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# Studies of age-hardening heat treatment on duralumin brick blocks for aerospace applications

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*Abstract*—**Aluminium alloys have wide range of applications in engineering field. The AA2219 alloy belongs to 2xxx series and is also called heat treatable alloys. Thus the strength of AA2219 alloys can be increased by the age-hardening heat treatment process. The application of AA2219 alloys includes fabrication of components in missiles, aircrafts and aero-space devices.**

**An investigation was conducted to explore the physical and mechanical properties of AA2219 alloy subjected to age-hardening heat treatment process. For this experimental procedure, a sample each was being cut from the extruded billet and the cast billet of AA2219. The samples were forged to rectangular blocks. These forged blocks were then subjected to precipitation heat treatment process and the mechanical properties were studied.**

**Test results reveal that aluminium AA2219 is best suited for age hardening heat treatment, enhancing the strength by 70%. Among cast and extruded components, extruded one brings higher strength which is also supported by microstructure analysis.**

## I. INTRODUCTION

Aluminium is a soft, light weight, malleable metal and can be easily machined, cast and extruded. It has density about one-third of the steel. Aluminium when unalloyed is soft and exhibits low strength. But when alloyed, they exhibit exceptional mechanical properties. The melting temperature of these alloys ranges from 482-600$^0$C. The use of commercially pure aluminium is limited to the applications, where moderate strength, high corrosion resistance and good weldability are desired. The applications of aluminium alloys include transport, packaging, high pressure gas cylinders, electrical conductors, aerospace sectors, marine sector and sporting goods.

AA2219 is an Al-Cu alloy (also called duralumin) and it contains 5.8%-6.8% of copper and small amounts of other alloying elements such as manganese, titanium and vanadium. They are precipitation-hardenable alloys. The precipitation hardening heat treatment process is employed in AA2219 in order to increase the strength and hardness [8]. In AA2219, the copper atoms are the alloying element which aids in the formation of precipitates [10].

The precipitation hardening of the aluminium alloys was introduced by A.Wilm in 1906. Wilm discovered that the strength of the aluminium alloy is increased when the alloy being heated at 550$^0$C, is cooled rapidly and left at room temperature [11]. In 1919, Mercia, Waltenberg and Scott [12][13] proposed an explanation regarding the hardening of Al-Cu alloy after quenching. They proposed that the increase in hardness with time after rapid cooling was due to precipitation of copper atoms out as particles from supersaturated solid solution.

The precipitation hardening process involves solution treatment, quenching and age-hardening. During the solution treatment the alloy is heated to an elevated temperature. The alloy is held at elevated temperatures for a time period [7], resulting to the formation of solid solution. This allows maximum amount of solute to dissolve and is thus homogenously dispersed with in the solvent. The material is then quenched and Cu atoms are trapped in the supersaturated solid solution. After quenching, the alloy is then age hardened naturally or artificially. This artificial ageing process allows the solute to diffuse with in the solvent and precipitate out of the solution. These precipitates when formed provide a barrier for dislocation motion and thus hardness is obtained.

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## II.PROCESS DETAILS

A. Visual inspection

The extruded and cast billets of aluminium AA2219 were taken as the raw material for the experimental procedure. Both the billets were visually inspected for any defects and ensured that the billets were defect free. The billets were cut to dimension of Ø240×185 using band saw cutting machine.

B. Forging it in to blocks:

Firstly the sample which was cut from the extruded billet was heated to $430\pm10^0$C and soaked for 2 hours and 45 minutes. The heated billet was then loaded to the 6Ton hammer forging machine and open-die forging was carried out. The forging cycle comprises of drawing and upsetting of the sample and a rectangular block is obtained at the end of the forging process.

After forging of the sample from the extruded billet, the forging of the sample from cast billet was carried out. The sample cut from the cast billet was heated to $430\pm10^0$C and soaked for 2 hours and 45 minutes. The heated billet was then loaded to the 6Ton hammer forging machine and open-die forging was carried out. A rectangular block was obtained as the end product.

C. Heat treatment of the blocks:

The forged blocks were heat treated in order to improve the mechanical properties. The temper designation adopted for the heat treatment of the blocks was T6.

The forged AA2219 blocks were loaded in to the drop-bottom furnace. The furnace temperature was set to $535\pm5^0$C and the rate of heating was maintained in such a way that it should be less than$70^0$C/hr. The blocks were heated to $535\pm5^0$C and were set to soak. The soaking time is dependent on the thickness of the block. As the block has the thickness of 105mm, the block was thus soaked for 5 hours.

The blocks, after attaining $535^0$C soak for 5 hours, were quenched within 15 seconds. Although, the cold-water immersion or flushing is the most common method of quenching because it produces the most effective quench. But this type of quenching presents problems involving the formation of residual stresses and warpage due to differential cooling rate. One approach to reduce the cooling rate differential is the use of a milder quenching medium. Therefore, the water which was used as quenching medium was heated below the boiling point i.e. up to $70^0$C. The blocks after solution treatment were quenched in to this hot water and thereby reduce the formation of residual stresses and warpage with in the blocks.

The blocks after quenching were then age-hardened. Here the age-hardening process was carried out at elevated temperatures. Therefore the process is termed as artificial age-hardening. The age hardening process was carried out in a Pit furnace at $180^o$C$\pm3^o$C, within 24hours after the solution treatment. The blocks after quenching were charged into the calibrated pit furnace for the age-hardening. The furnace temperature was set to $180^o$C$\pm3^o$C. After attaining $180^o$C, the blocks were set to soak for 19 hours followed by air cooling.

D. Material testing:

1) Tensile test:

The test coupons were removed from the core of the aged blocks. The test specimens were prepared as per ASTM B557M and the tensile tests were carried out using the Universal Testing Machine.Tensile test helps in determining tensile properties such as tensile strength, yield point and %elongation.

2) Brinell hardness test:

The hardness of the test specimens were known by using the brinell hardness testing machine. The specimen was placed on the anvil in such a way that the specimen was in contact with the ball. The load was applied and the indentations produced in the specimen were measured by using micrometer. The brinell hardness number was calculated as follows:

$$BHN = \frac{W}{(\pi D/2)\,(D-(D^2-d^2)^{1/2})}$$

3) Microstructure analysis:

The specimens were prepared as per ASTM E3. These specimens were polished using different grit size papers and finally etched using Keller's reagent for 8-15s. The etched samples were then viewed through the optical microscope.

## III. RESULTS & DISCUSSIONS

The heat treatment was performed for the purpose of improving the mechanical properties and metallurgical structure. After the heat treatment process, the mechanical properties of both the blocks were tested using the Universal Testing Machine (UTM). The brinell hardness number was measured by using Brinell hardness apparatus and the microstructures were analyzed using the Optical microscope.

i. Tensile test results:

The tensile properties for the blocks from extruded and cast billets were determined.

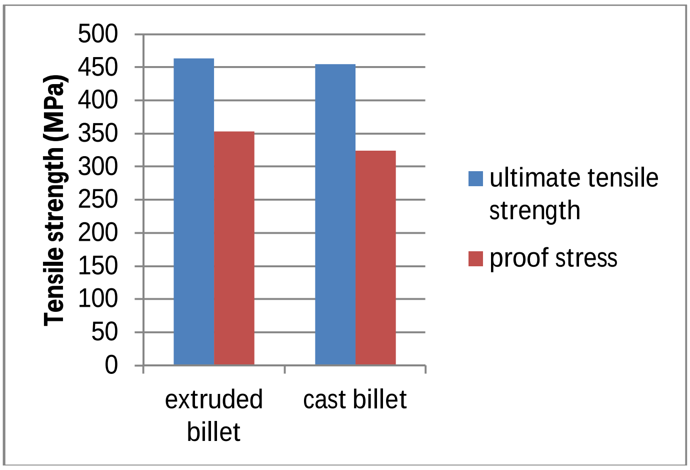


Figure 1. Tensile test results of extruded and cast billet

From the tensile test it was observed that the heat treated block which was obtained by forging of extruded billet has higher tensile strength (463MPa) while compared to the block from the cast billet. In addition, the results of extruded and cast billets are shown in figure 1 as a bar chart diagram. Hence it is noted that tensile strength of age hardening specimen is enhanced from 270MPa to 463MPa, a percentage increase of seventy percentages.

ii. Brinell hardness test:

The brinell hardness values for both blocks were determined and are shown in figure 2.

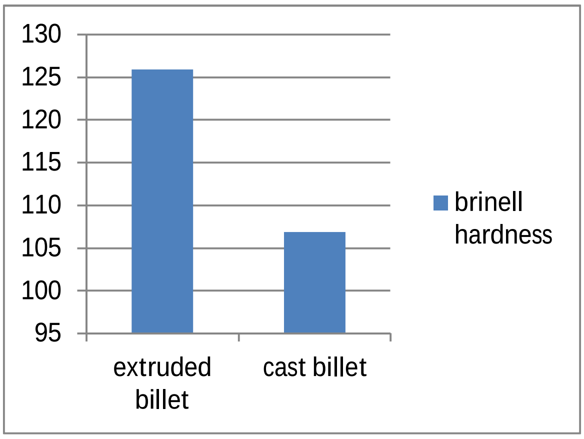


Figure 2.Brinell hardness for blocks from extruded and cast billet

From the above results it is revealed that the strength of extruded billet both on tensile and hardness are found higher than cast billet due to strain hardening effect. The result also reveals that the age hardening heat treatment process has doubled the hardness of AA2219 i.e. the increase in hardness from 60BHN to 126BHN was noted.

iii. Microstructure analysis:

The microstructures of both the heat treated blocks are shown in figure 3 and figure 4 respectively.

The microstructure of both these samples reveals the presence of precipitates of θ phase that is $CuAl_2$. In figure 3 the microstructure shows that the structure is free from micro porosity, stringers and segregation. The microstructure has fine grain structure.

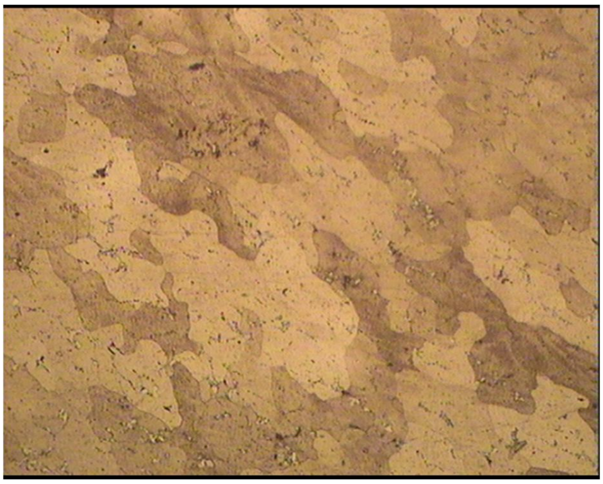

Figure 3.Microstructure of heat treated sample forged from the extruded billet

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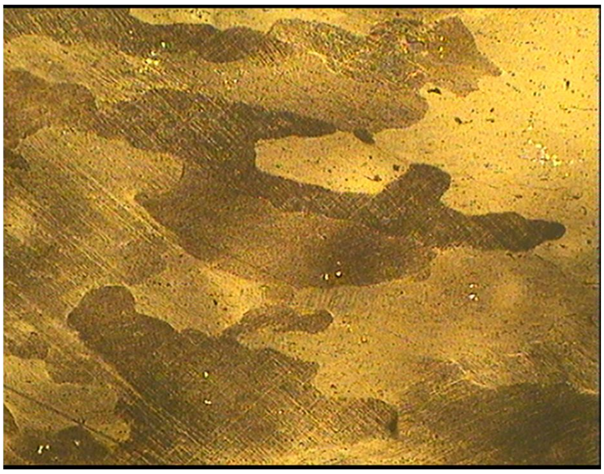

Figure 4.Microstructure of heat treated sample forged from the cast billet

But in figure 4 the microstructure reveals small coarsening of the grains when compared to that of the sample from the block which was forged from the extrude billet. This coarsening of grains is the main reason for slight lowering of strength in cast billet. Also, as the extruded billet was obtained by working of the cast billet, the strengthening rate is found higher when compared to the cast billet.

From the above results it is noted that precipitation hardening treatment gives more strength after age hardening. These billets as a final finished product are directly used as blocks in aerospace devices to withstand sufficient strength during operation.

## IV.CONCLUSIONS

From the above work the following are the conclusions

1. AA2219 aluminium-copper alloy taken for the investigation is best suited for precipitation hardening heat treatment.
2. Age-hardening heat treatment improves the strength of AA2219 by 70%.
3. Extruded billet after age-hardening gives better mechanical properties than cast billets.
4. In addition with strength, micro examinations reveal that the extruded heat treated billet is found free from defects such as micro porosity, grain coarsening and segregation and thereby the life of the block is enhanced.

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