Influence of Dimple Geometry on Coating Performance Under Uni-Directional Sliding

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Abstract. The 316L stainless steel as very low carbon content than 316 steel alloys and 316L is material generally used for medical implant purpose and other industrial applications because of its excellent corrosion properties. The only disadvantage with 316L is it has poor wear resistance. By surface texturing the tribological properties can be improved. DLC (Diamond Like Carbon) Coating were made over the surface texturing. DLC Coating is a nano-composite coating which has unique properties of natural diamond low friction, high hardness, and also high corrosion resistance. Various dimple structures were made on the pin to study about its performance and the ideal dimple structure is selected by using pin on disc experiment. D2 Steel disc is taken as the counter-part for this experiment.

1. Introduction
Grade 316 as carbon content in the range 0.03% to 0.08% and Grade 316 is a general molybdenum-bearing grade which is second in importance to 304 amongst the austenitic stainless steels and the molybdenum gives 316 better overall corrosion resistant properties than Grade 304, specific higher resistance to pitting and crevice corrosion in chloride environments. Grade 316L Stainless Steel offers higher creep, stress to rupture and tensile strength at elevated temperatures. Typical Applications of stainless steel 316L includes Food preparation equipment particularly in chloride environments, Pharmaceuticals, Marine applications, Architectural applications, Medical implants, including pins, screws and orthopedic implants like total hip and knee replacements, fasteners.

2. Fabrication of pin
316L Stainless Steel Rod with 540mm length and 8mm diameter is cut into 45mm length using lathe machine, so that 12 number of pin pieces is available for experimental work. 316L Stainless Steel Rod of length 45mm of diameter 8mm is step turned to diameter 4mm of length 5mm from any one side of the job as shown in Figure 1. The surface of 4mm diameter is mirror finished for surface texturing as shown in Figure 2.
3. Fabrication of disc
D2 steel is an flexible high-carbon (1.40% to 1.60%), air hardening tool steel and also it has high chromium (11.0% to 13.0%) content with high wear and abrasion resistant properties. It is also heat treatable and offers a hardness in the range of 55-62 HRC, and D2 steel is machinable in the annealed condition. D2 steel shows little deformity on correct hardening and due to its high chromium content it has mild corrosion resisting properties in the hardened condition. D2 steel rod is machined to 55mm diameter and 10mm thickness to form as disc and the machined disc is hardened at a temperature range of 900-1000°C as shown in Figure3. The hardness gets increased from 20 HRC to 60 HRC after the heat treatment. Both sides of the surface of disc is made smooth by surface grinding as shown in Figure4.

4. Surface texturing
Surface Texturing of Circular dimple, Horizontal Ellipse (major axis in horizontal direction), Vertical Ellipse (major axis in vertical direction) and Inclined Ellipse (major axis at 45º to x-axis) were made over the mirror finished surface over the pin. The laser surface texturing was effectuated on the stainless steel 316L pin (test specimen) with a Nd:YAG laser beam[1] and the dimple depth is of 2.5micron. Dimples will lower the coefficient of friction[2]. The dimensions of various shapes of surface texturing are shown in Figure 5 and Figure 6.
The SEM (Scanning Electron Microscope) were taken on the surface textured area on the pin [3]. The dimples made on the pin were clearly visible as shown in Figure 7 and Figure 8.

5. DLC coating
Diamond-like carbon (DLC) is amorphous carbon material which shows some properties of diamond and the characteristics of DLC are excellent abrasion and corrosion protection, low friction coefficient and excellent protection against cold welding. DLC coating finds its application in aerospace (aerospace fasteners and components), medical instruments, cutting and plastic injection moulding tools. It has an outstanding gliding property [4]. DLC coating were applied over the surface textured area of 4 micron thickness through PVD method (Physical Vapor Deposition) [5, 6] as shown in Figure 9.
6. Micro hardness
The Vickers test can be used for all metals and has one of the widest scales among hardness tests since the required calculations are independent of the size of the specimen. Vickers Pyramid Number (HV) or Diamond Pyramid Hardness (DPH) is the unit of hardness. The micro hardness for 316L SS is 272.5HV and for DLC coating is 343.9HV, where HV indicates hardness scale (Vickers).

7. Experimental setup pin on disc
The Pin on Disc is to determine the wear of the material during sliding[7]. Here 316L SS serves as pin, and the D2 steel acts as disc. The experiment is conducted with three different loads 10N, 20N, 30N as shown in Figure 10, 11 and 12 on four different surface texture DLC coated pin. The Pin on disc experiment has sliding distance of 2000m with a velocity of 2m/s. The coefficient of friction for each surface textured pin with DLC coating is determined and compared.

![Figure 9. DLC coated pin](image1)

![Figure 10. Coefficient of friction vs sliding distance for load 10N](image2)
In the Figure 10, graph has been made between COF versus Sliding Distance for the load of 10N. It can be observed that at lower normal load, the COF drops from an initial high value to very low value. It is clear that coulomb friction law is no longer valid when self-lubrication occurs[8].

![Figure 10](image1)

**Figure 10.** COF vs Sliding Distance for load 10N

In the Figure 11, graph has been made between COF versus Sliding Distance for the load of 20N. The COF increases up to a maximum value & then decreases before the end of the test. This behaviour is probably due to the formation of a tribo-film which builds up during sliding & reaches maximum effectiveness in decreasing COF after a given sliding distance[9].

![Figure 11](image2)

**Figure 11.** Coefficient of friction vs sliding distance for load 20N

In the Figure 12, graph has been made between COF versus Sliding Distance for the load of 30N. The DLC coated samples attain the lowest value of COF under most applied loads. This is probable due to the high hardness (H) of the coating which is effective in supporting the low shear strength graphitised tribo-film. At higher normal loads the COF starts to oscillate and this oscillation in the COF with sliding distance could be because of stick slip phenomenon.

![Figure 12](image3)

**Figure 12.** Coefficient of friction vs sliding distance for load 30N
8. Average coefficient of friction
The Average coefficient of friction for the above graphs for various loads and various dimples shapes has been made. It clearly defines the coefficient of friction for various DLC coated surface texturing.

![Figure 13. Average COF for load 10N](image)

![Figure 14. Average COF for load 20N](image)
9. Specific wear rate

The specific wear rate can be calculated from the formula:

\[
\text{Specific wear rate} = \frac{(\text{Initial mass} - \text{Final mass})}{(\rho F x L)}
\]

Where \( \rho \) = density of the pin g/mm\(^3\), \( F \) = Normal Load N, \( L \) = Sliding distance m.

Unit of Specific wear rate is mm\(^3\)/Nm.

The Specific wear rates for various DLC coated dimples were compared for corresponding loads. The specific wear rate for various dimples have been compared and analysed.

In the Figure 16, the graph for wear rate for various shape dimples for the corresponding load has been made & compared. The horizontal ellipse dimples have lesser specific wear rate compared to other dimples. This is probably due to the higher temperature & duration. The reason is that ellipse major
axis is perpendicular to sliding condition results in a greater converging wedge & also possesses optimum load carrying capacity [11].

10. Results and discussion

- Experimental investigation of DLC coated with various surface textured shapes were analysed using pin on disc apparatus with loading conditions of 10N, 20N and 30N with sliding speed of 2m/s and sliding distance of 2000m.
- The average coefficient of friction for various surface textured DLC coated pin were analysed.
- For 20N horizontal ellipse surface texturing has better coefficient of friction compared to other surface texturing.
- For 30N inclined ellipse surface texturing has better coefficient of friction compared to other surface texturing.
- The wear rate has been calculated and has been analysed for various surface texturing.
- The horizontal ellipse surface texturing has lower wear rate compared to other surface texturing.

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