



# A Review on Selective Laser Melting of AlSi10Mg Alloy: Processing, Microstructure and Performance Characteristics

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**Abstract:** Selective Laser Melting (SLM) has emerged as a key metal additive manufacturing process for producing complex, near-net-shape components with tailored properties for advanced manufacturing applications. Among aluminium alloys, AlSi10Mg is extensively used in SLM due to its excellent process ability, good castability, and favourable combination of strength, lightweight characteristics, and corrosion resistance, making it attractive for aerospace, automotive, and tooling industries. This review critically examines the influence of SLM processing from a manufacturing perspective, with emphasis on the interrelationships between process parameters, microstructure evolution, and resulting mechanical and tribological properties of additively manufactured AlSi10Mg alloy. The effects of laser power, scan speed, hatch spacing, layer thickness, and scan strategy on densification, defect formation, and microstructural features such as grain morphology and silicon distribution are discussed. Corresponding impacts on tensile strength, hardness, fatigue behavior, wear resistance, and friction characteristics are systematically reviewed. The role of post-processing routes, including heat treatment, hot isostatic pressing and surface finishing, in enhancing functional performance is also addressed. Key conclusions highlight that optimized SLM parameter windows and appropriate post-processing are essential to achieve balanced mechanical and tribological performance suitable for industrial deployment. Despite significant progress, gaps remain in standardized tribological testing, long-term fatigue behaviour, and scalable process optimization strategies. Addressing these challenges is crucial for the reliable and widespread manufacturing adoption of SLM-processed AlSi10Mg components.

**Keywords:** - Selective Laser Melting; AlSi10Mg Alloy; Additive Manufacturing; Microstructure Evolution; Mechanical Properties; Tribological Performance; Process Optimization.

## 1. Introduction

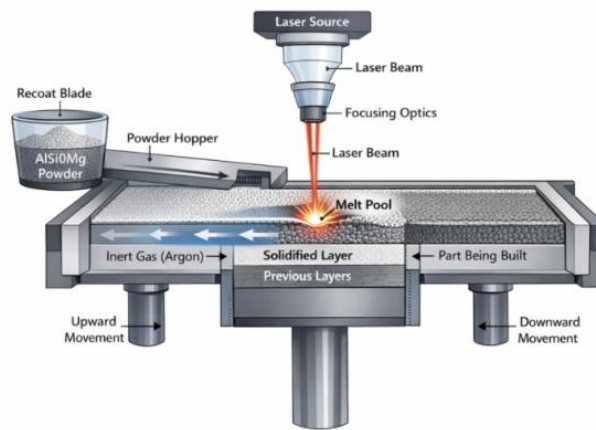
Additive Manufacturing (AM) has revolutionized modern manufacturing by enabling complex geometries, rapid prototyping and material-efficient production. Among AM techniques, Selective Laser Melting (SLM) has emerged as a leading method for fabricating high-performance metallic components, particularly aluminium-silicon alloys such as AlSi10Mg, which are valued for their high strength-to-weight ratio, corrosion resistance, and suitability in aerospace, automotive, and energy applications [1-4].

Despite its advantages, SLM of AlSi10Mg presents significant challenges due to the complex interplay of process parameters including laser power, scan speed, hatch spacing, and build orientation. For instance, an insufficient energy density, often resulting from low laser power, can lead to lack-of-fusion defects, thereby compromising the structural integrity and mechanical performance of the manufactured part [31].

These parameters critically influence microstructure, porosity, residual stresses, and anisotropic mechanical behaviour, thereby affecting component performance and reliability [5-8]. Defects such as lack of fusion, micro cracks, and surface roughness remain major concerns, often necessitating post-processing strategies like heat treatment or surface finishing enhancing mechanical and tribological properties [9-10].

Recent research has focused on optimizing SLM parameters using experimental design, empirical modelling, and advanced algorithms to achieve balanced mechanical performance. The demonstrated the application of the Osprey optimization algorithm to enhance hardness and wear resistance in AlSi10Mg components, highlighting the potential of multi-objective optimization approaches. However, a

comprehensive understanding linking process parameters, microstructure evolution, and functional performance remains limited [20].



**Figure. 1.1.** Schematic of Selective Laser Melting (SLM) process showing powder spreading, laser scanning, melt pool formation, and layer-by-layer fabrication under inert gas atmosphere [2-4].

## 2. Selective Laser Melting of AlSi10Mg Alloy

### 2.1 SLM Process Principle

Selective Laser Melting (SLM) is a powder bed fusion based metal additive manufacturing process in which metallic powder is selectively melted using a high-energy laser beam to fabricate three-dimensional components layer by layer. The process begins with the preparation of a digital model using computer-aided design (CAD) software. The model is then converted into a Standard Tessellation Language (STL) file and sliced into thin layers using specialized software [3].

During the fabrication process, a thin layer of metal powder is spread uniformly across the build platform using a recoater blade. A focused laser beam scans the predefined cross-section of the component and selectively melts the powder particles according to the sliced CAD data. The melted powder rapidly solidifies, forming a dense metallic layer. After completion of each layer, the build platform moves downward by a predefined layer thickness, typically between 20 and 50  $\mu\text{m}$ , and a new powder layer is deposited. This sequence is repeated until the entire component is fabricated [2, 4].

The interaction between the laser beam and metal powder plays a crucial role in determining the quality of the fabricated part. Parameters such as laser power, scanning speed, hatch spacing, and layer thickness influence melt pool formation, solidification behaviour, and defect formation. Due to extremely high cooling rates, often in the range of  $10^4$ – $10^6$  K/s, SLM produces refined microstructures that significantly enhance the mechanical properties of the manufactured components [2].

One of the key advantages of the SLM process is its ability to produce complex geometries that are difficult or impossible to fabricate using conventional manufacturing techniques. Additionally, the layer-by-layer fabrication approach enables material efficiency and design flexibility, making SLM a suitable manufacturing method for aerospace, automotive, and biomedical applications [1, 3, 5].

Powder Bed Fusion (PBF) is the fundamental working principle behind Selective Laser Melting (SLM) and other metal additive manufacturing technologies. In this process, a thin layer of metallic powder is spread uniformly across the build platform, and a high-energy laser selectively melts the powder particles according to the cross-sectional geometry of the component. The molten material rapidly solidifies and forms a dense metallic layer. After the completion of each layer, the build platform moves downward by a predetermined layer thickness, and a new powder layer is deposited. This sequential layer-wise deposition continues until the entire component is fabricated [2–4].

The quality of the final component is strongly influenced by the stability of the melt pool formed during laser scanning. When sufficient laser energy is supplied, complete melting and consolidation of powder particles occur, resulting in high density and good mechanical properties. However, insufficient energy input may lead to incomplete melting, which results in defects such as lack-of-fusion porosity. On the other hand, excessive laser energy can cause vaporization and keyhole formation, which may also produce pores within the material. Therefore, maintaining an appropriate energy balance is essential for achieving defect-free components in powder bed fusion processes [2, 4, 5].

The laser–material interaction and melt pool dynamics during SLM are illustrated in Figure 2.1 showing the relationship between rapid cooling and microstructure evolution

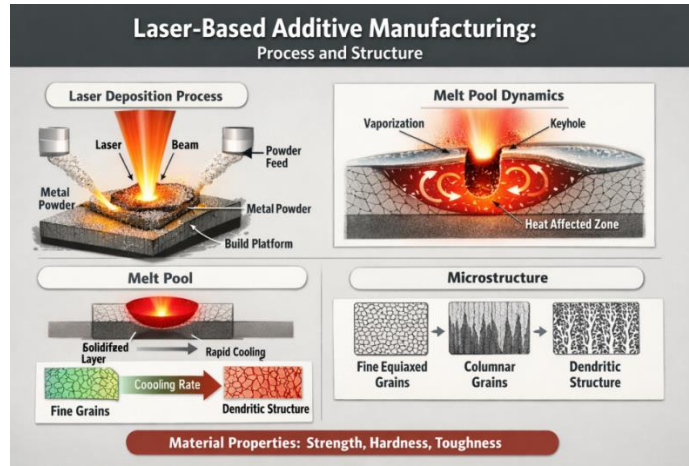


Figure 2 SLM process illustrating melt pool formation, rapid solidification, and microstructure evolution (adapted from [2], [3], [5])

### 2.1.1 Powder Characteristics

The characteristics of the powder feedstock play a critical role in determining the quality, density, and mechanical performance of components produced using Selective Laser Melting (SLM). Since SLM is a powder bed fusion process, the physical and chemical properties of the powder significantly influence powder spreading behaviour, laser absorption, melting stability, and final part integrity. Key powder characteristics include particle size distribution, particle morphology, and chemical composition. Proper control of these characteristics ensures uniform layer deposition, stable melt pool formation, and improved densification of the fabricated component [2, 3].

Metal powders used in SLM are generally produced using gas atomization techniques, which generate spherical particles with smooth surfaces. Such morphology improves powder flowability and enhances packing density within the powder bed. In the case of AlSi10Mg alloy, spherical powder particles also help reduce internal defects and improve layer uniformity during the recoating process. Any irregularity in powder shape or particle distribution can negatively affect the powder bed quality and lead to defects such as porosity or lack-of-fusion regions in the fabricated component [5].

Maintaining consistent powder quality is therefore essential for achieving stable process conditions and producing components with reliable mechanical properties.

### 2.1.2 Particle size, morphology and chemical composition

Particle size distribution is one of the most important parameters influencing powder bed behaviour in SLM processes. Typically, powders used for metal additive manufacturing have particle sizes ranging from 20  $\mu\text{m}$  to 60  $\mu\text{m}$ . A well-controlled particle size distribution ensures proper packing density and uniform melting during laser exposure. Fine particles increase the surface area and enhance packing density, which improves laser absorption and melting efficiency. However, extremely fine particles may reduce powder flowability and increase the risk of oxidation or agglomeration.

Particle morphology also plays an important role in powder performance. Gas atomized powders generally possess spherical morphology with smooth surfaces, which facilitates uniform spreading across the build platform. Spherical particles minimize friction between powder particles, thereby improving powder flowability and ensuring consistent layer thickness during the recoating process. Irregularly shaped particles or powders with satellites attached to larger particles can disrupt powder spreading and lead to uneven powder layers.

The chemical composition of the powder feedstock must also be carefully controlled to maintain the desired alloy properties. In AlSi10Mg alloy powders, aluminium serves as the primary matrix material, while silicon improves fluidity and reduces cracking during solidification. Magnesium contributes to precipitation strengthening and enhances mechanical performance after heat treatment. Any contamination or oxidation of the powder particles can negatively affect the melting behavior and reduce the mechanical properties of the

final component. Therefore, maintaining powder purity and proper storage conditions is essential for achieving consistent manufacturing quality [2, 3, 5]

### **2.1.3 Influence on flowability and densification**

Powder flowability is a crucial factor for successful operation of the SLM process because the powder must be spread uniformly to form thin layers across the build platform. Good flowability ensures uniform powder deposition and consistent layer thickness, which directly affects the dimensional accuracy and mechanical integrity of the final part. Powders with spherical morphology and optimized particle size distribution typically exhibit superior flowability compared to irregularly shaped powders.

Poor powder flowability can lead to uneven powder layers, which may result in incomplete melting, lack-of-fusion defects, and reduced part density. Additionally, powders with excessive fine particles may exhibit poor spreading characteristics due to increased interparticle forces such as van der Waals attraction.

Densification of the fabricated component is also strongly influenced by powder characteristics. A powder bed with high packing density promotes efficient heat transfer and uniform melting during laser scanning. This results in improved bonding between adjacent melt tracks and successive layers. Conversely, powders with low packing density may contain larger void spaces between particles, which can contribute to the formation of pores within the solidified material.

For AlSi10Mg alloys, proper control of powder characteristics combined with optimized process parameters can lead to near fully dense components with excellent mechanical properties. Therefore, powder characterization and quality control are considered essential steps in ensuring consistent performance of additively manufactured parts [2, 4].

## **2.2 SLM Process Parameters**

The SLM process is governed by the collection of process parameters presented in Fig. 4 [32-34]. The factors that received the most scholarly attention were laser power, scan speed, hatch space, layer thickness, and scan strategy. The Laser power manages the quantity of energy supplied to the substrate. Depending on the material, sufficient laser power is used for the complete melting of the powder particles as partial melting leads to defects upon solidification due to insufficient filling of the melt pool space. Equivalently, scanning speed regulates the solidification and melting rates. The hatch space determines the overlapping of adjacent tracks in a layer which allows them to bond together by metallurgical bonding. Layer thickness defines the thickness of powder distributed in a single layer. Larger layer thickness leads to incomplete melting [35] and defects [36], such as balling.

### **2.2.1 Laser power**

Laser power influences the energy input during welding. Higher laser power can increase penetration but may cause defects if excessive. The document mentions laser welding where flux absorbs laser energy to improve penetration [6].

On the other hand, excessively high laser power can cause excessive evaporation of material and formation of deep keyhole melt pools. These conditions may result in increased porosity, surface roughness, and thermal distortion. Therefore, an optimal laser power range must be selected to maintain stable melt pool dynamics and achieve high densification in SLM fabricated components [2, 4].

### **2.2.2 Scan speed**

Scan speed refers to the velocity at which the laser beam moves across the powder bed during the melting process. It directly affects the interaction time between the laser beam and powder particles. Lower scan speeds allow more time for heat transfer, resulting in increased energy input and deeper melt pools.

However, extremely low scan speeds may cause overheating and excessive melting, which can lead to distortion and residual stresses in the fabricated part. Conversely, higher scan speeds reduce the energy input and may result in incomplete melting of powder particles, producing lack-of-fusion defects. Therefore, selecting an appropriate scan speed is essential to balance the heat input and ensure consistent melting during the SLM process [5].

### **2.2.3 Hatch spacing**

Hatch spacing is defined as the distance between adjacent laser scanning tracks during the fabrication process. Proper hatch spacing ensures sufficient overlap between neighbouring melt tracks, which is necessary for achieving uniform densification and structural integrity of the component.

If the hatch spacing is too large, insufficient overlap between melt tracks can occur, leading to the formation of un-melted regions and internal porosity. In contrast, very small hatch spacing increases the overlap between tracks, which may result in excessive heat accumulation and residual stress development.

Therefore, hatch spacing must be optimized to maintain stable melt pool overlap and uniform microstructure formation [3].

### 2.2.4 Layer thickness

Layer thickness refers to the height of each powder layer deposited during the SLM process. It directly influences the build rate, surface finish, and mechanical properties of the manufactured component. Thin powder layers typically improve dimensional accuracy and allow better laser penetration, which enhances melting and bonding between successive layers.

However, thinner layers increase the total number of layers required to build the component, thereby increasing the overall manufacturing time. In contrast, thicker layers improve productivity but may reduce densification due to insufficient laser penetration. Therefore, an appropriate layer thickness must be selected to balance productivity and part quality in SLM manufacturing [5].

### 2.2.5 Energy density and scan strategy

Volumetric energy density is often used to describe the combined effect of process parameters in the SLM process. It is typically expressed as:

$$E = \frac{P}{v \times h \times t}$$

Where,

P = Laser power

v = Scan speed

h = Hatch spacing

t = Layer thickness

Energy density represents the amount of laser energy delivered per unit volume of material. An optimal energy density range is necessary to achieve complete melting and high part density. Low energy density may result in lack-of-fusion defects, whereas excessively high energy density can produce keyhole porosity and thermal distortion.

Process Parameters in SLM				
Laser related	Scan related	Powder related	Temperature related	Build-related
<ul style="list-style-type: none"> <li>•Laser power</li> <li>•Spot size</li> <li>•Pulse duration</li> <li>•Pulse frequency</li> </ul>	<ul style="list-style-type: none"> <li>•Scan speed</li> <li>•Scan spacing</li> <li>•Scan pattern</li> <li>•Scan strategy</li> </ul>	<ul style="list-style-type: none"> <li>•Particle size</li> <li>•Powder bed density</li> <li>•Layer thickness</li> <li>•Material properties</li> </ul>	<ul style="list-style-type: none"> <li>•Powder bed temperature</li> <li>•Powder feeder temperature</li> <li>•Temperature uniformity</li> <li>•Thermal gradient in build direction</li> </ul>	<ul style="list-style-type: none"> <li>•Build orientation</li> <li>•Part geometry and size</li> <li>•Support structure design</li> <li>•Layer-by-layer heat accumulation</li> </ul>

Figure 3 List of Process parameters controlling SLM Process [32]

## 3 Microstructure Evolution

### 3.2 Solidification Behaviour in SLM

3.3 Selective Laser Melting (SLM) is characterized by extremely rapid melting and solidification during the layer-by-layer fabrication process. The interaction between the laser beam and metallic powder generates a localized melt pool, which subsequently solidifies under very high cooling rates. These thermal conditions significantly influence the microstructure development of AlSi10Mg alloys. Due to the small melt pool size and rapid heat dissipation through the previously solidified layers and substrate, the solidification behaviour differs substantially from conventional casting processes. The resulting microstructure typically consists of refined grains and a fine distribution of silicon phases within the aluminium matrix. Rapid thermal cycles during the process also promote the formation of unique cellular structures and non-equilibrium phases. These microstructural features contribute to the enhanced mechanical properties commonly observed in SLM-processed aluminium alloys.

Studies have shown that the solidification process in SLM is strongly governed by process parameters such as laser power, scan speed, hatch spacing, and layer thickness, which determine the thermal gradient and cooling rate within the melt pool [30].

### 3.3.1 Rapid cooling rate

One of the distinguishing characteristics of the SLM process is the extremely high cooling rate, which typically ranges from  $10^3$  to  $10^6$  K/s. These rapid cooling conditions lead to the formation of a very fine microstructure compared with conventional manufacturing techniques. During solidification, the aluminium matrix nucleates rapidly while silicon atoms segregate along cell boundaries, forming a fine eutectic network surrounding the  $\alpha$ -Al grains.

The high cooling rate suppresses the formation of coarse dendritic structures commonly observed in cast aluminium alloys. Instead, a cellular microstructure with submicron cell sizes is produced. This refined structure enhances mechanical properties such as hardness and strength. In addition, rapid cooling can retain supersaturated solid solutions within the aluminium matrix, which may later precipitate during heat treatment to further strengthen the material [13].

### 3.3.2 Melt pool geometry

The geometry of the melt pool plays a critical role in determining the microstructural characteristics of SLM-fabricated components. When the laser beam scans across the powder bed, it creates a molten track that solidifies rapidly. The overlapping of successive tracks forms characteristic melt pool boundaries, which are often visible in microstructural observations.

The melt pool shape is generally semi-elliptical due to the Gaussian distribution of laser energy. Parameters such as laser power and scan speed directly influence melt pool width and depth. Higher laser power or lower scan speed typically results in deeper melt pools, whereas lower energy input produces shallow melt pools. Proper control of melt pool geometry is essential to ensure complete melting of powder particles and strong metallurgical bonding between adjacent layers. Irregular melt pool formation can lead to defects such as lack-of-fusion porosity and microstructural inhomogeneity [12].

## 3.2 Grain Structure and Texture

SLM-processed AlSi10Mg alloys generally exhibit a cellular or columnar grain structure due to directional solidification within the melt pool. The steep thermal gradients during solidification promote epitaxial grain growth along the build direction. As a result, elongated columnar grains often extend through multiple layers.

Within these grains, a fine cellular substructure is typically observed. The cells consist of aluminium-rich regions surrounded by silicon-rich boundaries. The cell size is usually in the range of 0.5–1  $\mu\text{m}$ , which is significantly smaller than that of cast aluminium alloys. The refined cellular microstructure contributes to higher hardness and improved strength.

## 3.3 Phase Formation

The primary phase in AlSi10Mg alloy produced by SLM is the  $\alpha$ -Aluminium ( $\alpha$ -Al) matrix. Rapid solidification promotes the formation of a supersaturated aluminium solid solution containing dissolved silicon and magnesium atoms. This super-saturation is much higher than that observed in conventionally cast alloys.

The  $\alpha$ -Al phase forms the structural framework of the material and provides good ductility and lightweight characteristics. Subsequent thermal treatments can lead to precipitation of strengthening phases from the supersaturated matrix.

## 3.4 Defects and Porosity

Despite the advantages of the Selective Laser Melting (SLM) process, various defects and porosity can develop if process parameters are not properly optimized [11–13]. Gas porosity typically originates from entrapped gases within powder particles or from the shielding atmosphere, which become trapped in the melt pool during rapid solidification, forming spherical pores within the material [14–17]. Although SLM components generally exhibit lower porosity compared to cast alloys, excessive gas entrapment can significantly reduce mechanical strength and fatigue resistance [18–20]. In contrast, lack-of-fusion defects occur due to insufficient energy input, leading to incomplete melting of powder particles or inadequate bonding between adjacent tracks and layers; these defects are usually irregular in shape and are commonly caused by low laser power, high scan speed, or excessive hatch spacing [21–25]. On the other hand, keyhole porosity is associated with excessive energy density, where high laser power generates deep vapor cavities (keyholes) in the melt pool that collapse during solidification, resulting in spherical pores [26–29]. The presence of such defects, particularly in high density, can adversely affect the structural integrity and fatigue performance of SLM-fabricated components [30–32].

Table 3.1: Defects in SLM – Causes, Characteristics, Effects

Defect Type	Main Causes	Characteristics	Effects on Properties	References
Gas Porosity	- Entrapped gas in powder particles - Shielding gas entrapment - High oxygen content	- Spherical pores - Smooth internal surfaces	- Reduced density - Lower tensile strength - Poor fatigue resistance	[14–17]
Lack-of-Fusion	- Low laser power - High scan speed - Large hatch spacing - Insufficient overlap	- Irregular-shaped voids - Unmelted/partially melted particles	- Severe reduction in strength - Crack initiation sites - Poor bonding	[21–25]
Keyhole Porosity	- Excessive laser power - High energy density - Deep vapor cavity formation	- Spherical or elongated pores - Located along melt pool depth	- Reduced fatigue life - Stress concentration - Structural instability	[26–29]
Balling Effect	- High scan speed - Low wettability - Improper energy input	- Discontinuous melt tracks - Bead-like structures	- Poor surface finish - Weak interlayer bonding	[18–20]
Cracking (Hot cracks)	- High thermal gradients - Residual stresses - Improper cooling rate	- Microcracks along grain boundaries	- Sudden failure - Reduced ductility and toughness	[30–31]
Residual Stress & Distortion	- Rapid heating and cooling - Thermal gradients - Lack of preheating	- Warping - Dimensional inaccuracies	- Reduced dimensional accuracy - Possible crack formation	[11–13, 32]

#### 4. Mechanical Properties

The mechanical properties of AlSi10Mg alloy fabricated through powder bed fusion processes such as Selective Laser Melting (SLM) and Direct Metal Laser Sintering (DMLS) are significantly influenced by the rapid solidification conditions and fine microstructure produced during the process. Compared with conventionally cast alloys, additively manufactured AlSi10Mg generally exhibits higher strength and hardness due to the refined cellular microstructure and the uniform distribution of silicon phases. However, the mechanical performance can vary depending on process parameters, build orientation, and post-processing treatments. Studies have reported that optimization of laser parameters and heat treatment conditions can further enhance the strength, ductility, and fatigue resistance of the alloy (12, 13).

##### 4.1 Tensile Properties

Tensile strength is a critical mechanical property of any fabricated component, and it is strongly influenced by various processing parameters. Factors such as laser power, hatch spacing, scanning speed, build orientation, baseplate preheating temperature, and processing atmosphere play a significant role in determining the tensile behavior of the material.

Yield strength, ultimate tensile strength (UTS), and elongation are key tensile properties that define the mechanical performance of SLM-fabricated AlSi10Mg alloys. Yield strength represents the stress at which plastic deformation begins and is generally higher in SLM-processed alloys compared to cast counterparts due to the refined grain structure and the presence of a silicon network along cell boundaries. Reported yield strength values typically range from 220 MPa to 300 MPa, depending on process parameters and heat treatment conditions, with strengthening attributed to the formation of a supersaturated  $\alpha$ -Al matrix during rapid solidification [14]. The ultimate tensile strength corresponds to the maximum stress the material can withstand before fracture, and SLM-manufactured AlSi10Mg commonly exhibits UTS values between 350 MPa and 450 MPa, significantly exceeding those of conventionally cast alloys. This enhancement is primarily due to the fine cellular microstructure and uniform silicon distribution, which improve resistance to plastic deformation [18, 29]. Despite the improvement in strength, elongation in as-built SLM materials is typically lower, ranging from 3% to 8%, mainly due to process-induced defects and residual stresses. However, appropriate post-processing heat treatments can enhance ductility by modifying silicon morphology and relieving internal stresses, thereby improving overall mechanical performance [28, 29].

## 4.2 Hardness and Elastic Properties

### 4.2.1 Microhardness Trends

Micro-hardness measurements are widely used to evaluate the local mechanical behaviour of additively manufactured materials. SLM-produced AlSi10Mg alloys typically show hardness values ranging from 100 HV to 135 HV in the as-built condition. The high hardness is primarily attributed to the fine cellular microstructure and the presence of silicon networks surrounding the aluminium cells. After heat treatment, silicon particles tend to coarsen and redistribute, which may slightly reduce hardness while improving ductility.

### 4.2.2 Young's Modulus

Young's modulus describes the stiffness of the material and is generally less sensitive to microstructural changes than strength or hardness. For AlSi10Mg alloys, the elastic modulus typically ranges between 65 GPa and 75 GPa, which is comparable to conventionally processed aluminium alloys. However, the presence of porosity and microstructural anisotropy may lead to minor variations in elastic behaviour.

## 4.3 Fatigue Behaviour

Fatigue performance is an important consideration for structural components subjected to cyclic loading. In SLM-fabricated AlSi10Mg alloys, fatigue properties are influenced by several factors including microstructure, surface condition, and internal defects.

### 4.3.1 Crack Initiation and Propagation

Fatigue cracks in additively manufactured components often initiate at surface irregularities or internal pores. Once initiated, cracks propagate along microstructural features such as melt pool boundaries or silicon networks. The refined microstructure produced by rapid solidification can slow crack propagation; however, the presence of pores may accelerate crack growth under cyclic loading conditions.

### 4.3.2 Influence of Defects and Surface Roughness

Surface roughness and internal porosity significantly affect fatigue life. Rough surfaces produced during the layer-by-layer fabrication process act as stress concentrators and promote early crack initiation. Similarly, lack-of-fusion defects and keyhole pores reduce fatigue strength by providing sites for crack nucleation. Post-processing treatments such as machining or polishing are often employed to improve fatigue performance.

## 4.4 Anisotropy in Mechanical Performance

Additive manufacturing processes frequently produce anisotropic mechanical properties due to directional solidification and layer-wise fabrication. In SLM-fabricated components, columnar grains tend to grow along the build direction, which results in differences in strength and ductility between vertical and horizontal orientations. Components tested parallel to the build direction may exhibit different tensile strength and elongation compared to those tested perpendicular to it. Optimization of scanning strategies and heat treatment conditions can help reduce anisotropy and improve isotropic mechanical behaviour.

## 5. Tribological Properties

Tribological performance refers to the friction and wear characteristics of materials in contact during relative motion. For AlSi10Mg alloys produced through additive manufacturing, tribological properties are strongly influenced by microstructure, hardness, and surface condition.

### 5.1 Wear Behaviour

#### Sliding Wear

Sliding wear occurs when two surfaces move against each other under load. In SLM-processed AlSi10Mg alloys, sliding wear resistance is generally improved due to the presence of hard silicon particles distributed within the aluminium matrix. These particles act as load-bearing elements and reduce material removal during sliding contact.

#### Abrasive and Adhesive Wear Mechanisms

Two common wear mechanisms observed in aluminium alloys are abrasive wear and adhesive wear. Abrasive wear occurs when hard particles or asperities plough the surface, creating grooves and material loss. Adhesive wear occurs when strong adhesive forces between contacting surfaces cause material transfer from one surface to another. In AlSi10Mg alloys, the presence of silicon particles can reduce adhesive wear by limiting direct metal-to-metal contact.

### 5.2 Friction Characteristics

#### Coefficient of Friction

The coefficient of friction (COF) of AlSi10Mg alloys typically ranges between **0.35 and 0.6**, depending on testing conditions such as load, sliding speed, and lubrication. Surface roughness and oxide formation also influence friction behaviour during sliding.

## Effect of Load and Sliding Speed

Increasing load generally increases the real contact area between sliding surfaces, which can raise friction and wear rates. Conversely, higher sliding speeds may lead to the formation of oxide layers that act as protective films, reducing friction in some cases.

## 5.3 Influence of Microstructure on Wear

### Role of Silicon Distribution

The distribution and morphology of silicon particles play a crucial role in determining wear resistance. A fine and uniformly distributed silicon network enhances hardness and provides better resistance to material removal during sliding.

### Hardness–Wear Relationship

There is generally an inverse relationship between hardness and wear rate. Materials with higher hardness tend to exhibit better wear resistance because the harder surface resists plastic deformation and material removal during contact.

## 6. Effect of Post-Processing Treatments

Post-processing treatments are often applied to improve the mechanical and tribological performance of additively manufactured components.

### 6.1 Heat Treatment

#### Stress Relief

Stress-relief heat treatment is commonly performed to reduce residual stresses generated during rapid heating and cooling cycles in the SLM process. This treatment helps prevent distortion and cracking while improving dimensional stability.

#### Annealing

Annealing involves heating the material to a moderate temperature followed by controlled cooling. This process reduces internal stresses and slightly modifies the microstructure, improving ductility and toughness.

#### T6 Treatment

T6 heat treatment consists of solution treatment, quenching, and artificial ageing. This treatment promotes the precipitation of strengthening phases such as  $Mg_2Si$ , resulting in improved tensile strength and hardness.

### 6.2 Surface Treatments

#### Machining

Machining operations such as milling or turning are often used to improve dimensional accuracy and reduce surface roughness. Smoother surfaces significantly enhance fatigue performance and wear resistance.

#### Shot Peening

Shot peening introduces compressive residual stresses on the surface, which improves fatigue resistance and delays crack initiation under cyclic loading.

#### Laser Polishing

Laser polishing can reduce surface roughness by re-melting a thin surface layer and allowing it to solidify smoothly. This technique is particularly effective for complex geometries produced by additive manufacturing.

### 6.3 Hot Iso-static Pressing (HIP)

#### Porosity Reduction

Hot iso-static pressing involves applying high temperature and pressure simultaneously to eliminate internal pores and improve density. HIP treatment significantly reduces internal defects in additively manufactured components.

#### Mechanical and Tribological Improvement

By reducing porosity and improving microstructural uniformity, HIP treatment enhances mechanical properties such as tensile strength, ductility, and fatigue life. Improved density also contributes to better wear resistance and tribological performance.

## 7. Conclusion and Future scope

This study provides a comprehensive understanding of the influence of SLM process parameters on the microstructure, mechanical behaviour, and tribological performance of AlSi10Mg alloy.

Key findings include:

- Optimized SLM parameters significantly improve tensile strength, hardness, and wear resistance while minimizing porosity and defects.
- Anisotropic behaviour persists along different build directions, highlighting the need for process-aware design.

- Fatigue and tribological performance are closely linked to microstructural features and surface integrity, suggesting targeted post-processing can enhance reliability.
- The identified research gaps underscore the need for integrated optimization approaches, defect control, and sustainable manufacturing strategies.

Collectively, these insights provide a foundation for advancing the industrial application of SLM-fabricated AlSi10Mg alloys in aerospace, automotive, and energy sectors, while guiding future investigations toward more robust, efficient, and reliable additive manufacturing practices.

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