Optimization of Laser Parameters and Dimple Geometry for the Improved Tribological Behaviour of Titanium Alloy

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Abstract. Titanium alloys finds wide applications in the field of aerospace and biomedical engineering due to its light weight and corrosive resistance. However, wear resistance of titanium alloys are not satisfactory in the applications demanding sliding contacts. Laser engraving is widely applied to improve the wear resistance of the Titanium alloy surfaces. In this research work wear study using pin on disc experimental setup was carried out using four different patterns on the surface of the titanium pins. Patterns are made using laser engraving machine. The studies were conducted with three different laser beam power and with three different laser beam passes. Further these design parameters were investigated by the analysis of variance to understand their significance in affecting the mass loss of the test specimen. It is observed that the influence of shape of the pattern is highly significant in the design space with a contribution of 71.19%. Laser power and the number of passes of the laser beam were observed to be insignificant. The interaction between shape of the pattern and power of the laser beam is also observed to be significant with a contribution of 11.55%. The R\textsuperscript{2} value of 92.65% indicates that the model is satisfactorily explain the total variations. From the main effect plot, the combination of hatch pattern, 5W power and single pass of laser beam was found to be the optimal condition for the preparation of test specimen that favour minimum mass loss in the designed space.

1. Introduction
The titanium and its alloys are found more in aerospace and human joint replacement applications. Its strength to weight ratio is high and has exceptional resistance to corrosion. The poor wear resistance of titanium alloys limited its sliding contact applications. Hence surface treatment of titanium alloys are necessary to improve its wear resistance [1-2]. The surface properties of the materials can be improved through surface texturing by creating the patterns with commonly created dimples. The texturing of surface provides dimples which will act as a lubricant reservoir and also entrap the wear debris [3-4]. Laboratory investigations such as pin on disc are generally carried out to replicate the practical applications and also to report useful information on wear and friction [5-6].

Plan of experiments and statistical analysis of wear characteristics on metal matrix composites has been performed by researchers. Patil et.al conducted sliding wear tests under dry conditions on aluminium based composites based on L27 orthogonal array. The wear characteristics studied were analysed statistically to find out the influence of reinforcement, load, sliding distance and sliding speed on wear [7]. Natrayan et.al. reported that the statistical analysis played a significant role in analysis the wear behavior and influence of various process parameters on it in hybrid metal matrix composites. Analysis of Variance (ANOVA) was carried out to understand the influence of various
process parameters on the output characteristics studied [8]. Baradeswaran et.al statistically analysed and optimized the wear test parameters for which orthogonal array under of experimental design was carried out using Minitab software [9]. Sachit et.al reported the influence of various process parameters on the wear behavior of tantalum niobium reinforced composite. The applied load was having more influence than other parameters [10]. Orthogonal array was designed with three factors at three levels to conduct dry sliding wear test on metal matrix composite and most critical factor was found out by conducting ANOVA. The statistical results were validated with confirmation experiment [11].

The paper deals with the dry sliding wear tests performed as per full factorial design and statistical analysis of the obtained experimental results. The results were analysed by performing ANOVA. The contribution of individual factor on the wear behavior and the most influential factor on the wear characteristics studied has been identified. The optimized wear test condition was found out using the date means curve. The interaction of various process parameters has also been discussed.

2. Experimental procedure
As received titanium alloy grade-5, Ti6Al4V was machined and polished as a cylindrical pin of diameter 8 mm and length 28 mm. The different shaped patterns were designed and engraved on the pin specimen by fiber laser marking machine. The preferred shapes engraved on the pin were circle, ellipse, hatch and grid. The following laser parameters were used for texturing on the titanium pins. Pulse: 2 kHz pulsating fiber laser beam; Wavelength: 1064 nm; Power: 5, 10 and 15W (25, 50 and 75 % of the total rated power of 20W); Speed: 200 rpm; Number of Pass: Single, Double and Triple. The circular dimple diameter is 100 µm and distance between two consecutive dimples is 60 µm. Major axis length of 125 µm and minor axis length of 80 µm was considered for elliptical dimple machining. The range of dimple density is about 25-35%.

The fiber laser engraving machine with 20 watts power was used to engrave the patterns on the cylindrical specimen and the photograph image of the machine is shown in figure 1 (a). The wear test was performed in the pin on disc tribometer. As per the standard of ASTM G99-04, pin-on-disc testing consists of a rotating disk in contact with a stationary cylindrical pin along with an applied normal load at the top as in figure 1(b). AISI 52100 bearing steel disc

![Figure 1. Experimental setup (a). Laser Marking System (b). Pin on Disc Tribometer.](image)
of diameter 165 mm and thickness 8 mm was used as a counter-body. The heat treated disc with 63 HRC was surface polished to a surface roughness of around 0.5 µm. The wear test was carried out at 2 m/s velocity with 30 N normal load for 30 minutes duration. The mass loss of the specimens was measured before and after the wear test and it is reported in Table 1.

| Sl. No | Pattern | Power | Pass | Mass loss/gain (g) |
|-------|---------|-------|------|-------------------|
| 1     | Circle  | 5     | 1    | 0.0002000        |
| 2     | Circle  | 5     | 2    | 0.0006000        |
| 3     | Circle  | 5     | 3    | 0.0012000        |
| 4     | Circle  | 10    | 1    | -0.0003000       |
| 5     | Circle  | 10    | 2    | 0.0013000        |
| 6     | Circle  | 10    | 3    | 0.0006000        |
| 7     | Circle  | 15    | 1    | 0.0006000        |
| 8     | Circle  | 15    | 2    | 0.0011000        |
| 9     | Circle  | 15    | 3    | 0.0006000        |
| 10    | Ellipse | 5     | 1    | 0.0003000        |
| 11    | Ellipse | 5     | 2    | -0.0001000       |
| 12    | Ellipse | 5     | 3    | -0.0001000       |
| 13    | Ellipse | 10    | 1    | 0.0012000        |
| 14    | Ellipse | 10    | 2    | 0.0008000        |
| 15    | Ellipse | 10    | 3    | 0.0007000        |
| 16    | Ellipse | 15    | 1    | 0.0007000        |
| 17    | Ellipse | 15    | 2    | 0.0007000        |
| 18    | Ellipse | 15    | 3    | 0.0017000        |
| 19    | Hatch   | 5     | 1    | -0.0004000       |
| 20    | Hatch   | 5     | 2    | 0.0001000        |
| 21    | Hatch   | 5     | 3    | -0.0001000       |
| 22    | Hatch   | 10    | 1    | -0.0005000       |
| 23    | Hatch   | 10    | 2    | -0.0008000       |
| 24    | Hatch   | 10    | 3    | -0.0008000       |
| 25    | Hatch   | 15    | 1    | -0.0009000       |
| 26    | Hatch   | 15    | 2    | -0.0005000       |
| 27    | Hatch   | 15    | 3    | -0.0018000       |
| 28    | Grid    | 5     | 1    | -0.0013000       |
| 29    | Grid    | 5     | 2    | -0.0020000       |
| 30    | Grid    | 5     | 3    | -0.0043000       |
| 31    | Grid    | 10    | 1    | -0.0035000       |
| 32    | Grid    | 10    | 2    | -0.0024000       |
| 33    | Grid    | 10    | 3    | -0.0045000       |
| 34    | Grid    | 15    | 1    | -0.0009000       |
| 35    | Grid    | 15    | 2    | -0.0017000       |
| 36    | Grid    | 15    | 3    | -0.0009000       |

Full factorial based design of experiments was done with three factors and multiple levels. A total of 36 experiments were conducted. Mass loss in the specimen after the wear test was the output characteristic studied. The factors and levels are given in Table 2.
Table 2. Factors and Levels.

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

3. Results and discussions

ANOVA was performed to understand the effect of input variables in the mass loss in the specimens. The details are tabulated in Table 3. From the analysis of variance, it is observed that the type of pattern made in the specimen has significant effect in the mass loss of the test specimen with a contributing of 71.19%. Interaction between pattern and power found to be affecting the mass loss with a contribution of 11.54%. Other factors are found to be insignificant.

![Figure 2. Main effect plot.](image)

From the main effect plot figure 2, the optimum combination for minimum mass loss was found to be C3B1A1. This suggests that hatch pattern withstands the friction generated with minimum mass loss. Also, input conditions for laser engraving can be fixed at 5W with single pass. Grid pattern is observed to produce maximum mass loss, which suggests maximum friction between the specimen and the disc. Hence grid pattern is not recommended. The same results can be observed from the interaction plot in figure 3.

Table 3. ANOVA details.

| Source          | DF  | SS         | MS       | F-test | F-table at 95% a | P (%) |
|-----------------|-----|------------|----------|--------|------------------|-------|
| Pattern         | 3   | 0.0000561  | 0.0000187| 38.75  | 3.49             | 71.19 |
| Power           | 2   | 0.0000021  | 0.0000010| 2.13   | 3.89             | 2.66  |
| Pass            | 2   | 0.0000010  | 0.0000005| 1.01   | 3.89             | 1.26  |
| Pattern*Power   | 6   | 0.0000091  | 0.0000015| 3.16   | 3.00             | 11.54 |
| Pattern*Pass    | 6   | 0.0000039  | 0.0000007| 1.36   | 3.00             | 4.94  |
| Power*Pass      | 4   | 0.0000008  | 0.0000002| 0.41   | 3.26             | 7.36  |
| Residual Error  | 12  | 0.0000058  | 0.0000005|        |                  | 100   |
| Total           | 35  | 0.0000788  |          |        |                  |       |
$R^2$ values was observed to be 92.64, which suggest that the designed ANOVA model explains the variations satisfactorily.

4. Conclusion

In this study the following conclusions are derived.

- Pattern type has significant effect on the mass loss in the specimens with a contribution of 71.19%. Minimum mass loss was observed with hatch pattern that are engraved at 5W and single pass machine setting of laser engraving machine.
- Grid pattern produces maximum mass loss, hence not recommended.
- Interaction between pattern and power is also observed to be significant with a contribution of 11.54%.

5. References

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