Laser parameter optimization and unidirectional sliding wear performance of surface textured Ti6Al4V alloy

A Karthikeyan, R Mithun Krishnan, M Prem Ananth*, S Ponnuvel and V Sridharan
Department of Mechanical Engineering, Sri Venkateswara College of Engineering, Chennai- 602 117, India

*Email: premananth@svce.ac.in

Abstract. In this research work, a study on the coefficient of friction observed in samples made from Ti6Al4V titanium alloy textured with different types of patterns was made. Analysis of Variance (ANOVA) based on design of experiments was done to understand the contribution of type of pattern, laser power and number of passes used for texturing in affecting the coefficient of friction. The analysis indicated that the samples textured with hatch pattern produced minimum coefficient of friction while grid pattern produced maximum coefficient of friction. Along with hatch pattern single pass and 5W power setting in the laser engraving machine produced the optimum condition. The interaction between the pattern type and number of passes also contributes for the variations in the coefficient of friction.

Keyword: Titanium Alloy, Texturing, coefficient of friction and Anova.

1. Introduction
The exceptional properties such as lesser modulus, higher corrosive resistance, superior biocompatibility and higher strength to weight ratio possessed by titanium alloys leads to its higher application in the field of human joint replacement, automobile and aerospace applications [1-2]. The wear resistances of titanium alloys are poor and poor wear resisting property limited its applications in sliding contact. Hence, a suitable attempt to improve the surface properties of titanium alloys is necessary [3]. The titanium alloy surface properties can be enhanced by creating dimples through laser texturing. The regularly patterned surface creates dimples which will perform as a reservoir and also capture the wear debris formed during sliding test [4]. Laboratory wear test analysis such as pin on disc is normally carried out to reproduce the practical applications and also to study the useful information on friction and wear characteristics [5]. Many researchers have undertaken statistical analysis of wear behavior of metals and reported the outcome based on it. The experiments were planned according of Design of Experiment. The wear experiments for aluminum-based metal matrix composites were designed based on L27 orthogonal array. The influence of reinforcement, load, sliding distance and sliding speed on wear were studied statistically and reported [6]. Analysis of Variance (ANOVA) was performed to understand the contribution of various input process parameters on wear of hybrid metal matrix composites. Statistical analysis was instrumental in analysing the role of various input parameters on output characteristic studied [7]. Baradeswaran et.al used orthogonal array using Minitab software to design their experiment and statistically analyzed and optimized the wear test parameters [8]. Sachit et.al reported that the applied load was the most contributing factor for wear on tantalum niobium reinforced composite based on their statistical analysis results [9]. Virkunwar et al used orthogonal array
design with three factors at three levels to conduct dry sliding wear test on AL6061 reinforced with rice husk ash particles. The input factor that contributed the most for wear was found out by conducting ANOVA. The statistical results were validated with confirmation experiment [10].

The paper presents the statistical analysis of coefficient of friction in various surface modified titanium alloy during wear tests under dry sliding condition. The experiments were carried out as per full factorial design and statistical analysis by performing ANOVA. The influence of individual design factor on the coefficient of friction and the most influential factor on the wear characteristic has been identified. From the data means curve the testing condition that gave most preferred output was found out. The interaction of various process parameters has also been discussed.

2. Experimental Procedure
Grade 5, Ti6Al4V was procured as a cylindrical rod and machined as a cylindrical pin of 8 mm diameter and 28 mm length. This pin is used as specimen in the pin on disc experiment and the experimental setup is shown in Figure 1. The rectangular patterns different shapes were designed by EZCAD software and engraved on top of the pin specimen by fiber laser marking machine. The following geometries were engraved on the pin specimen: circle, ellipse, hatch and grid. The laser parameters such as Wavelength: 1064 nm; Power: 5, 10 and 15W; Number of Pass: one, two and three; Pulse: 2 kHz; Speed: 200 rpm were used for texturing on the pin surfaces. The circular dimple diameter is 100 µm and its pitch is 160 µm. Major and minor axis length is 125 µm and 80 µm respectively for elliptical pattern machining. The dimple density range of is about 25-35%.

![Figure 1. Pin on Disc Tribometer experimental setup](image)

ASTM standard G99-04 was used for pin-on-disc testing procedures. The pin on disc tribometer consists of a rotating disk in contact with preloaded stationary cylindrical pin. Force sensor is provided to measure the frictional force during sliding and Linear variable differential transducer is also provided to measure the wear parameters continuously during sliding. Heat treated EN-31 with 63 HRC steel disc of thickness 8 mm and diameter 165 mm was used as a counter-body. The wear test was carried-out under 50 N normal load at 2 m/s velocity and the test duration is 30 minutes. The friction data was continuously monitored and recorded during the wear test and it is reported in Table 2.

The experiments were designed using full factorial design of experiments with three factors and multiple levels. The factors and levels are given in Table 1. A total of 36 experiments were conducted (Table2). Coefficient of friction was the output taken for further analysis.
### Table 1. Factors and Levels.

| Factors | Levels |
|---------|--------|
| Pattern | Circle | Ellipse | Hatch | Grid |
| Power (W) | 5 | 10 | 15 | - |
| Pass | 1 | 2 | 3 | - |

### Table 2. Experimental Details.

| Sl. No | Pattern | Power | Pass | Coefficient of friction |
|--------|---------|-------|------|-------------------------|
| 1      | Circle  | 5     | 1    | 0.549                   |
| 2      | Circle  | 5     | 2    | 0.574                   |
| 3      | Circle  | 5     | 3    | 0.592                   |
| 4      | Circle  | 10    | 1    | 0.550                   |
| 5      | Circle  | 10    | 2    | 0.550                   |
| 6      | Circle  | 10    | 3    | 0.664                   |
| 7      | Circle  | 15    | 1    | 0.627                   |
| 8      | Circle  | 15    | 2    | 0.666                   |
| 9      | Circle  | 15    | 3    | 0.588                   |
| 10     | Ellipse | 5     | 1    | 0.562                   |
| 11     | Ellipse | 5     | 2    | 0.695                   |
| 12     | Ellipse | 5     | 3    | 0.590                   |
| 13     | Ellipse | 10    | 1    | 0.620                   |
| 14     | Ellipse | 10    | 2    | 0.565                   |
| 15     | Ellipse | 10    | 3    | 0.603                   |
| 16     | Ellipse | 15    | 1    | 0.610                   |
| 17     | Ellipse | 15    | 2    | 0.573                   |
| 18     | Ellipse | 15    | 3    | 0.604                   |
| 19     | Hatch   | 5     | 1    | 0.564                   |
| 20     | Hatch   | 5     | 2    | 0.598                   |
| 21     | Hatch   | 5     | 3    | 0.575                   |
| 22     | Hatch   | 10    | 1    | 0.642                   |
| 23     | Hatch   | 10    | 2    | 0.562                   |
| 24     | Hatch   | 10    | 3    | 0.541                   |
| 25     | Hatch   | 15    | 1    | 0.564                   |
| 26     | Hatch   | 15    | 2    | 0.553                   |
| 27     | Hatch   | 15    | 3    | 0.538                   |
| 28     | Grid    | 5     | 1    | 0.458                   |
| 29     | Grid    | 5     | 2    | 0.697                   |
| 30     | Grid    | 5     | 3    | 0.647                   |
| 31     | Grid    | 10    | 1    | 0.686                   |
| 32     | Grid    | 10    | 2    | 0.639                   |
| 33     | Grid    | 10    | 3    | 0.623                   |
| 34     | Grid    | 15    | 1    | 0.690                   |
| 35     | Grid    | 15    | 2    | 0.689                   |
| 36     | Grid    | 15    | 3    | 0.645                   |
3. Results and Discussion
The frictional characteristics of different shape of the dimples are compared in Figure 2. The friction coefficient values shown in figure for different shape patterns tested at 50 N normal load and patterns are engraved at 5 W power with single pass. The higher value of friction coefficient is observed in grid pattern and large fluctuation in friction coefficient is observed for ellipse and circle pattern. The friction coefficient for hatch pattern is observed as steady, comparatively low and less fluctuating as in Figure 2. The average coefficient of friction values was calculated from the pin on disc experimental values for the specimens engraved with different powers and passes and it is shown in Table 2.

![Figure 2. Coefficient of Friction Vs Sliding Distance for the different dimple shapes](image1)

ANOVA was performed to understand the effect of input variables on the coefficient of friction. The details are Tabulated in Table.2. From the analysis of variance, it is observed that the type of pattern made in the specimens has a contribution of 21.96%. Interaction between power and pass found to be contributing for 26.11% of total variation.

![Figure 3. Main effect plot](image2)
From the main effect plot shown in Figure 3 and from the values in Table 3, the optimum combination for minimum coefficient of friction was found to be A3B1C1. This suggests that the coefficient of friction between the disc material and the specimen was at its minimum value when hatch pattern was used. Other optimum input conditions for laser engraving were observed to be 5W power and single pass. Also, from the Figure 3, it is clear that the grid pattern produces maximum coefficient of friction, hence is not recommended. From the interaction plot shown in Figure 4, it is observed that the range of variations in the coefficient of friction values with different patterns were minimum with single pass and 5W power setting in the laser engraving machine.

Table 3. ANOVA details.

| Source          | DF | SS          | MS    | Ftest | Ftable at 95% | P (%) |
|-----------------|----|-------------|-------|-------|---------------|-------|
| Pattern         | 3  | 0.023219    | 0.007740 | 3.31 | 3.49          | 21.96 |
| Power           | 2  | 0.002546    | 0.001273 | 0.54 | 3.89          | 2.41  |
| Pass            | 2  | 0.002435    | 0.001218 | 0.52 | 3.89          | 2.30  |
| Pattern*Power   | 6  | 0.013231    | 0.002205 | 0.94 | 3.00          | 12.52 |
| Pattern*Pass    | 6  | 0.008594    | 0.001432 | 0.61 | 3.00          | 8.13  |
| Power*Pass      | 4  | 0.027601    | 0.006900 | 2.95 | 3.26          | 26.11 |
| Residual Error  | 12 | 0.028085    | 0.002340 |      |               | 26.57 |
| Total           | 35 | 0.105711    |       |       |               | 100   |

4. Conclusions
In this study the following conclusions are derived.
1. The friction coefficient for hatch pattern is observed as steady, low and less fluctuating as compared with other patterns.
2. Pattern type has a contribution of 21.96%. Minimum coefficient of friction was observed with hatch pattern.
3. Single pass and 5W power setting in the laser engraving machine produced optimum engraving conditions.

4. Grid pattern produces maximum coefficient of friction, hence not recommended.

5. Interaction between pattern and pass was observed to be 26.11%.

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