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# Influence of T6 heat treatment on A356 and A380 aluminium alloys manufactured by thixoforging combined with low superheat casting

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**Abstract:** The effects of T6 heat treatment on thixoforged A356 and A380 aluminium alloys were studied. Low superheat casting (LSC) technique was carried out to prepare proper specimens for thixoforging process. The samples were poured at 20 °C above their liquidus temperatures which provided the formation of equiaxed grains instead of dendritic growth. Produced billets were reheated for varied time from 20 to 80 min and thixoforged with 50% deformation rate. After thixoforging process, the samples were T6 heat treated for both A356 and A380 alloys. The microstructural evaluation and hardness alteration of thixoforged, solution treated and aged specimens were examined comparatively by using optical microscopy, scanning electron microscopy with energy-dispersive X-ray spectroscopy and Brinell hardness equipment. T6 heat treatment provided relatively uniform microstructure with newly formed precipitates that are $Mg_2Si$ and $Al_2Cu$ for A356 and A380 billets, respectively. Accordingly, hardness after artificial aging was increased considerably and reached HB 93 for A356 and HB 120 for A380 alloys.
**Key words:** T6 heat treatment; thixoforging; low superheat casting; aluminium alloy

## 1 Introduction

Lightweight alloys such as aluminium and magnesium have become recently prominent to overcome fuel efficiency and environmental pollution concerns in automotive industry. A356 and A380 aluminium casting alloys have been widely used in automobile components to provide progress on those concerns due to their tremendous castability, weldability, corrosion resistance and high strength-density ratio [1−3]. Semi-solid metal (SSM) processing of aluminium alloys has been developed as an alternative to conventional die casting method for manufacturing net-shaped products [4]. SSM techniques require non-dendritic structure in order to obtain “thixotropic” properties which are related to the success of the forming process [5]. Thixotropy can be described as a behaving of the materials like solid and liquid phases. This behavior enables to fill die more uniformly than fully liquid state casting methods owing to the laminar manner instead of turbulent flow [6]. To manufacture the starting material (ingot or billet) with thixotropic properties, several methods have been developed like recrystallisation and partial remelting (RAP), cooling slope (CS) casting, magnetohydrodynamic (MHD) stirring and strain induced melt activation (SIMA) [7,8]. Low superheat casting (LSC) is one of the attractive ways to produce proper starting material with reduced cost by comparison with other methods. In LSC process, subjected metal is cast at just above its liquidus temperature and equiaxed non-dendritic grains that spheroidize during further SSM process are formed. There are various explanations about the non-dendritic formation mechanism. According to MULLINS and SEKERKA [9], very low undercooling with very high saturation of nucleation sites may be the main reason for equiaxed grain formation instead of dendrites. Another claimed theory is “secondary nuclei” caused by applied agitation to molten metal during solidification [10]. Agitation causes to rupture dendrite arms, change growing morphology and generate grain-refined microstructure by dendrite fragmentation. CHALMERS [11] also showed that low casting temperature promotes the formation of equiaxed grains and makes them grow uniformly. In spite of those researches and unmentioned others, much work is required to know accurate conversion mechanism from dendritic to equiaxed particles.

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SSM techniques are mainly divided into thixo and rheo routes. Thixoforging, which belongs to the thixo route, is a kind of SSM forming method where the material is heated into the temperature that both solid and liquid phases of alloy coexist, and then are shaped in an open die to manufacture near net-shaped components [12]. As for non-dendritic structure, wide solidification interval and continuous transition from solidus to liquidus temperatures are necessary for the success of thixoforging process. From this point of view, A356 and A380 aluminium alloys were chosen due to their adequate fluidity and castability features with thixotropic properties. Al−Si alloys are generally heat treated so as to acquire optimum combination of strength and ductility. WANG et al [7] conducted T6 heat treatment on A356 alloy wheels and reported that heat treated wheels show better tensile strength due to $Mg_2Si$ precipitation and eutectic transformation into globular Si particles. SALLEH et al [12] concluded that tensile strength of thixoforged A319 alloy reached 298 MPa after aging while it was 241 MPa for untreated sample. There is no comparative study about the effects of T6 heat treatment on thixoforged A356 and A380 alloys in the literature. In this work, T6 heat treatment was applied to thixoforged A356 and A380 billets obtained by LSC process. The micrographs with hardness measurements of both thixoforged and T6-treated alloys were given and results were discussed.

## 2 Experimental

1000 g of recycled A356 and A380 alloy ingots were used for each casting operation. Chemical compositions of these alloys are shown in Table 1. Sliced ingots were melted in a clay/graphite crucible by using electric resistance furnace and poured into cylindrical steel mould. The pouring temperatures were selected 20 °C above the liquidus temperatures which were 615 °C for A356 and 595 °C for A380. Accordingly, LSC processes of A356 and A380 alloys were carried out at 635 and 615 °C, respectively. Produced billets were cut with the dimensions of 40 mm in diameter and 40 mm in height. One as-cast specimen of each alloy was reserved for further comparative analysis. The rest of the samples were reheated 20°C below their liquidus temperatures (595 °C for A356 and 575 °C for A380) and held in these semi-solid regions for 20−80 min. After holding step, specimens in a semi-solid condition were forged in a preheated open die with 50% deformation rate by using hydraulic press. All thixoforged samples were sliced into three pieces, one of them was reserved for characterization and the other two were subjected to subsequent T6 process. T6 heat treatment was conducted into the following steps: solution treatment, quenching and artificial aging. Solution treatment temperatures were chosen at 20 °C below the solidus temperatures of various alloys, thus A356 and A380 alloys were solution treated for 4 h at 535 and 520 °C, respectively. All treated samples were water-cooled and those of each two samples were analyzed at their existing state while the others were artificial aged at 180 °C for 4 h. For the microstructural investigations, ground and polished sample surfaces were etched with 0.5% HF solution. All micrographs were taken by Nikon Eclipse MA100 optical microscope and Brinell hardness measurements were performed by universal test device with load of 62.5 kg and tip diameter of 2.5 mm. Energy-dispersive X-ray spectroscopy (EDS) was used for elemental analysis by using a Jeol JSM 5410 LV scanning electron microscope (SEM).

**Table 1** Chemical compositions of A356 and A380 aluminium alloys

| Alloy | Si | Fe | Cu | Mn | Mg | Zn |
|---|---|---|---|---|---|---|
| A356 | 7.288 | 0.144 | 0.011 | 0.028 | 0.354 | 0.008 |
| A380 | 8.220 | 0.686 | 3.586 | 0.189 | 0.222 | 0.952 |

| Alloy | Cr | Ni | Ti | Pb | Al |
|---|---|---|---|---|---|
| A356 | 0.003 | 0.0031 | 0.123 | 0.0117 | Bal. |
| A380 | 0.018 | 0.124 | 0.037 | 0.0806 | Bal. |

## 3 Results and discussion

All SSM processes were carried out to avoid dendritic solidification structure that naturally was formed by conventional casting methods. LSC technique is one of the ways to produce billets with non-dendritic microstructures for using them in further thixoforging process. Thixoforged billets were also subjected to T6 heat treatment to enhance mechanical properties owing to precipitation of dissolved atoms. Different phases that formed after thixoforging of A356 and A380 alloys are shown in Fig. 1. $\alpha$(Al), eutectic and polyhedral Si phases were formed in A356 billet while additionally Fe-rich and Cu-rich phases were observed in A380 alloy.

The micrographs of thixoforged and T6-treated A356 billets are shown in Fig. 2. A356 is a hypoeutectic Al−Si alloy that can flow adequately even under low superheat conditions. As a consequence of its remarkable fluidity, LSC operation was successfully done without any pouring problem and non-dendritic $\alpha$(Al) phase surrounded by Al−Si eutectic structure was formed in the as-cast specimen. A356 and A380 were also manufactured by permanent mould casting at 730 °C for comparison and their microstructures are shown in Fig. 3. $\alpha$(Al) was intrinsically solidified in dendritic structure and eutectic was formed as needle-like morphology. LSC process rearranged the eutectic with smaller needles and $\alpha$(Al) phases with suppressing dendritic growth.