WEAR BEHAVIOR OF SELECTIVE LASER MELTED AlSi10Mg FOR THE AS- PRINTED AND VARIOUS HEAT TREATED CONDITIONS

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ABSTRACT

Exploring the effects of various process parameters in Selective Laser Melting

(SLM) — laser power, scan speed, scan spacing, and island size utilizing a Concept Laser M2 system — has been a crucial investigation in the fabrication of AlSi10Mg alloy structures. Understanding how temperature impacts the wear properties of AlSi10Mg, particularly through SLM, is a significant aspect of this study. The mechanisms binding the powder during the process, be it melting or solid-state/liquid-phase sintering, are temperature-dependent. Hence, local temperature fields play a vital role in maintaining process stability and ensuring the quality of the fabricated components.

Furthermore, the study also delves into the influence of heat treatment on Aluminum applications, particularly focusing on the effect of various heat treatments on AlSi10Mg. This initiative aims to enhance the wear resistance of the material, especially for applications in the automobile industry, such as brake drums or brake discs.

A two-factor interaction model reveals that laser power, scan speed, and the interaction between scan speed and scan spacing significantly impact the porosity development in the built structures. Employing statistical methods to minimize porosity fraction, the study derived optimal process parameters.

KEYWORDS: Selective Laser Melting, Heat Treatment, Solution Heat Treatment, Precipitation Heat Treatment, Wear Analysis, Microstructure Analysis, Hardness, Ductility.

INTRODUCTION

Selective Laser Melting (SLM) stands as a notable technique within the realm of Additive Manufacturing (AM). In SLM, a laser source is utilized to meticulously scan a powder bed, guided by the CAD-data outlining the intended structure of the component. The laser's high intensity is instrumental, causing the metal powder particles to undergo complete melting and subsequently fuse, resulting in the formation of components that are nearly entirely dense. Aside from potential surface polishing, this process involves the successive melting and cementing of metal powder particles in layers, ultimately yielding components that are nearnet-shaped.

Additive Manufacturing is a technique of fabricating the components which are highly complex. In this method of manufacturing, the components are fabricated like layer by layer process and it produce 3D models by merging a number of 2D slices with certain thickness and every layer is built up by addition of materials. In recent developments, The Additive laser manufacturing (ALM) is being developed for instant manufacturing of the complex components by using three different technologies such as (DLF) Direct laser fabrication, (EBM) Electron beam melting and (SLM) Selective laser melting.

Among these procedures, the selective laser melting process has a greater order of precision in manufacturing than the others. It has a smaller diameter of (100m) with high developed concentrated energy matter due to its fibre laser. A high intensity laser beam scatters the powder layers, and the powder particles absorb the energy via a powder coupling process.

Because of its beneficial features, such as outstanding castability, weld ability, and exceptional corrosion resistance, aluminum-silicon (Al-Si) alloys are highly sought for a variety of applications. These alloys are widely used in a variety of industries, including automotive, aerospace, and home sectors, owing to their attractive combination of mechanical qualities, improved heat conductivity, and low weight.

A thorough understanding of the impact of process parameters is critical in the field of Additive Manufacturing (AM), particularly when using the Selective Laser Melting (SLM) technology. Laser power, scan speed, scan spacing, and island size are all key factors in the manufacture of AlSi10Mg alloy components utilising a Concept Laser M2 system. The influence of these factors on porosity development inside produced components is critical for fine-tuning the SLM process and assuring high-quality product manufacturing.

Additive Layer Manufacturing (ALM) has a 30-year history and has evolved as a popular approach for building three-dimensional things by stacking several twodimensional slices. This technique has advanced significantly over time, particularly in recent years, allowing for the rapid production of metallic components using processes such as electron beam melting (EBM), direct laser fabrication (DLF), and selective laser melting (SLM).

The aerospace industry places a high value on SLM powder-bed technology, notably for producing components made of Ti-alloys and Ni-super alloys. The potential cost reductions, simplification of production phases, and enhanced design flexibility are driving this focus. The demand for lightweight constructions with complicated geometry has resulted in an increase in research papers on Alalloy Additive Layer Manufacturing (ALM).

To understand the complicated microstructures of the as-fabricated samples, a variety of analytical approaches such as scanning electron microscopy (SEM), transmission electron microscopy (TEM), and scanning TEM were used to analyse AlSi10Mg produced using laser powder bed technology. In longitudinal sections, microstructure examination revealed common columnar Al grains with an average diameter of around 10 mm. However, particular locations displayed variances in microstructural characteristics.

The AlSi10Mg alloy, classified as a hypoeutectic alloy within the Al-Si-Mg system, is in great demand for a variety of applications in the aerospace, automotive, and heat exchange sectors. Its allure originates from beneficial traits like as lightweight nature, minimal thermal expansion, recycling costeffectiveness, and powerful mechanical capabilities. The form and size of eutectic silicon are critical elements in influencing its mechanical characteristics in this alloy system. McDonald et al. discovered that bigger, rounder eutectic silicon phases can generate stress fractures, affecting mechanical characteristics.

PROPOSED SOLUTION

There are various effective methods and best practices aimed at addressing the challenges encountered when utilizing AlSi10Mg in the selective laser melting (SLM) process. These strategies are intended to enhance the overall process, elevate part quality, and optimize material properties. Key steps include:

1. **Thorough Process Parameter Optimization:** Conduct an extensive study to optimize process parameters like laser power, scanning speed, hatch spacing, and layer thickness. Adjust these parameters iteratively to achieve the best density, microstructure, and mechanical properties for AlSi10Mg.
2. **Controlled Powder Storage:** Store the AlSi10Mg powder in a controlled environment with minimal exposure to oxygen to prevent oxidation.
3. **Inert Gas Atmospheres:** Employ inert gas atmospheres during powder handling and within the SLM machine to minimize oxidation throughout the printing process.
4. **High-Quality Powder:** Utilize a superior quality, spherical AlSi10Mg powder characterized by a consistent particle size distribution and excellent flow ability.
5. **Optimized Powder Management System:** Fine-tune the powder management system on the SLM machine to ensure a steady and even powder flow during the printing process.
6. **Advanced Thermal Management:** Implement sophisticated thermal management techniques, such as localized heating or preheating the construction platform, to diminish temperature gradients and effectively regulate residual stresses.

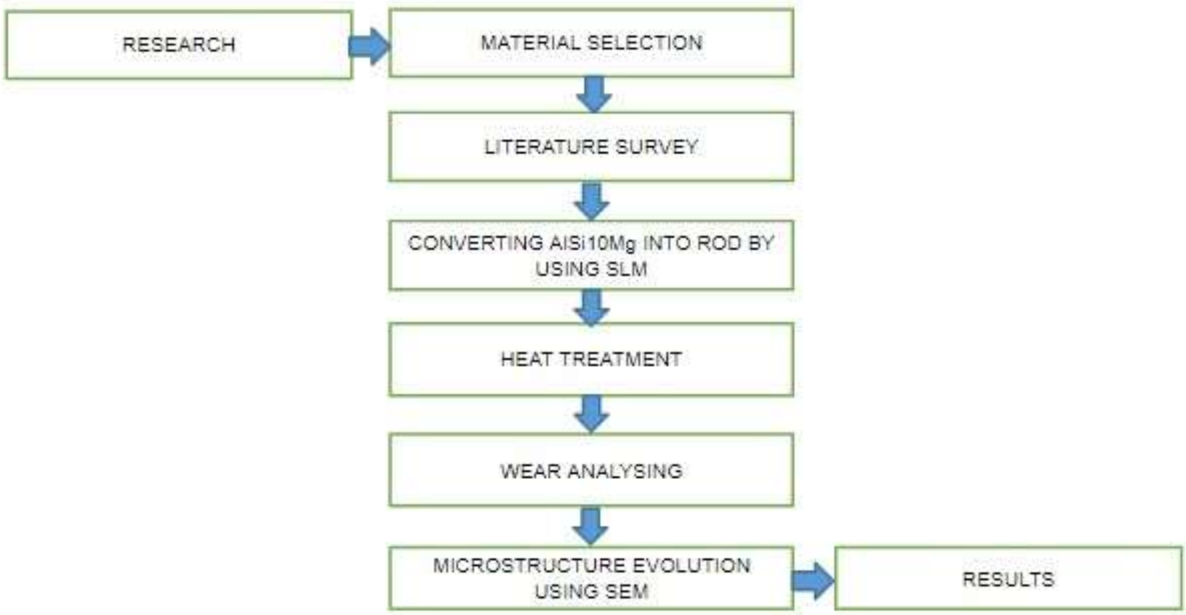
OBJECTIVE OF THE PROPOSED

Based on the findings of the literature review, the objectives of this study will be clearly articulated. The minimum number of objectives will be equal to the number of students in the batch, and the individual contributions of each student will be based on these objectives. Procedure/Flow Diagram Synthesis: A flow diagram will be shown to explain the proposed work's synthetic approach.

Each block in the flow diagram will be discussed briefly, highlighting the procedures involved in the Selective laser melting machining process in AlSi10Mg alloy employing various heat treatment settings. Components,
Tools, Data Collection Techniques, Procedures, Testing Methods, and Standards Selection: This section will go over the process of selecting components, instruments, data gathering strategies, processes, testing methodologies, and standards for the research. It will offer a complete summary of the decisions made as well as the reasoning behind them.

AlSi10Mg is a popular aluminium alloy recognised for its good strength-toweight ratio and other mechanical qualities. It is used in a variety of sectors, including aerospace and automotive, since coarse and acicular eutectic silicon phases form cracks in the stress environment, deteriorating mechanical properties. As a result, it is vital that the coarse and acicular eutectic silicon phases be adjusted in order to improve the mechanical properties of the AlSi10Mg alloy and meet increased application requirements in aerospace and other areas. The precipitation of the Mg2Si phase by adding magnesium to the Al-Si alloy improves ductility and strengthens the matrix without losing other mechanical properties.

METHODOLOGY AND PROPOSED WORK



The Specific Objectives Include

- Evaluate the wear resistance of AlSi10Mg alloy before and after heat treatment process.
- Investigate the changes of microstructure of AlSi10Mg alloy induced by Heat treatment process.
- Determine the relationship between the process parameters of Selective laser melting with various heat treatment conditions to resulting wear resistance and micro structural changes.
- Optimize the process parameters of Selective laser melting processing to achieve the desired improvements in wear resistance, and microstructure of AlSi10Mg alloy.

Experimental Setup

This section will offer a full overview of the experimental setup utilized for the AlSi10Mg alloy Selective laser melting technique. It will include details about the tools, equipment, and materials utilized, as well as any changes or adaptations.

Techniques

The numerous strategies used for data gathering throughout the experimental phase will be explored in this section. The selective laser melting beam fibre laser has a focused laser beam diameter of The following processing parameters have been optimized: laser power, laser scan speed, powder layer thickness, and scan spacing parameters. The muffle furnace, SEM, and wear properties instruments utilized for data collection will be detailed, as will any calibration methods done.

Methods

This section will describe the testing techniques used to assess the microstructure analysing and wear characteristics of the AlSi10Mg alloy following the heat treatment procedure. Microstructure analysis, wear testing, and other relevant tests may be included. Specific testing processes, such as sample preparation and testing settings, will be described.

In a Selective laser melting machine, a gas-atomized AlSi10Mg powder with a consistently dispersed particle size range of 20 mm to 63 mm and AlSi10Mg is fused and transformed into rod shape form with dimensions of length 30 mm and diameter 10 mm.

Chemical composition of the investigated AlSi10Mg alloy (Wt.%).

Si	Fe	Mn	Mg	Ni	Zn	Pb	Sn	Ti	Al
9.92	0.137	0.004	0.291	0.04	0.01	0.004	0.003	0.006	Bal

The SLM-produced AlSi10Mg specimens were solution-treated for 8 hours at temperature of 530 °C, followed by water quenching, using the usual T6 heat treatment technique.

Fig: Solution Heat Treatment using muffle furnace

Following the solution heat treatment, the specimens were immediately exposed to 8 hours of artificial aging at 160 °C and the samples were equally cooled at room temperature.

MICROSTRUCTURE CHARACTERIZATION

The microstructure of as-built and heat-treated SLM AlSi10Mg specimens was examined using a field emission scanning electron microscope. For microstructure examination, the specimens were ground and polished using a double polishing disc. Keller reagent (vol. 2.5% HNO3, vol. 1% HF, vol. 1.5% HCl, vol. 95% H2O) was used to demonstrate the general structure of the polished sample.

Following heat treatment and artificial ageing of the solution, eutectic Si is rejected from the supersaturated Al, yielding small Si particles known as phase B. At this point, the cellular boundaries become fuzzy, and temperature causes Si particles to precipitate at the Al-Si cellular borders, resulting in a significant decrease in their amount.

Hardness Factor

Si atoms trapped inside the Al matrix quickly precipitate onto the existing eutectic Si network during the solution and artificial ageing processes, minimising solid solution strengthening. Concurrently, the space between Si particles widens dramatically, resulting in a drop in tensile and yield strengths. Two key aspects must be considered when measuring the ductility of as-built SLM samples and solution heat-treated specimens.

To begin with, the decrease in the number of Si particles and their increased size lead to a decrease in localised stress or strain. Second, solution heat treatment aims to reduce residual strains caused by the SLM procedure.

These two variables explain the enhanced ductility seen in solution heat-treated AlSi10Mg specimens. However, ductility decreases with artificial ageing because to the over-aging effect.

(hardness) Hv

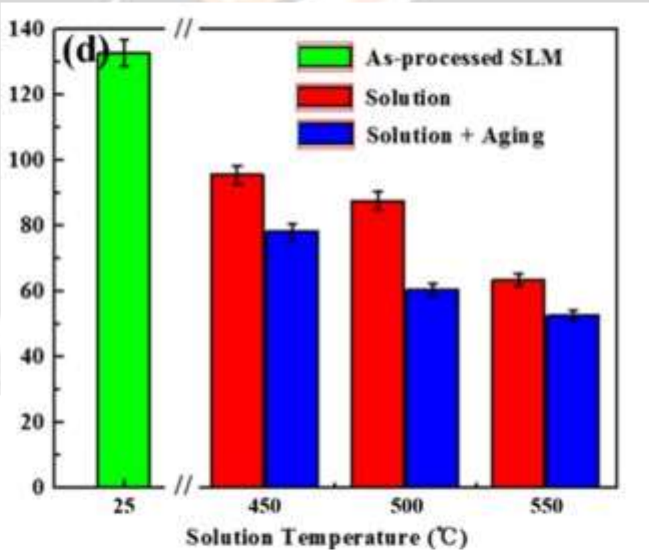


Fig 4.16.1 Hardness graph of ST

WEAR PROPERTIES

The hardness of the T6 alloy was found to be lower than that of the as-built alloy, attributed to the effects of precipitation hardening during the heat treatment. This outcome is likely due to the disappearance of the molten pool and cellular structure during the solution heat treatment of the T6 alloy, causing a softening of the Al matrix.

The wear analysis was conducted using a pin-on-disc setup. Wear characteristics were assessed by measuring wear loss (in grams) for the three alloys: 0.0185 g (as-built), 0.0178 g (DA), and 0.0156 g (T6). Comparative analysis revealed a

15.7% reduction in wear loss for the T6 alloy compared to the as-built alloy, indicating superior wear resistance for the T6 alloy. Generally, higher material hardness and strength correlate with improved wear resistance. Interestingly, in this study, despite having the lowest hardness value, the T6 alloy demonstrated the highest level of wear resistance among the three alloys.

CONCLUSIONS

This study provides a comprehensive investigation into the impact of solution and artificial ageing heat treatments on the phase, microstructure, and mechanical properties of SLM-manufactured AlSi10Mg specimens. The key findings and conclusions are outlined below:

1. The solubility of Si atoms in the Al matrix is established to be 8.89 at% for as-built specimens. With increasing solution temperature, the solubility decreases rapidly. During artificial ageing, the solubility of Si atoms in the Al matrix further decreases.
2. The as-built AlSi10Mg specimens exhibit an ultrafine eutectic microstructure due to the high cooling rate and thermal fluctuations in the SLM process. This microstructure is characterized by a eutectic Si network comprising spherical Nano-sized particles embedded in an Al matrix, contributing to enhanced hardness.
3. Upon undergoing the solution heat treatment, Si atoms precipitate from the supersaturated Al matrix, forming small Si particles. The size of these Si particles increases with higher solution temperatures, while their quantity decreases. Subsequent artificial ageing results in further coarsening of the Si particles. Hardness testing revealed a 5.2% increase in hardness for the DA alloy compared to the as-built alloy, whereas the T6 alloy experienced a significant 33.5% reduction in hardness. Additionally, wear testing indicated that the T6 alloy displayed the least wear loss and a notable 15.7% improvement in wear resistance compared to the asbuilt alloy, highlighting the superior wear resistance of the T6 alloy.

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