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Influences of Particle Impingement Angle and Velocity on Surface Roughness, Erosion Rate, and 3D Surface Morphology of Solid Particle Eroded Ti6Al4V Alloy

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In this study, it is aimed to investigate the effects of particle impingement angle and velocity on the surface roughness, erosion rate, and surface morphology of solid particle eroded Ti6Al4V alloy. Ti6Al4V samples were eroded in erosion test rig under various particle impingement angles (15°, 30°, 45°, 60°, 75° and 90°) and impingement velocities (33 m/s, 50 m/s, and 75 m/s) by using 120 mesh garnet erodent particles. Subsequently, erosion rates and surface roughness values of samples were analyzed and calculated as a function of particle impingement angle and velocity. Moreover, 3D surface morphologies of the eroded samples were prepared by using high definition scanner and image processing programs. Results show that erosion rates, surface roughness values and surface morphologies of Ti6Al4V alloy have been varied significantly depending on the both particle impingement angle and velocity. Erosion rates of Ti6Al4V alloy were decreased with increases in particle impingement angle; on the other hand, the surface roughness values were increased with increases in particle impingement angle. Both erosion rates and surface roughness values were increased with increases in particle impingement velocity. Finally, the surface morphologies of the eroded samples were evaluated deeply. It is concluded that the surface morphology variation of the Ti6Al4V alloy depending on the particle impingement angle and velocity were well correlated with the erosion rates and the surface roughness values.

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1. Introduction

Titanium alloys (specifically Ti6Al4V alloy) have been extensively used in aerospace applications due to their good mechanical, chemical and physical properties such as high strength to weight ratio, high toughness, low density, and high working temperature. Yet, they present relatively poor wear resistance owing to their poor tribological properties [1–5]. Titanium alloys used in aerospace applications (specifically turbine blades) exposed to sand/dust due to environmental conditions (especially dust/sand storms in deserts) are subjected to solid particle erosion.

Solid particle erosion is a process which occurs by progressive removal of material from the surfaces of the target material due to repeated impact of erodent particles [6–8]. It has been reported that solid particle erosion causes severe damages in various engineering applications [6–10]. Hence, many researchers have investigated the solid particle erosion behavior of various engineering materials for last decades [1–10]. The studies have specifically focused on aerospace applications due to vulnerability of aircraft structures working in dusty environments. It is understood that deterioration of the material properties due to solid particle erosion is inevitable, if the aircraft structures have to operate in dusty environments and exposed to the impact of the particles. Therefore, it is vitally important to examine solid particle erosion behavior of aircraft materials.

In this study, solid particle erosion behavior of Ti6Al4V alloy have been examined in detail by using various characterization methods. It is aimed to investigate the effects of the particle impingement angle and the velocity on the surface roughness, the erosion rate and the surface morphology of the solid particle eroded Ti6Al4V alloy.

2. Materials and methods

Ti6Al4V alloy used in this study was supplied by TIMET (Titanium & Medical & Mining Company, Turkey) in the form of 100×100 cm^2 sheets (thickness of 3 mm). The samples were cut to sheets of 40×40 mm^2 by using a guillotine shear. Chemical composition, mechanical and physical properties of the samples are given in Table I.

TABLE I

Chemical composition, mechanical and physical properties of Ti6Al4V samples.

Titanium alloy	Ti-6Al-4V
ASTM GRADE (UNS NO.)	Grade 5 (R56400)
Chemical composition (wt%) (max. values unless range is shown)	
0.08C; 0.25Fe; 0.05N; 0.20O; 5.50–6.75Al; 3.5–4.5V; 0.0150H	
Mechanical properties	
ultimate strength	896 MPa
yield strength	827 MPa
nominal hardness	33 HRC
Physical properties	
density	4.43 g/cm^3
melting point approximate	1650 °C

The erosion test rig used in this study and SEM photo of garnet particles used in this study are given in Fig. 1. Accelerated particles impacted the specimen, which can be hold at various impingement angles (15°–90°) by adjustable sample holder shown in Fig. 1. Solid particle erosion test parameters are given in Table II.

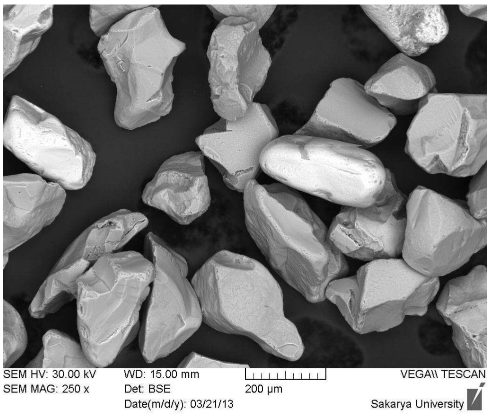

Fig. 1. SEM photo of erodent particles.

TABLE II

Test parameters.

erodent type	garnet
erodent size	120 mesh (90–125 μm)
particle impingement angle	15°, 30°, 45°, 60°, 75°, 90°
acceleration/blast gun pressure	1.5 bar, 3 bar, 4 bar
impingement particle velocity	33, 50, 75 ms^{-1}
test temperature	25 °C
nozzle diameter	5 mm
nozzle length	50 mm

The surface roughness of eroded Ti6Al4V samples were examined by using a optical surface profilometer (Bruker ContourGT InMotion) and influences of the solid particle erosion test parameters on the surface roughness of Ti6Al4V samples were evaluated. Finally, surface damages of the eroded samples were captured by using a common flatbed scanner (HP Scanjet G2710) and 3D surface topographies of the samples were created by using an image analysis software (Image J software).

3. Results and discussion

In Fig. 2, the erosion rates (Fig. 2a) and arithmetic surface roughness values (Fig. 2b) of the Ti6Al4V alloy depending on the particle impingement angle and velocity are given. In Fig. 2a, the erosion rates of the Ti6Al4V alloy are varied dramatically depending on the particle impingement angle and velocity. The maximum erosion rate is observed between 30° and 45° impingement angles at both velocities. Hence, it is concluded that Ti6Al4V alloy shows semi-ductile erosion behavior as mentioned in literature [9, 10]. On the other hand, the erosion rates of the samples are increased with increase in particle impingement velocity. In Fig. 2b surface roughness of the samples depending on the examined parameters are given. It can be seen that the surface roughness is significantly changed depending on the both particle impingement angle and velocity. It is clearly observed that surface roughness is increased with augmentation in particle impingement velocity. On the other hand, the surface roughness is increased up to impingement angle of 75°, however it is decreased at impingement angle of 90°. As a result, it can be said that the surface roughness of the Ti6Al4V alloy is generally increased with increases in particle impingement angle and velocity.

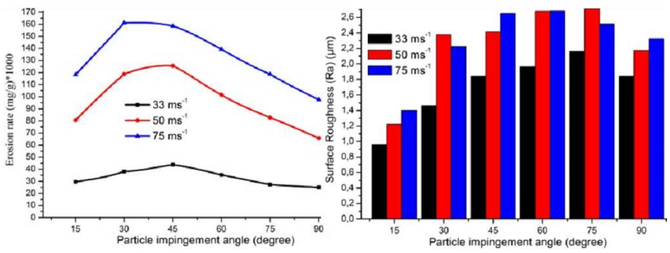

Fig. 2. The variation of erosion rates and arithmetic surface roughness values of Ti6Al4V alloy depending on particle impingement angle and velocity.

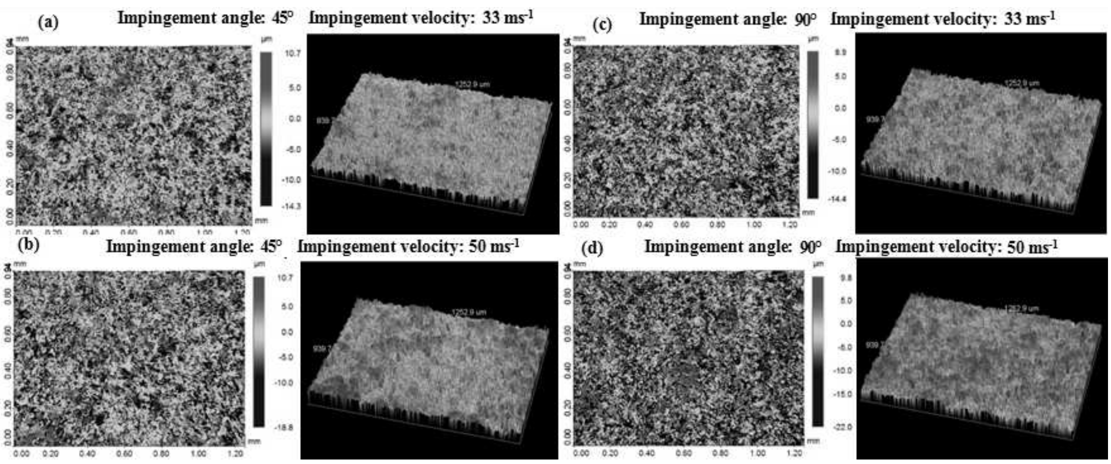

Fig. 3. Surface roughness maps and 3D surface morphologies of the samples.

In this present study, the surface roughness maps and 3D surface morphologies of eroded Ti6Al4V alloy are obtained by optical surface profilometer. In Fig. 3 the surface roughness maps and 3D surface morphologies of the samples depending on the particle impingement angle and velocity are given. It is evident from Fig. 3, that increasing impingement velocity enhances the surface roughness as the impingement angle was kept constant. Striking velocity of an abrasive particle to a semi-ductile surface like Ti6Al4V intensely affects surface roughness. Chipping off is the dominant mechanism in 45° impingement angle and increasing particle velocity caused a rougher surface due to the allocated chip formation (Fig. 3a and b). At normal incidence (90°), surface of the Ti6Al4V undergoes a plastic deformation caused by local high flux abrasive particles. Increasing the velocity of abrasive particles at 90° also increases the surface roughness (Fig. 3c and d). Impingement angle has a crucial effect on surface roughness. At 45° the intensity of striking particles per unit area is less when compared at normal incidence (90°). Hence, the higher surface roughness value occurred at 90°.

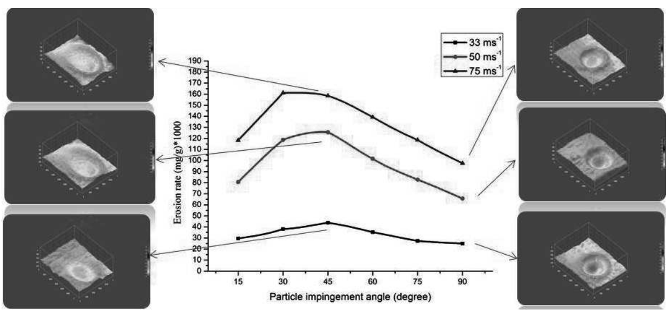

Fig. 4. 3D surface images of the samples depending on the particle impingement angle and velocity.

Macrovisualization of whole erosion crater is difficult by using conventional imaging methods such as optical surface profilometer. In order to visualize accurate macro surface damage of eroded Ti6Al4V samples, a capturing process by a common flatbed scanner is preferred and image processing is carried out by Image J program. In Fig. 4, a unified 3D surface topography macro visualization presented to illustrate the effects of impingement angle and velocity. At 45° impingement angle, erosion crater spread over the entire surface. Conversely, at 90° impingement angle the erosion crater is localized. Accordingly, a deeper erosion crater formed at 90°. Red color region at 90° impingement angle macro 3D surface images implies that the maximum roughness area arises from intensive repeated impacts of erodent particles.

4. Conclusions

In this study, particle impingement angle and velocity effects on the solid particle erosion behavior of Ti6Al4V alloy have been investigated by performing solid particle erosion tests, optical surface roughness measurements, and a novel 3D surface morphology analysis. The conclusions of the study are given below.

1. The erosion rates of the Ti6Al4V alloy increased with increases in particle impingement velocity. Ti6Al4V alloy showed semi-ductile erosion behavior and as a result maximum erosion rate was observed at 30° and 45° particle impingement angles.

2. The surfaces roughness of the samples was dramatically affected by both particle impingement angle and velocity. Surface roughness values, surface roughness maps and 3D surface roughness morphology results obtained by optical profiler showed that surfaces roughness of the samples was increased with augmentation in particle impingement angle and velocity.

3. The novel 3D surface topography analysis method presented in this study provides significant data about the eroded surfaces of the samples. The macro 3D surface morphology of the samples showed that both particle impingement angle and velocity have vitally affected the solid particle erosion behavior of Ti6Al4V alloy. The results obtained by presented method were well correlated with the results obtained by optical profiler. It was concluded that the ease of operation, low cost and specifically the efficiency of the macro surface display were major advantages of the presented method. Yet, more studies have to be carried out in order to use this novel method more accurately and precisely.

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