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Research Article

Tribological behavior of polydopamine/polytetrafluoroethylene coating on laser textured stainless steel with Hilbert curves

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Abstract: Shallow Hilbert curve patterns with easily programmable texture density were selected for laser texturing of stainless steel substrates. Two different texture path segment lengths (12 and 24 μm) and four different laser power percentages (5%, 10%, 15%, and 20%) were investigated. The textured and smooth substrates were coated with thin polydopamine/polytetrafluoroethylene (PDA/PTFE) coatings for tribological property assessment. The effects of texture density (texture area coverage) and laser power on the durability and friction of the coated surfaces were studied. Laser texturing the substrates improved the coating durability up to 25 times, reduced the friction coefficient, and prevented coating global delamination. The textures fabricated with a laser power of 15% and a texture path segment length of 12 μm yielded the best coating durability. The textures provided the interlocking for the PTFE coating and thus prevented its global delamination. Furthermore, the PTFE inside the texture grooves replenished the solid lubricant worn away in the wear track and prolonged the coating wear life.

Keywords: polytetrafluoroethylene (PTFE); coating; durability; laser texturing; Hilbert curve; stainless steel

1 Introduction

Controlling the coefficient of friction (COF) between two rubbing surfaces is of great importance in achieving an efficient mechanical movement [1]. Solid lubricant coatings reduce the COF between two surfaces while still supporting the applied load. One such example is polytetrafluoroethylene (PTFE). PTFE is a useful solid lubricant because it is chemically inert, has high-temperature resistance, and has low maintenance costs [2]. PTFE coatings have a wide range of applications for minimizing COF in mechanical parts. However, pristine PTFE coatings have low wear resistance and low load-bearing performance because of their poor adhesion to the working surfaces. This fact limits applications where thin PTFE coatings can be applied [3].

Several studies have enhanced the wear behavior of thin PTFE coatings [4–6]. Using an adhesive polydopamine (PDA) underlayer that bonds to both substrate and PTFE coatings is an excellent approach that resulted in improving the wear resistance of thin PTFE coating 500 times without affecting its COF [4]. Since the PDA layer is very thin and could attach to all types of material surfaces [7, 8], it could be added as an adhesive underlayer to boost the durability of thin PTFE films without significantly increasing the total film thickness [4].

Surface texturing is another approach for improving the wear resistance under dry sliding contact [9–13]. Studies showed that applying MoS_2 and graphite coatings on microtextured surfaces of steel [14, 15], TiN [16], and TiCN [17] improved the durability of the coatings even for demanding tribological applications. A few studies also reported the combined effect of laser surface texturing and PTFE coating for improving

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tribological performance. Wang et al. [18] laser-drilled micro-hole array into laser-clad Fe-based alloy coatings on carbon steel and then deposited MoS_2-PTFE powders by electrophoretic deposition. They showed that the combination of 20% micro hole density with MoS_2-10 wt% PTFE powders resulted in the lowest COF. Fan et al. [19] investigated the effect of textured spray-coated PTFE on the micro-dimple-textured Al_2O_3/Ni layered ceramic substrate. They observed 5 times improvement in the durability of textured PTFE coating on the textured substrate compared to smooth PTFE on the untextured substrate. Lu et al. [20] coated PTFE by vacuum impregnation on smooth and laser textured plasma electrolytic oxidization (PEO) treated 2024 aluminum alloy. They examined the tribological behavior of the samples and observed significantly improved durability due to the surface textures. The textures provided reservoirs for PTFE to compensate for the PTFE inside the wear track.

The aforementioned studies only investigated PTFE coatings with a thickness of more than 20 μm and texture depths of more than 50 μm [18–20]. Deep textures may significantly weaken the mechanical properties of the substrate and will not benefit thin coatings since the coating could not be replenished from the deep valleys of the textures. Also, these studies only investigated the effect of circular dimples that were as large as 50 μm in diameter [18–20]. There is no previous study that combined laser texturing stainless steel substrates with PDA/PTFE coatings. We hypothesize that fabricating laser textures on stainless steel substrates with a shallow Hilbert curve pattern could improve the durability of thin PDA/PTFE coatings. A Hilbert curve is a bidirectional type of space-filling curve that can be defined by its path segment length (Fig. 1). The texture density can be easily adjusted by changing the path segment length within an arbitrary texture area and the bidirectional nature of the curve could minimize the direction sensitivity of the tribological performance. The curve consists of one continuous line, which allows a laser to continuously cut the curve without turning on and off the laser between line segments, which may lead to inconsistency in the cut pattern at the beginning and end of the line segments. This texture pattern has not been studied for tribological performance before. In the current work, the effects of the laser texture density (texture area coverage) and laser power (LP) were studied to evaluate the effect of shallow Hilbert curve textures on the friction and wear of thin PDA/PTFE coatings.

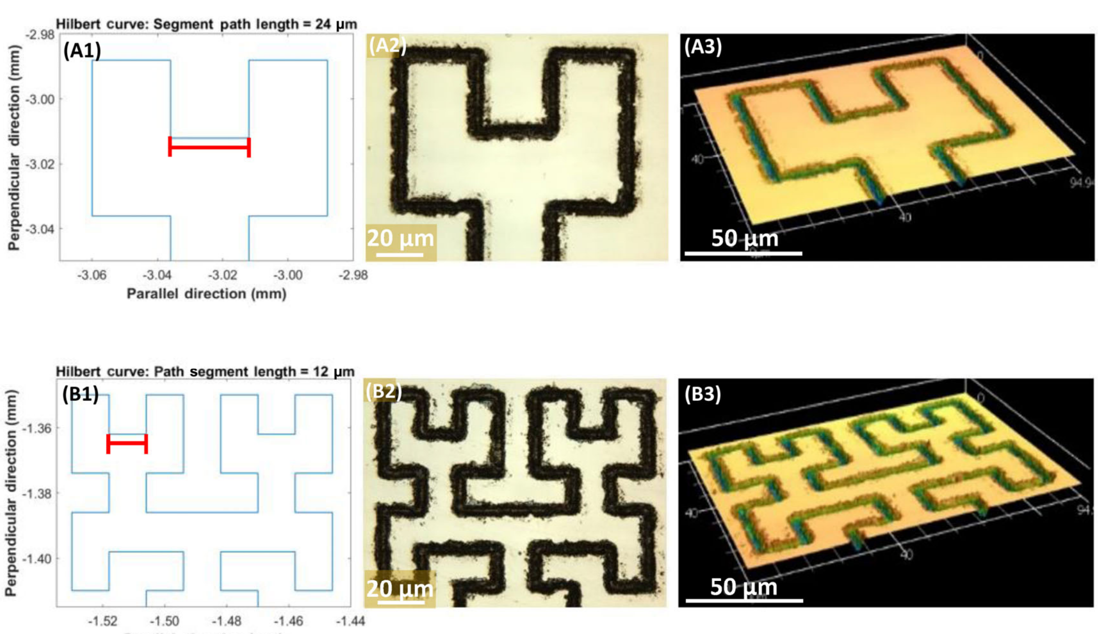

Fig. 1 Line plots from the mathematical models of Hilbert curves and the top-down and 3D oblique-angle views of the optical images of laser textured Hilbert curves on polished stainless steel surfaces with two texture path segment lengths of (A) 24 μm and (B) 12 μm. Red lines in (A1) and (B1) represented the texture path segment length.

2 Experimental methods

2.1 Sample fabrication

316 stainless steel substrates (McMaster-Carr) were chosen as the substrate for laser texturing and coating deposition because it is a material commonly used in ball bearings. Square-shaped substrates (25.4 mm × 25.4 mm) of 2.5 mm thickness were polished with sandpaper grit 320 (Buehler, IL, USA), 6 μm polycrystalline diamond suspension (Buehler, IL, USA), and 0.06 μm amorphous colloidal silica suspension (Buehler, IL, USA) for 3, 12, and 15 min, respectively, to obtain a mirror-finished surface. Then samples were rinsed with water and wiped with acetone.

An A-series femtosecond laser micromachining system (32-Oxford Laser A5 Femtosecond, Oxford Lasers Ltd., UK) was used to texture Hilbert curve patterns on the polished stainless steel substrates. The laser is a diode-pulsed solid-state femtosecond laser (Carbide CB1-05, Light Conversion, Inc.) with a wavelength of 515 nm, a pulse length of 290 fs, and the maximum average laser power of > 5 W at 60 kHz per wavelength. A custom MATLAB script was used to generate the Hilbert curve patterns and export the curve path as G-code for the femtosecond laser system to execute. The laser power (LP) and laser texture density (the ratio of textured area to the total area of the substrate) were varied. Four laser powers of 5%, 10%, 15%, and 20% of the measured maximum laser power of 2.6 W were applied with a laser frequency of 600 Hz and an R.A. divider of 1,200. These laser parameters were chosen because they allow the generation of shallow grooves with less laser debris. Also, they provide the desired textured area density, making it easy for coating thin PDA/PTFE films inside the texture grooves. The path segment lengths of the Hilbert curves were set to 12 and 24 μm, respectively, for achieving different laser texture densities. Samples were labeled as P(X, Y), where X is the texture path segment length in μm, and Y is the laser power in the percentage of 2.6 W.

Next, smooth and laser textured stainless steel substrates were cleaned by washing sequentially in deionized (DI) water with detergent, then in acetone, followed by in isopropanol in a sonication bath, each with a duration of 20 min. PDA/PTFE coatings were then deposited on the clean substrate according to our published research [4]. Briefly, 0.04 g of dopamine hydrochloride (DA, Sigma Aldrich) was dissolved into 25 mL of DI water, and 0.025 g of tris (hydroxymethyl) aminomethane (T1503, Sigma Aldrich) was added to it to obtain a pH of 8.5. Smooth and laser textured stainless steel substrates were placed in the above solution in a rocking bath to deposit PDA adhesive underlayer with 25 rpm rocking rate and 7° rocking angle at 60 °C for 45 min. The stainless steel substrates were then dip-coated with an aqueous PTFE dispersion (Teflon Dispersion DISP30, Fuel Cell Earth) with 60 wt% of PTFE. The dipping and withdrawal speed was 10 mm/min, and soaking time was 1 min. A small area on the top portion of the samples was not coated by PTFE to create a height

Table 1 Sample types with different texture path segment lengths and different laser power having different texture densities. All samples were textured with a laser frequency of 600 Hz and an R. A. divider of 1,200.

Sample type	Substrate	Laser texture path segment length (μm)	Laser power (% of 2.6 W)	Texture density (Area coverage %)
P(0, 0)	Polished stainless steel (SS)	0	0	0
P(12, 5)	Laser textured SS	12	5	19.21 ± 6.8
P(12, 10)	Laser textured SS	12	10	32.03 ± 5.2
P(12, 15)	Laser textured SS	12	15	44.01 ± 7
P(12, 20)	Laser textured SS	12	20	51.56 ± 5.9
P(24, 5)	Laser textured SS	24	5	9.23 ± 3.2
P(24, 10)	Laser textured SS	24	10	17.18 ± 2.7
P(24, 15)	Laser textured SS	24	15	24.00 ± 3.2
P(24, 20)	Laser textured SS	24	20	27.69 ± 3.5

step for PTFE thickness measurements. Immediately after the PTFE coating, samples were heated at 120, 300, and 372 °C, each for 4 min to drive off water and surfactant, and sinter the PTFE particles respectively.

2.2 Sample characterizations

The surface roughness of the smooth and laser textured stainless steel substrates, the profiles of the Hilbert curve texture grooves on stainless steel, and the PDA-coated stainless steel substrates were measured using a 3D laser scanning confocal microscope (VK-X260, Keyence Corporation). The counterface and the wear tracks from the durability tests were also imaged by it. The surface roughness and topography of the PDA/PTFE coatings on smooth and laser textured stainless steel substrates, as well as the profiles of texture grooves on PDA/PTFE-coated stainless steel substrates, were measured using an atomic force microscope (AFM, Dimension Icon, Bruker) with a ScanAsyst air AFM tip (Bruker) having a 0.4 N/m spring constant.

The PTFE layer thickness was measured using a stylus contact profilometer (Dektak 150, Bruker Nano Surfaces) at three different locations over the intersection between the PDA layer and PTFE layer, and the average value was reported. The scan length was 2000 μm and the scan duration was 60 s. The profiles of the wear tracks were also measured by the stylus profilometer. X-ray photoelectron spectroscopy (XPS) was applied (PHI Versaprobe XPS system, Physical Electronics) to measure the elements and chemical states inside the wear tracks.

A custom MATLAB script was used to calculate the texture density of the Hilbert curve textures from images obtained by the 3D laser scanning confocal microscope. At least 5 images were sampled for each parameter combination.

2.3 Tribological tests

Durability tests were run on smooth and laser textured stainless steel substrates coated with PDA/PTFE using a tribometer (UMT-3, Bruker). All tests were conducted in a linear reciprocating motion with a ball-on-plate configuration. Cr steel balls (McMaster-Carr) having diameters of 6.35 mm were used as counterfaces. A normal load of 2 N was applied during the test with a stroke length of 5 mm and a sliding speed of 10 mm/s. The failure standard was set to friction forces larger than 0.65 N, which is equivalent to a failure COF threshold of 0.325. Neglecting the impact of PDA/PTFE coating and laser textured grooves, the Hertzian contact pressure that corresponds to 2 N normal load on stainless steel was 615 MPa. All tests were run at room temperature and relative humidity of 30%. These testing parameters were chosen to accelerate the test to failure time.

3 Results and discussion

3.1 Surface texture characterization

Table 1 shows the sample types and the corresponding laser power, texture path segment length, and texture density on the stainless-steel substrates. Texture density was calculated based on optical images as the ratio of the textured area to the total area of the substrate using a custom MATLAB script. At least 5 images were sampled for each parameter combination. The texture density was controlled by using two different path segment lengths of the Hilbert curves and varying the laser power. It can be seen that increasing the path segment length decreased the texture density while increasing the laser power increased the texture density due to the wider texture grooves generated with higher laser power.

The line plots from the Hilbert curve mathematical model and the optical images of the laser textured Hilbert curves on stainless steel substrates with path segment lengths of 12 and 24 μm are shown in Figs. 1(A) and 1(B), respectively. The effects of laser power on the fabricated texture densities are presented in Fig. 2. It is shown that increasing the laser power resulted in deeper and wider texture grooves. Wider texture grooves resulted in larger texture area coverage. Also, higher laser powers resulted in more debris generated around the texture grooves, which could have a detrimental effect on the tribological performance.

Figure 3(A) illustrates the average texture density associated with each texture path segment length and laser power. It can be seen that reducing the texture path segment length and increasing laser power increased the average texture density and average

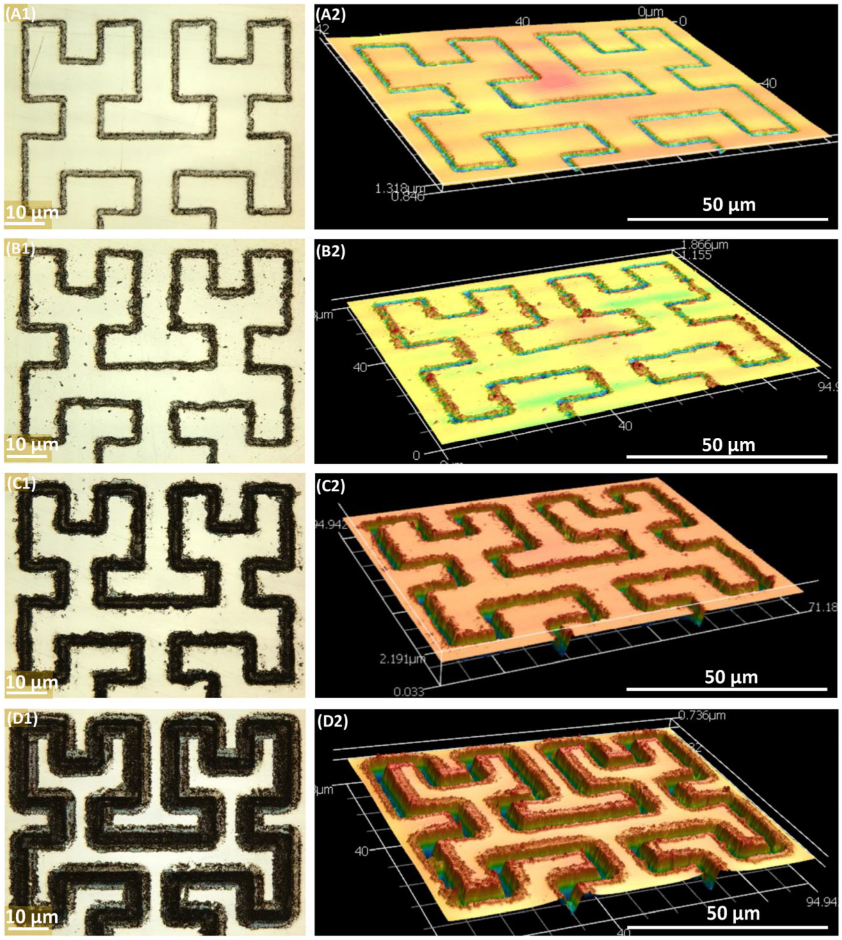

Fig. 2 Effect of different laser powers on the Hilbert curve textures: (A) LP = 5%, (B) LP = 10%, (C) LP = 15%, and (D) LP = 20%.

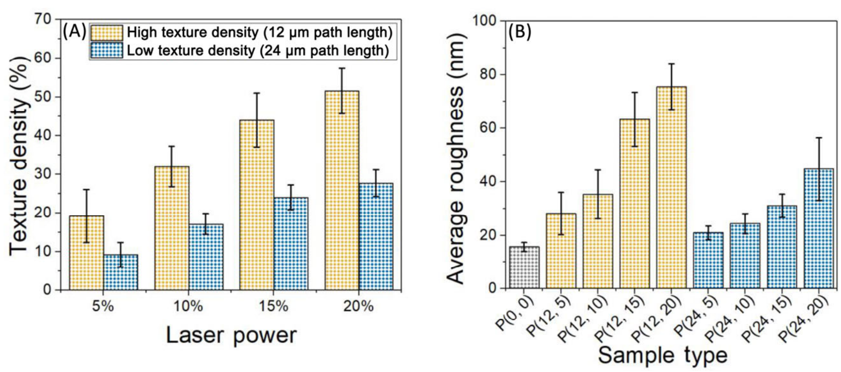

Fig. 3 Texture density and average surface roughness of surfaces with two different texture path segment length of 24 and 12 μm and four different laser powers: (A) texture density and (B) average surface roughness of smooth and laser textured stainless steel substrates.

surface roughness because of wider and deeper texture grooves. The smooth stainless steel had a smaller average surface roughness than laser textured stainless steel. Substrates with higher texture density had a larger average surface roughness than substrates with lower texture density. The average depth and width of texture grooves with different laser powers are demonstrated in Fig. 4. As expected, the texture path segment length could not affect the groove size. The depth of the texture grooves increased with the laser power. It was 0.3 μm when the laser power was 5% and increased to 1.8 μm when the laser power was

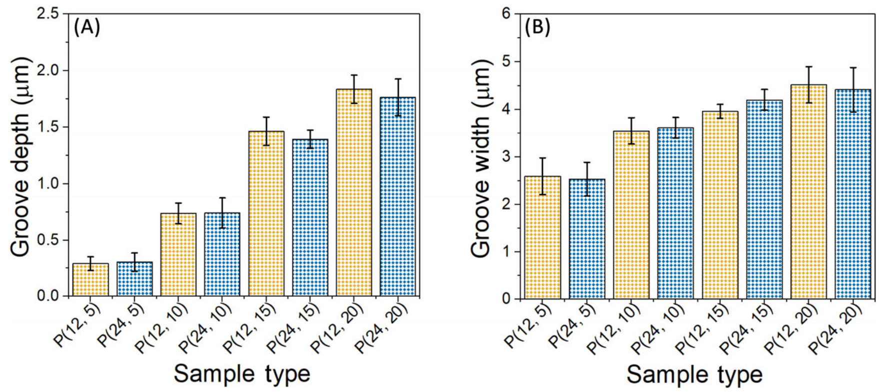

Fig. 4 Measured groove depth and width of Hilbert curve textures fabricated with different laser powers and texture path segment length: (A) depth and (B) width.

20%. Similarly, the width of the texture grooves increased with the laser power from 2.5 μm for 5% laser power to 4.4 μm for 20% laser power. It was shown that the selected laser parameters resulted in shallow texture grooves (< 2 μm) compared to textured depths reported in previous studies that were larger than 50 μm [18–20]. Deep texture grooves could hamper the lubrication recovery since solid lubricant would get stuck inside the grooves.

Figure 5 illustrates the surface topography profiles of laser textured grooves on stainless steel, the PDA deposited stainless steel, and PDA/PTFE coated stainless steel measured by Dektak. As shown, the depth of the grooves decreased in each step after depositing PDA and PTFE coatings, indicating the PDA and PTFE were successfully deposited inside the texture grooves. The measured average thickness of the PTFE coatings based on the difference in height between the exposed PDA layers outside the textured area and the PDA/PTFE coatings was at 1.65 ± 0.098 μm but the average difference between the depth of the textured grooves of the PDA deposited stainless steel and that of the PDA/PTFE coated stainless steel was less than 0.75 μm. This difference indicates that the PTFE thickness inside the texture grooves was less than the thickness of PTFE on the smooth area. Furthermore, the difference in the texture groove depths fabricated using different laser power before and after coating PTFE indicated that deeper and wider texture grooves fabricated using higher laser powers had more PTFE stored. The profile of textured grooves on P(12, 5) became almost flat after coating with PDA/PTFE, indicating it is easier to fill the shallowest grooves. This can also be seen in the average surface roughness data illustrated in Fig. 6. It is shown that the average surface roughness of PDA/PTFE coatings on P(12, 5) and P(24, 5) was similar to the average surface roughness of the coatings on smooth stainless steel, P(0, 0). As discussed above, the texture groove profile of PDA/PTFE on these two laser textured surfaces was almost flat resulting in an average surface roughness similar to that on smooth surfaces. Coating PDA/PTFE increased the average surface roughness of the remaining textures due to the

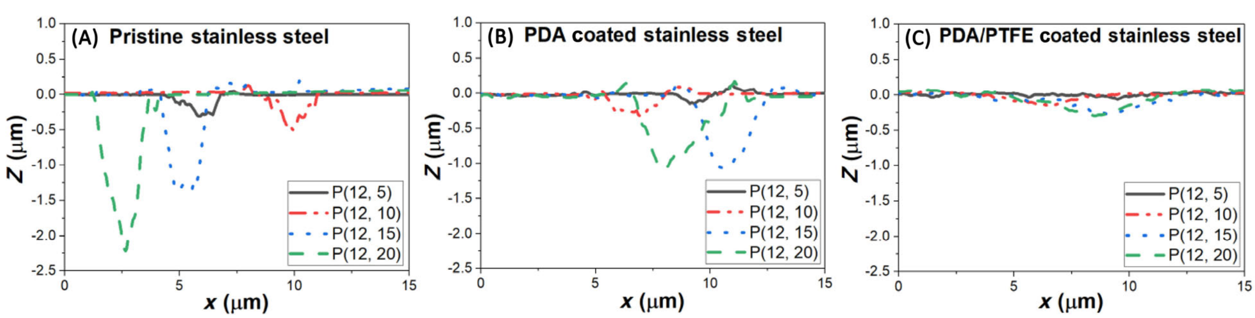

Fig. 5 Surface topography profile of the textured grooves on (A) pristine, (B) PDA-coated, and (C) PDA/PTFE-coated laser textured stainless steel measured by Dektak.

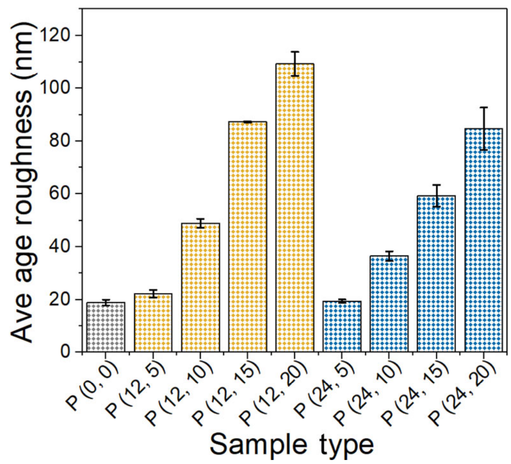

Fig. 6 Average surface roughness of PDA/PTFE coatings on smooth and laser textured stainless steel.

additional roughness introduced by the PDA/PTFE coating. As the laser power increased, the surface roughness of PDA/PTFE coatings also increased due to the deeper grooves cannot be filled by the thin PDA/PTFE coatings. PDA/PTFE coatings on laser textured surfaces with 12 μm texture path segment lengths had a larger roughness value than those on laser textured surfaces with 24 μm texture path segment lengths fabricated with the same laser power because of the existence of more textured grooves underneath the coatings.

Figure 7 shows the images of PDA/PTFE coatings on the smooth (Figs. 7(A1) and 7(A2)) and laser textured (Figs. 7(B1)–7(E1) and 7(B2)–7(E2)) stainless steel measured by AFM. The wide field of view images (Figs. 7(A1)–7(E1)) present the overall look of the PTFE coatings. The texture grooves from higher laser powers were darker (deeper) and more noticeable in the AFM images. Higher magnification images are provided for a closer look at the PTFE particles inside the texture grooves. Figures 7(C2)–7(E2) showed the textured grooves were fully covered with spindle-like PTFE particles. Also, there was no evidence of coating protrusion inside or on the edge of texture grooves.

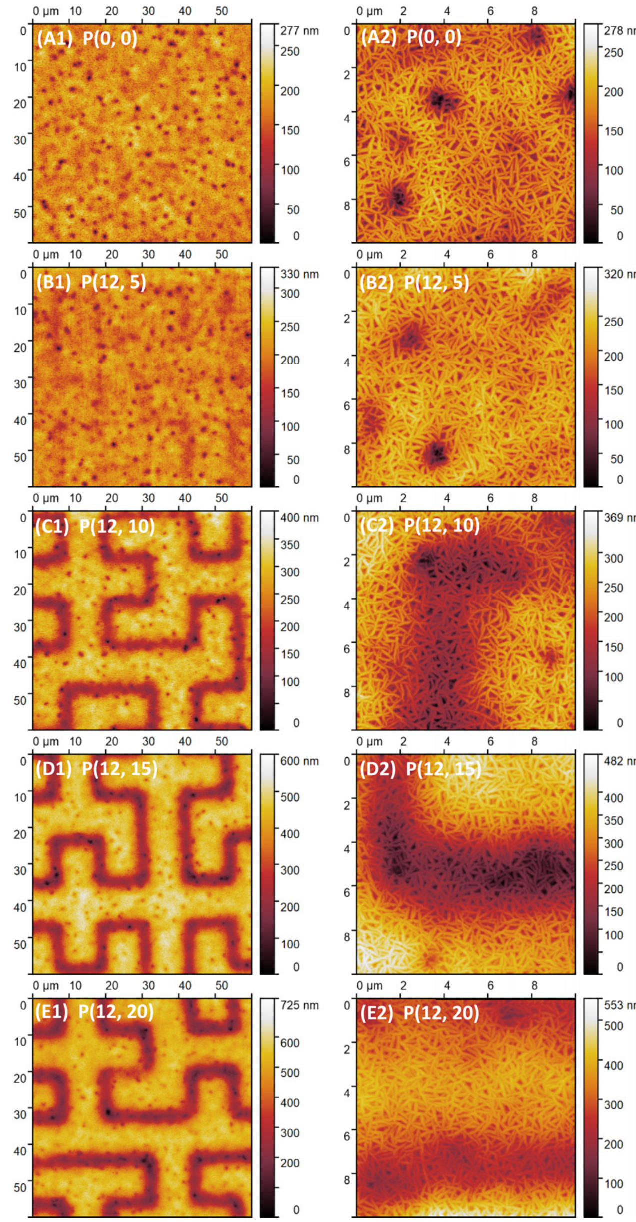

Fig. 7 AFM images of PDA/PTFE coatings on smooth and laser textured stainless steel with two scan sizes. The texture path segment length is 12 μm in all images and the laser power is: (A1) and (A2) 0, (B1) and (B2) 5%, (C1) and (C2) 10%, (D1) and (D2) 15%, and (E1) and (E2) 20%.

3.2 Tribological test results

Figure 8 illustrates the COF of the PDA/PTFE coatings on smooth and laser textured substrates during the durability tests. As shown, the coatings on laser textured stainless steel had smaller COF than coatings on smooth stainless steel over the test duration. Several peaks existed on the COF graph of samples associated with laser textured stainless steel (pointed with arrows of the same color as each curve). These peaks might represent the points where the coatings were recovered from failure. In other words, although the counterface ball reached the stainless steel, the PTFE stored inside the textured grooves replenished the wear track, and as a result, the complete coating

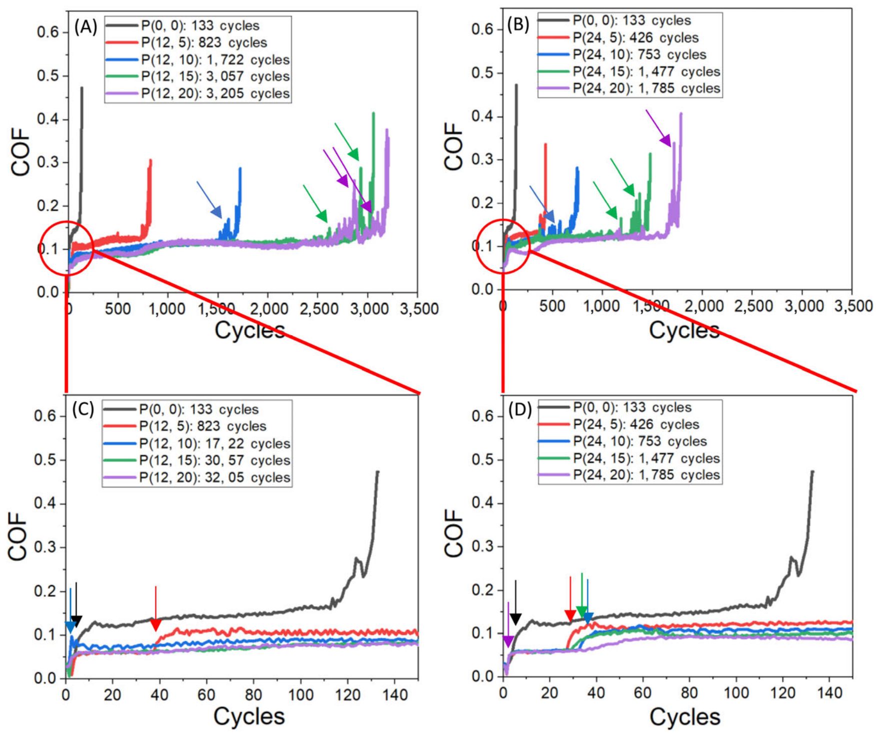

Fig. 8 COF of the PDA/PTFE coatings on smooth and laser textured stainless steel substrates during the durability tests: Texture path segment length of (A) 12 μm, (B) 24 μm, (C) and (D) zoom-in plots of the first 150 cycles of (A) and (B), respectively.

failure was delayed. This is confirmed by the XPS analysis of the wear track on the PDA/PTFE coating on the P(12, 15) sample after failure shown in Fig. 9. As shown, F1s and C1s peaks typically present in PTFE were found inside the wear track. This confirms that the durability test results were valid because if the sharp peaks were the failure point, the substrate would have been over rubbed by the counterface ball, and hence, Fe would be the dominant element in the XPS analysis. The close-up looks at the first 150 cycles during which the control sample failed show a step increase in the COF curve during the first few cycles (Figs. 8(C) and 8(D)) (pointed with arrows of the same color as each curve). This step increase happened when the counterface ball compacted the loosely connected rough PTFE coating particles, which led to smoother coatings and higher contact area and thus increased COF. Most of the COFs for coatings on laser textured substrates experienced a second step increase on their graphs. The second step possibly happened when the counterface ball compacted the PTFE stored inside the texture grooves. After this point, the COF remained flat and steady until the sharp peaks occurred.

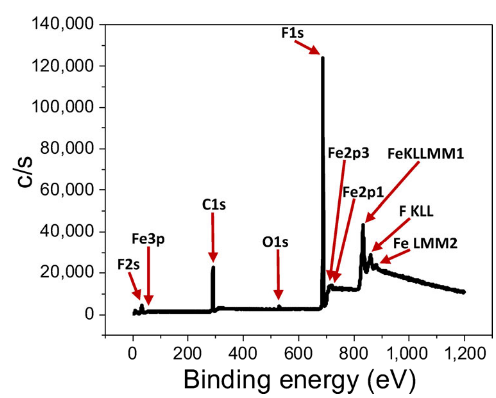

Fig. 9 XPS analysis of elements inside the wear track after durability test failure on sample P(12, 15).

Figure 10 shows the tribological test results. As shown in Fig. 10(A), laser texturing the stainless steel substrates significantly improved the durability of the PDA/PTFE coatings from 140 cycles for PDA/PTFE on smooth stainless steel to almost 3,500 cycles for PDA/PTFE on laser textured stainless steel (25 times improvement). Generally, samples with high laser power had longer durability than samples with low laser power. This is because higher laser power made the texture grooves deeper and wider with more PTFE stored inside the grooves. It also led to a larger

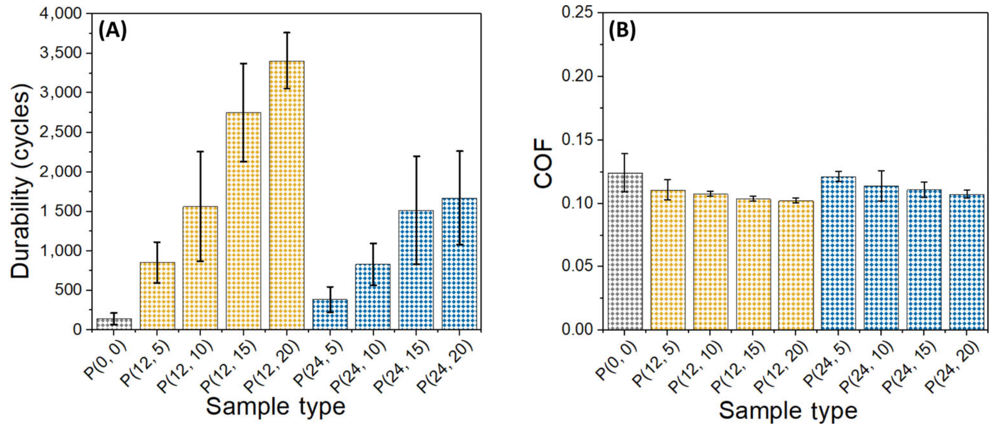

Fig. 10 Tribological test results: (A) durability and (B) COF of PDA/PTFE coatings on smooth and laser textured stainless steel.

surface roughness, which provided the interlocking for the coating. Both of these factors played a part in the remarkably improved durability of the textured samples. While the largest improvement of durability life for PTFE coatings reported in the previous studies was only up to 8 times, this study showed 25 times improvement in the durability life of thin PTFE coatings.

As shown in Fig. 10(B), the PDA/PTFE coatings on the laser textured stainless steel had a lower COF than the one on smooth stainless steel due to the less contact area between counterface ball and coatings. In addition, coatings on substrates with high texture density had a lower COF than coatings on substrates with low texture density. This is mainly because the counterface ball was in contact with the smoother area on samples having low texture density than samples having high texture density.

Figure 11 illustrates the optical images of the ball counterfaces and the wear tracks of the PDA/PTFE coatings on the smooth and laser textured stainless steel substrates after the durability tests. There was only a small amount of PTFE residue inside the wear track of the coating on the smooth substrate (arrows on Figs. 11(A2) and 10(A3)), indicating global delamination has occurred. As shown in Fig. 12, the wide and flat wear track profile on the smooth substrate was consistent with global delamination. Moreover, the amount of transferred PTFE on the counterface ball for test on the coated smooth substrate was relatively high even though it had short wear life. In contrast, the wear tracks on the coated laser textured substrates had no sign of global delamination. As a consequence of longer durability (testing duration), the width of the wear track

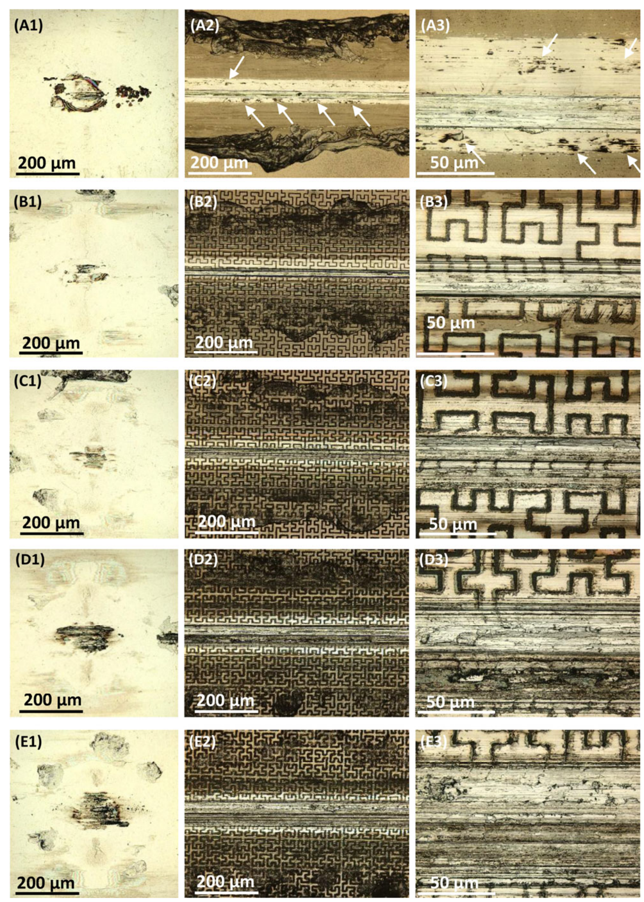

Fig. 11 Optical images of the counterface balls and wear tracks: (A1)–(E1) counterface balls and (A2)–(E2) wear tracks after the durability test on PDA/PTFE coatings on smooth and laser textured stainless steel with the texture path segment length of 12 μm and LP of (A) 0, (B) 5%, (C) 10%, (D) 15%, and (E) 20%. (A3)–(E3) are zoom-in images of (A2)–(E2). The arrows in (A2) and (A3) point to small amounts of PTFE residue inside the wear track.

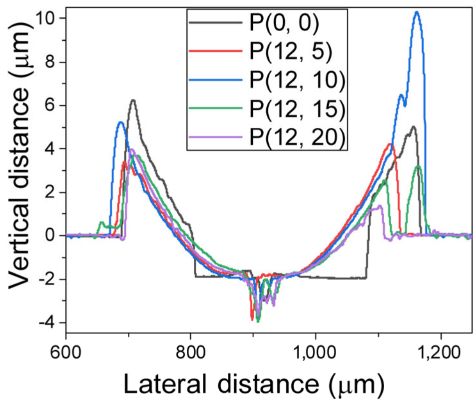

Fig. 12 Surface topography profiles of the wear tracks after the durability test on the PDA/PTFE coatings on smooth and laser textured stainless steel substrates.

enlarged as the laser power used to fabricate the laser textured substrates increased, so did the amount of transferred PTFE on the counterface ball. The surface topography profiles of the wear tracks on the coated laser textured substrates (Fig. 12) were curved and only the center part of the coating was removed, indicating the laser textures can provide interlocking to prevent PDA/PTFE coatings from global delamination.

Figures 13 and 14 present the wear tracks of progressive tests with an increasing number of testing

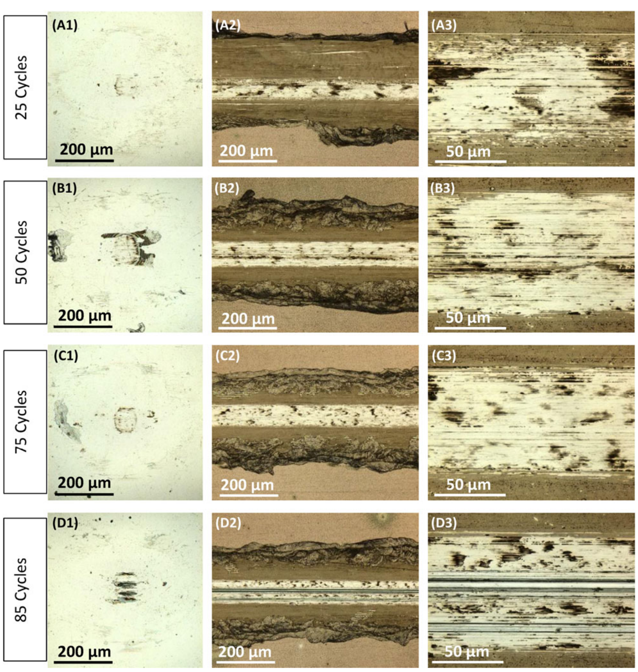

Fig. 13 Optical images of the counterface balls and wear tracks: (A1)–(D1) counterface balls and (A2)–(D2) wear tracks after progressive test on the PDA/PTFE coatings on smooth stainless steel. (A3)–(D3) are zoom-in images of (A2)–(D2).

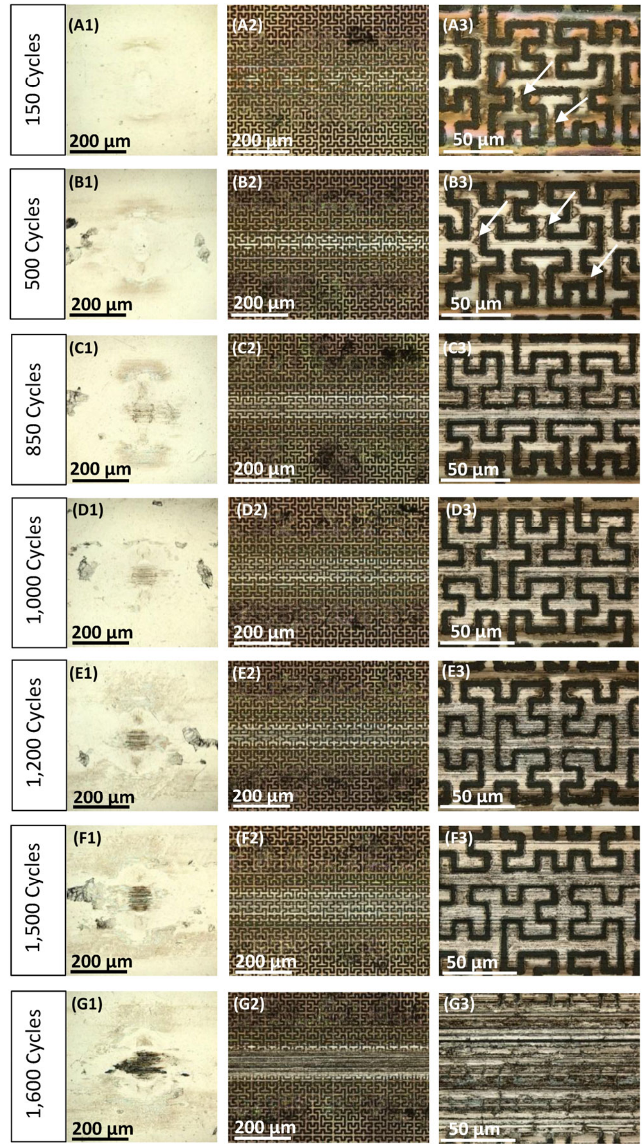

Fig. 14 Optical Images of the counterface balls and wear tracks: (A1)–(G1) counterface balls, and (A2)–(G2) wear tracks after progressive tests on the PDA/PTFE coatings on laser textured stainless steel. (A3)–(G3) are zoom-in images of (A2)–(G2). The arrows in (A2) and (A3) point to small amounts of PTFE residue inside the wear track. The arrows in (A3) and (B3) point to the PTFE coating transferred from inside the textured grooves to the worn top surface of the wear track.

cycles on the coated smooth and laser textured substrates, respectively, to uncover the wear mechanism of PDA/PTFE coatings. PTFE residue inside the wear tracks on the smooth substrate explained the global delamination regardless of the number of cycles that the counterface ball had rubbed the coating (Fig. 13). Even though there was relatively less transferred PTFE on the counterface ball after 25 cycles, delamination inside the wear track was noticeable. Also, the wear tracks on the smooth substrates were wide and flat from the beginning of the test until the coating failed at 85 cycles and the substrate was worn. In contrast, the wear track on the laser textured surfaces (Fig. 14) was not obvious when tested for 150 cycles, while it became wider and deeper as the test ran for more cycles indicating an abrasive wear mechanism. After 1,600 cycles of the test (failure cycle of this sample), the substrate was exposed, and the textures were damaged. As discussed before, the progressive tests also showed that the PTFE from inside the textured grooves transferred to the worn top surface of the wear track (arrows in Figs. 14(A3) and 14(B3)). After the counterface ball rubbed the coating halfway for 850 cycles (Figs. 14(C2) and 14(C3)), the texture grooves started to become shallower until they completely vanished, and the coating failed after 1,600 cycles of the test (Figs. 14(G2) and 14(G3)). During the testing, the PTFE stored inside the texture grooves got picked up by the counterface ball and transferred back to the wear track, making the test last longer. Also, the amount of transferred PTFE on the counterface ball was minimum until 500 cycles and it increased gradually until the failure of the test, indicating that PTFE was replenished at a relatively constant rate.

Figure 15 presents the wear track profiles corresponding to the progressive tests in Figs. 13 and 14. As discussed above, the wear tracks on the coated smooth substrates were wide and flat indicating the global delamination of PTFE, while the wear tracks on the coated laser textured substrates were curved indicating abrasive wear. Also, the depths of the wear tracks on the smooth substrates were almost the same from 25 cycles to 85 cycles. The depth of the wear tracks on the coated laser textured substrate, however, increased as the test continued from 150 cycles to 1,600 cycles. The grooves on the wear track profile associated with 85 cycles on smooth and 1,500 cycles on laser textured substrates indicated the failure point where the counterface ball contacted the stainless steel substrate.

4 Conclusions

Stainless steel substrates were laser textured with Hilbert curves of two different texture path segment lengths using four different laser powers. Higher laser powers resulted in deeper and wider laser texture grooves, as well as larger average surface roughness. Laser power and texture path segment length both significantly changed texture density. Polydopamine/polytetrafluoroethylene (PDA/PTFE) was coated on smooth and laser textured stainless steel. Coatings on laser textured substrates had larger surface roughness and showed significantly longer durability with coatings on P(12, 20) having the longest durability of 3,500 on average compared to coatings on smooth substrates which had the durability of only 140 cycles on average. However, a laser power of 15% was selected as the desirable laser power since the 20% laser power resulted in surface debris. In addition, coatings on laser textured substrates had a slightly lower COF than coatings on smooth substrates. Moreover, laser texturing the substrates prevented the global delamination inside the wear track and PTFE stored in the textured grooves replenished the PTFE to the top surface of the wear track. These results

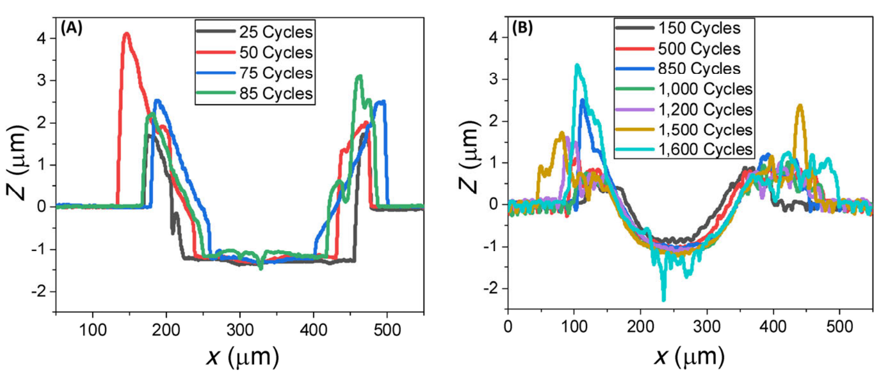

Fig. 15 Surface topography profile of the wear tracks on the PDA/PTFE coatings on (A) smooth and (B) laser textured stainless steel from progressive tests in Figs. 14 and 15.

suggested that the Hilbert curve texture can be used to significantly extend PDA/PTFE coating wear life while lowering the COF.

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