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TAILORING SURFACE MORPHOLOGY AND TOPOGRAPHY OF SHOT-PEENED Ti6Al4V VIA GRIT BLASTING

OBLIKOVANJE POVRŠINSKE MORFOLOGIJE IN TOPOGRAFIJE ZLITINE Ti6Al4V S PESKANJEM PO PREDHODNEM OBSTRELJEVANJU NJENE POVRŠINE Z JEKLENIMI KROGLICAMI

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The present study aims to reveal the effectiveness of grit blasting when modifying the surface properties of a Ti6Al4V alloy deteriorated due to shot peening. Ti6Al4V samples shot-peened under different parameters were grit-blasted (at impingement angles of 30° and 90°, blasting pressures of 1.5 bar and 3 bar). Grit blasting proved to be an effective way of tailoring the surface topography as the surface roughness of shot-peened samples (approx. 10 µm) declined to approx. 2 µm. The surface modifications mainly occurred via micro-ploughing and micro-cutting wear mechanisms, indicating that grit blasting at 30° was more favourable than at 90° for modifying the deteriorated surface properties after shot peening. Shot-peened samples behaved similarly to mirror-polished unpeened samples during grit blasting, showing that the modified surface and subsurface properties obtained via shot peening have an insignificant effect on grit blasting of the alloy. A quantitative analysis of the area covering the embedded particles on the surface of the alloy due to grit blasting showed that the area almost doubled when the alloy was grit blasted at 90° compared to 30°, highlighting an excessive amount of embedding, which would be critical when surface decontamination is important.

Keywords: erosive wear, shot peening, surface engineering, titanium alloy

V pričujočem članku avtorji predstavljajo študijo, ki poizkuša oceniti učinkovitost peskanja površine Ti zlitine Ti6Al4V po poškodbah nastalih zaradi njene površinske obdelave s postopkom obstreljevanja s kroglicami iz nerjavnega jekla. Vzorce Ti6Al4V so obstreljevali pri različnih pogojih in jih nato peskali pod udarnima kotoma 30° in 90° ter udarnima tlakoma 1,5 bara in 3 bare. Peskanje je učinkovito preoblikovalo topografijo površine. Hrapavost površine se je s cca 10 µm zmanjšala na približno 2 µm. Modifikacije površine so v glavnem nastale preko obrabnih mehanizmov mikro-pluženja (nastanka brazd mikronske velikosti) in mikro-rezanja. Preizkusi so pokazali, da je peskanje pod udarnim kotom 30° bolj ugodno kot peskanje pod kotom 90° glede poprave poškodovane površine zaradi obstreljevanja s kroglicami iz nerjavnega jekla. Vzorci, ki so bili površinsko obdelani z jeklenimi kroglicami so se obnašali podobno kot neobdelani površinsko spolirani in peskani vzorci. To kaže na to, da ima peskanje zlitine nepomemben vpliv na modifikacijo površine in spremembe lastnosti nastale pod površino zlitine zaradi obstreljevanja s kroglicami. Kvantitativna analiza površine obdelane s peskanjem je pokazala, da je velikost obdelane površine pri peskanju pod kotom 90° skoraj podvojena v primerjavi s peskanjem pod kotom 30°. To kaže na pokrivanje peskane površine, kar je lahko kritični parameter pri čiščenju površine.

Ključne besede: erosivna obraba, peskanje, inženiring površin, zlitina na osnovi titana

1 INTRODUCTION

Shot peening (SP), which is well known for its low cost and high applicability[1], is a mechanical surface treatment that improves the fatigue behaviour of materials.[1–4] This is achieved by modifying their properties such as grain size, hardness and residual stress profile.[1,3,4] SP further changes the surface morphology and topography of materials as a result of the repeated impact of shots,[3,5] which may lead to the development of undesired surface properties (e.g., high surface roughness,[3] microcrack formation[3] and surface contamination[5,6]), limiting their usage in applications where surface properties are of a significant importance.[3,5]

Titanium alloys (especially Ti6Al4V alloy) have been widely used in aerospace and biomedical applications due to their specific mechanical properties, biocompatibility, corrosion resistance and high-temperature behaviour.[1,2,5–7] Numerous studies focused on improving the fatigue behaviour of a Ti6Al4V alloy with SP[1–4] and some studies reported that SP could result in a high surface roughness and deteriorated surface integrity, which detrimentally affected the fatigue behaviour.[3,8] Thus, further surface treatment is needed to overcome the undesired surface properties of shot-peened materials.[5] For instance, in biomedical applications, the surface roughness value R_a should be kept within a certain range (1–2 µm)[9]

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to obtain desired biological outcomes (e.g., osseointegration[5] and cell proliferation[5]). Grit blasting (GB) is a method that has been proposed for remodifying deteriorated surface properties of shot-peened materials.[10] However, it has not yet been fully investigated how GB and its process parameters modify the surface properties of a shot-peened Ti6Al4V alloy. This study reveals the effects of GB and its main process parameters on modifying the deteriorated properties of a Ti6Al4V alloy shot-peened under different parameters.

2 EXPERIMENTAL PART

2.1. Materials

Grade 5 Ti6Al4V alloy was obtained in the bar form (ϕ 20 mm) and then cylindrical samples were cut (a thickness of 10 mm). The cut samples were metallographically prepared to obtain mirror-polished surfaces. SP was applied on the polished samples using two different sizes of stainless-steel shots with a 450 HV hardness (diameters of 0.09–0.14 mm (S10) and 0.7–1.0 mm (S60)) for peening durations of 5 min and 15 min using a custom-designed SP system, as detailed elsewhere.[11] Finally, shot-peened samples were grit blasted with alumina particles (Al_2O_3) via a custom-designed GB system using the following parameters: a GB duration of 30 s; GB pressures of 1.5 bar and 3 bar; impingement angles of 30° and 90°; and a grit size of 80 mesh.

2.2. Characterisation

After GB, the surfaces of the samples were cleaned with ultrasonication using alcohol for 15 min. Then, the mass-loss change of the samples was determined using an electronic balance (an accuracy of ±0.1 mg). The surface morphologies of the samples were investigated using a scanning electron microscope (SEM) equipped with an energy dispersive X-ray spectrometer (EDS). To calculate the area covering the embedded particles based on the GB parameters, the SEM images of grit-blasted surfaces were post-processed and quantitively analysed using ImageJ®. The surface roughness of shot-peened and grit-blasted samples was determined using a profilometer (Mitutoyo SJ-310); more specifically, a line of 4 mm scanned on each sample surface along with the mean-roughness value R_a.

3 RESULTS AND DISCUSSION

The surface topographies and morphologies of materials after GB primarily depend on the active wear and deformation mechanisms that occur during GB. Samples peened under the most severe peening parameters (S60 shots for 5 min and 15 min) were selected for a morphological analysis. **Figure 1** illustrates the grit-blasted surface morphologies of shot-peened alloy, indicating that micro-cutting and micro-ploughing wear mechanisms were dominant on the surface grit-blasted at an impingement angle of 30° (**Figures 1a** and **1b**) where the black regions shown in the SEM images are alumina particles embedded into the alloy surfaces during GB. Plastic deformation and particle embedment were dominant on the surface grit blasted at 90°.

The embedding of particles during GB and erosive wear were previously qualitatively presented, especially for ductile metals,[5,8,12] but they have not yet been quantified. **Figure 2** illustrates the area covering the particles embedded into the surface of the alloy grit-blasted at dif-

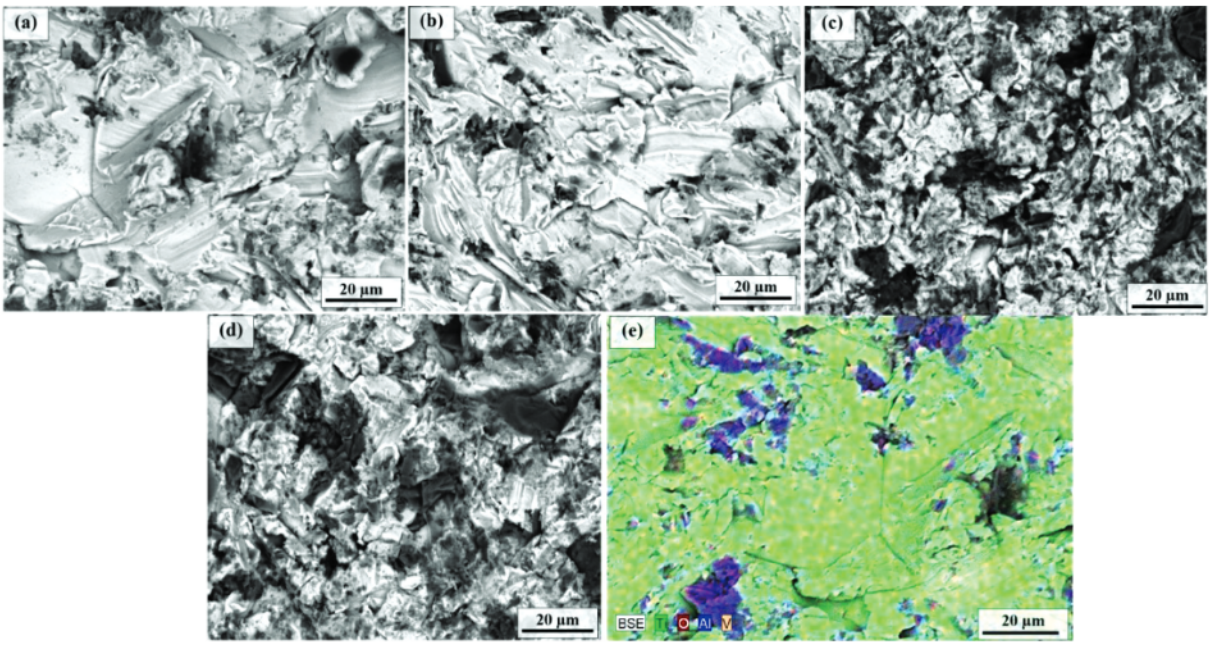

Figure 1: Back-scattered electron images of surface morphologies of grit-blasted samples at 30°: a) S60, 5 min, b) S60, 15 min, at 90°, c) S60, 5 min, d) S60, 15 min, e) EDS map of a)

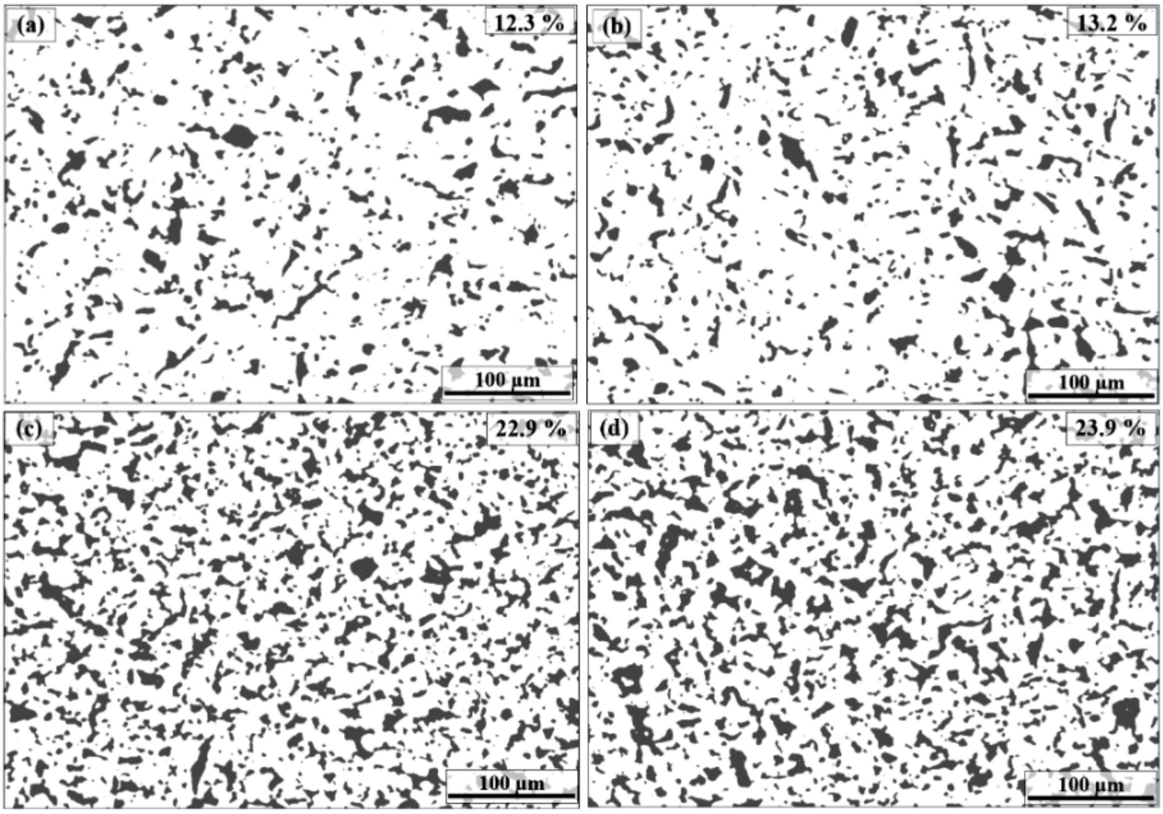

Figure 2: Image analysis of areas of embedded particles after GB at 30°: a) S60, 5 min, b) S60, 15 min, at 90°, c) S60, 5 min, d) S60, 15 min

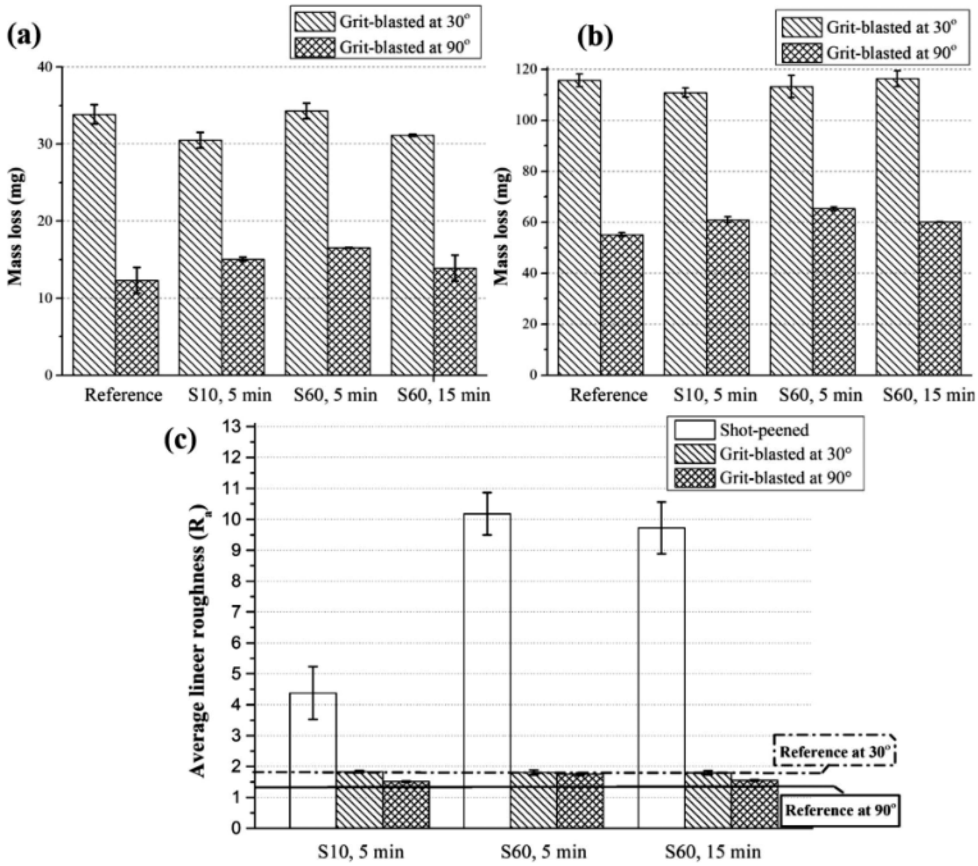

Figure 3: Mass loss of GB samples: a) 1.5 bar, b) 4 bar, c) R_a after GB at 1.5 bar

ferent parameters (top right-hand corner) where red regions are embedded alumina particles. The embedding of particles almost doubled at 90° compared to 30°, which could detrimentally affect the surface and the mechanical properties of the alloy such as biological response, wettability, and adhesion strength for coating applications.[2,8] The particles are slightly more prone to embed into the grit-blasted surfaces of the samples shot-peened for a longer durations.

The mass loss largely increased with the GB pressure and it nearly doubled in the samples grit-blasted at 30° compared to 90°, proving the high efficiency of the surface modification with GB at 30° (**Figures 3a** and **3b**). The micro-cutting and micro-ploughing were the dominant erosive wear mechanisms that occur at low impingement angles, and they caused a higher amount of material removal compared to that removed at normal angles, agreeing well with the variation in the mass loss depending on the impingement angle (**Figures 3a** and **3b**).[13] The initial R_a values for the samples shot-peened under different parameters were very different from each other, indicating the severity of the plastic deformation due to SP. The R_a values for the samples shot-peened under different parameters were in a range of 4–10 μm, and GB led to sharp decreases in the R_a (**Figure 3c**). The R_a of the samples shot-peened after GB was below 2 μm and was almost the same as for the grit-blasted reference samples. Both the reference and shot-peened samples grit-blasted at 30° had a higher Ra than that of the samples grit-blasted at 90°, which could be attributed to the variation in the wear and deformation mechanisms based on the particle impingement angle, as previously discussed.[13] The final R_a of the samples after GB was practically the same, showing that the subsurface and surface features modified with SP did not affect the GB performance.

4 CONCLUSIONS

GB changed the surface topography as the initially increased R_a induced by SP (approx. 10 μm) declined to approx. 2 μm. Micro-ploughing and micro-cutting wear mechanisms remodified the surface morphology of the alloy during GB at 30°, leading to a large mass loss and a decreased R_a. GB at 90° led to an embedding of particles (approx. 23 %). As the embedding of particles may deteriorate the surface and mechanical properties of the alloy, GB at 30° was more favourable than GB at 90° when tailoring the deteriorated surface properties of the shot-peened alloy. The study revealed that GB, used after SP, could modify the surface roughness of a shot-peened Ti6Al4V alloy, making it similar to that of a mirror-polished unpeened alloy, regardless of the surface- and subsurface-property (e.g., hardness and surface topography) changes due to SP. Thus, GB can provide a robust solution to tailoring a problematic surface roughness of shot-peened materials, which is of critical importance, particularly for the performance of implants and coating applications.

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