Comparative study of Al6061 and AlSi10Mg produced by Selective Laser Melting Process

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Abstract. Alloy 6061 has an excellent corrosion resistance property. The main advantage of the Aluminium alloy is lightweight. The alloy may be high in strength and suitable for heat treatment. This article discusses the comparison between two different materials namely As-received Al6061 and AlSi10Mg of the component produced by Selective Laser Melting process (SLM). Selective Laser Melting is one of the techniques of Additive Manufacturing or 3D printing. In recent years, Additive manufacturing is increasingly used in several industries including healthcare, automotive, aerospace and defence.

1 Introduction
As-received component and SLM 3D oriented materials are subjected to the heat-treatment process. The cast components in an aluminium alloy, when processed conventionally, often require heat treatment to improve mechanical properties. Heat treatment includes T6 cycle of solution annealing, quenching and age hardening. For applications which require a combination of good thermal properties and low weight, parts in EOS AlSi10Mg serve the purpose [3]. Solution heat treatment applies to heat-treatable alloys. It involves a heat treatment process in which alloying constituents are taken into solution, followed by rapid quenching [4]. Additive manufacturing is a process which can produce complex shapes which are quite difficult through traditional casting and machining methods. The process has the flexibility in material selection and can give high accuracy of final parts after fabrication of the component [6].

Some of the most common processes in additive manufacturing are Selective Laser Melting (SLM), Ballistic Particle Manufacturing (BM), Liquid Thermal Polymerization (LTP), Fused Deposition Modelling (FDM) etc. Here, the Additive Manufacturing technique was used. Selective laser melting, an additive manufacturing technique can melt the metal fully and convert into a solid three-dimensional part [4,6]. Some of the alloys used in the process are 15-5 stainless steel, cobalt-chromium, titanium Ti6Al4V, aluminium AlSi10Mg [1]. The material used here is aluminium alloy AlSi10Mg (Silicon - 10%, Magnesium - 0.20-0.45%, Aluminium – balance).
2 Experimental Work

Square shape rod of 10mm length and 5.8mm height of samples were produced using an SLM 280HL machine. In the build operation, 3 samples were produced. Then comparison was done with As-received Al6061 rod with a 25mm length and height of 30mm diameter. For the study of mechanical properties (strength, hardness), a tensile test was performed. Then microstructure was analysed for both materials of Al6061 and AlSi10Mg of heat-treated using Vertical muffle furnace. The furnace had its maximum temperature up to 950°C with a chamber size of 180mmx200mm under non-heat-treated conditions. The following parameters (scanning speed, laser power, hatch angle) were used in the processing of SLM AlSi10Mg alloy.

- Layer thickness-30μm
- Laser power
  - Standard contour-320W, 560mm/s (laser scan speed)
  - Down contour-80W
  - On part contour-320W, 50mm/s (laser scan speed)
- Infill stripe type exposure with a stripe of 7mm and an overlap of 0.2mm with a laser power of 370W and a scan speed of 1300mm/s. Hatch spacing of 0.13mm
- Up-skin -no exposure pattern, with laser power 360W and scan speed 1000mm/s
- Hatch spacing 0.21mm
- Down skin- no exposure pattern, with laser power 360W and scan speed 1500mm/s. Hatch spacing 0.1mm.
- Hatch angle rotation of 67° every layer
- The laser power of 370W and scan speed of 3100mm/s, unidirectional scanning. Layer thickness is 60μm

Build Orientation

As-Built(AlSi10Mg)  As received Al6061

Tensile test specimen for As-received Al6061 in the non-heat treated condition

2.1 As received Al6061 and 3D printed AlSi10Mg

The material chosen for the research is Al6061 and AlSi10Mg. The chemical composition for Al6061 and AlSi10Mg was analysed by using Optical Emission Spectroscopy [1,2].
Table 1. Elemental composition of As-received Al6061

| Element | Composition |
|---------|-------------|
| Si      | 0.698       |
| Fe      | 0.595       |
| Cu      | 0.726       |
| Mn      | 0.326       |
| Mg      | 1.657       |
| Cr      | 0.145       |
| Ni      | 0.035       |
| Zn      | 2.237       |
| Ti      | 0.025       |
| Ag      | <0.00050    |
| Al      | 93.38       |

Table 2. The elemental composition of 3D printed AlSi10Mg

| Element | Composition% |
|---------|--------------|
| Al      | Balance      |
| Si      | 9-11         |
| Fe      | 0-0.055      |
| Cu      | 0-0.1        |
| Mn      | 0-0.45       |
| Mg      | 0.20-0.45    |
| Ni      | 0-0.05       |
| Zn      | 0-0.10       |
| Pb      | 0-0.05       |
| Sn      | 0-0.05       |
| Ti      | 0-0.15       |

3 Results and Discussions

3.1 Microstructure (Comparison between Al6061 and AlSi10Mg)

The microstructure of the samples was observed through optical microscopy [1,2,4,7].
Optical microscope Image of Fig.1a As-received Al6061 showed the presence of Si needles in an Al-matrix at Non-Heat treated condition. Fig1b A1Si10Mg shows the presence of porosity in an Al-matrix at Non-Heat Treated Condition.

3.2 Tensile Test
The tensile test was performed For As received Al6061[Fig2] and the result was as illustrated
3.3. Fracture Surface
SEM images (Fig 3a, 3b) of the fracture surface of As-received Al6061 and Engineering stress-strain curve (Fig 2) showed that the As-received Al6061 material is in a ductile manner in non-heat treated condition. The SEM image (Fig 3b) represented the elongated dimples which were seen in non-heat treated Al6061 and also enhanced ductility. It is hard to analyse the material as ductile or brittle as it is based on elongation present only [1,6,7]. The fractography (Fig 3a) indicated that the material breaking point occurred on high load=12.382 KN.

3.4. Heat treatment process

![Heat Treatment Cycle](image)

![Heat Treatment Cycle](image)
The samples As-received Al6061 and AlSi10Mg were heat-treated following a T6 condition by solution heat treatment (SHT) for 30 minutes at 530°C [8,9] (figure 4). After this quenching was done, followed by artificial ageing at three different temperatures 140°C, 150°C, 160°C for 2 hours. Here the temperatures did not change the morphology of the Al6061 and AlSi10Mg samples. But the temperatures showed an effect in the hardness of the materials. After ageing, the hardness levels were 71.66Hv at 160°C, 67.8Hv at 150°C, and 66.2Hv at 140°C respectively for As-received heat-treated Al6061 sample. In AlSi10Mg SLM sample, the hardness level was 72.4Hv at 160°C. Better hardness was observed when compared to that of Al6061. The storage time between quenching the samples and start of the ageing process was kept to a minimum of 1 hour[9].

3.5. Microstructure (Al6061 vs AlSi10Mg with heat treatment)

The microstructure of the samples subjected to the heat-treatment process, followed by T6 condition was observed.

The Image(Fig5a), shows, Precipitates Formed and uniformly distributed in Al phases.
Figure 5b. Solution heat treatment of As-built AlSi10Mg at 530°C

The Image(Fig 5b), it was observed that the voids nucleated at the Si particles. This void affect the hardness, of the material

Figure 6. SEM image of T6 condition at 160°C (As received Al6061)

The SEM image(Fig6) shows the silicon and magnesium were dispersed in an Aluminium matrix, coarser Silicon particles were uniformly distributed.

Figure 7. SEM image of T6 condition at 160°C (As-built of SLM of AlSi10Mg)

The SEM image(Fig7) showed fine microstructure, which was achieved after heat treatment of solution Annealing and Ageing.
3.6. Hardness

The hardness test was carried out to evaluate the influence of heat treatment on the hardness of the specimen[7]. From the test conducted(Vickers hardness), it was observed that hardness of heat-treated specimen was lower than that of As-built specimen. The higher hardness value indicates a fine dispersion of Si particles in the Al matrix. Hence, the As-built specimen held higher hardness value. After solution treatment, a decrease in the hardness value was observed in As-built Al6061. The hardness value decreases on increasing solution treatment temperature. In this research, the microstructure of As-received Al6061 and AlSi10Mg in heat-treated and Non-heat-treated were studied. As received microstructure showed that precipitates were formed in the aluminium matrix at Non-heat treated condition. The SLM of AlSi10Mg contained defects like porosity in Non-heat treated condition.

The pores in the SLM parts are classified into three types namely fusion errors, gas pores and shrinkage pores. The formation of pores would result in poor metallurgical bond [4]. Various mechanical properties of aluminium alloys have been reported in the literature, such as tensile behaviour, hardness. Aluminium 6061 is tested, and the stress-strain curve shows that material is in ductile condition and better ductility based on elongation [1].
Proceeding heat treatment T6 condition, Si particles are distributed uniformly along with the alpha aluminium matrix and Si particles up to 0.719%. For the heat-treated material, voids nucleate at Si particles by de-cohesion. After treatment, the microstructure has no fine grains. Also, there is a reduction of contributing grain boundaries to strengthening [1,2,6,7].

4 Conclusion
In the study of research, Aluminium alloys have better strength when compared to other materials. In research work, it is clearly explained that As-received Al6061 is ductile and its good strength is shown through stress versus strain curve.

On comparing As-received Al6061 and SLM of AlSi10Mg, AlSi10Mg is better Hardneabilty than that of As-received, and Fine microstructure was achieved at the Heat Treatment condition(Ageing)

This research finds out problem identification in these components through the works conducted. After the heat treatment process, the hardness is decreased within an ageing time of 2 hours. After ageing, the hardness of the material is slightly reduced because of Time, Temperatures, In Al6061 Defects are lesser than that of Asbuilt AlSi10Mg, But Better Hardenability is Achieved in AlSi10Mg. Selective laser Melting process of AlSi10Mg Process have less time to produce the material compared to conventional Process and Low in cost

In future ultrafine grain refinement can be achieved for increased better strength, hardness and reducing porosity by using severe plastic deformation technique (SPD) of Equal Channel Angular Pressing (ECAP) method.

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