Comparison of cast and extruded stock for the forging of AA6082 alloy suspension parts

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Abstract. High-precision near-net shape parts with excellent surface qualities can be produced with the forging process with a minimum of finishing operations thanks to the good formability of aluminium alloys. There has been a rapid increase in the use of aluminium forgings predominantly in the automotive industry, where weight savings for reduced fuel consumption and exhaust emissions is mandated by legislation. Aluminium forgings provide, in addition to low weight, high strength, good corrosion resistance and a fibrous grain structure to improve fatigue resistance. Typical commercial forging stock is the round bars produced by the extrusion of cast billets. An alternative process route that has received increasing attention in recent years is the casting of forging stock by a horizontal direct chill casting technique to make smaller billets without the need for extrusion to reduce their diameter. The anisotropy imparted to the forging stock via extrusion, often regarded as useful for the forging, is certainly missing in the former. However, cast stock has been reported to be more resistant to the formation of coarse surface grains than the extruded counterpart. The present work was undertaken to compare the casting and extrusion routes for the manufacture of 6082 alloy forging stock.

Introduction

Forging is a near-net shape manufacturing process where metal is pressed, pounded or squeezed under high pressure into high performance components [1]. Forgings offer higher strength and ductility with respect to cast and machined parts, owing to an improved soundness and uniformity in chemistry. Additionally, forged components enjoy a favourable grain structure that can be oriented in the direction of principal stresses encountered in service with a proper selection of starting material, die design and process parameters [2]. Hence, forgings are better suited for those structural applications where reliability and human safety are critical.

The ever increasing need for lightweight solutions in the transportation industry give aluminium forgings a considerable edge [3]. There has been a rapid increase in the use of aluminium forgings particularly in the automotive industry, where weight savings for reduced fuel consumption and exhaust emissions is mandated by legislation. In addition to light weight, aluminium forgings provide high strength, good corrosion resistance and fatigue resistance. Thanks to the outstanding formability of aluminium alloys and to the development of modern, efficient presses, it is possible to produce high-precision aluminium parts that fully conform to the strict requirements of the automotive industry with only a minimum of additional finishing operations. High performance aluminium parts such as suspension arms and steering columns have thus become standard in most passenger cars.

The characteristic feature of aluminium alloy forgings is a dense fibrous microstructure achieved by properly designed material flow that is governed by the extent and rate of deformation and temperature [3]. Optimum mechanical properties, i.e. strength, ductility, toughness and fatigue, are obtained in the fibre direction. However, friction and high shear strains in the contact zone between the work piece and the die can lead to a recrystallised surface layer that often degrades the service performance of the component.
The type and quality of the forging stock has a significant effect on the quality and the performance of the forging [4]. While extruded bar is the typical forging stock particularly in the manufacture of long parts like control arms, there has been a great interest to replace the extruded forging stock with cast billets of the same diameter [4-8]. The use of cast billets as forging stock not only avoids coarse grained sections but also reduces the production costs by 15–20% with respect to the extruded bars [7]. The combination of casting and forging has thus been reported to offer a great potential. The most extensively used forging alloy is the age-hardening EN AW 6082 alloy because of its excellent combination of mechanical properties and corrosion resistance [9]. The objective of this investigation is to compare the cast material with the standard extruded forging stock in the manufacture of EN AW 6082 automotive suspension components.

### Experimental Procedures

The EN AW 6082 alloy used in the present investigation (Table 1) was cast industrially with a vertical DC caster in the form of 6m long ingots with a diameter of 203 mm. The cast ingots were homogenized at 580 °C for 8 hours to dissolve coarse eutectics and the Mg2Si particles formed during solidification and to obtain a fine distribution of Mn and Cr containing dispersoids to control recrystallization. They were subsequently cooled to room temperature at an average rate of 400 °C/h to achieve a delicate balance between the precipitation and solute saturation.

<table>
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<tr>
<th>Si</th>
<th>Fe</th>
<th>Mn</th>
<th>Mg</th>
<th>Cu</th>
<th>Ti</th>
<th>Cr</th>
<th>Zr</th>
<th>V</th>
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<td>1.022</td>
<td>0.1186</td>
<td>0.597</td>
<td>0.842</td>
<td>0.0168</td>
<td>0.0233</td>
<td>0.0020</td>
<td>0.0012</td>
<td>0.0124</td>
</tr>
</tbody>
</table>

Further processing of the EN AW 6082 ingots into forging stock followed two different routes. The first route involved direct extrusion of 600 mm long billets sectioned from the homogenized ingots into 400 mm long round bars with a diameter of 42 mm on a 2700 ton industrial extrusion press. The billets were preheated to 450 °C and extruded at a rate of 3 m.min⁻¹ so as to achieve a press exit temperature of approximately 500 °C. The round bars thus obtained were quenched in water at the press exit. The second route involved electric discharge machining of 400 mm long round bars with a diameter of 42 mm from the homogenized billets. The cast and extruded round bars were preheated to 490 °C and were forged on a 1600 ton forging press into suspension parts shown in Fig.1. The forged components were solutionized at 520 °C for 4 hours and quenched in water before they were artificially aged at 180 °C for 8 hours.

Billet samples thus obtained were prepared with standard metallographic techniques: ground with SiC paper, polished with 3 micron diamond paste and finished with colloidal silica. They were examined after etching with a 0.5%HF solution using an Olympus BX51M model optical microscope. The XRD patterns were recorded with a Shimadzu XRD 6000 Diffractometer equipped with CuKα radiation. Cast, extruded, forged and heat treated samples were anodised in Barker’s solution, 5 ml HBF₄ (48%) in 200 ml water, and then examined with an optical microscope under polarized light. Hardness was measured with a microhardness tester under a load of 30 g and with a dwell time of 20 s.

![Fig. 1. Photo of the control arm investigated in the present work.](image-url)
Results and discussion

The microstructure of the DC-cast 6082 billet section is shown in Fig. 2. The homogenized billet is characterized with a dendritic network of the $\alpha$-Al solid solution matrix with a dispersion of $\text{Mg}_2\text{Si}$ precipitates and $\alpha_c\text{Al}_{12}(\text{Fe}, \text{Mn})_3\text{Si}$ compound particles at interdendritic sites. A surface layer of approximately 50 µm is free of precipitates owing to a much higher cooling rate during post soaking cooling. This layer contains, however, many $\alpha_c\text{Al}_{12}(\text{Fe}, \text{Mn})_3\text{Si}$ intermetallic compound particles implying inverse segregation of the alloying elements during DC casting. The rest of the billet section typically contains a high population of $\text{Mg}_2\text{Si}$ precipitates inside the matrix grains owing to the presence of dispersoids in the present alloy. The Al-Fe-Si platelets have broken into $\alpha_c\text{Al}_{12}(\text{Fe}, \text{Mn})_3\text{Si}$ particle stringers in a necklace configuration during soaking. These structural features are

![Fig. 3. XRD spectra of (a) the cast-homogenized billet and (b) the extruded profile.](image)

![Fig. 4. Microstructure of the extruded profile across the longitudinal section: (a) surface, (b) quarter depth and (c) centre.](image)
confirmed with the XRD analysis of the homogenized billet (Fig. 3a) and suggest that the homogenization treatment has produced the desired microstructural transformations across the billet section.

The microstructure of the extruded section is similar to that of the homogenized billet with predominantly Mg$_2$Si precipitates and $\alpha_c$-Al$_{12}$(Fe,Mn)$_3$Si compound particles (Fig. 4). The distribution of the soluble and insoluble particles suggest a strong directionality that is linked with the plastic flow of the extrusion deformation. This directionality is limited at the surface owing to a dynamic recrystallization process often encountered in 6XXX alloys during extrusion process. This surface layer is formed in the extrusion process due to the relatively higher temperatures due to frictional heating and high strains at the surface that encourages dynamic recrystallization. The dispersion of the Mg$_2$Si precipitates is particularly affected.

**Fig. 5.** Evolution of grain structure (a-c) and particle features (d-f) of the extruded profile (a, d), the forged component (d, e), after the T6 heat treatment (c, f).

**Fig. 6.** Section macrographs of suspension parts produced by the forging of 6082 extruded stock after T6 heat treatment. Extrusion press exit temperature: (a) 500 °C, (b) 460 °C and (c) 430 °C.
The evolution of the microstructural features during the rest of the process sequence, i.e. after forging and solutionizing and artificial ageing, is manifested in Fig. 5. While the insoluble as well as soluble particle features are typical of the production process, the striking change occurs in the grain structure. The fibrous grains inherited from the extruded profile with the exception of the surface layer, is largely retained after the forging operation (Fig. 5b). The matrix fibers, however, are often divided into a very fine dynamically recrystallized grain structure. Such small grains are very prone to abnormal grain growth that becomes inevitable during the solution heat treatment, producing grains several millimeters big across the section of the forging (Fig. 5c). This coarse grain structure may be limited to the surface of the forging or spread over the entire section once the process parameters are not adequately fine tuned (Fig. 6).

The second processing route employed in the present work involved the forging of the cast 6082 stock obtained from the same billet the round bars forged in the first route were extruded. This facilitates a direct comparison of the potential of the cast vs extruded forging stocks in the manufacture of suspension parts. Fig. 7 shows the section macrostructure of the as cast rod compared with the extruded rod. Extruded material has a relatively smaller grain structure on the transverse section owing to the deformation of the extrusion process and a layer of coarse grains at the surface while the cast bar exhibits the standard billet structural features. A uniform grain structure across the section and homogeneous distribution of the insoluble Al-Fe-Mn-Si intermetallic and soluble Mg$_2$Si particles is expected to make a favourable impact.

![Fig. 7. Section macrographs of 6082 (a) extruded and (b) cast forging stock.](image)

The grain structure of the 6082 forging produced from cast stock is shown in Fig. 8. Coarse grains the predominant feature of the forging produced from extruded stock are entirely missing. The suspension component produced via forging of the cast stock offers a much superior surface quality with respect to the component produced by the forging of the extruded stock owing to a much smaller and more uniform grain structure at the surface of the forged component after the T6 heat treatment. The hardness of the forging produced from the cast forging stock is $111 \pm 3$ HV, slightly higher than its counterpart produced from the extruded stock, $106 \pm 8$ HV. The consistently higher hardness can be accounted for by the much smaller grain structure that facilitates a more efficient solutionizing and precipitation during the T6 heat treatment. It should be noted, however, that the fibrous grain structure that is typical of forgings produced from the extruded stock is no longer present in the forgings produced from the cast stock. The fibrous grain structure is often credited for the superior fatigue properties of the forgings. Hence, the fatigue properties of the forgings produced from the cast vs extruded stock need to be investigated.

**Summary**

It is fair to conclude from the present work that the overall structural quality of the forging produced from cast stock is better than its counterpart produced from the extruded stock. However,
Fig. 8. (a) The control arm forged from cast 6082 stock, (b) section macrostructure and (c,d,e) grain structures at locations marked in part (a).

Further work is required, particularly regarding the fatigue properties of the forged components, to identify the impact of the fibrous grain structure of the latter on the performance of the forging.

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References

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