, magnesium, and brass	0.8	0.	1.6	2.4	3.2	4.8	6.3
Steel	0.8	1	2.4	3.2	4.0	4.8	6.3
Martensitic stainless steel	0.8	1	2.4	3.2	4.8	6.3	8.0
Austenitic stainless steel	1.6	2	3.2	4.0	4.8	6.3	8.0
Titanium	1.6	2	3.2	4.8	6.3	8.0	9.5
Superalloys	1.6	2	3.2	4.8	6.3	8.0	9.5
Refractory alloys	2.4	3	4.0	4.8	6.3	8.0	9.5

Match tolerances:

A lateral shift of one die half with respect to the other half, generally moves all other features on opposite sides of the forging. Table M4.7.7 summarizes typical tolerances with respect to piece weight and material.

Table M4.7.7: Typical Match Tolerances in mm (Source: Design for Manufacturability Handbook by James G Bralla, 2nd Ed)

	Forging size: weight after trimming(mm)							
Alloy family	To 2.3kg	To 11kg	To 23kg	To 45kg	To 90kg	To 225kg	To 450kg	Over 450 kg
Aluminum, magnesium, brass, and steel	0.4	0.8	1.2	1.6	2.4	3.2	4.0	4.8
Stainless steel, titanium, and superalloys	0.8	1.2	1.6	2.4	3.2	4.0	4.8	6.3
Refractory alloys	1.6	2.4	3.2	4.0	4.8	6.3	8.0	9.5

Straightness tolerances:

In relatively long, a thin part, a typically recommended straightness tolerance is 0.3 percent of the length.

Flash-extension tolerances:

The most common flash-removal method is the use of punching operation in contoured dies. Recommended conventional flash-extension tolerances are given in Table M4.7.8 and these are appropriate when this procedure is acceptable.

Table M4.7.8: Typical Flash-Extension Tolerances in mm (Source: Design for Manufacturability Handbook by James G Bralla, 2nd Ed)

Forging size: weight after trimming, mm								
Alloy family	To 5kg	To 10kg	To 25kg	To 50kg	To 100kg	To 250 kg	To 500 kg	Over 500 kg
Aluminum, magnesium, brass, and steel	0.8	1.6	2.4	3.2	4.8	6.3	8.0	9.5
Stainless steel, titanium, and superalloys	1.6	2.4	3.2	4.8	6.3	8.0	9.5	12.7
Refractory alloys	3.2	4.8	6.3	8.0	9.5	12.7	15.8	19

Draft angles: Common tolerances on draft angles are +2° and -1°.

Radii:

The conventional tolerance imposed on all corner and fillet radii is plus or minus one- half the radius. On any corner, when metal is to be removed, the plus radius tolerances are provided. Minus radius tolerance, only limits the sharpness of the forged corner, is not imposed.

Total tolerances: In a forging drawing, the tolerances provided for each dimension whether it is plus or minus, are arithmetic sums of all individual tolerances that apply to the surfaces involved. Dimensions for forging should be provided in such a way that enough metal will be available on every surface to satisfy all functional requirements of the finished part.