Research Article

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Effects of Thermal Spray Coatings on Surface Protection and Mechanical Performance of AlSi10Mg Alloy Produced by Additive Manufacturing

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ABSTRACT

In this study, AlSi10Mg alloy produced by additive manufacturing was produced as a tensile test sample according to ASTM E-8 standard. The produced materials were subjected to coating process with 60% Al_2O_3 -40% TiO_2 and 87% Al_2O_3 -13% TiO_2 powder mixtures at two different rates with powder flame spray coating, which is one of the thermal spray coating methods. After coating, tensile test of the samples was performed and the most suitable mixing ratio of Al_2O_3 and TiO_2 mixtures was determined and the strength ratios were compared. In addition to these, the post-corrosion strength values of the samples subjected to salt spray test after coating were examined and the effects of both different coating rates and corrosion were investigated. The changes on the surface after corrosion process and the fracture surface examinations of the samples after tensile test were examined with scanning electron microscope (SEM). The results showed that the sample coated with 60% Al2O_3-40% TiO_2 without corrosion process had the highest strength value with a value of 437.65 MPa. It provided an increase of approximately 6% compared to the uncoated and uncorroded material. It was observed that the samples coated with 87% Al_2O_3-13% TiO_2 caused a decrease in the strength value compared to the untreated uncoated sample.

1. Introduction

Additive manufacturing (AM), commonly known as 3D printing, has enabled the production of complex geometries, enabling designs that are difficult or impossible to achieve with traditional methods. Unlike machining methods, which remove material to bring the material to the desired form, additive manufacturing builds components layer by layer from digital models [1,2]. This method offers significant advantages in terms of material efficiency, design flexibility, and customization. Thanks to these features, additive manufacturing has become quite attractive in sectors such as aerospace, automotive, and medical, where lightweight structures, performance optimization, and part assembly are critical [3]. Metal additive manufacturing encompasses a variety of technologies, the most important of which are Laser Powder Bed Fusion (L-PBF) and Directed Energy Deposition (DED). L-PBF, a powder-based additive manufacturing technique, is particularly suitable for the production of parts with fine details and high dimensional accuracy. This method creates components by melting metal powders layer by layer with a high-power laser. On the other hand, DED method is preferred for the production and repair of large components since it produces by depositing molten material. Among these methods, L-PBF method is more adopted in the production of Al-Si alloys due to its superior surface quality and microstructural control [4-6]. AlSi10Mg alloy is one of the most widely used aluminum alloys in additive manufacturing

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and is known for its excellent strength-to-weight ratio, corrosion resistance, low coefficient of thermal expansion and high wear resistance [7]. These properties make it an ideal choice, especially in the aerospace and automotive sectors, where weight reduction and performance under harsh environmental conditions are important [3]. In the aerospace industry, AlSi10Mg is used in structural components, engine parts and heat exchangers, while in the automotive sector, it is preferred in calipers, fasteners and other parts requiring high performance [8]. Many studies have been conducted to improve the mechanical and corrosion performance of AlSi10Mg versions produced by additive manufacturing methods. Rapid heating and cooling cycles in the L-PBF process increase strength and hardness by creating fine-grained microstructures. However, these thermal cycles can cause metallurgical defects such as residual stresses and porosity, which can negatively affect the corrosion resistance of the material [9,10]. Studies have shown that AlSi10Mg produced by the L-PBF method may be susceptible to various corrosion mechanisms such as pitting, intergranular corrosion and stress corrosion due to melt pool boundaries and microstructural heterogeneities [11,12]. To overcome these difficulties, researchers have investigated various finishing techniques such as heat treatments, surface polishing and coating applications [13]. Among these techniques, thermal spray coatings, which reduce the effects of metallurgical defects by creating dense and protective surface layers, stand out. Thermal spray coatings are widely used in applications where corrosion and wear resistance are critical, especially in the aviation industry, such as turbine blades and structural components. The bonding mechanism is mostly mechanical, but in some cases metallurgical observations are made. Thus, the properties of the coating vary depending on the combination of kinetic and thermal energy [14]. There are 5 basic thermal spray coating methods commercially. These coatings are divided into those using combustion and electrical energy. Combustion and powder/wire flame spray coating, HVOF and explosion coating methods are included. Plasma and wire arc are two other coating methods that use electrical energy to help melt consumables. The best thermal spray coating method varies depending on the purpose of use, the material to be coated and environmental conditions. Although HVOF and plasma methods have better mechanical results, they have disadvantages because they are not portable, expensive and require advanced technology. In this study, flame spray coating was used because it is a cheap method and can be applied on large surfaces and in the field [15].

In this study, a new data study was presented to the literature by investigating the effect of Al_2O_3-TiO_2 coatings at different ratios with the Powder Flame Spray method on the mechanical and corrosion resistance of AlSi10Mg alloy produced with the L-PBF method. In previous studies, studies examining the mechanical and chemical properties by combining the advantages of additive manufacturing with flame spray coating technologies were not conducted. This experimental study aimed to increase the performance of AlSi10Mg and provide a wider application area, especially in the aviation and automotive sectors.

2. Material and Methods

The samples were produced by laser powder bed fusion production method on Aconity Midi machine using AlSi10Mg powder with particle size range of 20-63 μm. The chemical composition of AlSi10Mg alloy by mass (%) is given in Table 1.

Table 1. Chemical composition of AlSi10Mg alloy

Elements%										
Al	Si	Mg	Fe	Mn	Ti	Zn	Cu	Ni	Pb	Sn
Balance	10.0	0.30	0.55	0.45	0.15	0.10	0.05	0.05	0.05	0.05

Samples were produced using the process parameters specified in Table 2. The placement and orientation of the samples are shown in Figure 1.

Table 2. L-PBF process parameters

Parameter	
Linear Energy Input	350 W
Scan Speed	1450 mm/s
Scan Strategy	Stripe
Layer Thickness	0,03 mm
Focal Offset	-1.6780 mm
Screed Preheat Temperature	-
Build Room Temperature	25°C
Spreader Speed	150 mm/s
Shielding Gas Composition	Argon
Scan Gap	0.15

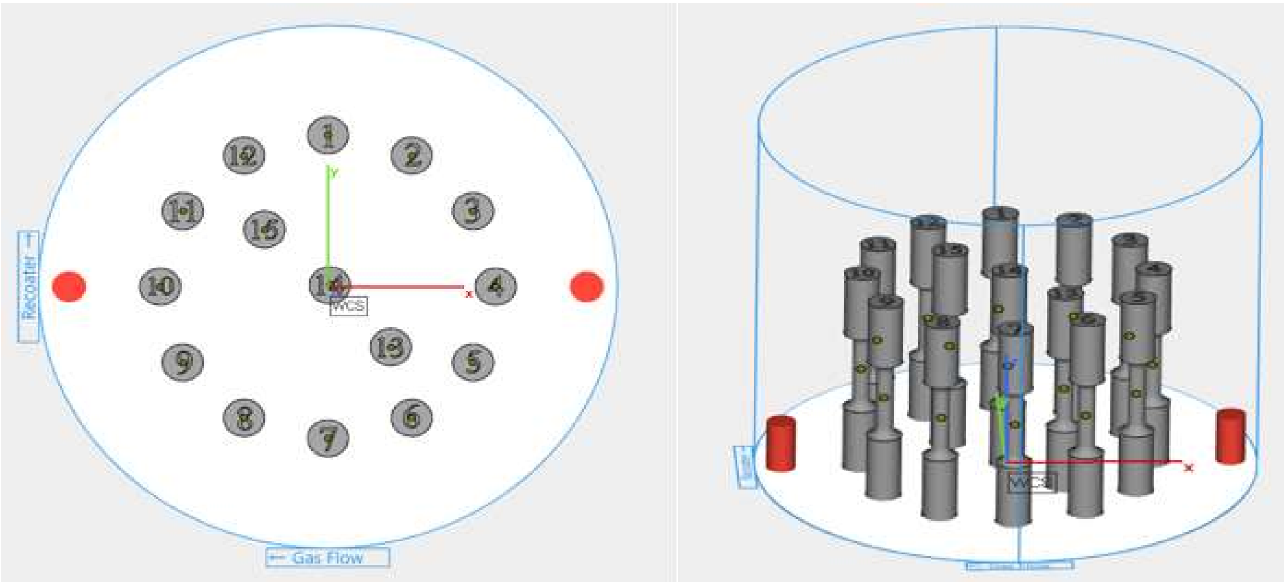

Figure 1. Aconity MIDI sample layout a) top b) isometric

The produced tensile test samples were subjected to the coating process with powder flame spray coating, which is one of the thermal spray coating methods. Two different ratios of powder mixture were prepared for the coating. Coating ratios, corrosion time and sample codes are shown in Table 3. The coating process was carried out at a thickness of 50 um. Coating thickness measurements were made with Minitest 650 device.

Table 3. Coding of samples, coating rates and corrosion times.

Samples	Coating	Corrosıon Tıme
A	%60 Al_2O_3, %40 TiO_2	0 h
B	%87 Al_2O_3, %13 TiO_2	0 h
C	Uncoated	0 h
D	%60 Al_2O_3, %40 TiO_2	48 h
E	%87 Al_2O_3, %13 TiO_2	48 h
F	Uncoated	48 h

All samples were placed in the salt spray tester at a 14-degree angle and exposed to salt spray for 48 hours in the Weisstechnik® SaltEvent SC Salt Spray test chamber. Tensile tests of the samples after corrosion were performed with INSTRON 5982 and INSTRON AutoX-750 EXTONSOMETER devices. Jeol JSM-6060LV SEM was used to examine the corrosion status of the samples and the coating surfaces.

3. Results and Discussion

Tensile test results of samples produced as tensile test samples according to ASTM E8, with and without coating, are shown in Table 4. The best strength value among the coated samples made at two different ratios was obtained in the 60% Al_2O_3-40% TiO_2 coated samples, which were not corroded and coded as A. It is thought that the decrease in the strength value of the samples coated with 87% Al_2O_3-13% TiO_2 compared to the other samples is due to the fact that Al_2O_3 is harder and more brittle [14,15]. While Al_2O_3 is hard and brittle, the addition of TiO_2 has a positive effect on strength by stopping crack propagation. Higher TiO_2 content increases bond strength. In addition, the thermal expansion coefficient of the AlSi10Mg alloy, which is the substrate material, is high. The coating containing 40% TiO_2 is more compatible with Al in terms of thermal expansion coefficient. This reduces the stresses between the coating and the substrate. Low stresses are an advantage for high tensile strength [16-19]. Samples coated with 60% Al_2O_3 -40% TiO_2 ratio showed an increase of 6% compared to uncoated samples. Samples with 87% Al_2O_3 -13% TiO_2 coating, coded as B, showed a decrease of approximately 1% compared to uncoated samples. This value is negligible. However, if the coating process creates micro cracks or internal stresses on the surface of the main material, there may be a decrease in tensile strength. In particular, the brittleness of ceramic coatings may cause premature rupture under tensile stresses. Although the yield and tensile strength of sample B were measured lower than the others, the % elongation and E values were higher than the uncoated state. The higher modulus of elasticity of the coated material is due to the fact that ceramics are hard and rigid materials by nature [20].

When the same samples were subjected to a salt test for 48 hours and then subjected to a tensile test, a linear decrease in the strength value of all samples was observed. If there are micro cracks or pores on the surface after coating, corrosion agents, namely chloride ions in the salt test, can progress through the gaps and damage the main material. Therefore, it is thought that there is a decrease in the tensile strength of the material [21].

Table 4. Yield strength, tensile strength, Elongation % and modulus of elasticity obtained after tensile test of the samples

Sample codes	**Yield Strength (MPa)**	**Tensile Strength**	**Elongation %**	**E (Elasticity modulus MPa)**
A	286,83	437,65	3.86	60171
B	262,11	411,44	3.94	58474
C	273,42	413,94	3.78	56692
D	263,31	410,09	3.80	56339
E	257,53	398,02	3.63	52172
F	265,28	395	3.34	50878

Figure 2 shows the fracture surface microstructures of the samples examined after the tensile test. Figure 2 (a, b, c) shows the samples without corrosion and (c, d, e) shows the samples with corrosion. In the images, blue arrows indicate ductile fracture and red arrows indicate brittle fracture. The images generally show that ductile fracture is dominant with dimple regions. There are cleavage planes in some places. In materials produced by additive manufacturing, internal stresses or micropores due to layered production can affect the fracture behavior in this way. It is noteworthy that the ductile structure is less in Figure 2 a and b compared to c. The reason for this is that the ceramic coated on a metal material cannot absorb the stresses sufficiently and may exhibit brittle fracture. There is a thermal expansion difference between the ceramic coating and the metal substrate. This difference also affects the fracture morphology [22,23].

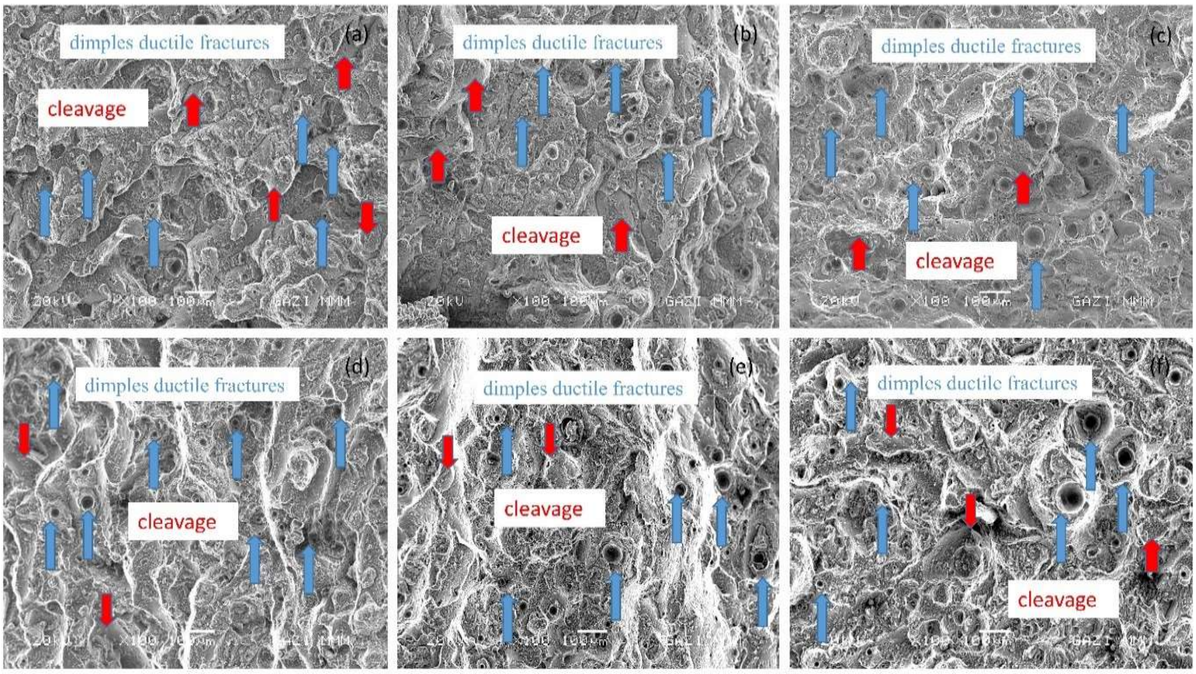

Figure 2. SEM images of the fractured surface of the samples; images of sample codes (a) A (b) B (c) C (d) D (e) E (f) F

Figure 3 shows the surface images of the samples without corrosion. Figure 3 (c) shows the surface image of the sample produced by additive manufacturing and not coated. Figure 3 (b) shows the coating with a higher Al_2O_3 ratio with 87% Al_2O_3 and 13% TiO_2, coded as B. Since the excess Al_2O_3 negatively affects the conductivity, it was observed that this image gave some burning and scattering in the SEM microstructures. It was observed that the coating powder mixtures in spherical form passed into melting form under the effect of heat in certain regions [22]. Figure 3a shows the surface microstructure of the sample coated with 60% Al_2O_3 and 40% TiO_2.

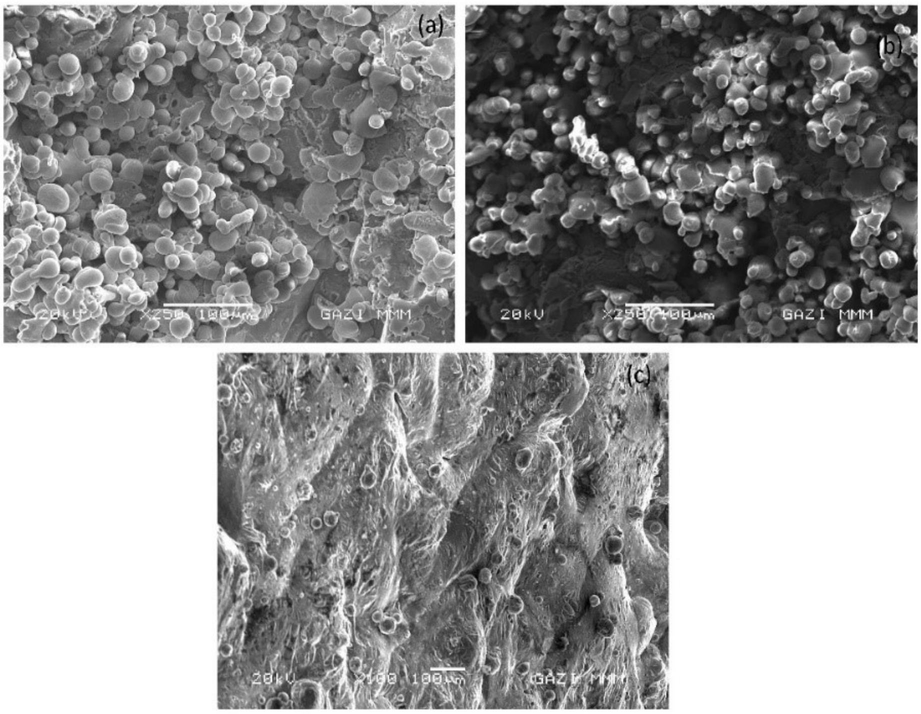

Figure 3. Surface SEM images of uncorroded samples (a) A (b) B (c) C; sample codings

Figure 4 shows the SEM microstructures and EDS analyses taken from the surfaces of samples D, E, F after corrosion. It was observed that the uncoated sample F shown in Figure 4 (c) formed distinct pits and particles after corrosion. The surface quality of the parts produced by additive manufacturing is rough. This causes corrosion to start more quickly. The EDS analyses shown in Figure 4 (d) also prove the deterioration caused by Na and Cl elements on the surface. In Figure 4 (a), it was seen that the coating made with 60% Al_2O_3, 40% TiO_2 showed resistance to corrosion and no corrosion was observed in any area. In Figure 4(b), corrosion was observed in a small area of the coating made with 87% Al_2O_3, 13% TiO_2 compared to Figure 4(a).

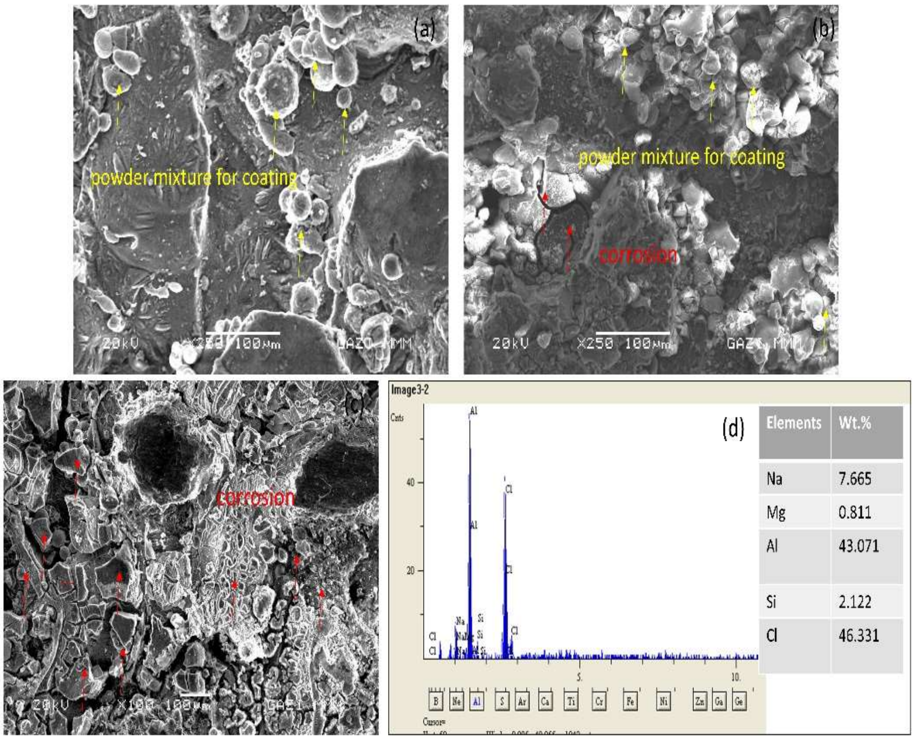

Figure 4. SEM microstructures and EDS analyses of sample surfaces after Corrosion

4. Conclusion

In this study, the surface protection properties of AlSi10Mg alloy, which is frequently used in defense industry applications, were investigated with thermal spray coating and the effects of the coating on corrosion and tensile strength after the salt spray test were investigated. After the salt test, a decrease occurred in the yield and tensile strength values of all samples. The tensile strength of the uncorroded A sample coated with 60% Al_2O_3-40% TiO_2 was 437.65 MPa, which was the highest strength value. It was observed that the ductile fracture surface image was more pronounced in the uncoated C sample. In the microstructure examinations conducted after the salt test, the resistance of the coating against corrosion was also proven by EDS analysis. It was observed that the uncoated F sample corroded formed distinct pits and particles after corrosion. As a result, the effects of different coating rates on mechanical properties and corrosion have been revealed. In subsequent studies, detailed data studies can be carried out by finding optimum values by changing corrosion times and coating thicknesses.

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Conflict of Interest Statement

The authors declare that there is no conflict of interest

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