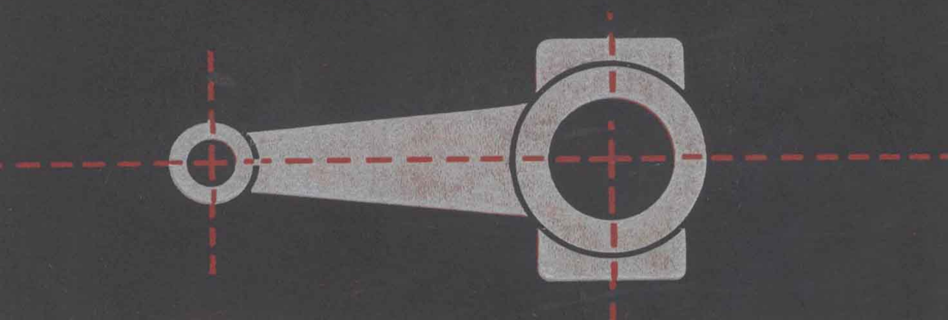
ALUMINUM FORGING DESIGN



KAISER
ALUMINUM

ALUMINUM FORGING DESIGN

FIRST EDITION

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The high strength-to-weight ratio of aluminum forgings offers superior performance for a majority of varied applications. Physical advantages over cast or wrought machined stock are well established. This is due principally to the unique grain orientation and flow, providing optimum strength and toughness at the points of greatest stress. Thus, forgings are usually specified where components require a high degree of reliability and where unit failure could result in personal injury, lost time and expensive repairs.

The dependability, long service and excellent economies now being realized by aluminum forging users in nearly every industry are amply demonstrated by such typical and varied applications as those listed below:

- Tool handles
- Transformer hangers
- Air cylinders and pistons
- "C" clamps
- Power tool housings
- Calculating machine parts
- Transmissions
- Pipe fittings
- Ladder fittings
- Propellers
- Water faucets
- Car wheels
- Non-magnetic chucks
- Builders' Hardware
- Automobile bumpers
- Structural fittings
- Trailer hitches
- Steering units
- Landing gear
- Trailer legs and jacks
- Orthopedic components
- Locking devices
- Light standards
- Oar locks
- Boat fittings
- Outboard motor mounting brackets
- Nozzles

The need for a concise book on the basics of aluminum forging design, to aid manufacturers in drafting preliminary as well as

PHOTO OPPOSITE: This forged aluminum steering gear component for a jet aircraft is made from aluminum alloy 5083, weight 3.1 lbs.

final specifications for potential products, has steadily increased along with the greater performance demands being made upon modern metal components. However, before beginning such a discussion, it may be advantageous to sum up briefly various aspects of the process that influence design. Data on the most common forging alloys, along with engineering and metallurgical information will be found on pages 63 through 84.

Production of aluminum forgings* starts with the cutting of forging stock to lengths required from bars or billets on manual and semi-automatic type circular cutoff saws, abrasive wheels and, for smaller diameters, on shears. Cut stock may then be deburred or edge-relieved, prior to forging. Large, complicated parts which require several operations must have closely-controlled reheating each time additional forging is accomplished. Although many forgings are made in a single impression, most require rolling, upsetting or blocking prior to the finish forging operation. Die design is especially critical for single heat forgings, since there is no opportunity between operations to remove any conditions which could result in rejects.

Preworking of Stock

Even such preliminary steps as blocking, upsetting and rolling have their effects upon design. These particular operations aid in filling the die much more readily during the finish forging operations and in establishing proper grain flow.

Blocking, for instance, imparts the general shape and modified contour. This is necessary when a forging design has an abrupt cross sectional change which would prevent free flow of metal to certain areas; or, the metal movement required may be excessive for a finish impression alone. In such instances, the blocker die modulates the transition and helps insure a smooth flow of metal to produce the grain-directional characteristics for structural soundness and maximum strength.

In many instances, it is possible to preform the stock by means of supplemental tooling operations, so that the starting volume is reduced considerably. *Side cylinders* (page 5) are often used

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*For a more detailed account, please refer to Kaiser Aluminum's book, FORGING PRODUCT INFORMATION.

in instances where a thicker section near the center is needed.

Another system of reducing or displacing material is by *drawing*, where stock is reduced on one or both ends by hammering or pressing to the desired cross section. *Fullering* is similar, except that the cross section is reduced in the center of the billet. Other methods of reducing cross section include *extruding* and *rolling*. In the former method, metal is confined in a die and forced through an orifice of the desired diameter. In rolling, material is passed through a set of reducing rolls, where the metal is displaced to elongate a relatively short billet quickly. Although *bending* does not displace material, this method is often used to change a shape to closely resemble the finished part. Two or more of these various methods of preworking are often used in conjunction with each other.

Types of Forgings

Forgings are basically grouped into two broad types—*open die* and *closed die*. Actual forging is accomplished through *impact* or *pressure*.

Hand forgings are worked to the desired or approximate shape in simple, open, flat dies.

Closed die forging employs impressions machined in matching steel die blocks to shape parts. Whereas hand forgings generally depend upon machining to obtain their final configuration, die forgings require little or no machining. *Closed die* forgings include those made by a variety of methods using hammers, presses, forging machines and other equipment. Such forgings are designated as *blocker type, conventional, precision, draft-free, extruded* (forged or impact extrusions), *rolled ring* and *upset*.

Equipment

Equipment for forging is roughly divided into three broad classes: *hammer or impact, press and upsetting,* and special equipment including *ring rollers, bulldozers, counterblow hammers, impactors* and similar types of machines used to compress and work ingot, rod, bar or other wrought products.

Hammers employ a weighted ram which is moved vertically in such a manner that the downward stroke of the ram creates an impact against a lower stationary member or anvil. By inserting dies and the aluminum stock between the ram and lower member, the impact is used to move and shape the metal into the desired contour. Forging hammers include the *board drop*, *steam drop*, *air drop* and *air lift gravity*. All hammers work on the principle of high impact.

Presses can be categorized as *mechanical* and *hydraulic* types. The former is typified by a "set" stroke, while the latter has a variable stroke adjustable to predetermined speed, pressure and dwell time. A mechanical press has a ram that moves in a vertical direction by mechanical means, the downward stroke imparting a force against a stationary lower member; movement of the ram is performed through a crankshaft or eccentric. Hydraulic presses employ water or oil to amplify and transmit the power through a cylinder and piston arrangement. Many modifications are possible in both approach speed and pressing speed.

The *forging machine* or *upsetter* is power-operated equipment developed primarily to gather or upset metal into a set of dies. The upsetter contains a stationary and a moving die plate. The crank, connected to the heading slide, is in front of the die plates. Stock is placed in the stationary die; the moving or gripper die moves against the stationary die, gripping the stock tightly. As the header slide moves forward, it forces the heading tool against the stock to force the latter into the die cavities.

Forging rolls are used for reducing short, thick sections of metal stock to longer, slimmer sections. Technique is similar to that of a rolling mill in that the material is reduced between the rolls. A basic difference is that on a forging roll, material is fed and discharged from the same side. The contour in the rolls does not cover the entire periphery of the rolls. Thus, the stock is passed between the rolls into the blank space and when the revolving roll brings the contour into position it picks up the stock and reduces it. A blank clearance space is provided for a portion of each revolution, the operator using successive grooves in the rolls for successive passes, inserting the bar in the blank spaces in the proper sequence. The stock is picked up by the rolls and after the necessary amount of rolling in each pass the bar is ejected.

The *bulldozer* is similar to a horizontal press, exerting its pressure over a large area. It is especially adapted for forming and bending operations on long pieces preparatory to forging in the blocking and finishing impressions in closed - impression dies mounted in drop forging hammers. Because of a long pressure stroke, and greater working space, bulldozers are advantageous for large parts that cannot be put under the ordinary type of press for lack of room.

Ring rollers produce endless rings by forging hollow-billet. Such a billet is placed over an arbor and pressure is applied to the outside diameter. The billet is rotated as pressure is applied, thus reducing wall thickness and increasing diameter.

Precision radial or rotary forgings are made from round or square, solid or hollow billets. Outside surfaces are formed smoothly over a variety of contours with simple hammers, in many cases interchangeable from one piece to another. Where hollow pieces are involved, inside contours may be held to close limits by use of mandrels. The workpiece is chuck fed and the operation is almost automatic, controls governing the operation somewhat in the manner of a turret lathe. Both horizontal and vertical machines are available. These have several hammers, eccentric driven, which strike from 400 to 600 blows per minute with up to 220 tons of force. These operate synchronously, striking on all sides simultaneously.

Side cylinders are auxiliary rams for attaching to the frames of hydraulic presses; they operate in a horizontal plane at right angles to the vertical movement of the main ram. These cylinders greatly extend the scope of complex forging shapes produced readily on basic equipment.

Trimming presses are employed for flash removal in mass production. "Flash" is excess metal not required to fill the finished die cavity and is squeezed out over the flash land at the parting line of the dies. This is removed with hot or cold trim dies, by sawing or grinding. On high-volume forgings or those with complex outlines, the use of a trimming die is generally more economical. Such dies have a sharp cutting edge made to the exact shape of the forging at the parting line and are employed in conjunction with a punch having a matching contour to provide a shearing edge. Mechanical presses are the principal type of equipment used for trimming and coining.

The *coining* or *sizing press* is especially built for exerting heavy pressure over relatively small areas. Coining equipment regularly gives tolerances of 0.005 to 0.010 in. Coining often eliminates machining or further finishing entirely.

Where holes *(punchouts)* are required, punches and dies for single or multiple holes (symmetrical or irregular) are employed. If production warrants, it is often possible to combine trim and punchout operations in a single set of dies.

Heating Equipment

Furnaces are part of the basic equipment in any forging plant. *Pre-heat* furnaces, employing gas, oil or electricity, are used for pre-heating stock in the range of 600° to 900° F. As each alloy has its own narrow range, it is important that closely controlled heats be utilized. *Heat-treating* furnaces, used for developing proper metallurgical properties in aluminum forgings, must be capable of holding heat within ± 5°. *Aging* furnaces are similar to those used in heat-treating; aging is carried out in the temperature range of 240 to 460°, and controlled with ± 10 F. *Die heating ovens,* operating at controlled temperatures from 250 to 900°F, heat the dies to facilitate metal flow and prevent die damage.

DESIGN FACTORS

The drawing board is an essential stage in planning a forged aluminum part; however, only part of the considerations and advantages are evident at that stage. In addition to end-use requirements and manufacturing costs, the criteria related to how other components in an assembly are affected by the part must be analyzed from all aspects. For example, the high strength with light weight of an aluminum forging results in lower inertia losses in reciprocating parts and lower stresses in rotating members. The lighter loads may, in turn, allow smaller bearings and lighter crankshafts.

Resourceful design "squeezes" the most out of the side benefits. The design must be close to optimum, yet not so rigid that it will restrict the forging shop from using practical methods for shaving costs, such as determining forging plane or parting line to best advantage. Furthermore, final shape of a forging should not be fixed until all concerned parties are consulted. Each may contribute helpful suggestions.

Some of the ground rules covering design, which will be introduced in the sections to follow, include draft, webs, parting line, forging plane, radii, dimensioning and tolerances.

Draft Angles should match or meet at common edges, thus lowering die costs, as well as setup time. Other plus factors include better metal flow, simplification of flash trimming, detection of mismatch at parting line, more accurate jigging for finish work, better stress distribution, improved appearance, and cleaner machining cuts.

Webs should taper into the flange and for best results should be somewhat thicker than published minimums. Because of their thinness, webs generally cool first. When the temperature of a section or the entire part drops below the heat required for forging, the entire part must be reheated prior to further forging operations. Die life is shortened when thin webs are designed without taper. Punching out sections of the web reduces forging weight. Although each punchout concentrates stresses, this often can be overcome by forging a bead around the edge of the hole. For extra thin webs, dimensional tolerances in length, width and straightness usually must be eased to avoid secondary straightening or cold restriking in a separate die.

Parting line and *forging plane* locations should be left to the shop. The former will affect die costs, forging costs, grain flow characteristics, number of preform dies, flash removal and often the amount of metal removed in machining. Parting lines may vary from a simple plane to a complex intersection of curved surfaces on several planes.

Corner radii on external corners should be kept uniform throughout, to avoid necessity for different die cutting tools for filleting, as well as for other reasons which are discussed in various appropriate sections later in this book.

Fillet radii or internal corners should be large enough to permit smooth flow, thus preventing laps and cold shuts. Small radii which are below those recommended can be forged by first preforging the blank in a blocker impression, built into the same die block.

Dimensioning a forging is a design procedure followed to assure the maximum tolerance advantages obtainable in the forging process. Aluminum forgings are dimensioned to intersections of plane surfaces. Distances are given to points which lie deepest in the die or farthest from the parting line. Exceptions are fillet radii in the plan view; these may be dimensioned at the point closest to the parting line. Forgings that are symmetrical about a parting line only, require overall dimensions.

Angular dimensioning should be avoided. Instead, dimensional ordinates for surfaces other than 90° and 180° should be used so that larger tolerance (± ½°) from angular dimensioning will not conflict with those from linear dimensioning.

One of the main advantages of aluminum forgings is that tolerances are highly reproducible. Forging allowances are prescribed because of uneven shrinkage and die wear. Etching the forged part to remove die lubricant in order to inspect for defects removes a small amount of metal but this is routinely closely controlled. Die-sinking tolerances are normally shown on the drawing separately. Ordinarily, these are ± 0.010 in. but can vary from ± 0.030 down to ± 0.002 in. Length and width tolerances apply to all dimensions except those across the parting line, which are covered in die closure tolerances.

Die closure tolerances must be applied to the thickness dimensions across the parting line. In addition to the factors which determine length and width tolerances, the closure dimensions of the forging at the beginning of a forging run, when the die is cooler, differs from those present as the die temperatures increase. Bulky forgings have more consistent accuracy than thin-webbed, deep-ribbed forgings, which require greater die closures. Tolerance for all precision dimensions should be justified from the cost standpoint, but once the cost for one closure dimension is established and accepted all die closure dimensions can have similar accuracy without appreciable added cost.

Mismatch tolerances are limited by the clearance in the guides of the presses or clearance in the locked dies. Mismatch is added to forging length and width but does not apply to closure dimensions.

Flash tolerances should be used where forgings will not mate with other components. Should flash conflict with clearance of mating surfaces, it can be removed completely or to any specified limit by machining. This is costly as a rule and should be avoided.

Draft-free forgings with straight perpendicular surfaces are usually designed so that flash extends beyond the perpendicular surfaces. Thus, no-draft forgings cannot be conventionally die trimmed. On simple shapes, with side walls the same height, flash can be sawed off. Where wall heights vary, excess metal must be removed by machining. When draft-free forgings are designed with conventional flash, regular removal methods can be used.

Straightness tolerances are necessary primarily because of warpage after cooling and heat treating. This deviation applies independently to contoured surfaces as well as plane surfaces, but checking contoured surfaces with special templates usually increases costs. Cold restriking in a die will improve the straightness as well as give a partial stress-relief to insure against subsequent warpage from this cause.

Coining tolerances apply to distances between opposing surfaces. Several areas on a forging may be coined simultaneously, provided total area is not excessively large. When coin-sizing more than one boss on a single part, the relationship between them may not be improved due to the spring back between.

Corner and fillet radii tolerances are provided mainly to allow for die wear during production. Standard tolerances are 15%, with a minimum of 1/32 in.

Draft

With most aluminum forgings, a few degrees of angular slope is necessary on vertical die surfaces to facilitate removal of the forgings from the die. This angle is referred to as draft, and is normally expressed as an angle from the equipment stroke axis, and is perpendicular to the forging plane, Fig. 1.

The amount of draft required on a given forged part is influenced by the equipment used in the forging operation as well as the type of forging produced. Other factors to consider are economy and end usage.

Draft angles vary from five to seven degrees for conventional forgings produced on hammers and from one to five degrees for conventional and precision forgings produced on mechanical or hydraulic presses. Draft-free forgings having zero degrees draft are generally produced on hydraulic presses, and sometimes on mechanical presses.

Depending upon the configuration, it is sometimes possible to tilt the forging in a die so that the sides provide a natural draft which

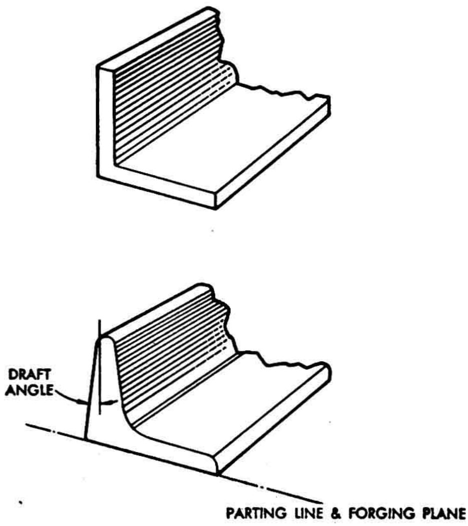

Fig. 1—Draft required to permit removal of part from die; machined part is shown at top.

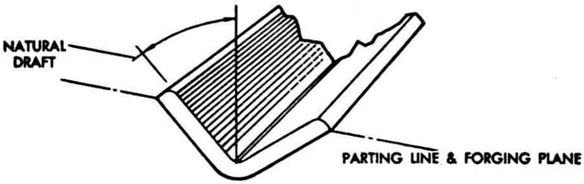

Fig. 2—Example of natural draft.

eliminates the need for adding material to create draft. An example of an aluminum forging tilted to acquire natural draft is shown in Fig. 2.

Where normal draft angles fail to match at the parting line, the draft in one die should be increased until both sides meet at the parting line. This can be accomplished by increasing the width of the shallower impression for its entire length or by adding a slight ledge or web at the parting line. These alternate methods are illustrated in Fig. 3.

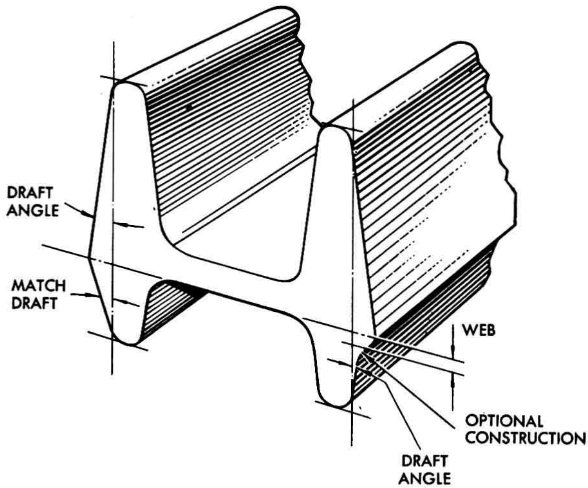

Fig. 3—Methods of matching die impressions.

The match condition is generally preferred, but in some instances where matching draft adds considerable weight, as well as die sinking time, adding draft on one side of the die may prove more economical.

A match draft condition is desirable from a production standpoint since it facilitates layout inspection, die setup, flash trimming and inspection for mismatch. In the finished part, match draft improves forging appearance, reduces jigging problems and, under most conditions, helps in making cleaner machining cuts.

Webs and Punchouts

Web thickness is an important factor when practicability of many forging designs is considered. In basic channel sections such as "U" shape or "H" type forgings, strict adherence to design standards will increase tooling costs, and, consequently, forging piece price. Forging tolerances are also adversely affected by excessively thin webs.

As the web area of the forging is usually the thinnest portion it will cool more rapidly. Due to this lowering of temperature the metal becomes less plastic and requires more forging pressure or more blows from a hammer. When the temperature of the forging drops below the plastic flow point, the forging must be reheated and forged again. In some instances, where web thicknesses are thinner than the design standards dictate, as many as four forging heats may be required to forge the thin panel to the proper tolerance.

Higher per piece prices will now be reflected due to these excessive forging operations. Tooling costs will be higher, due mainly to decreased tool life.

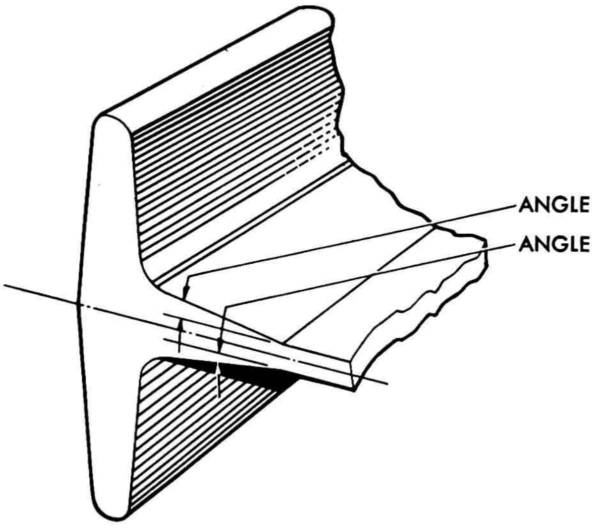

Fig. 4 — Example of a tapered web, used to facilitate forgeability.

To improve the relative forgeability and maintain the thinner web, a taper may be incorporated, Fig. 4. This taper greatly assists the flow of the plastic aluminum outwards from the center and into adjacent ribs or flanges, resulting in fewer forging heats (operations), longer tool life, and faster production all of which are usually reflected in lower piece costs.

tapered webs is encountered most often in a forging whose web area is totally entrapped by deep ribs or flanges.

When weight limitations prohibit the use of the standard web thickness, as shown in Table 1, the designer may meet weight requirements by punching out a portion of the web. This punchout

TABLE 1

WEB THICKNESS STANDARDS

(Example of unconfined web is shown in top two drawings and a confined web in the bottom two)