Evaluation of Commercial Oleophobic Coatings for Aerospace Applications in Harsh Environments

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Analytical approach to determine the coefficient of friction at nano-level through lateral or friction force microscopy

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***Abstract*—This paper investigates the coefficient of friction at nano-levels of commercially available oleophobic coatings when applied over Inconel 718, which has widespread applications in the aerospace industry. The coatings were investigated in simulated sand-storm conditions, using uni-directional controlled sand blasting. The particle size and speed of collision during the sand-blasting procedure was carefully selected to simulate sand-storm conditions. The value for nano level coefficient of friction has been determined using lateral or friction force microscopy (LFM/FFM). The analysis has been used to formulate a value of friction coefficient which in turn is associative of the amount of wear the coating can bear before the exposure of the base substrate to the harsh environment. The analysis aims to validate the coefficient of friction value as marketed by the coating manufacturers and more importantly test the coating in real-life aerospace applications to justify its use.**

***IndexTerms*—Inconel 718, Oleophobic coating, LFM, FFM, aerospace**

INTRODUCTION

Since the introduction of the Lateral Force Microscopy (LFM) to evaluate tribology of amorphous carbon layers [1], the technology has been widely adapted for the study of frictional effects ranging from micro scale to nano scale. At these scales, the performance and operating lives of the micro/nanotribological devices is reduced due to high surface forces, such as adhesion and friction [3]. LFM is considered as the most effective and informative technology for adhesive and frictional phenomenon. Friction and wear rate are fundamental characteristics of a machine with relative motion. LFM has played an important role in investigating co efficient of friction and wear rate for different materials at nano scale [3 - 6]. Surface roughness has also been a subject of study using AFM techniques [7 - 9] because irrespective of the material, the co-efficient of friction can be altered by modifying its surface roughness [7]. AFM is considered to be the nano-scale version of a profilometer for imaging of surfaces [2]

Coating is a form of surface modification where one material is deposited on the other to improve properties such as hardness, roughness and wear resistance [10]. Amorphous carbon [9] and TiN coating [10] on various materials, to observe their tribological and corrosive properties and to validate surface roughness, have been studied recently. Metal coatings can be hydrophobic ‘water repellent’, hydrophilic ‘water loving’ and similarly oleophobic and oleophilic. Inconel 718 is a common aeronautical material which is classified as a difficult-to-machine material [12]. It is a high strength, corrosion resistant, nickel-chromium alloy. Inconel 718 has mostly been studied when cut with tools coated with carbide. High speed machining and excessive coolant are used while machining Inconel 718 due to its incredible strength therefore the need to coat it to make it suitable for machining.

The word oleophobic means ‘fear of oil’. Water is considered as the most oleophobic substance. A metal can be coated by different methods such as Dip coating, Spraying, electrochemical deposition etc. Oleophobic surfaces are of great interest for anti-fouling, self-cleaning, low drag and oil-water separation applications. There is a wide variety of such coatings available for composites and metals and the research for the same still continues with the development of superoleophobic and superhydrohobic coatings [14].

Despite its widespread usage little work has been done to confirm the efficacy properties and consequently the co efficient of friction at nano-level of commercially available oleophobic coating when applied over Inconel 718. The value for nano level coefficient of friction will be determined using lateral force microscopy (LFM) which will help in enhancement of surface properties and material life prediction. The analysis aims to validate the co efficient of friction value as marketed by the coating manufacturers.

EQUIPMENT

The equipment used for finding out a value for the coefficient of friction is ezAFM by Nanomagnetics Instruments as shown in Fig.1. ezAFM was used in Friction Force Microscopy (FFM) mode in this investigation. FFM was used with, FN, FL and FT channels enabled.PPP-LMFR probes by Nanosensors were used for FFM.

Fig. 1. ezAFM by Nanomagnetics Instruments in DHA Suffa University.

TABLE I
SUMMARY OF SAMPLES FOR EXPERIMENT

Type of Coating	No. of Samples
No Coating	02
Enduroshield Stainless Steel Coating	02
Dupont Non-Stick Dry Film Lubricant Coating	02
Rust-OleumNeverWet Multi-Surface Liquid Repelling Treatment	02

III. EXPERIMENTAL METHODOLOGY

Eight (08) samples each measuring 12 mm in diameter and 5 mm in height were obtained from cold drawn rods of Inconel 718, cut using a 250 mm diameter abrasive disc mounted on Labotom-5 as shown in Fig. 2. The samples were then grinded from one flat side of the cylinder using emery papers of grit size 320, 400 and 800 as per the instructions provided by the coating manufacturer. After grinding, the samples were observed under AFM in FFM mode to derive a value for the coefficient of friction. The samples were then coated with 03 different commercial oleophobic coatings as described in Table.1. Coated samples were left to cure overnight for effective adhesion with base substrate.

Scanning was accomplished on a 5µm x 5µm area at 64 pixels resolution. Since we're using AFM to derive the co efficient of friction value, uniformity of the entire surface is not an important factor and we can easily scan it at multiple locations to gather useful information. This procedure was kept constant for all the samples.

To simulate sand storm conditions, dry sand particles were bombarded on the substrate using an air blower. A diffuser was used to regulate the particle speed to about 26 m/s. A prototype chamber is fabricated, schematics of which are shown in Fig.3. Sand particles measuring around 90 - 180 micron in size were bombarded gradually onto the coated Inconel 718 samples at 90 degree. The time for each bombardment was 40 seconds. The samples were then analyzed under the AFM in FFM mode.

Fig. 2. Cut sample of Inconel 718 obtained byabrasive cutting with water as coolant in Labotom-5.

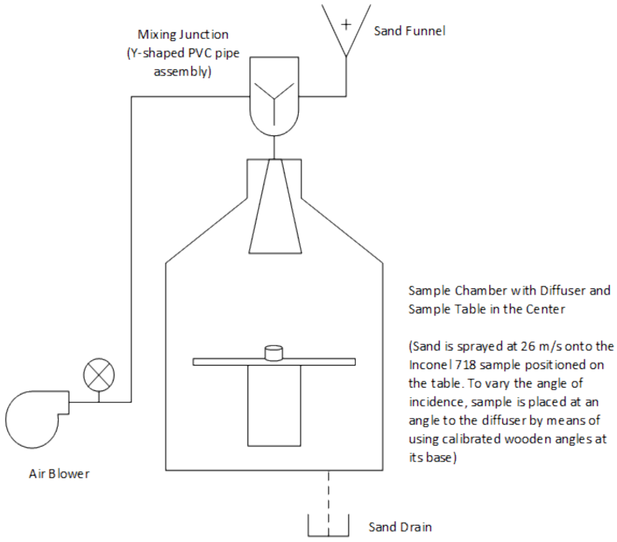

Fig. 3. Schematics of the Sand-Storm Chamber. Air from the blower and sand from the sand funnel are mixed inside the Y-shaped PVC pipe assembly and are bombarded through a diffuser onto the Inconel 718 sample. Diffuser reduces the particle speed considerably to achieve realistic sand storm impact conditions.

IV. RESULTS AND DISCUSSION

The samples were observed after coating and sanding under FFM to obstain the images in Fig. 4.Further, the following Table.2 summarizes the values of the coefficient of friction before and after sanding in each case.

TABLE II
SUMMARY OF VALUES OF COEFFICIENT OF FRICTION

Type of Coating	Coefficient of Friction	
	Before Sanding	***After Sanding***
No Coating	0.156	0.227
Enduroshield Stainless Steel Coating	0.161	0.209
Dupont Non-Stick Dry Film Lubricant Coating	0.145	0.250
Rust-OleumNeverWet Multi-Surface Liquid Repelling Treatment	0.151	0.222

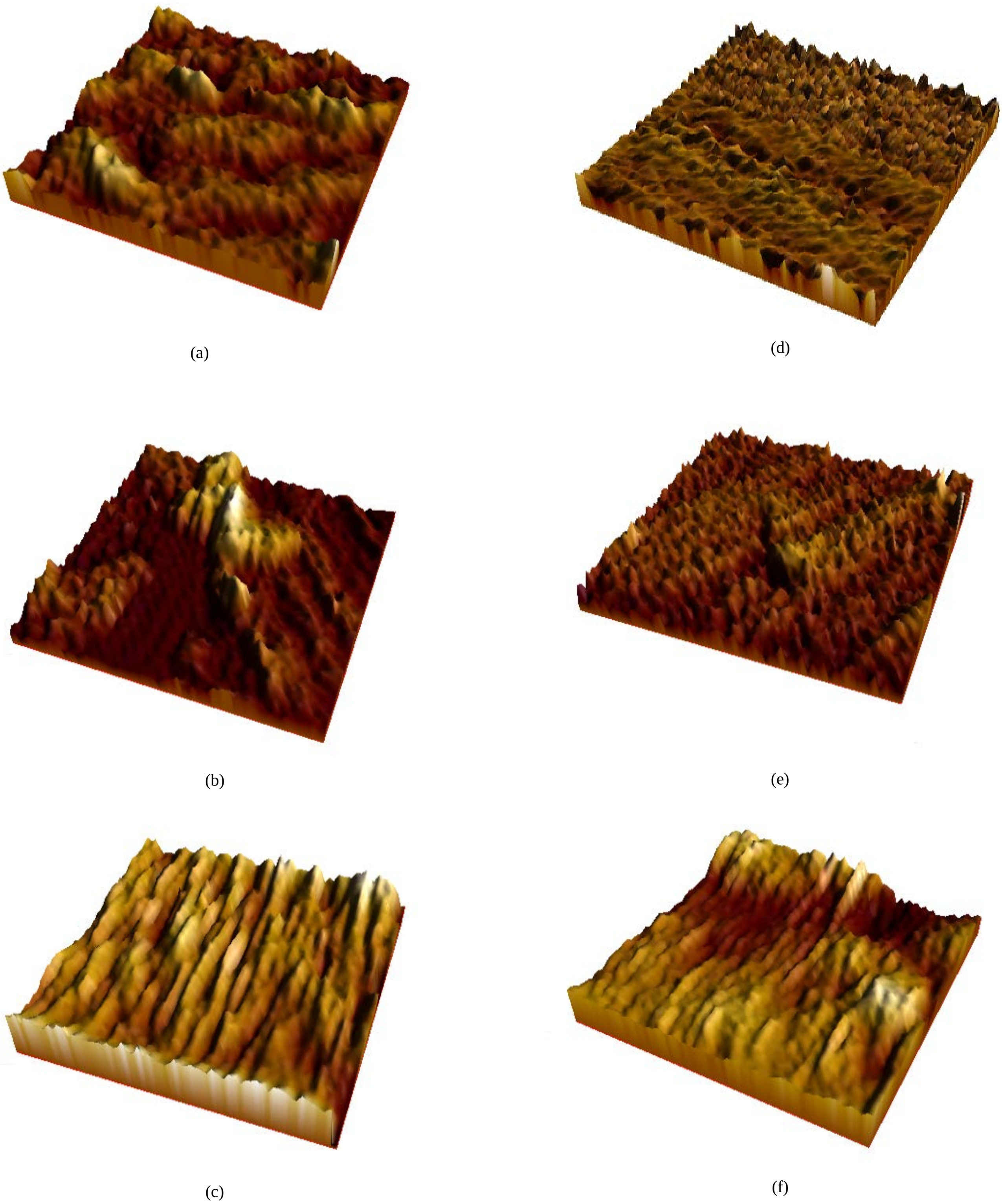

Fig. 4. Surface Imaging in FFM mode where a) Dupont Non-Stick Dry Film Lubricant Coating before sanding, b) Enduroshield Stainless Steel Coating before sanding, c) Rust-Oleum NeverWet Multi-Surface Liquid Repelling Treatment before sanding, d) Dupont Non-Stick Dry Film Lubricant Coating after sanding, e) Enduroshield Stainless Steel Coating after sanding, and f) Rust-Oleum NeverWet Multi-Surface Liquid Repelling Treatment after sanding are shown.

The results show a characterisitic difference in the values of the coefficient of friction. The most significant being in the Dupoint Non-Stick Dry Film Lubricant of about 0.105. The least significant difference is in the Enduroshield Stainless Steel Coating of about 0.048. Also, Enduroshield Stainless Steel treatment had a clear mirror-like physical appearence.

Fig. 5 gives a comparison of coefficient of friction before and after sanding for all the conditions. It is evident that the coefficient of friction changes drastically when the samples are exposed to sand.

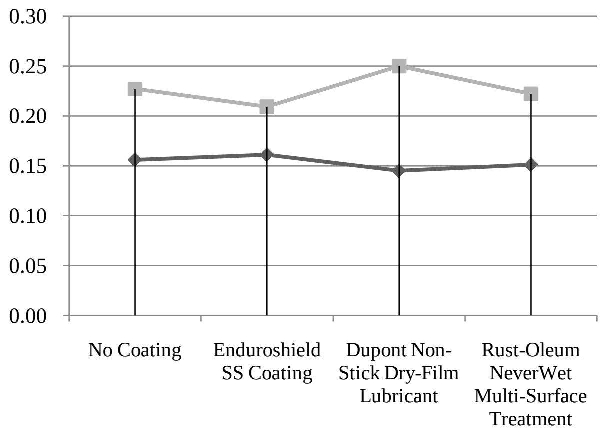

Fig. 5. The graphs shows the significant change in coefficient of friction value for Dupont Non-Stick Dry-Film Lubricant coating. Enduroshield Stainless Steel Coating shows the smallest change.

The lateral and normal forces at each of the 64 points was obtained using 'Contact mode' analysis. The ratio of the forces data obtained is related by the Amonton's Friction Law,

$$\mu = \frac{F_L}{F_N} \quad (1)$$

where μ is the coefficient of friction, $F_L$is the lateral friction and $F_N$is the normal loading force.

V. CONCLUSION

From the graphs and values obtained for the samples of Inconel 718 coated with oleophobic coatings and observed under AFM before and after sanding, it can be concluded that:

- The coefficient of friction was found to be lowest for Enduroshield Stainless Steel Coating, which has a clear mirror-like physical appearance. Therefore, physical appearance may be a significant factor to quickly compare the coating's viability of usage.
- The friction coefficient increases when exposed to sand.
- The maximum difference in friction coefficient is for DupontNon stick Dry Film Lubricant.

VI. FUTURE WORK

In the next phase of experiments we'll check for the effect of coating's thickness on the coefficient of friction. The coating's thickness would be moderated by applying multiple coats and verifying it under Scanning Electron Microscope (SEM) to ensure uniformity. Further, these coatings would be analyzed for other harsh conditions for justifying its use in Pakistan.

Another significant parameter for consideration is the surface roughness. A detailed study is in progress on the roughness of these coatings for aerospace usage.

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