A novel processing route for the manufacture of EN AW 6082 forged components

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An attractive combination of strength and formability, corrosion resistance and recyclability has made the age-hardening EN AW 6082 one of the most popular aluminium forging alloys. 6082 alloy forgings are thus used extensively in automotive suspension components. The conventional manufacturing cycle starts with the casting of 6082 billets that are subsequently extruded into smaller diameter forging stock. The relatively higher temperatures generated by frictional heating and high strains introduced at the surface during extrusion encourage recrystallisation and produces a heterogeneous structure with fully recrystallised small grains at the surface, fibrous grains at the centre. Hence, the surface of the forged 6082 components inevitably undergoes grain growth once exposed to high temperatures during the solution heat treatment. An attempt was made in the present work to identify an alternative process to achieve a homogeneous section structure with no evidence of coarse grains across the section, which in turn will ensure a better fatigue performance and a longer service life.

Keywords: Aluminium forging, EN AW 6082, T5 and T6 heat treatment, Fatigue, Suspension components

Introduction

There has been a rapid increase in the use of aluminium forgings in the automotive industry, where weight savings is a critical requirement for reduced fuel consumption and exhaust emissions.[1] 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.[2]

A very attractive combination of mechanical properties and corrosion resistance has made the age-hardening EN AW 6082 one of the most popular aluminium forging alloys.[3] 6082 automotive parts work under cyclic loading and have to maintain high-impact strength and hardness.[4] Automotive suspension components manufactured from the 6082 aluminium extrusion alloy can be heat treated to rather high hardness levels. The conventional manufacturing cycle starts with the semi-continuous casting of 6082 billets that are subsequently extruded into smaller diameter forging stock. The relatively higher temperatures generated by frictional heating and high strains introduced at the surface during extrusion encourage recrystallisation and produces a heterogeneous structure with fully recrystallised small grains at the surface, fibrous grains at the centre. Hence, the surface of the forged 6082 components inevitably undergoes grain growth once exposed to high temperatures during the solution heat treatment.[5–8] The abnormally coarse surface grains not only degrade the surface quality but also impair the resistance of the suspension components to cyclic loading that is known to be very sensitive to the surface micro and macro structural features.

Processing parameters have a big impact on the strength of the final product and thus need to be fine-tuned to ensure a uniform structure and uniform properties for high strength forged components.[8] The present work was undertaken to achieve a more homogeneous section structure with no evidence of coarse grains across the section, which in turn will ensure a better fatigue performance and a longer service life. This was done by eliminating the separate solution heat treatment step from the conventional manufacturing cycle. The section structures and mechanical properties of the forged components in T5 temper were compared with those of the counterparts produced in T6 temper.

Experimental procedures

The EN AW 6082 ingots (Table 1), cast with a vertical DC caster in the form of 203 mm diameter, 6-m long ingots, were homogenised at 580 °C for 8 hours and were subsequently cooled to room temperature; 600-mm long billets sectioned from the homogenised ingots were extruded into 400-mm long round bars with a diameter of 42 mm at press exit temperatures between 490 and 520 °C and were finally quenched in water at the press exit.

The forging stock thus obtained was processed in two different routes. One of the two processing cycles

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Table 1 Chemical composition of the EN AW 6082 alloy used in the present investigation

Si	Fe	Mn	Mg	Cu	Ti	Cr	Zr	V	Al
1·0	0·20	0·551	0·802	0·042	0·020	0·181	0·005	0·013	97·12

employed a solution heat treatment and an aging treatment (T6 route) following the forging process (Fig. 1*a*). The extruded round bars were preheated to 500–520 °C and were forged on a 1600 ton forging press into suspension parts shown in Fig. 1*c*. The forged components were solutionised at 520–530 °C for 4 hours and quenched in water before they were artificially aged at 170–190 °C for 8 hours (Fig. 1*a*).

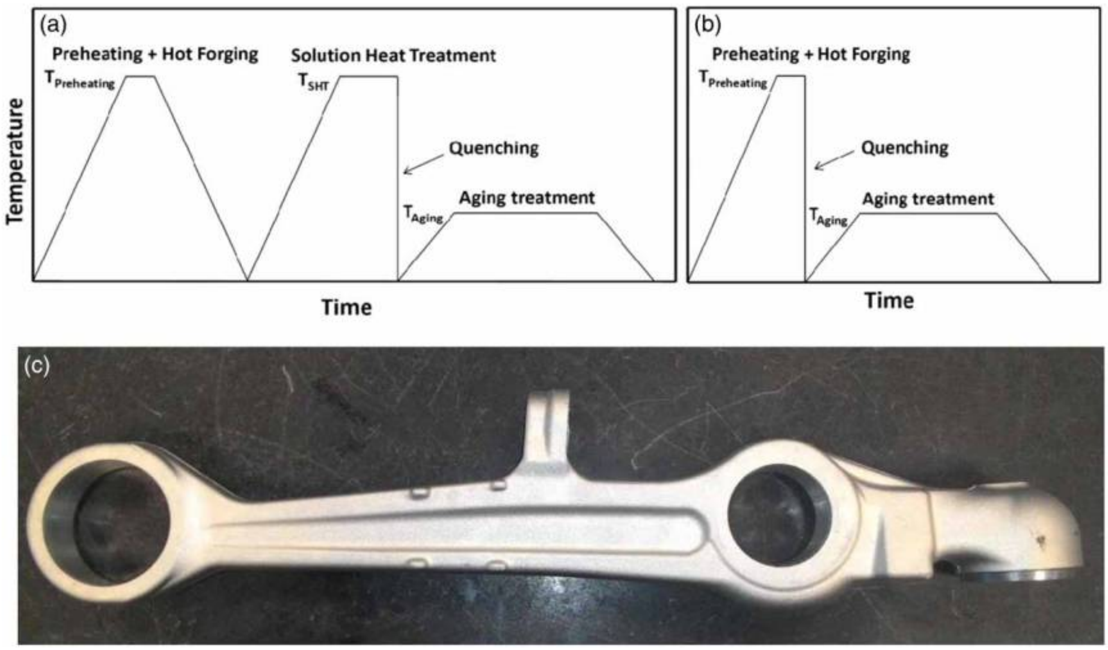
The novel processing cycle, on the other hand, skipped the solution heat treatment and employed only an artificial aging heat treatment following the forging step (T5 route). The extruded round bars were again preheated to 500–520 °C and were forged on a 1600 ton forging press into suspension parts and immediately quenched after the forging step. The forgings thus obtained were directly artificial aged at 170–190 °C (Fig. 1*b*).

Samples sectioned from the extruded forging stock were prepared with standard metallographic techniques: ground with SiC paper, polished with 3 micrometre diamond paste and finished with colloidal silica. Sections from the forging stock, forged and heat-treated components were etched with the Tucker's reagent and were also anodised in Barker's solution, 5 mL HBF 4 (48%) in 200 mL water, and then examined with an optical microscope under polarised light.

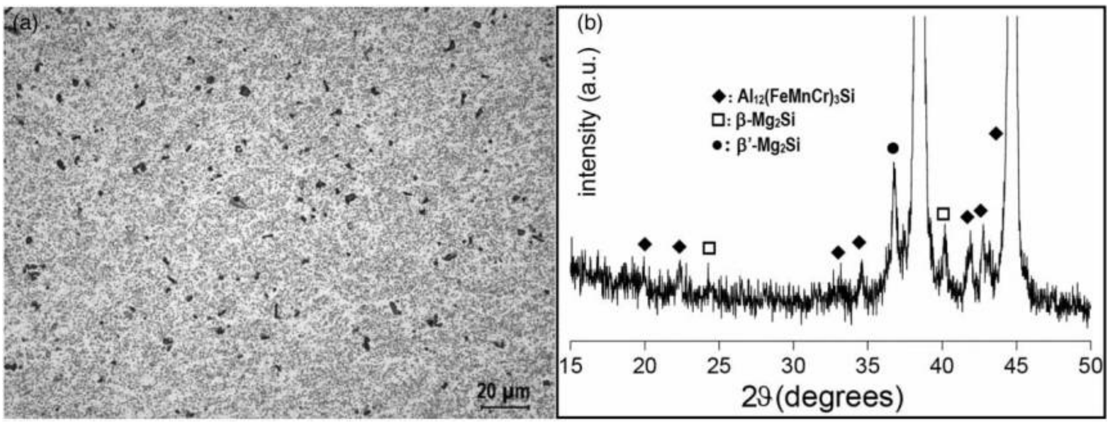
The chemical compositions of the forgings were checked with a Spectromaxx Optical Emission Spectroscopy Unit. Hardness of the forgings was measured with a Brinell Hardness Tester under a load of 250 kgf by using 5 mm diameter steel ball with a dwell time of 10 seconds. The tensile tests were performed using a screw-driven ALSA tensile testing machine in air at room temperature. The cross-head speed was 1 mm min^{-1}. The strain was measured with an extensometer attached to the sample and with a measuring length of 30 mm. The 0·2% proof stress was reported as the yield stress.

Results and discussion

The EN AW 6082 forging stock is characterised with a fine dispersion of Mg_2Si precipitates and intermetallic particles identified by XRD analysis to be cubic α_c - $Al_{12}(Fe,Mn)_3Si$ particles (Fig. 2).The latter have apparently fragmented during the extrusion process and are thus relatively smaller than those typically observed in as-cast 6082 billets.[8] The addition of Cr is believed to be responsible for the increased volume fraction of Fe-based intermetallic particles and the predominance of the cubic phase over the monoclinic β-Al_5FeSi variety.[9] Both the soluble Mg_2Si precipitates and the insoluble intermetallic compound particles are aligned in the extrusion direction. Fibrous grains elongated in the extrusion direction are predominant across much of the section (Fig. 3). These fibres become thinner and are gradually replaced by small equiaxed grains near the surface. Finally, the surface grains are very fine and entirely equiaxed owing to strain and temperature gradients that peak at the surface during the extrusion process. The surface layers are believed to have recrystallised during the extrusion process due to the relatively higher temperatures generated by frictional heating and high strains introduced at the surface that encourage recrystallisation. The extruded bar does not exhibit coarse surface grains,



1 *a* T6 and *b* T5 processing for the manufacture of suspension components; *c* the suspension component forged from 6082 alloy



2 *a* Microstructure on the transverse section of the extruded 6082 forging stock and *b* the X-ray diffraction spectrum

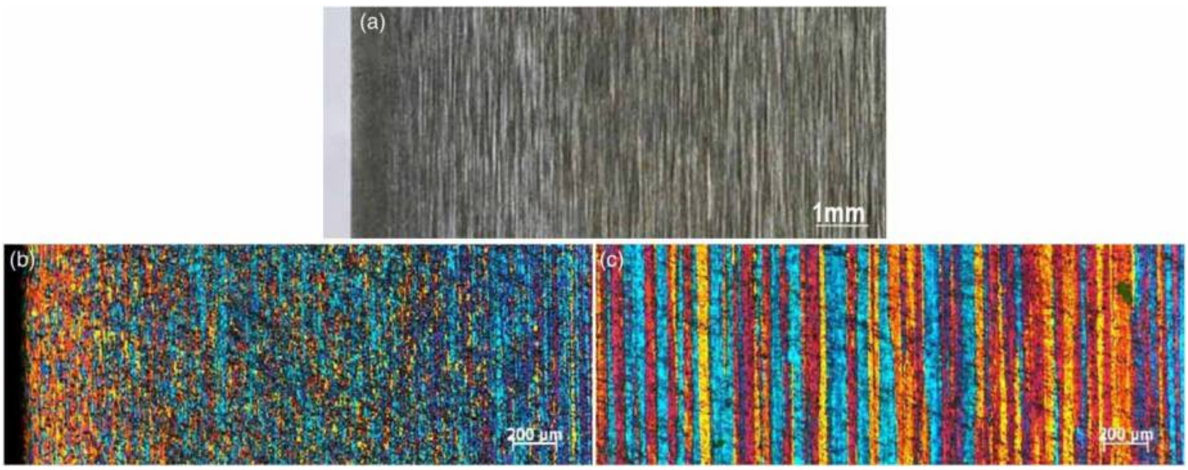
typical of extruded 6082 alloys,[5–7,10,11] possibly owing to the addition of as much as 0·18 wt-% Cr in the alloy.

The grain structure of the forging stock was largely retained after the hot forging operation with the exception of some additional fibering across the section at locations where the plastic flow associated with the shaping process was substantial. The surface layers remain relatively undeformed during forging owing to the frictional conditions that limit the plastic flow near the surface.[1] Aluminium sticks to the surface of the tool under high pressures and at high temperatures involved in the hot forming of aluminium alloys[12] allowing deformation only in the interior of the billet. The addition of extra Cr in the present alloy is also believed to have played a key role in inhibiting grain growth during the hot forging operation. Grain boundary pinning provided by Cr-bearing intermetallic particles avoids grain growth and thus helps to improve the grain structure.

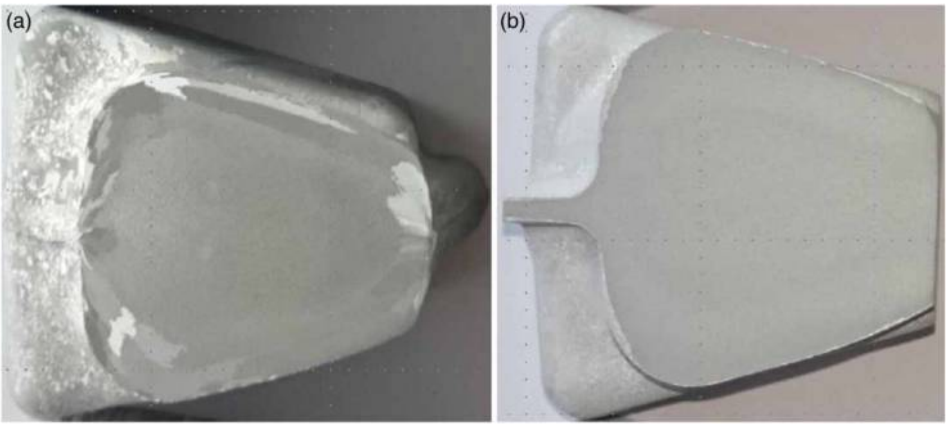
There was, however, a marked change in the section structure of the forgings after the solution heat treatment. The grain structure typical of the forgings produced with the conventional processing cycle, in the T6 temper, is illustrated in Fig. 4*a*. There has been substantial grain growth during the solution heat treatment producing very coarse grains at the surface of the forgings. Occasionally, more severe cases were encountered during industrial scale production cycles where the suspension components suffered through-thickness coarse grain structures.

The thickness of this coarse grain zone in the solutionised suspension components is consistent with that of the fine equiaxed grain zone in the forged pre-cursor, suggesting that the coarse surface grains have formed through the growth of the very fine recrystallised grains of the forging during the subsequent solution heat treatment. The rather small strain energy owing to the rearrangement of the structure in addition to the very small initial grain size at the surface both favour grain growth over recrystallisation during a subsequent high temperature thermal exposure. It is worth noting, however, that forgings produced from a similar 6082 alloy with no Cr have suffered a coarse grain structure across the entire section after the solution heat treatment. It is thus fair to conclude that Cr addition improves the grain structure of the forging stock as well as that of the suspension component.

The second set of suspension components were produced without a separate solution heat treatment. A number of revisions were implemented in the manufacturing cycle, particularly in the preheating, forging and post-forging operations to ensure sufficient Mg and Si solute levels before the artificial aging treatment. The post-forging cooling practice is particularly critical in this process cycle because of the increase volume fraction of Cr-bearing dispersoids.



3 *a* Macrostructure of the extruded 6082 forging stock in the extrusion direction from the surface to the centre of the profile and the grain structures at *b* the surface and at *c* the centre



4 Macrostructures of the transverse section of the suspension components manufactured with the *a* conventional and *b* the novel processing cycle

Table 2 The mechanical properties of suspension components produced with and without a separate solution heat treatment

Process	σ_y, MPa	σ_{UTS}, MPa	A_{50}, %	Hardness, HB
w/ solutionising	279 ± 18	310 ± 23	16 ± 4	97 ± 0·9
w/o solutionising	296 ± 10	363 ± 7	25 ± 3	96 ± 0·2

There is a marked improvement in the grain structures of suspension components produced without a solution heat treatment. A very fine grain structure across the entire section with no evidence of coarse grains even at the outermost skin of the parts is evident (Fig. 4*b*). The elimination of the solution heat treatment step in the manufacturing cycle is indeed responsible for this remarkable improvement in the grain structure of the suspension components since the counterparts processed with a solution heat treatment exhibit rather deep peripheral coarse grain zones.

The mechanical properties of the forgings produced conventionally and with the new process are listed in Table 2. The profound improvement in the grain structure of the latter, with predominantly fibrous grains across the entire section, is reflected rather nicely by its relatively higher strength as well as its much higher elongation values. It is fair to conclude from the hardness measurements that the revised hot forging practice together with a precisely controlled post-forging cooling cycle produced sufficient levels of Mg and Si in solution to offer adequate age hardening during the subsequent artificial aging cycle. The fine fibrous grain structures impact not only the strength of the suspension parts but also impart outstanding ductility to these safety critical structural parts. A much smaller grain structure at the surface is expected to make a very favourable impact on the fatigue strength of these suspension components. Needless to say, the process proposed in the present study for the manufacture of automotive suspension components not only improves the quality but also offers significant cost savings.

Summary

An attempt was made in the present work to identify an alternative process to achieve a homogeneous section structure with no evidence of coarse grains across the section, which in turn will ensure a better fatigue performance and a longer service life. A marked improvement is noted in the grain structures of 6082 alloy suspension components produced without a solution heat treatment. This improvement in grain structure leads to higher strength and ductility. The novel process proposed for the manufacture of automotive suspension components not only improves the quality but also offers significant cost savings.

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