HEAVY MOVABLE STRUCTURES, INC.
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ADVANCES IN METALWORKING TECHNOLOGY FOR HEAVY MOVABLE STRUCTURES

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METALWORKING AND INFRASTRUCTURE IN THE U.S.

In 2015, North American forging manufacturers supplied $6.2 million in open die and rolled ring forgings for bridges and other Department of Transportation work.[1] According to the American Society of Civil Engineers, US bridges are in poor condition, receiving a "C+" grade.[2] As a result, the Federal Highway Administration estimates that nearly 25% of the nation's bridges require repair and replacement as existing structures near the end of their life spans and struggle to handle increasing traffic.[3]

Bridges are considered structurally deficient if significant load-carrying elements are found to be in poor or worse condition due to deterioration and/or damage. A "deficient" bridge, when left open to traffic, typically requires significant maintenance and repair to remain in service and eventual rehabilitation or replacement to address deficiencies. The high percentage of deficient bridges and the large existing backlog are, in part, due to the age of the network. One-half of all bridges in the Unites States were built before 1964, while the average age of the nation's 607,380 bridges is currently 42 years.[4]

When bridge owners must select a process and supplier for the production of a critical metal component, they face an enormous array of possible alternatives. Many metalworking processes are available, each offering a unique set of capabilities, costs and advantages. The forging process is ideally suited to many part applications. In fact, forging is often the optimum process, in terms of both part quality and cost, especially for applications that require maximum part strength, custom sizes or critical performance specifications. **So why, in the peak of bridge construction (c. 1960), did so many engineers choose castings over forgings?**

Unfortunately, most Federal bridge safety standards were not created until the late 1960s, in response to the Ohio River bridge collapse. The failure was caused by corrosion and decay of the bridge which weakened it to the point of collapse, killing 46 people. After analysis it was discovered that during the casting process, a microscopic crack formed in a steel eye-bar used in the bridge's construction, over time stress and corrosion fatigue caused the crack to grow until the component failed. Today, it is well known that castings lack the continuous grain flow, refined grain structure, and directional strength necessary for critical, load bearing operations. The lack of properly oriented grain flow as well as grain refinement can lead to potential part integrity problems causing failures in the field.

In the '60s, there were hundreds of casting foundries in the U.S. who could supply the complex or large metal components required for bridgework. Castings were cheap and plentiful when compared to steel forgings at that time. As demand for steel castings outpaced supply however, companies began to look outside of the US and Canada for solutions, which ultimately impacted the supply chain in two ways:

1) It gave birth to an off-shore option for steel castings which reached its height and inflict significant damage on the domestic industry in the decades to follow.
2) OEMs were not content back then to wait for the off shore option to fully develop, casting users moved aggressively to invest in a substitute process – steel fabrication. In fact, the presence of fab

[1] Forging Industry Association. 2015 Open Die and Custom Seamless Rolled Ring Forging Industry Annual Report of Orders and Shipments. Cleveland: Forging Industry Association, 2016.
[2] "Infrastructure Grades for 2013." 2013 Report Card for Americas Infrastructure. American Society of Civil Engineers, n.d. Web.
[3] Diment, Dmitry. Bridge & Elevated Highway Construction in the US. Rep. no. 27371b. 2015 ed. Vol. December. IBISWorld.
[4] (2007) Structurally deficient bridges in the United Stateshearing before the Committee on Transportation and Infrastructure, House of Representatives, One Hundred Tenth Congress, first session, September 5, 2007Washington : U.S. G.P.O.

shops within virtually every manufacturing plant – which we take for granted today – did not exist before the late 1970s and is the direct result of the aforementioned.

At present, the North American steel foundry industry is a shadow of its former self. In 2015, fewer than 200 steel casting plants remain, down from a 1970s high of more than five times that many.

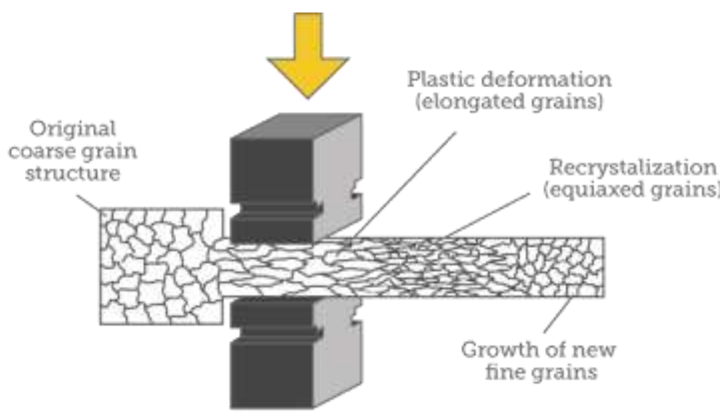
Today's more demanding material users are increasingly obliged by everyday economic and competitive realities to seek a better supply-chain solution and stronger, sounder and technically superior product. However, when it comes to making decisions about the bridge construction and repair, the question still asked is …"casting, fabrication or forging?" The reality that the forging process has come a long way since the 1960s is slowly being recognized. Engineers and metallurgists have increased their education around metal working processes and begun to evaluate the long term benefits of forgings compared to castings or fabrications. Additionally, technological advances have made forgings every bit as competitively priced as alternate methods while providing the means to address the structurally deficient or functionally obsolete challenges faced within the US Infrastructure industry.

WHAT IS FORGING?

There are several forging processes available, including impression die (also known as closed die), cold forging, and extrusion. However, here we will discuss in detail the methods, application and comparative benefits of the open die forging processes. We invite you to consider this information when selecting the optimum process for your critical applications.

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. Shrinkage 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 reduction of cast structure, voids and segregation.



How the open die forging process affects the crystal structure.

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.

OPEN DIE COMPARED TO CASTINGS AND FABRICATIONS

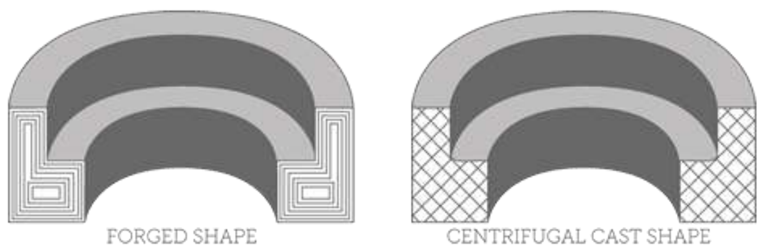
Forging delivers significant economic, manufacturing, and quality advantages when compared to alternative metalworking processes such as directional strength, structural strength, and impact strength.

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 porosity. These qualities translate into superior metallurgical and mechanical qualities, and deliver increased directional toughness in the final part.

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 non-metallics, 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.



IMPACT STRENGTH

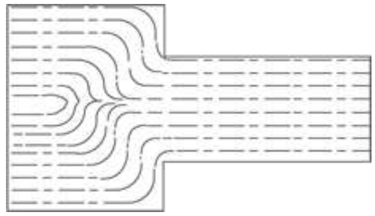
Parts can also be forged to meet virtually any stress, load or impact requirement. Proper orientation of grain flow assures maximum impact strength and fatigue resistance. The high-strength properties of the forging process can be used to reduce sectional thickness and overall weight without compromising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

Forging also provides means for aligning the grain flow to best obtain desired directional strengths. It is well known that bridges are prone to cracking and fatigue problems. Therefore, it is helpful to understand how proper orientation of grain flow can ensure maximum fatigue resistance.

In open die forging, the metal (once subjected to the compressive stress) will flow in any unconstrained 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. This results in even better resistance to fatigue and stress corrosion than a forging that does not contour the component.

FORGED GRAIN FLOW

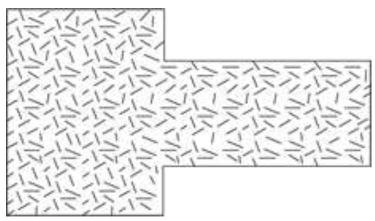
Forgings to near-net shape offer contoured grain flow, yielding greater impact and directional strength. Grain flow is oriented to improve ductility, toughness, and increase fatigue resistance.



FORGING GRAIN FLOW

CAST GRAIN FLOW

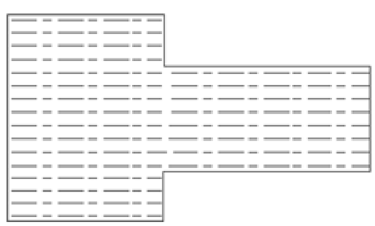
Castings typically do not have a grain structure, which is not desirable for critical, load bearing components.



CASTING GRAIN FLOW

MACHINED GRAIN FLOW

Machined parts have a uni-directional grain flow which has been cut when changing contour, exposing grain ends. This renders the material more liable to fatigue and more sensitive to stress corrosion cracking.



MACHINED GRAIN FLOW

This predictable structural integrity inherent to the forging process reduces part inspection requirements, simplifies heat treating and machining, and ensures optimum part performance under field-load conditions. The high-strength properties of the forging process can be used to reduce sectional thickness and overall weight without compromising final part integrity.

Additionally, forging can measurably reduce material costs since it requires less starting stock to produce many part shapes. Less machining is therefore needed to finish the part, with the added benefits of shorter lead time and reduced wear and tear on equipment. Virtually all open die forgings are custom-made one at a time, providing the option to purchase one, a dozen or hundreds of parts as needed. In addition, the high costs and long lead times associated with casting molds or closed die tooling and setups are eliminated.

Furthermore, by providing weld-free parts produced with cleaner, forging-quality material and yielding improved structural integrity, forging can virtually eliminate rejections (as opposed to fabrications). 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 or geometry can be manufactured relatively quickly and economically.

ADVANCES IN OPEN DIE FORGING

Forging suppliers have long used tooling to achieve near net or finish size and shape. Each forging process utilizes forge tooling in different ways to best reduce input material and machining process time. For example, tooling is the cornerstone for impression (aka closed die) forgings. This application is ideal for higher volume repeatable products. The tolerances achieved offer reduced machining needed to obtain finished shapes or sizes.

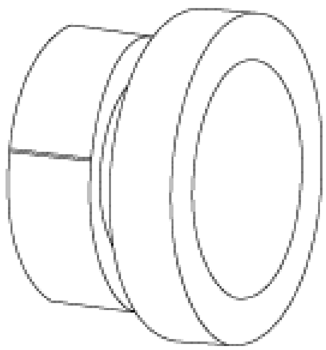
However, over recent years, tooling has allowed the open-die process to become cost competitive when compared to other metalworking alternatives. Although the open die forging process is often associated with larger, simpler-shaped parts such as bars, blanks, rings, hollows or spindles, it can be considered 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.

Many open die manufacturers stock a wide variety of loose tools that can be used to achieve various shapes closer to finish than would be achievable through a pure open die process. Advanced forge shops now offer shapes that were never before thought capable of being produced by the open die forging process. This offering is ideal for prototypes or low volume production where the die block cost for impression die does not provide economic justification. The immediate availability of this tooling can also allow for a shortened production lead time offering flexible order quantities and reduced lead time in situations where needed.

BEARING HOUSING

Manufacturing components with welded plate or welded ends produce quality issues from inconsistencies in using different metalworking processes. Inclusions are common and welded parts often require extensive weld repair and re-inspection. By making the component as a single forged piece with integral flanges, we are able to assure consistent quality throughout the part, eliminate instances of inclusion and remove the welding time altogether. The strength and structural integrity of the forged material meets demanding application requirements, resulting in less rework, fewer rejections and increased part life. Additionally, the elimination of welding shortens part production process time and the component is better able to withstand the rigors of field use.

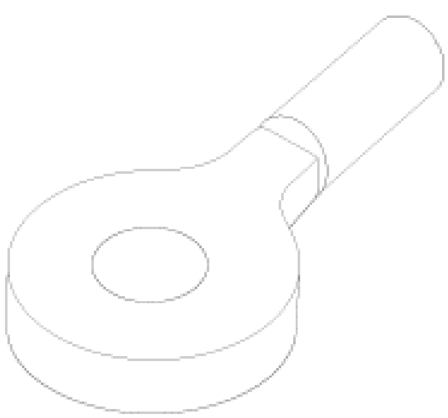
Previous Processing Problems	Forging as the Solution



ANCHORAGE BARS AND LINKS/GUDGEON ASSEMBLIES

This product is often made from a cast head welded to a hot rolled bar. Due to the lack of uniform grain structure within castings, this product often proves too weak for the intended application, resulting in shortened product life. Cracking is common in the weld layer, causing failures in the field. Additionally, welding the two pieces together is time consuming and excessive heating required during the welding process changes the hardness and tensile properties in the weld zone, making it necessary to re-heat treat the part. Fortunately, this product can be manufactured as a single-piece forging instead, improving properties and eliminating non-value-added steps. The elimination of welding provides dimensional stability, reduces the amount of inspection, and simplifies inventory management. Most importantly, the strength and structural integrity of the forged material meets demanding application requirements, resulting in less rework, fewer rejections and increased part life.

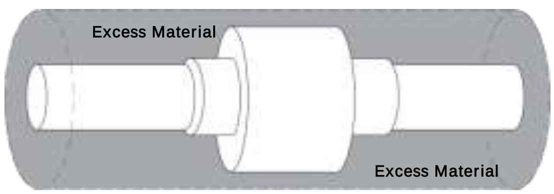
Previous Processing Problems	Forging as the Solution

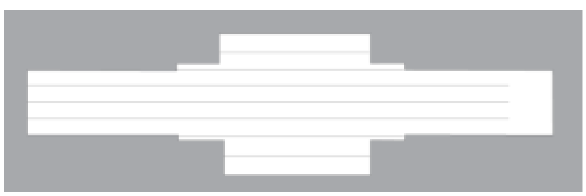


PINIONS, FLOATING SHAFTS, TRUNNIONS

Machining a solid bar to form a pinion, floating shaft or trunnion causes wasteful use of material, labor and time. Inclusions are common on the machined surface, which may cause product rejections and result in excessive time and costs spent repairing the part. Additionally, grain flow within the bar is exposed when machined, thus making the material more susceptible to fatigue failure due to exposed grain ends. A custom forging, on the other hand, requires less starting material than a straight round bar machined to shape. Material cleanliness is optimized by controlling melt practices and teaming processes, eliminating material rejections due to inclusions. Less machining saves money, time and tool life while producing a closer-to-finish shape. Lastly, contoured grain flow within a forged stepdown yields greater impact and directional strength.

Previous Processing Problems	Forging as the Solution

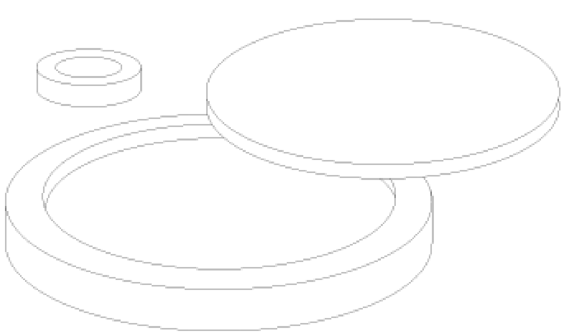




FABRICATED SHEAVE/WHEEL

Fabricating a sheave or wheel with multiple parts increases the risk for error and requires continual sourcing management. Added processing for welding of the fabrication proves to be costly and time consuming. Also, welding distortion is a major concern. A single piece forging is less prone to error due to the removal of steps, such as managing multiple suppliers, welding and nondestructive testing for the weld zones…ultimately saving time and money. Additionally, since no welding is required, the options for materials are not limited to weldable grades.

Previous Processing Problems	Forging as the Solution



CONSIDERATIONS

Many factors should be considered when converting to a forging, including the ability to redesign a product as well as the design requirements (typically shape). Oftentimes, securing engineering's approval is the key to making an individual conversion actually happen. When reviewing your component, it is helpful to take a step back and ask, "What is the purpose of my design?" Don't get stuck with a historical design that doesn't take advantage of today's technological advancements. The best results occur if you're willing to think creatively and challenge traditional methods.

More than anything else, you should partner with a forge supplier that is willing to work with your engineers to educate them about conversions, about forgings, and about the newly expanded range of product types (complex parts) that can be produced as a forging. Rather than dismissing the idea as impractical or impossible, consider the technical and/or economic merits of any particular conversion project.

About the Presenters

Sarah Marski is a Senior Account Manager and Business Segment Leader at Scot Forge Company with 12 years of experience in the sales department working with a wide variety of customers in a multitude of industries.

Jeremy Copley has 15 years forging experience, 12 on the shop floor, seven as a blacksmith and is currently in an engineering role at Scot Forge Company.