FORGING SOLUTIONS
Design Engineering Information From FIA

ROLLED RING – CASE STUDIES

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CASE STUDY FROM THE FILES:
Seamless rolled-ring forgings superior to casting in large rotary kilns

“Riding tires”—large seamless rolled-ring forgings that surround and support the huge cylindrical bodies of rotary kilns, industrial dryers and balling drums—must withstand heavy in-service loads. See figure on the right. Here, the surface quality of the tire and corresponding roller makes forgings the best choice, because of the high rolling contact pressure between tire and roller.

Compared to castings, which are prone to imperfections like porosity, inclusions, and shrinkage cavities, seamless rolled-ring forgings are virtually free of internal flaws. In addition, outside diameters of castings often require weld repairs to achieve an acceptable surface, and can have a detrimental effect on trouble-free performance. If not done properly, these welds can pop out, resulting in expensive failures via lost production time and ring replacement. In these applications, forgings out perform castings and are cost competitive.

Longer service results, because as forged rings wear, the underlying material is at least as good as the initial surface. This is not the case with castings. When cast rings are made, a continuous ring riser is required to minimize the number of voids, inclusions and other intrinsic flaws in the part. Acceptable quality requires pouring significantly more metal than a finished cast ring would contain.

When it comes to machining, forgings also have the edge. Consistently acceptable uniform composition and internal microstructure give forgings the advantage over castings, which may have to be scrapped or repaired by welding if a blow hole opens up during machining operations.

Because of demonstrated performance benefits, rotary kilns utilize forgings for rollers and shafts, as well as for tires.

Forged from 1045 steel, the "riding tires" for rotary kilns outperformed cast A27 steel and usually cost less as a final product.
CASE STUDY FROM THE FILES:
Forged tube support replaced bar stock, eliminated all machining and cuts cost by 85%

In a concerted effort to reduce costs of its metal components, a major manufacturer of medium- and heavy-duty industrial and agricultural equipment worked closely with a local forging company to redesign a machined bar stock component as a more cost-effective forging. After conversion, the results were better than expected, for a simply configured, volume-sensitive component. The steel forging cost less than one-sixth that of machined bar stock.

Previously, four different operations were required to produce the part. First, a long piece of 1020 hot-rolled bar was cut in two, then flame cut, ground, and was finally placed into a lathe fixture where the bottom was turned. By making it a forging, the company was able to produce it close enough to net shape to eliminate all machining operations—a reduction from four in-plant operations down to none. See top figure. As received from the forger, the components were directly installed on the equipment. See bottom figure.

The as forged steel tube support was ready for assembly, as compared to the bar stock version, which required extensive machining.

<table>
<thead>
<tr>
<th>COST ANALYSIS FOR STEEL TUBE SUPPORT</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL COST OF MACHINED BAR STOCK = 100%</td>
</tr>
<tr>
<td>RAW MATERIAL COST = 7%</td>
</tr>
<tr>
<td>SAW, FLAME CUT, SHOT BLAST = 10%</td>
</tr>
<tr>
<td>BORE OPERATION, DEBURR = 83 %</td>
</tr>
<tr>
<td>TOTAL COST OF FORGING = 15%</td>
</tr>
</tbody>
</table>
CASE STUDY FROM THE FILES:

*Capability analysis brought process into control, boosted quality of forged automotive parts*

Capability studies are powerful tools in controlling the forging process. In this example (relatively high volume aluminum die forgings), too many automotive parts were being produced outside the specification range. Although practically all parts could be reworked to bring them within the blueprint tolerance range, adjusting the process should theoretically produce all parts to specification.

To analyze the situation, engineers conducted a capability study using the die closure dimension (thickness), which is normally the dimension of interest for evaluating how well the process is “in control.” If this dimension is correct, so are all other dimensions.

Initial capability analysis showed that the spread was too wide for the specification, and that the process was off center, as indicated by a low process capability index or $C_{pk}$. By definition, $C_{pk} = \frac{\text{specification tolerance range}}{\pm 3\sigma}$ of the process capability range. A process capability index, $C_{pk}$, of greater than 1.33 means that more than 99.94% of the forged products are within the specified blueprint tolerance.

Adjusting specific process variables brought the process back into control, achieving a $C_{pk}$ of 1.3820 versus the initial value of 0.0123. See table. The adjustments also brought the mean value much closer to center. See figure above. Consequently, all parts produced after process adjustment fell within the specification limits. Rework dropped from 49% to 0.

Other benefits included not only reduced inspection, but also the elimination of part sorting and restriking or other...
erwise reworking parts to make them acceptable. Correspondingly, productivity and cost effectiveness also increased.

Finally, once the process was centered with a relatively high $C_{pk}$, it was relatively simple to maintain. Only statistical sampling and plotting of control chart points were necessary to monitor production. Once a process is adjusted, it tends to stay "in control."

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>2.9543</td>
<td>2.9085</td>
</tr>
<tr>
<td>Std. dev.</td>
<td>0.0281</td>
<td>0.0081</td>
</tr>
<tr>
<td>% &lt; L.S.L.</td>
<td>0.89</td>
<td>0.0000</td>
</tr>
<tr>
<td>% &gt; U.S.L.</td>
<td>48.8</td>
<td>0.0000</td>
</tr>
<tr>
<td>$C_{pk}$</td>
<td>0.0123</td>
<td>1.3820</td>
</tr>
</tbody>
</table>

Process capability, % of blueprint tolerance:

| Specification limits (L.S.L. - U.S.L.) | 2.870-2.960 |
| 3σ limits (Before)                        | 2.870-3.039 |
| 3σ limits (After)                        | 2.884-2.933 |
| 4σ limits (Before)                        | 2.842-3.067 |
| 4σ limits (After)                        | 2.876-2.941 |
CASE STUDY FROM THE FILES:

Rolled rings outperformed fabrications, cut costs in safety-critical cranes

Seamless rolled rings are replacing both plate and welded fabrications which cannot provide the required high performance of forged mounting rings in safety-critical applications. Referred to as matched rings for mounting the forged bearings of construction/mining equipment like cranes and excavators, these seamless rolled rings have outer diameters ranging from 20 in. to 185 in. See figure on the right.

In the field, the use of plate caused structural failures due to laminar separations within the plate and poor low-temperature performance. Additionally, poor weld quality in nested ring assemblies was not uncommon. Here, the lack of full penetration welds lead to unexpected failure due to both flatness problems and non-uniform stresses.

Because the bearings and rings for turntables of cranes were subjected to such demanding conditions, problems associated with non-forged products led to catastrophic equipment failures, such as cranes falling off their pedestals or tipping over, as well as shear failures in excavators. Fortunately, rolled rings provided a metallurgically sound, matched mounting surface, increased the safety factor dramatically, and eliminated serious liability concerns related to plate fabrication.

Made of low-carbon steels such as 1026, 1030 and 1035, rolled rings had mechanical properties far superior to those of A36 plate—the direct result of circumferential grain flow compared to the unidirectional grain of plate.

Economy was another plus for forging versus labor-intensive, on-site fabrication. In actuality, cost savings were further increased due to the typically longer life of forged rings.

In practice, a fabrication has a bearing mounted to it, with a gantry on top. Even in normal use, a non-uniform mounting surface or a welded fabrication with "hard spots" will decrease the life of an expensive bearing by imparting tremendous loads to the bearing. Tilt and moment loads compress the front of the bearing, while the back of the bearing undergoes a reduced load. If the mounting surface is not machined or matched to the bearing, early fatigue failures (dynamic) or pure case core crushing (static) can result. Net consequences are failure of an expensive bearing and...
costly down time. Forged mounting rings also prolong the life of bearings, which, depending on size, may cost as much as $100,000. Longer life from reduced loads is the result of a very flat, matched mounting surface rather than an out-of-square, out-of-flat fabrication.

By educating designers and builders of such equipment, rolled-ring producers can eliminate fabrication-related problems for numerous worldwide customers. Consequently, performance successes for rolled mounting rings have expanded to rubber-tired track machines, rail machines, and ship cranes.
CASE STUDY FROM THE FILES:

Forged aluminum ejector cut cost, provided critical dimensions

Forged from 2014 aluminum alloy, an ice-cube ejector for refrigerators held up where cast, powder metal, and plastic components just could not perform. The 1 oz. forging provided the required strength and critical dimensions needed to mesh with mating parts and function without water leaking, which would stop the icemaker from operating.

In the interest of cost savings, the manufacturer explored non-forging options. If water leaked and froze, the casting snapped in half under pressure when trying to push down and eject the ice cubes. It was the same result with both the powder metal (PM) and plastic versions. Although plastic and PM parts cost less initially, continual replacement of parts in the field was an extremely costly option and a short-lived one. The OEM certainly did not want its reputation tarnished. Forgings provided superior strength and unmatched service life. According to the forger, life cycle cost savings were significant.

Conventionally forged from 6 in. sections cut from 1 in. diameter 12 ft. long rods, the aluminum ejector was forged two at a time to maintain size and maximize die life. See figure. Flash was removed by clipping and, at the same time, a shaving operation was performed on the web thickness. The parts were then solution heat treated and aged to provide the required in-service strength and proper hardness for machining. Next, the forging went into an automatically fed saw that made two parts from one forging. Prior to vibratory deburring, parts were gauged to ensure straightness and thickness from one end of the part to another. After drilling and counter-boring of the center hole, the parts were clear anodized for additional corrosion resistance.

For proper function, the ejector had to meet stringent engineering specification, including a number of critical dimensions. For example, the pad diameters had to be accurate to prevent leading water and restriction of ejector movement. For the center pad, diameter was held to 0.798 to 0.810 in.

Web thickness also was critical in meeting assembly tolerances for mating parts. Essentially, the draft was shaved off, creating a straight wall. Excess thickness (0.095 to 0.085 in., as forged) was reduced to 0.085 in.

Even though dimensional tolerance of the forge was considered minimal for this part, secondary operations like shaving and automatic sawing hold critical dimensions to the close tolerances required.