

EFFECT OF CHEMICAL AND ELECTROCHEMICAL POST-PROCESSING ON THE SURFACE QUALITY OF WE43 LATTICE STRUCTURES

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Abstract

This study investigates chemical and electrochemical post-processing of additively manufactured WE43 Mg alloy in order to remove adhered partially melted powder particles. The objective was to evaluate the influence of different etching media on surface morphology, strut removal uniformity, and the extent of localized corrosion damage. Chemical etching was performed in 30% and 50% H₃PO₄ solutions. In both cases, intensive strut surface phosphating occurred, accompanied by excessive material dissolution and localized corrosion attack of the base struts. Etching in a 5% mixture of HCl and HNO₃ resulted in visible pitting and significant surface oxidation. The most favorable results were achieved by electrochemical etching in a 5% HNO₃ solution in water-ethanol mixture for 300 s under applied voltage of 1V. This treatment enabled controlled and homogeneous removing of adhered particles without pronounced corrosion attack and minimal oxidation of base struts compared to the other tested conditions. The results demonstrate that appropriately selected electrochemical parameters provide a more controlled surface modification route for additively manufactured WE43 alloy, minimizing localized corrosion effect while ensuring uniform surface refinement. The findings contribute to optimizing post-processing strategies for Mg alloys produced by additive manufacturing, where controlled surface quality and preservation of structural integrity are critical for subsequent functional performance.

Keywords: WE43, magnesium alloy, etching, additive manufacturing, post processing

1. INTRODUCTION

Additive manufacturing (AM) process of Mg and its alloys has attracted increasing attention due to their unique properties, such as combination of low density, favorable mechanical properties (high specific strength), and their biodegradability [1-2]. Among them, WE43 alloy, containing yttrium and rare earth elements, is particularly promising for lightweight structural and biomedical applications due to its enhanced strength and good corrosion resistance [1-3]. However, due to the layer-by-layer fabrication inherent to AM processes, printed components typically exhibit characteristic surface imperfections, including the presence of partially melted powder particles adhered to their surfaces [1, 2, 4]. These surface irregularities are critical in lattice structures, where the high surface-to-volume ratio amplifies their impact on mechanical properties and corrosion behavior [5-7]. Adhered or partially fused particles on the surface act as stress concentrators and preferential corrosion initiation sites, accelerating localized degradation and reducing fatigue performance [1, 5-6]. In addition, they hinder subsequent surface treatments, especially protective coating deposition, by impairing adhesion and promoting non-uniform coverage, which lead to decrease in corrosion resistance [2, 6-7]. Therefore, the post-processing is essential to ensure controlled surface refinement and preserving the integrity of lattice geometries [8-10]. Conventional post-processing includes mechanical, chemical, and electrochemical treatments. Mechanical methods are often unsuitable for complex lattice structures due to limited availability and risk of structural damage [1]. Chemical and electrochemical etching offers a relatively simple, low cost and

scalable solution, however, it can be associated with poor selectivity, excessive material removal, and susceptibility to localized corrosion attack [1-2]. The proper treatment process can improve control over material dissolution enabling more uniform surface refinement. Despite the growing interest in AM Mg alloys, there is a lack of systematic studies comparing chemical and electrochemical post-processing routes specifically for lattice structures made from WE43 Mg alloy [2]. The influence of different etching media on surface morphology, uniformity of strut thinning, and the extent of corrosion-induced damage has not been sufficiently clarified. This study aims to evaluate the effectiveness of selected chemical and electrochemical post-processing methods in removing adhered powder particles from additively manufactured WE43 lattice structures. The findings are intended to contribute to the optimization of post-processing strategies for Mg alloys produced by AM, where precise control of surface quality is crucial for their subsequent application.

2. EXPERIMENTAL PART

The Body-Centered-Cubic (BCC) unit cells with strut diameter of 2 mm were produced using the SLM 280HL machine (Nikon SLM Solutions AG, Lübeck, Germany). A magnesium alloy WE43 (Luxfer MEL Technologies, Manchester, UK) with a particle size distribution of 28-60 μm and an average size of 39.8 μm is used. Its chemical composition is listed in **Table 1**. Process parameters were set according to a recommendation: laser power of 150 W, scanning speed of 700 $\text{mm}\cdot\text{s}^{-1}$, 50 μm layer thickness, 120 $^{\circ}\text{C}$ platform heating, inert Ar atmosphere during production.

Table 1 Elemental composition of WE43 powder (wt%)

Element	Mg	Y	Zr	Nd	Si	Cu
Composition	Balance	3.96	0.56	2.30	<0.01	<0.01

The surface of the samples was chemically or electrochemically etched and cleaned to remove excess material, which was formed as a result of the sintering processes. Etching was carried out either chemically in three variants under the following conditions: 1) in a 30% phosphoric acid solution, 2) in a 50% phosphoric acid solution, or 3) in a 5% mixture of HCl and HNO_3 (1:1) in ethanol. Alternatively, etching was performed electrochemically in a 5% HNO_3 solution in ethanol with water (1:1) under an applied voltage of 1 V using LectorPol-5 electrolytic polishing machine (Struers). The maximum etching duration was consistently 300 s. after the etching, all samples were rinsed with alcohol and air-dried.

The morphology of the samples and their structure were assessed using a Zeiss EVO LS-10 scanning electron microscope (Carl Zeiss Ltd., Cambridge, UK) with an Oxford Instruments Xmax 80 mm^2 EDS detector (Oxford Instruments plc, Abingdon, UK).

3. RESULTS AND DISCUSSION

A graphical comparison of mass losses for the etching solutions shows that the highest mass loss was consistently observed for 30% H_3PO_4 (**Figure 1**). In this case, the etching process was too rapid and led to significant removing of adhered particles (**Figures 2a, b**). However, surface micrographs and structural analysis (**Figure 2c** and **Figure 3a**) reveal that the surface was covered with pits and a cracked phosphate layer. Etching in 50% H_3PO_4 proceeded more gradually, however, phosphate layer formation and localized corrosion were still observed (**Figure 2d**). For the HCl + HNO_3 mixture, the mass loss rate was comparable to that of 50% H_3PO_4 , but the sample surface was covered with residues of $\text{Mg}(\text{OH})_2$. At longer etching times, small isolated pits indicating the onset of localized corrosion were also observed (**Figure 2e** and **Figure 3b**). The most gradual and uniform etching was achieved using electrochemical method in an HNO_3 solution. The lowest mass loss corresponded to the complete removal of adhered particles, while the base material (scaffold strut) remained unaffected (**Figure 2f**). Detailed observation showed a uniformly etched surface without pitting and without the presence of corrosion product layers (**Figure 3c**).

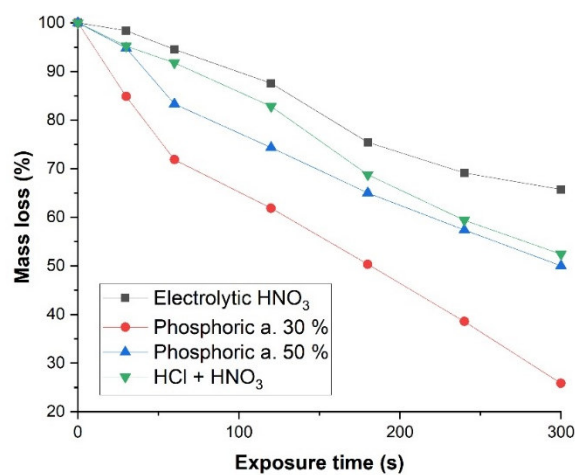


Figure 1 Comparison of mass loss induced by the employed etching solutions

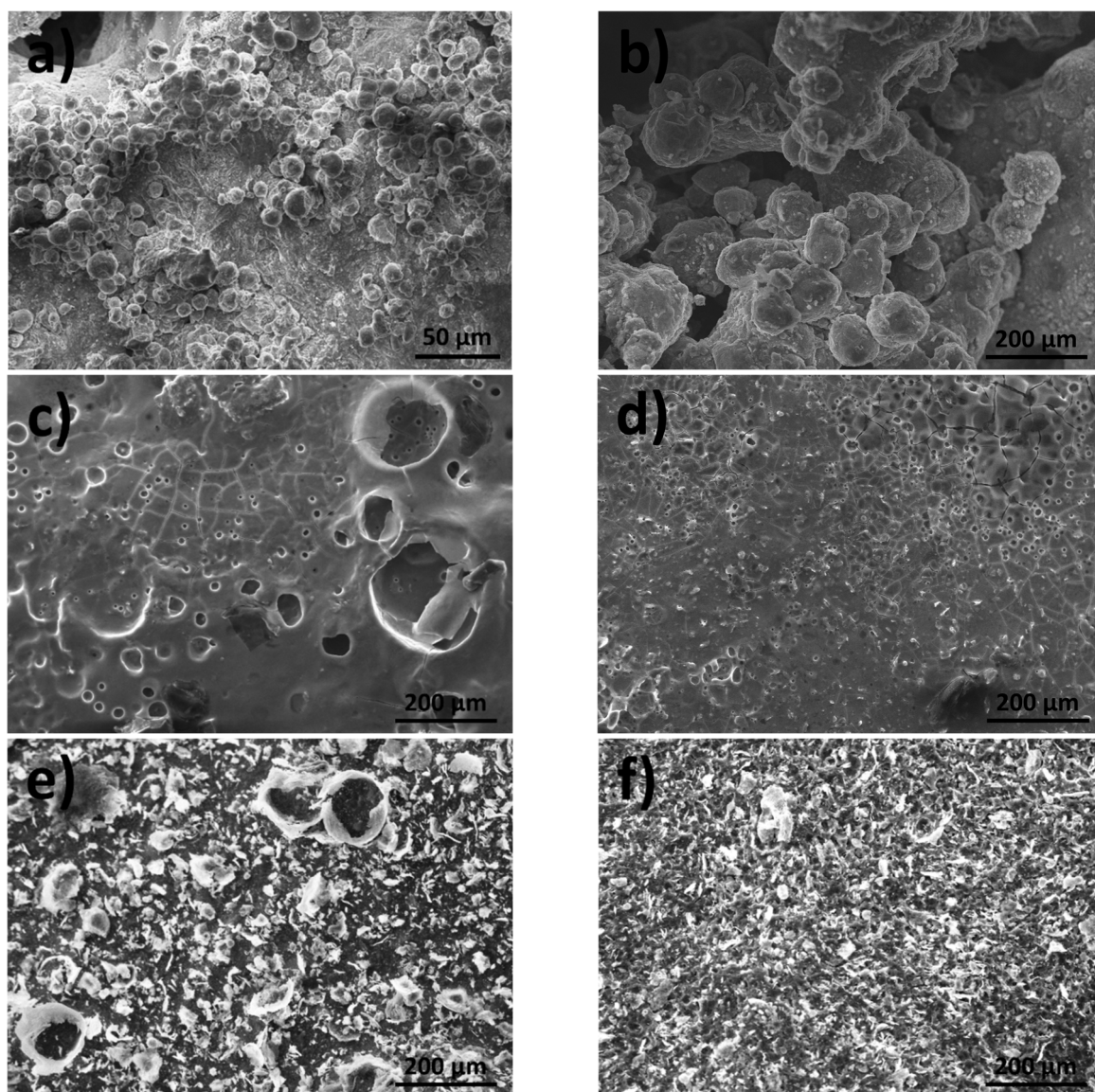


Figure 2 Surface morphology of etched samples, a) Reference, b) Reference – detail, c) Phosphoric a. 30 %, d) Phosphoric a. 50 %, e) HCl+HNO₃ (1:1), f) 5% HNO₃ (electrochemically etched)

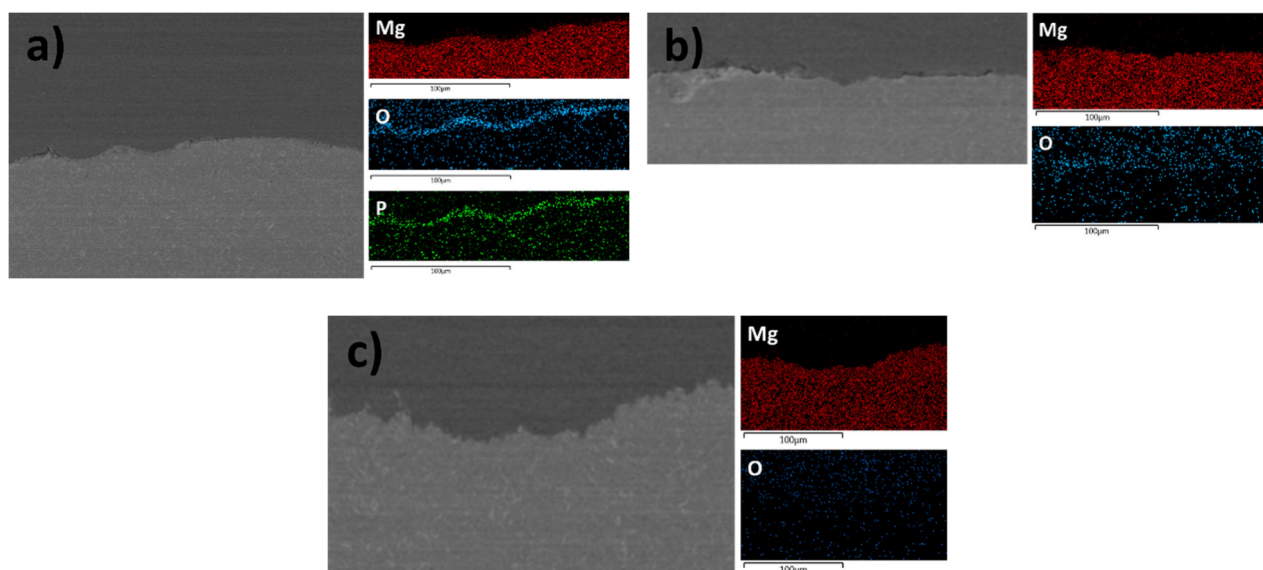


Figure 3 Elemental analysis of the surface layer of selected samples, cross-section, a) Phosphoric a. 30 %, b) HCl+HNO₃ (1:1), c) 5% HNO₃ (electrochemically etched)

The results indicate that the effectiveness of removing of adhered particle is controlled by the balance between etchant aggressiveness and its selectivity. Although etching in 30% H₃PO₄ produced the highest mass loss (**Figure 1**), the process was excessively aggressive, leading to degradation of the base material (scaffold struts). The presence of a cracked phosphate layer (**Table 2** and **Figure 3a**) and pitting suggests unstable surface film formation accompanied by localized corrosion (see also **Figure 2c**). The use of 50% H₃PO₄ led to a more gradual material removal. However, phosphate layer formation and localized corrosion were still observed [1, 2, 11-14]. This indicates insufficient selectivity of the etching. The HCl+HNO₃ (1:1) mixture resulted in comparable mass loss (**Figure 1**), but the formation of Mg(OH)₂ together with oxidized residues and oxide crusts of adhered powder and the appearance of isolated pits point to lower selectivity, localized attack and insufficient residues removal (**Table 2**).

In contrast, electrochemical etching in 5% HNO₃ in mixture of alcohol and water provided controlled and uniform material removal (**Figure 2f**). The lower mass loss, combined with complete particle elimination, absence of pitting and subdued formation of corrosion products, such as magnesium hydroxide (**Table 2**), demonstrates improved selectivity and etching process stability. This behavior can be attributed to the externally controlled dissolution conditions.

Table 2 Elemental composition of the samples after etching (measured from the surface) (wt%)

Sample	Reference (before etching)	Phosphoric a. 30 %	Phosphoric a. 50 %	HCl+HNO ₃ (1:1)	5% HNO ₃ (electrochemical)
Element					
O	8.22	59.72	49.89	14.97	4.47
Mg	84.30	12.74	25.15	64.84	84.11
Nd	4.47	0.50	0.93	3.92	2.04
Y	2.00	1.10	2.78	16.28	9.37
P	-	25.94	21.26	-	-

4. CONCLUSION

- Electrochemical etching in 5% HNO₃ proved to be the most effective post-processing route for WE43 lattice structures, enabling uniform removal of adhered particles while preserving the base material (scaffold struts).
- In contrast, chemical etching in phosphoric acid or in the mixture of HCl+HNO₃ (1:1) led to excessive material dissolution, phosphate layer formation or surface oxidation, and localized corrosion.
- Overall, the results showed that electrochemical processing as a more controlled and reliable method for surface refinement of additively manufactured Mg alloy lattices.

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