All Metals & Forge Group
OPEN DIE FORGINGS & SEAMLESS ROLLED RINGS

presents

Forging Solutions

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Forging Solutions
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Facts About Forging
When buyers must select a process and supplier for the production of an important metal part, they face an enormous array of possible alternatives. A great many metalworking processes are now available, each offering a unique set of capabilities, costs and advantages. The forging process is ideally suited to many part applications, however some buyers may be unaware of the exclusive benefits available only from this ancient form of metal forming. In fact, forging is often the optimum process, in terms of both part quality and cost-efficiency—especially for applications that require maximum part strength, special sizes or critical performance specifications.

There are several forging processes available, including impression or closed die, cold forging, and extrusion. However, here we will discuss in detail the methods, application and comparative benefits of the open die and seamless rolled ring forging processes. We invite you to consider this information when selecting the optimum process for the production of your metal parts.
A Historical Perspective

Perhaps the oldest mechanical method of metalworking known to man, forging traces its origins from ancient Egypt through the blacksmith shops of the pre-industrial period, and directly to the high-technology forging plants of today.

To meet the changing needs of industry, forging has evolved to incorporate the tremendous advances in equipment, computers and electronic controls that have occurred in recent years. These sophisticated tools complement the creative human skills which, even today, are essential to the success of every forging made. Modern forging plants are capable of producing superior quality metal parts in a virtually limitless array of sizes, shapes, materials and finishes.
Forging Defined
At its most basic level, forging is the process of forming and shaping metals through the use of hammering, pressing or rolling. The process begins with starting stock, usually a cast ingot (or a "cogged" billet which has already been forged from a cast ingot), which is heated to its plastic deformation temperature, then upset or "kneaded" between dies to the desired shape and size.

During this hot forging process, the cast, coarse grain structure is broken up and replaced by finer grains. Low-density areas, microshrinkage and gas porosity inherent in the cast metal are consolidated through the reduction of the ingot, achieving sound centers and structural integrity. Mechanical properties are therefore improved through the elimination of the cast structure, enhanced density, and improved homogeneity. Forging also provides means for aligning the grain flow to best obtain desired directional strengths. Secondary processing, such as heat treating, can also be used to further refine the part.

No other metalworking process can equal forging in its ability to develop the optimum combination of properties.
Open Die Forging Process

Open die forging involves the shaping of heated metal parts between a top die attached to a ram and a bottom die attached to a hammer anvil or press bed. Metal parts are worked above their recrystallization temperatures-ranging from 1900°F to 2400°F for steel-and gradually shaped into the desired configuration through the skillful hammering or pressing of the work piece.

While impression or closed die forging confines the metal in dies, open die forging is distinguished by the fact that the metal is never completely confined or restrained in the dies. Most open die forgings are produced on flat dies. However, round swaging dies, V-dies, mandrels, pins and loose tools are also used depending on the desired part configuration and its size.

Although the open die forging process is often associated with larger, simpler-shaped parts such as bars, blanks, rings, hollows or spindles, in fact it can be considered the ultimate option in "custom-designed" metal components. High-strength, long-life parts optimized in terms of both mechanical properties and structural integrity are today produced in sizes that range from a few pounds to hundreds of tons in weight. In addition, advanced forge shops now offer shapes that were never before thought capable of being produced by the open die forging process.
Open Die Forging Process continued

Steps to produce a typical spindle-shaped part:

1. Rough forging a heated billet between flat dies to the maximum diameter dimension.

2. A "fuller" tool marks the starting "step" locations on the fully rounded workpiece.

3. Forging or "drawing" down the first step to size.

4. The second step is drawn down to size. Note how the part elongates with each process step as the material is being displaced.

5. "Planishing" the rough forging for a smoother surface finish and to keep stock allowance to a minimum.
The Seamless Rolled Ring Forging Process

The production of seamless forged rings is often performed by a process called ring rolling on rolling mills. These mills vary in size to produce rings with outside diameters of just a few inches to over 300" and in weights from a single pound up to over 300,000 pounds.

The process starts with a circular preform of metal that has been previously upset and pierced (using the open die forging process) to form a hollow "donut". This donut is heated above the recrystallization temperature and placed over the idler or mandrel roll. This idler roll then moves under pressure toward a drive roll that continuously rotates to reduce the wall thickness, thereby increasing the diameters (I.D. and O.D.) of the resulting ring.

Seamless rings can be produced in configurations ranging from flat, washer-like parts to tall, cylindrical shapes, with heights ranging from less than an inch to more than 9 feet. Wall thickness to height ratios of rings typically range from 1:16 up to 16:1, although greater proportions can be achieved with special processing. The simplest, and most commonly used shape is a rectangular cross-section ring, but shaped tooling can be used to produce seamless rolled rings in complex, custom shapes with contours on the inside and/or outside diameters.
The Seamless Rolled Ring Forging Process

*Producing a ring "preform" by the open die forging process:*

1. Starting stock cut to size by weight is first rounded, then upset to achieve structural integrity and directional grain flow.

2. Work piece is punched, then pierced to achieve starting "donut" shape needed for ring rolling process.

3. Completed preform ready for placement on ring mill for rolling.

4. Ring rolling process begins with the idler roll applying pressure to the preform against the drive roll.

5. Ring diameters are increased as the continuous pressure reduces the wall thickness. The axial rolls control the height of the ring as it is being rolled.

6. The process continues until the desired size is achieved.
Forging Advantages: Part Integrity

1. Directional Strength
By mechanically deforming the heated metal under tightly controlled conditions, forging produces predictable and uniform grain size and flow characteristics. Forging stock is also typically pre-worked to refine the dendritic structure of the ingot and remove defects or porosity. These qualities translate into superior metallurgical and mechanical qualities, and deliver increased directional strength in the final part.

2. Structural Strength
Forging also provides a degree of structural integrity that is unmatched by other metalworking processes. Forging eliminates internal voids and gas pockets that can weaken metal parts. By dispersing segregation of alloys or nonmetallics, forging provides superior chemical uniformity. Predictable structural integrity reduces part inspection requirements, simplifies heat treating and machining, and ensures optimum part performance under field-load conditions.

3. Impact Strength
Parts can also be forged to meet virtually any stress, load or impact requirement. Proper orientation of grain flow assures maximum impact strength and fatigue resistance. The high-strength properties of the forging process can be used to reduce sectional thickness and overall weight without compromising final part integrity.

Cross section of continuous grain flow of custom forged contoured ring.
Grain Flow Comparison

**Forged Bar:**
Directional alignment through the forging process has been deliberately oriented in a direction requiring maximum strength. This also yields ductility and resistance to impact and fatigue.

**Machined Bar:**
Unidirectional grain flow has been cut when changing contour, exposing grain ends. This renders the material more liable to fatigue and more sensitive to stress corrosion cracking.

**Cast Bar:**
No grain flow or directional strength is achieved through the casting process.
Forging Advantages: Part Flexibility

1. Variety of Sizes
Limited only to the largest ingot that can be cast, open die forged part weights can run from a single pound to over 400,000 pounds. In addition to commonly purchased open die parts, forgings are often specified for their soundness in place of rolled bars or castings, or for those parts that are too large to produce by any other metalworking method.

2. Variety of Shapes
Shape design is just as versatile, ranging from simple bar, shaft and ring configurations to specialized shapes. These include multiple O.D./I.D. hollows, single and double hubs that approach closed die configurations, and unique, custom shapes produced by combining forging with secondary processes such as torch cutting, sawing and machining. Shape designs are often limited only by the creative skills and imagination of the forging supplier.

3. Metallurgical Spectrum
Forgings can be produced from literally all ferrous and non-ferrous metals. The forging process itself can be adjusted-through the selection of alloys, temperatures, working methods and post-forming techniques-to yield virtually any desired metallurgical property.

4. Quantity and Prototype Options
Virtually all open die and rolled ring forgings are custom made one at a time, providing the option to purchase one, a dozen or hundreds of parts as needed. An added benefit is the ability to offer open die prototypes in single piece or low volume quantities. No better way exists to test initial closed die forging designs, because open die forging imparts similar grain flow orientation, deformation, and other beneficial characteristics. In addition, the high costs and long lead times associated with closed die tooling and set-ups are eliminated.
Economic Advantages

1. Material Savings
Forging can measurably reduce material costs since it requires less starting metal to produce many part shapes.

For example, with a torch cut part (A), all corner stock and the full center slug are lost, even though you pay for the excess material. With a forging (B), the part is shaped to size with minimal waste.

2. Machining Economies
Forging can also yield machining, lead time and tool life advantages. Savings come from forging to a closer-to-finish size than is capable by alternative metal sources such as plate or bar. Less machining is therefore needed to finish the part, with the added benefits of shorter lead time and reduced wear and tear on equipment.

3. Reduced Rejection Rates
By providing weld-free parts produced with cleaner forging quality material and yielding improved structural integrity, forging can virtually eliminate rejections.

4. Production Efficiencies
Using the forging process, the same part can be produced from many different sizes of starting ingots or billets, allowing for a wider variety of inventoried grades. This flexibility means that forged parts of virtually any grade can be manufactured more quickly and economically.
Comparative Analysis

When Compared to:
Open Die and Rolled Ring Forged Metal Parts Deliver:
- Machined Bar
- Contoured grain flow yielding greater impact and directional strength
- Cost savings in material and reduction of waste
- Less machining and longer tool life
- Broader material options and size ranges

When Compared to:
Open Die and Rolled Ring Forged Metal Parts Deliver:
- Weldments/ Fabrications
- Superior and more consistent metallurgical properties
- Reduced labor, rejection and rework/replacement costs
- Stronger parts due to the elimination of welds
- Single-piece design and inspection efficiencies
- Simplified production requirements
- Single and low volume quantity options
- Prototypes with comparable properties
- Near-net shapes with short lead times and the elimination of tooling costs

When Compared to:
Open Die and Rolled Ring Forged Metal Parts Deliver:
- Castings
- Directional grain flow and superior final part strength
- Structural integrity and product reliability
- Reduced process control and inspection requirements
- More predictable response to heat treating

When Compared to:
Open Die and Rolled Ring Forged Metal Parts Deliver:
- Centrifugal Castings
- Greater near-net part design flexibility reducing machining time
- Sound, quality, rejection-free parts
- Cost savings with the elimination of die, mold and set-up costs
- Continuous grain flow for the optimum combination of fatigue strength and toughness

When Compared to:
Open Die and Rolled Ring Forged Metal Parts Deliver:
- Torch Cut Plate
- Significantly greater size and grade flexibility
- Elimination of porosity and laminations
- Reductions in waste and material costs
- Controlled directional grain flow yielding optimum strength, toughness and fatigue resistance

When Compared to:
Open Die and Rolled Ring Forged Metal Parts Deliver:
- Closed Die/ Impression Die Forging
- Single and low volume quantity options
- Prototypes with comparable properties
- Near-net shapes with short lead times and the elimination of tooling costs
Forging and Other Processes Q&A

Q. What is "grain flow"? I've heard "grain flow" mentioned on several occasions when discussing forgings. What exactly is "grain flow" and what does it do (or not do) for me.

A. Forgings are produced using the open-die forging process through the controlled application of compressive stresses while the metal is heated in the plastic regime. The metal, once subjected to the compressive stress, will expand in two other directions unless constrained in either direction. The expanding metal will stretch the existing grains and, if the temperature is within the forging temperature region, will recrystallize and form new strain free grains. The formation of the new grains is not random, however. The new crystal structure is oriented along the direction of the metal flow and can be used to enhance the properties of the forged component by producing a forging that closely follows the outline of the component resulting in even better resistance to fatigue and stress corrosion than a forging that does not contour the component. Other contributors to grain flow are the expansion of microsegregated regions and/or inclusions in the direction of the metal flow. The effect of the elongated microsegregated regions and/or inclusions can be controlled through the use of high quality material and due attention to the forging technique.

Q. What are the benefits of a seamless hollow-core forging?
What are the benefits, with respect to residual stresses, of a seamless hollow-core forging over rolled and welded plate that is subsequently processed (machining, heat treating, etc.)?

A. In general, distortion of a component will occur when the stress states of either the individual components or the assembly as a whole shift from one state of equilibrium to a new equilibrium state. The presence of residual stresses in the components act as a source of potential energy similar in nature to a spring fixed in a compressed state. If the fixture holding the spring remains intact, the spring does not expand. However, once the fixture is removed, the spring expands until it reaches a new state of equilibrium; either another fixed point or a point where the potential energy of the spring is expended and the spring is extended. So too will the potential energy in a component due to residual stress remain unchanged until the equilibrium state is altered; either through mechanical means (metal removal or cold/warm straightening, etc.) or thermal means (welding, heat treatment, etc.).

(continued...)
A. Using this model, it is apparent that the key to minimizing distortion is to select a fabrication process that (1) uses input material with little or no residual stress and (2) will permit a subsequent processing path that introduces as little residual stress as possible. To form a plate into a cylinder will, in most cases, necessarily require stretching the metal beyond its yield point to both hold the cylindrical shape and allow for the subsequent spring-back. If it is assumed that the starting plate is essentially free of residual stress due to processing at elevated temperatures (a large assumption indeed), the equilibrium state of the plate is subsequently changed during rolling through the introduction of tensile and compressive stresses that shift the equilibrium state to that of a cylindrical shape (requiring a weld to hold it in place because of the tendency to spring back, in particular with materials having a high yield strength).

Understanding the proportional relationship between stress and strain (elastic modulus - ironically sometimes referred to as the spring constant) it can be intuitively understood that the stretching will spring back to a new state that now has residual stress present. In addition, the introduction of the longitudinal weldment to complete the cylindrical shape further disrupts the system through the introduction of thermal energy. The severity of the residual stress will increase with increases in either, or all, of the yield strength of the base metal, circumference of the tube, and plate thickness. Once the desired shape is achieved, it will remain in that shape as long as no subsequent processing or service conditions that alters the stress state is performed (machining or welding for example). When the part does distort, additional mechanical work is required to revive the desired shape resulting in an often "circular" manufacturing path. These costs are sometimes (often?) not considered when selecting a rolled and welded cylinder.

Consider, now, a seamless hollow-core Scot Forge forging that is forged at elevated temperatures with dynamic recrystallization (the immediate formation of stress-free grains upon deformation). The stresses introduced during forging to produce the cylindrical shape are immediately removed through the recrystallization of the crystal structure resulting in an essentially stress-free forging. Consequently, a rolled and welded assembly possesses significantly higher residual stress than a forged seamless cylinder (hollow-core). Furthermore, no thermal stresses from welding are introduced during formation of the cylinder as a seamless forged hollow-core, unlike the rolled and welded plate method. To summarize, the Scot Forge seamless hollow core forging is far more stable and possesses a higher degree of structural integrity (no welds!) than a rolled and welded cylinder assembly for an often lower overall cost.
Q. What is the optimum reduction needed for forging?

Forging reduction should be sufficient to consolidate the defects inherent to the casting process such as porosity and other voids while achieving a general wrought structure by breaking down the cast structure. A 3 to 1 reduction is usually sufficient to achieve these results. Depending on the alloy and customer requirements, higher reduction may be necessary to achieve certain additional mechanical or physical requirements.

Q. What is the ASTM standard for ultrasonic testing of forgings? Is there a similar standard to ASTM 578 (ultrasonic testing for plate) for forgings?

A. The most common ultrasonic standard practice for forgings is ASTM A388, Standard Practice for Ultrasonic Examination of Heavy Steel Forgings. Unlike ASTM A578, this standard does not include acceptance criteria so I would suggest using ASTM A788, Supplementary requirement S20, for starters. You can find the current revision of ASTM Standards at the following link:
http://www.astm.org/cgi-bin/SoftCart.exe/STORE/standardsearch.shtml
?L=mystore+radl5786+1019794827

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All Metals & Forge Group is an ISO 9001:2008, AS/EN9100:2009 Rev. C manufacturer of open die forgings and seamless rolled rings, a certification it obtained and has held since 1994. AM&FG was one of the first companies in its industry to obtain an ISO certificate of registration since the company’s founding in 1972. AM&FG maintains one of the most stringent quality processes and standards in the industry to ensure that our customers receive the finest forged material with the tightest tolerances in exactly the condition that best suits their finish machining needs.

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