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AlSi10Mg POWDER CHARACTERISTICS AND WEAR MECHANISM OF PARTS FABRICATED THROUGH LASER POWDER BED FUSION TECHNIQUE

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Abstract: *AlSi10Mg is a widely used aluminum alloy in various industries due to its excellent combination of mechanical properties, lightweight nature, and good casting properties. This study investigates the tribological properties of AlSi10Mg parts fabricated using additive manufacturing (AM) with both unused (fresh) and recycled powder. AM, particularly laser powder bed fusion (LPBF), enables the production of complex geometries with high precision using unused and recycled powder feedstock. This work explores the tribological behavior of AlSi10Mg samples using unused and recycled powder. The powder characteristics, including particle size distribution, morphology, and chemical composition, are analyzed to understand the changes induced by the recycling process. Microstructural analysis of the fabricated parts is conducted to examine the influence of recycled powder on the material's microstructure, including grain size, porosity, and phase distribution. Tribological tests are performed to evaluate the wear resistance and friction behavior of the samples produced from unused and recycled powders. A ball-on-disc test is employed under fixed loading conditions and sliding speeds. The wear rates, friction coefficients, and wear mechanisms are analyzed to determine the impact of powder recycling on the tribological performance of AlSi10Mg. The research aims to establish a correlation between the tribological properties and the type of powder used. Research also examines the critical powder characteristics that influence the wear and friction behavior of the AlSi10Mg powder.*

Keywords: *Additive Manufacturing, AlSi10Mg, Hardness, Roughness, Friction, Wear, Wear Mechanism*

1. INTRODUCTION

Aluminum alloys are gaining popularity in manufacturing due to their light weight, excellent mechanical properties, and low thermal expansion. While they offer similar strength to steel, and could potentially be used in applications requiring wear resistance, their wear behavior hasn't been studied extensively [1]. In harsh environments where parts are constantly rubbing against each other, material breakdown is a common cause of failure, reducing the reliability of the system. One way to address this is by improving the hardness and other mechanical properties of the aluminum alloy.

Additive manufacturing has witnessed substantial growth and offers exciting new ways to build things in recent years due to its excellent manufacturing capabilities and novel production methodologies [2-4]. However, the mechanical suitability aspect in terms of material wear and its mechanism has not received much attention and needs rigorous assessment. Selective Laser Melting (SLM) is a leading metal 3D printing (additive manufacturing) technique. It builds complex parts layer by layer by melting and solidifying metal powder. The complete melting process in SLM creates very dense parts, almost as dense as the original bulk material. The development of metal 3D printing methods like SLM has revolutionized manufacturing. Aluminum alloys are particularly well-suited for SLM and are a popular research topic because they are widely used in aerospace, automotive, and marine applications, and because there's a strong push to make things lighter [5]. Aluminum alloys offer a unique combination of beneficial physical, mechanical, and chemical properties, which can be further enhanced through the SLM process. Research into SLM of aluminum alloys, both with single materials and composites, is rapidly increasing. While the material itself is crucial for achieving desired properties, the specific process parameters used during manufacturing are equally important and significantly influence the strength and final properties of the finished part.

This research analysed at how wear resistance varies in parts made from an aluminium-silicon-magnesium alloy (AlSi10Mg) produced using a selective laser melting (SLM) technique, which investigates the wear anisotropy in an alloy sample. In the present work, different scanning strategies such as island and the continuous scanning patterns utilized for sample fabrication using both fresh and recycled powder. To simulate real-world wear conditions, like those found in bearings used in cars, we used a ball-on-disk tester with steel balls. Bearing steel balls are used as a standard sliding counterpart material to investigate the friction and wear properties. After the tribological tests, we used a scanning electron microscope to examine the worn surfaces and analysed the surface microstructure. Overall, the island strategy with 2 mm hatch style and 45° scan rotation have achieved better wear resistance and friction coefficient compared to the continuous hatch style. The wear behavior is found to be anisotropic because the wear behavior of the material is not uniform, which changes depending on the test direction.

2. MATERIALS AND METHODS

Samples of the aluminum alloy AlSi10Mg were created using selective laser melting (SLM), a 3D printing technique. Both fresh and recycled AlSi10Mg powder, with particle sizes ranging from 10 to 45 µm, were used. Both types of powder contained many smaller particles between 1 and 10 µm. These fine particles, while increasing the surface area for laser absorption during SLM, can also clump together (agglomerate), which can negatively impact how densely the powder packs during the build process. The larger particles ranged from 10 to 37 µm. Overall, the particles were mostly spherical, with an average diameter of 15 µm. Table 1 shows the SLM process parameters used for aluminium sample fabrication.

Table 1: Parameters used for the selective laser melting process for sample preparation

Gas flow rate (l/min)	4
Pressure (bar)	2
Laser power (W)	100
Scan speed (mm/s)	500
Layer thickness (µm)	15
Hatch space (µm)	60
Spot size (µm)	50
Exposure time (µs)	Continuous wave

Wear tests were performed using a custom-built ball-on-disk (BoD) tribometer in a controlled environment of room temperature and 40% relative humidity. A 4mm diameter bearing steel ball (AISI 52100, with a roughness of 3 µm and oil-quenched at 150°C) was slid against the rotating sample disk at a constant speed of 1000 RPM. Friction force and coefficient of friction (COF) were measured using a strain gauge and a data acquisition system with LabVIEW software. To ensure reliability, each test was repeated at least three times, and the average values were recorded. The tests were conducted with a sliding speed of 0.41 m/s, 30,000 sliding cycles, and a 5N contact load. After the tests, a scanning electron microscope (W-SEM, JSM-6010LA-JEOL Ltd., Japan) was used to analyze the shape and structure of any wear particles and to examine the worn surfaces of the samples.

3. RESULTS AND DISCUSSION

Two different scan strategies were used: continuous and island. For the continuous strategy, two samples were made with scan angles of 0 and 45 degrees. For the island strategy, the initial island size was 2mm x 2mm (length x width). To see how island size affects the final part, additional samples were made with a larger island size of 5mm x 5mm, while keeping all other manufacturing settings the same. Figure 1 shows the fresh and the recycled powder sample of AlSi10Mg [1] contain a large number of fine particles with size ranging between 1 µm – 10 µm and larger particles between 10 µm - 37 µm.

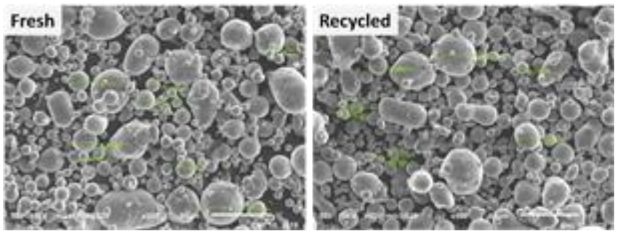
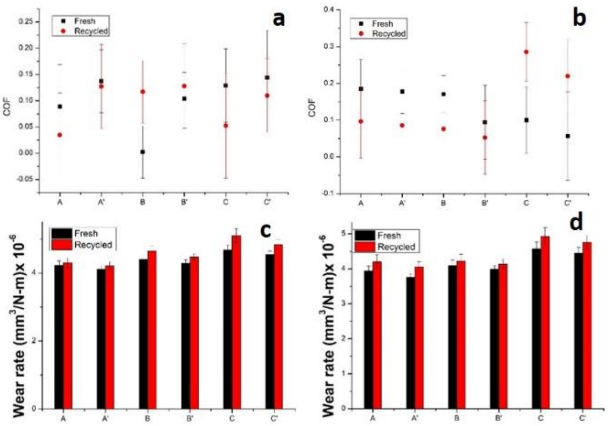


Figure 1. Microstructure and particle size distribution of AlSi10Mg particles

The coefficient of friction (COF) performance of AlSi10Mg samples fabricated by recycled and fresh powder is shown in Figure 2(a-d). Figure 2a shows the coefficient of friction (COF) for samples scanned at 0 degrees. With this scan angle, the 5mm island size now performs significantly better and achieve lower friction than the 2mm island size. This highlights the impact of the hatch design on the x-y plane after finishing operation. Before this, the effect of the island scan strategy was masked by surface roughness. After finishing, the load is distributed across all islands, minimizing the effect of single-point contact and reducing friction compared to the y-z plane. The lowest COF achieved on the x-y plane with the 5mm island is 0.002. In opposition, for continuous scanning, the recycled powder samples exhibit lower friction than the fresh powder samples, likely due to oxidation and lubrication from silicon particles. A similar trend is observed at a 45-degree scan angle (Figure 2b), where recycled powder performs better than fresh powder, but continuous scanning again results in higher friction than 0-degree scanning due to increased adhesion at the asperity junctions.

Figure 2c presents the wear rates for all samples, both fresh and recycled, at different scan angles. These results demonstrate the advantage of the island scan strategy at both 0 and 45-degree rotations. Particularly, the wear behavior is opposite to the friction behavior and follows a clear pattern: wear rate increases on the top surface (x-y plane) and decreases on the side surface (y-z plane) with increasing load. The only exception is the side surface of the recycled powder sample with continuous scanning, which shows a high wear rate. In this case, excessive abrasive particles detached from the surface, dominating the wear mechanism across the entire sliding track.



Abbreviations: A-Island (2 mm) top surface (*x-y* plane), A'- Island (2 mm) side surface (*y-z* plane), B-Island (5 mm) top surface (*x-y* plane), B'- Island (5 mm) side surface (*y-z* plane), C-Continuous top surface (*x-y* plane), C'- Continuous side surface (*y-z* plane)

Figure 2. Friction and wear performance of aluminium alloy at 0° and 45° scan rotation

Table 2 presents the hardness value of samples at different scan angles.

Table 2: Vickers hardness value of samples made at different scan rotation.

Angle	Sample	Fresh Hardness (HV)		Recycled Hardness (HV)	
0	Island (2mm)	Top	136	Top	135
		Side	134	Side	132
0	Island (5mm)	Top	134	Top	133
		Side	132	Side	130
0	Continuous	Top	130	Top	129

		Side	129	Side	128
45	Island (2mm)	Top	139	Top	137
		Side	138	Side	136
45	Island (5mm)	Top	137	Top	134
		Side	135	Side	133
45	Continuous	Top	134	Top	132
		Side	131	Side	130

The wear results revealed three distinct stages of wear anisotropy, each associated with a different microstructure resulting from the chosen scanning strategy (please see Figure 3). The finest microstructure, achieved with the 2mm island scan, exhibited the lowest wear due to its dense structure and high hardness, preventing grain detachment during sliding [1]. Increasing the island size to 5mm created a moderate microstructure characterized by two distinct interfaces: one with trapped wear debris and another smooth sliding surface. The larger island size requires more scan time, leading to this separation of interfaces. While the trapped debris can influence sliding, the smooth interface still provides some level of consistent wear behavior. Finally, the continuous scanning strategy produced a coarse microstructure (though this is implied rather than explicitly stated), which is associated with the highest wear rate.

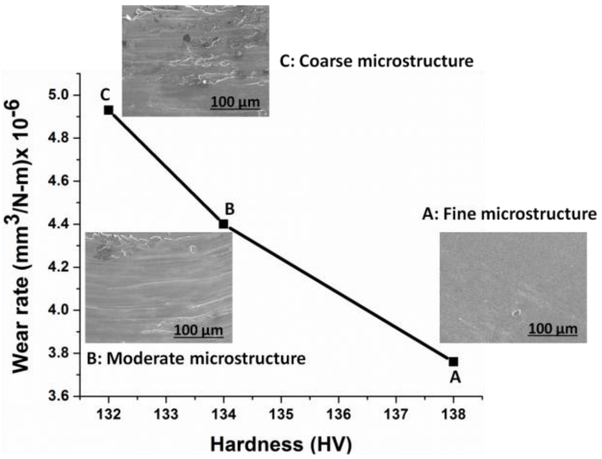


Figure 3. wear anisotropy stages and mechanism

4. CONCLUSION

The wear behavior of SLM-fabricated AlSi10Mg samples is significantly influenced by scan angle rotation and hatch style. Samples fabricated with a 45° scan rotation and island hatching demonstrated superior wear resistance compared to those produced with a 0° rotation and continuous hatching. The type of detached abrasive particles plays a crucial role in determining the wear mechanism and severity.

The coefficient of friction is dependent on the formation of an effective film between the counter-body and the sample. The presence of a silicon particle network on the surface microstructure suggests a lubrication mechanism at both top and side surfaces. Aluminum oxides were observed in the wear microstructures, forming at the ball-sample interface due to increased sliding temperature. This oxide formation contributes to reduced wear and friction.

Fresh powder samples exhibited lower wear rates, making them suitable for contact applications. Recycled powder, specifically at a 0° scan rotation, showed a surface modification effect that improved friction performance. This suggests the potential for reusing recycled powder, although further investigation at other scan rotations is necessary.

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