Effect of Laser surface texturing on coating adherence and tribological properties of CuNiIn and MoS2 coating

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Abstract

In aero gas turbine engine, copper nickel indium (CuNiIn) and molybdenum loaded disulphide (MoS2) duplex coating is applied on Ti6Al4V blades in bladed disk configuration of low pressure and high pressure compressor. Coating between blade and disk is provided to prevent fretting wear due to direct metal to metal contact of Ti6Al4V. Generally, grit blasting will be done for preparation of the surface before the application of coating. Laser surface texturing (LST) process can be explored by aero engine industry as a new surface preparation process for compressor blades. To compare two different surface preparation methods, Ti6Al4V surface is prepared by two different processes, conventional grit blasting as well as laser surface texturing (LST). LST with different elliptical and square patterns are created on Ti6Al4V. Surface topography is analyzed by SEM and WLI. CuNiIn is sprayed by atmospheric plasma spray (APS) and MoS2 on top of CuNiIn by painting and curing. Effects of surface preparation on coating adherence as well as on tribological properties are studied. The results showed that geometry and dimensions of LST pattern influences the coating adherence and wear performance. LST process can be optimized for better performance and explored as an alternative surface preparation process in industry for thermal spray coatings.

1. Introduction

From inception of titanium and its alloys from early 1950s, these become important materials in a very less span for the aerospace, energy and chemical industries. High strength-to-weight ratio, excellent corrosion resistance and its mechanical properties makes titanium a very good choice for several critical applications. Titanium alloys are used in many applications in gas turbine engine. Many critical and highly stressed airframe parts of civil and military aircrafts are also made of titanium alloys [1].

Ti6Al4V, Grade 5 alloy is the widely used α + β titanium alloy. This high-strength alloy is being used from cryogenic temperatures up to 427°C. Ti6Al4V is commonly used in annealed condition as well as in the solution treated and aged condition. Some applications include: gas turbine aero engine components, rocket engine cases, helicopter rotor hubs, fasteners, critical forgings requiring high strength-to-weight ratios etc. [2]. Critical and wide application in aero gas turbine engine is high speed compressor rotating disk, aerofoils blades, casings and vanes.

But these titanium alloys are very poor in galling, fretting and can lead to fretting failure. Use of unlubricated tribological system in titanium and its alloys should be avoided in practical application [3]. Figure 1 shows a fan rotor of Ti6Al4V which is bladed disk configuration with total 130 blades in three stages of low pressure compressor rotor. Aerofoil is assembled in disk with dovetail configuration where both the parts blade and disk is manufactured from Ti6Al4V alloy and creates direct metal to metal contact.

All 130 joints between aerofoil and rotating disks are subjected to sliding motion with small amplitude and high frequency vibrations during the engine operation and may lead to fretting failure if not protected
properly. In order to prevent this kind of failure, CuNiIn + MoS$_2$ coating is provided on the blade dovetail. Figure 2 shows first stage low pressure compressor blade of aero gas turbine engine. The dovetail of blade is coated with CuNiIn by thermal spray process. This CuNiIn coating is sprayed on compressor blade dovetail as anti-fretting coating for preventing direct metal to metal contact. In order to roughen the surface for CuNiIn coating adhesion, the dovetail surfaces are cleaned and then grit blasted with alumina grit. In thermal spray industry, grit blasting is used as a standard process to prepare and roughen the surface of blade dovetail. Roughening with blasting increases the contact area for mechanical anchoring of coating with blade dovetail.

CuNiIn thickness of 13 µm to 51 µm is applied on one of the mating parts usually on compressor blades in case of bladed disk configuration [4]. Interface wear is further improved using dry film lubrication with molybdenum disulphide coating on top of copper based coating. This molybdenum disulphide (MoS$_2$) lubricating coating up to a thickness of 13 µm -18 µm is applied on top of CuNiIn coating before assembling the blade with disk. MoS$_2$ coating can withstand temperature up to 300°C. This duplex configuration coating of CuNiIn and MoS$_2$ is used in engine to improve the tribological properties and prevent fretting failure between two contacting surface of titanium alloy. Figure 3 shows the microstructure of CuNiIn and MoS$_2$ coating which is applied on grit blasted surface. For ease of quality evaluation of the coating as per standards, higher coating thickness up to 350 µm is coated on samples. 25 mm dia x 6 mm thick Ti6Al4V sample is used for microstructure studies of coating. Sample surface is grit blasted with 18–20 mesh alumina grit before coating. Figure 3 indicates that there is no fixed pattern of anchoring on grit blasted surface. Many up and downs with pits of the order of 50–100 µm on grit blasted surface are observed. During blasting, if surfaces less than 3 mm thickness are not supported properly by fixturing, it can lead to distortion due to induced residual stresses in blasting process. Distorted surfaces require repair in pre or post coating operations. But adherence of CuNiIn coating with aerofoil blade substrate is mainly depends on surface preparation. Any variation in surface preparation can lead to detachment or removal of the coating during service life and can lead to fretting failure.

Freimanis et al. [5] investigated CuNiIn coating systems between titanium blades and rotor of jet engine. Study shows that at 221°C, titanium from disk surface gets transferred to CuNiIn coating in the absence of molybdenum disulphide lubricant. This creates metal to metal contact of titanium between disk and blade and damages the coating. This increases the chances of fretting wear and fretting failure. At temperatures higher than 221°C, copper gets segregated on the surface and also in coating. Fayeulle et al. [6] studied the fretting behaviour of Ti6Al4V alloy. It is reported that wear debris after detachment are oxidised into TiO and TiO$_2$. Hager et al. [7] investigated the effect of fretting wear of metallic plasma spray coatings in Ti6Al4V alloy in unlubricated condition. Coefficient of friction for CuNiIn coating against Ti6Al4V surface is lowest at 0.7 whereas, all other coatings exhibited CoF between 0.7–0.9. Same wear mechanism is observed for all coatings and substrate. Since the contact between thermal spray coating and Ti6Al4V surface is unlubricated, all the sprayed coating tested was not able to protect the Ti6Al4V surface.
Hanger et al. [8] studied the fretting wear behavior of Ti6Al4V interface surface with application of nickel graphite composite coatings. Substrate is grit blasted and then plasma sprayed with 100 µm thick nickel graphite coating with 5%, 10%, 20% graphite content. It is revealed that nickel graphite coating reduced the interface wear on mated Ti6Al4V surface by formation of lubricating graphite and nickel oxide film.

Bonding of any coating with Ti6Al4V substrate depends on pretreatment of substrate surface. There are different methods for pre-cleaning, intermediate cleaning like alkaline, emulsion, solvent cleaning etc. [9]. Pretreatment does surface cleaning and removes the outer surface impurities like oil, grease and oxides. After proper cleaning, surface roughness needs to be created. Grit blasting process is widely followed by industry for creating surface roughness thereby increasing the contact surface area [10]. Figure 4 shows 2D topography of grit blasted Ti6Al4V surface. Grit blasting process does not create any fixed and repeated pattern of roughness. Peaks and troughs on blasted surface allows molten or semi molten powder particles to flow in to gaps and solidify around the asperities on the surface. This results in mechanical interlocking between coating and substrate. Mechanical interlocking is the main mechanism for adhesion of thermal spray coating with substrate [11]. But grit blasting has drawback of distortion of thin component due to induced residual stresses in blasting.

In addition to grit blasting, there are different surface treatment processes like chemical reaction, conventional and nonconventional machining processes which can also create roughness. Recently, ablating by a laser source called laser surface texturing has gained much interest among researchers. Creation of predefined surface texture by LST is found to be an innovative and effective method to improve the adhesion strength of thermal spray coatings with component surface. Surface texturing creates predefined patterns and increases Ra by up to 4 times. Shear strength value is also increased up to 3.48 times by selecting a suitable pattern in laser texturing process [12]. Surface texturing helps in improving the mechanical anchoring and adhesive strength of the joint. Surface texturing on aluminum alloy AA5052-H32 sheet created by desktop micro rolling has increased total effective surface area for bonding. This helped in improving the mechanical anchoring and in turn adhesive strength of joint [13]. Two different laser sources CO₂ laser and fiber laser were used to create texturing on 316L stainless steel and significant increase in adhesive strength is observed with both lasers [14].

Surface texturing helped to improve adhesion strength of Ti6Al4V and carbon fiber reinforced plastic (CFRP) three times as compared to non-textured surface [15]. Different types of patterns can be created by laser texturing on Ti6Al4V alloy to get the desired roughness [16]. Pattern topography can be optimized for range of applications with an aim of improving adhesive strength up to two to three times [17]. Laser micro textures on Ti6Al4V also promotes lubrication absorption and retention which improves the wear and frictional properties of the surface as compared to non-textured surface [18]. Naveed Ahmed et al. [19] studied laser milling of Ti6Al4V with different set of laser parameters. Microstructure analysis of sub-layer underneath the laser treated area does not reflect any changes in microstructure of Ti-6Al-4V substrate.
High temperature durability of bond coatless thermal barrier coating system on single crystal Ni-based AM1 single crystal alloy is improved after laser texturing [20]. Laser texturing with groves in stainless steel increased the adhesion strength of atmospheric plasma sprayed molybdenum coating by 49.7% as compared to grit blasted surface [21]. Surface texturing of triangular pattern was created by LST on die steel (50Cr) substrate. TiN coatings were deposited by a multi-arc ion deposition method. Under oil lubricating condition, compared to uncoated and coated samples, textured and coated surface exhibited an enhanced tribological performance and adhesive bond strength [22]. Kedong Zhang et al. [23] studied the cutting performance of PVD TiAlN coated tools with WS2 solid lubricant film. Nanoscale textures on TiAlN coating surface improves the effective life of initial WS2 layer for a longer period as compare to non-textured tool. Jianliang Li et al. [24] studied the tribological properties of silver plating with laser textured nickel plating as an intermediate layer between substrate and silver plating. The effect of laser textured intermediate nickel electroplated layer on tribological properties of silver coating at room and high temperatures was investigated by the ball-on-disk friction and wear tests. It is found that coefficient of friction of silver coating on the textured surface is better as compared to un-textured. Roughness due to texture is able to trap the wear particles and accommodate the lubricant in gaps. Hengzhong Fan et al. [25] laser textured Al2O3/Ni layered ceramics with PTFE coating in different texturing patterns to obtain super hydrophobic and high wear resistance PTFE coatings. It is found that LST improved the hydrophobicity maximum up to 2 times that of the un-textured PTFE coating. This resulted in increase in wear life of coating up to 5 times that of the un-textured surface coating. Investigation has shown that texturing has improved the tribological properties of brass and aluminum alloy. After texturing, there is reduction in wear of 32% on brass 360 and 25% on AA6061-T6 aluminum alloy [26]. For machining of Ti6Al4V material, perpendicular, parallel and cross texture pattern were created on coated and un-coated tool rake face of WC/Co carbide tools using wire EDM. Effect of texture orientation is studied on uncoated, TiN and TiAlN coated tools. Texturing improved machinability of Ti6Al4V both with uncoated and coated textured tool. Perpendicular texture on TiAlN coated tool shows better machinability than TiN. Friction force reduction is also noticed in textured tool [27].

As reported in earlier study by Vishal et al. [28], copper nickel indium plating CuNiIn is sprayed by atmospheric plasma spray process on Ti6Al4V substrate. Two different processes are used to prepare surface for CuNiIn coating application. One surface is prepared by grit blasting process and other by laser texturing. Two types of square texture patterns are created by varying texturing parameters. Effect on coating adherence due to variation in surface preparation process is compared. Coating adhesive strength values for laser textured pattern and a grit blasted samples are evaluated. Interface quality of the coating is improved and coating adhesive strength of 18.67 MPa is achieved on laser textured surface which is 9.82% greater than coating adhesive strength with grit blasted surface. It is concluded that a texturing pattern can be optimized for improved adhesive strength.

From the literature survey it was observed that there are very few researchers actually implementing LST in surface preparation for thermal spray coating. Even though LST has greater repeatability in creating texture on surface, there is no inclination shown in research for industrial application of LST for surface
preparation in aero gas turbine engine. Surface preparation by LST on small aero engine components like compressor blade will lead to greater repeatability and less rejection in surface preparation for anti-fretting coating application. Very few researchers have carried out LST on Ti-6Al-4V alloy. There is no report or literature related to tribological behavior of CuNiIn and MoS$_2$ duplex coating with LST. There is a scope for LST process to be used as a surface preparation process for small components. LST will overcome the limitations of grit blasting process such as non-uniformity of blasting pattern in different directions, induced stresses, prevention of deformation in thin components and practical difficulties in inspection of blasted component surfaces.

In earlier study, square geometry of laser texture pattern was fixed and coating adhesive strength of 9.82% greater than grit blasting is achieved in laser texturing by varying texturing parameters [28]. In the present a work, Ti6Al4V surface prepared by grit blasting is compared with elliptical and square texture surface prepared by laser texturing. Four different textures are created by laser texturing on different Ti6Al4V samples by varying texture dimensions and laser scanning parameters. CuNiIn coating is sprayed by atmospheric plasma spray process on grit blasted as well as on all textured samples. Molybdenum disulphide lubricating coating on top of CuNiIn coating is applied by paint spray and drying process. Effect of different laser textured patterns on coating substrate interface quality is reported. Pin on disk wear test is conducted on Ti6Al4V samples with MoS$_2$ and without MoS$_2$ lubricating coating. Effect of different texturing patterns on tribological properties of coating is also reported.

2. Experimental

2.1 Substrate Preparation

Ti6Al4V is used as a substrate material in this study. Chemical composition of Ti6Al4V alloy is shown in Table 1. 25 mm diameter and 6 mm thick substrate is used for microstructure studies and 8 mm diameter and 50 mm long samples are used for wear studies. All samples are machined and alkaline cleaning in ultrasonic cleaner is carried out before proceeding for LST or grit blasting.

| Elements | Ti | Al | V | Fe | O | C | N |
|----------|----|----|---|----|---|---|---|
| Wt (%)   | Bal.| 6  | 4 | 0.25| 0.2| 0.08| 0.05|

2.2 Laser Surface Texturing

Nd: YAG nanosecond laser with wavelength of 1064 nm and frequency of 3 kHz is used as a source for LST. Laser source having Gaussian distribution profile with beam focus diameter of 7 µm is adopted. Laser movement is controlled by CNC with X, Y and Z manipulator. Square and elliptical geometry is selected as a texture patterns. Particle size of CuNiIn coating is in the range of 45–75 µm. Two types of
square and two types of elliptical patterns are textured. Width and pitch of the pattern is kept much higher than CuNiIn coating particle size distribution range. Pattern dimensions, laser power and scanning speed are varied. This will provide variation in depth of pattern. Table 2 shows the geometrical dimension and LST parameters of square and elliptical textures. Figure 5 shows the schematic of LST set up. The LST pattern geometry is created on two types of samples, 25 mm diameter, 6 mm thick samples for microstructure studies. 8 mm diameter and 50 mm long samples are textured for pin on disk wear tests.

| Pattern | Width/Minor dia µm | Length/Major dia µm | Pitch µm | LST parameters |
|---------|---------------------|----------------------|----------|----------------|
|         |                     |                      |          | Scanning speed (mm/s) | Power (W) | Frequency(kHz) |
| Square-1 | 200                | 200                  | 400      | 75             | 20        | 3             |
| Square-2 | 190                | 190                  | 300      | 50             | 20        | 3             |
| Ellipse-1 | 180                | 300                  | 300      | 75             | 35        | 3             |
| Ellipse-2 | 200                | 280                  | 400      | 50             | 35        | 3             |

### 2.3 Thermal Spray and Paint spray coating

Thermal spray coating of samples is carried out on MultiCoat thermal spray coating facility (M/S Oerlikon Metco, Switzerland). Atmospheric plasma spray (APS) with 80kW, 9MB plasma spray torch is used for thermal spray coating of samples. Test samples are mounted on turn table with fixture. Samples of 25 mm diameter x 6 mm thick and 8 mm diameter x 50 mm long are sprayed in a single set up with 6 axes robot integrated with 2 axis turn table. Coating all samples with robot in same set up will ensure uniformity of coating. Cu36.5Ni5In powder is (Metco 58NS) alloy powder and produces very dense coatings with porosity content less than 0.5% along with low oxide content. This coating is best suited to resist wear by fretting [29]. Powder is stirred well and pre-heated to 50°C to remove any moisture before spraying. Thermal spray coating process parameters for coating of Metco58NS is listed in Table 3. These spray parameters are established spray parameters to meet CuNiIn coating quality requirements of specified hardness, low oxide and less porosity [29]. Spray particle velocity and temperature is recorded during spray process with integrated particle diagnostic setup (AccuraSpray G3C, M/S Tecnar Automation Ltd, Canada).
| Plasma Spray Parameter     | Values (Unit) |
|----------------------------|---------------|
| Primary gas- Argon         | 40 NLPM       |
| Secondary gas- Hydrogen    | 7.5 NLPM      |
| Powder feed rate           | 40 g/min      |
| Spray distance             | 125 mm        |
| Current                    | 505 A         |
| Surface speed of test speci men | 75 m/min     |
| Translation speed          | 5.3 mm/sec    |

Recorded spray particle average velocity and temperature are 150–185 m/s and 2000°C − 2090°C, respectively. MoS₂ paint spray coating is done on top of CuNiIn coating using gravity feed spray gun (Devilbiss Pro lite). Samples are then cured at 190°C for 1 hour.

2.4. Characterisation

Surface morphology of textured and grit blasted samples is studied using White light interferometry (WLI) [Rtec Instrument USA]. Scanning electron microscopy (Carl Zeiss) and optical microscopy (Huvitz - Metallurgical Microscope with imaging software) is used for microstructure studies. Coated samples are sectioned using wirecut EDM (Makino U86 wire EDM) for microstructure studies. Wirecut EDM being non-conventional machining, does not cause any cutting forces on coated surface and will not disturb coating structure during sectioning. Grinding and polishing of samples is done using automated grinding and polishing machine (Chennai Metco, India) in single setup.

2.5 Pin on disk wear test

Pin on disk wear test is performed on 8 mm diameter and 50 mm length pin against Ti6Al4V disk. All pins are coated on 8 mm diameter face with CuNiIn coating of 50µm thickness. MoS₂ lubricating coating of 15µm-20µm is applied on CuNiIn. The tribological performance of CuNiIn coating with MoS₂ and without MoS₂ was studied. Based on initial trials on bare Ti6Al4V pin, load is fixed at 75 N for testing on coated pins. Sliding speed is kept at 2 m/s and sliding distance is set as 2000 m.

3. Results And Discussion

3.1 Surface topography of grit blasted and laser textured samples

Comparative study of surface prepared by grit blasting process and laser texturing process is performed. Grit blasting is carried out on the sample by 18–20 mesh alumina grit with pressure of 1.8 bar and
standoff distance of 200 mm (Mecshot pressure blasting machine). Samples are then ultrasonically cleaned in acetone for 5 minutes before analysis. Figure 6 (a) and 6 (b) shows WLI and SEM image of samples which are grit blasted. Roughness value Ra obtained is 5.76 µm.

SEM image of grit blasted sample shows entrapment of grit on the surface which is already cleaned with ultrasonic process. Grit entrapment on blasted surfaces is one of the main concerns of grit blasting process. If grit entrapment is more, it may cause delamination or detachment of the coating from surface. Figure 4 shows 2D topography of grit blasted surface showing randomness in peaks and valleys. There is no fixed pattern and spacing between asperities.

Varieties of patterns can be created on Ti6Al4V by variation in LST parameters [16]. 25 mm diameter and 8 mm thick flat samples are textured with four different pattern as per the parameters listed in Table 2. Samples are then ultrasonically cleaned in acetone for 5 minutes before analysis. Figure 7 (a-b) shows WLI 3D topography and 2D topography of ellipse-2 pattern. Figure 8 (a-b) shows surface morphology of elliptse-2 pattern. Figure 9 (a-b) shows WLI 3D topography and 2D topography of square-1 pattern. Figure 10 (a-b) shows surface morphology of square-1 pattern. Intense and concentrated heat input by laser source ablates the metal. Resolidified metal is observed at the periphery of elliptical pattern (Fig. 8 (a-b)) and in square pattern (Fig. 10 (a-b)). Surface roughness for any surface will be understood by amplitude parameter which is called roughness. But spacing between the roughness profile is also very important to understand surface [30]. There is a fixed spacing between square to square and ellipse to ellipse in laser texturing. As compared to 2D topography of grit blasted surface (Fig. 4), 2D topography of laser textured surface (Fig. 7 (b) and 9 (b)) shows pillars, asperities and valleys. 3D WLI images of laser textured surface (Fig. 7 (a) and 9 (a)) also shows uniformity in texturing. LST created fixed pattern for mechanical anchoring of the coating. This kind of surface texture which is fixed in pattern will never be achieved by grit blasting process.

Components of aero gas turbine like dovetail of aerofoil blades having 3 to 4 mm width and 100–150 mm length can be easily processed by LST to create a fixed repeated patterns at faster rate. LST process will provide high repeatability and productivity if process is used on small components with high volume. LST becomes typical case of mass production of small components. Titanium alloy is used under different operating condition in aero gas turbine and needs different types of thermal spray coatings like abradable, wear resistance, anti-fretting etc [31–33].

3.2 Evaluation of Surface Roughness
### Table 4
Surface texture parameters of different LST patterns

| Type of pattern | Ra (µm) | Rt (µm) | Rz (µm) | Wa (µm) | Wmax(µm) |
|-----------------|---------|---------|----------|---------|----------|
| Square-S1       | 5.423   | 44.64   | 29.17    | 27.35   | 185.0    |
| Square-S2       | 7.491   | 48.35   | 38.28    | 19.64   | 109.1    |
| Ellipse-E1      | 5.775   | 36.32   | 25.31    | 23.05   | 110.6    |
| Ellipse-E2      | 4.755   | 32.07   | 24.13    | 28.95   | 144.3    |

Surface roughening is mandatory before coating. Earlier work reports surface roughening by single type of square pattern on titanium alloy with CuNiIn anti-fretting coating [28]. Evaluated surface texture parameters for square and elliptical pattern inspected by 3D WLI profilometer for the present work is indicated in Table 4. Random or repetitive deviation of the surface from nominal surface is called surface texture. Surface texture includes roughness, waviness, lay and flaws. Roughness is surface irregularity of smaller wavelength. Waviness is surface irregularities of longer wavelength greater than roughness sampling length and shorter than waviness sampling length [30]. In the present study, Average roughness (Ra), Maximum height of the roughness (Rt), Average maximum height of the profile (Rz), Waviness average (Wa) and maximum height of waviness (Wmax) is taken for more clarity and understanding the texture of surface. Average surface roughness (Ra) value of grit blasted sample is 5.76 µm and Ra of four textured patterns are Square S1-5.423 µm, Square- S2 7.491 µm, Ellipse-E1 5.775µm and Ellipse-E14.755 µm. These average roughness values are not having considerable variation from grit blasted surface to textured surface. But there is a considerable variation in other roughness parameters like Rt, Rz, Wa and Wmax. The pattern square-S1 and ellipse-E2 has higher pitch of 400µm as compared to 300 µm pitch in sample square-S2 and ellipse-E1. Higher Wa & Wmax values are achieved in square-S1 and elliptical-E2 texturing where pattern pitch is higher.

#### 3.3 Coating Substrate Interface Evaluation

CuNiIn coating microstructure on the four different types of laser textured pattern Square-S1, Square-S2, Ellipse-E1 and Ellipse-E2 is shown in Fig. 11 (a-d), respectively. All the four microstructure reveals that there is a repeatability in surface created by laser surface texturing as compared to unevenness of grit blasted surface (Fig. 3). Mechanical interlocking is the main mechanism in bonding of coating with the substrate [11]. Out of four LST patterns, coating is mechanically found interlocked with the laser surface textured pattern in two types of pattern square S1 (Fig. 11a) and ellipse E2 (Fig. 11d). Coating is found adhered to laser textured Ti6Al4V substrate. Whereas, there is a complete detachment of coating with the substrate in pattern square S2 (Fig. 11b) and ellipse E1 (Fig. 11d). It can be concluded that samples with higher pitch are having good coating adherence as compared to sample with lower pitch. Further investigations on width ‘W’ and depth ‘D’ (Fig. 12) of the profile created by LST process will provide more information about mechanical interlocking of the coating with the surface textures.
Surface roughening on titanium alloys improves the adhesion [34]. Figure 12 shows the analysis of profiles created by laser surface texturing on Ti6Al4V surface. The textured surface with square S1 pattern has higher pitch of 400 µm, higher Wa and Wmax. The dotted rectangles shown in Fig. 12 are having dimensions ‘D’ depth of the hole and ‘W’ width (diameter) of the hole in which CuNiIn coating splat is deposited. This analysis is done for all the four texture patterns. Table 5 shows the variation in depth and width of coating splat in laser textured patterns.

| Pattern     | Width variation W [µm] | Depth variation D [µm] |
|-------------|------------------------|------------------------|
| Square-S1   | 116 to 75              | 27 to 38               |
| Square-S2   | 82 to 64               | 14 to 27               |
| Ellipse-E1  | 117 to 62              | 14 to 22               |
| Ellipse-E2  | 85 to 63               | 23 to 54               |

Pattern square-S1 and ellipse-E2 have higher depth of texturing ‘D’ as compared to square-S2 and ellipse-S1. Maximum depth of texturing ‘D’ is found in ellipse-2 as compared to square pattern S1. Pattern square-S2 and ellipse-E1 has low depth which is affecting the bonding of coating with Ti6Al4V substrate. Width of texture ‘W’ in ellipse E1 is varying from 117 µm to 62 µm which is on higher side about same pattern has less depth of texture between 14 µm to 22 µm that is causing delamination in ellipse E1 texture. Hence depth of texture ‘D’ has more influence on mechanical interlocking of coating than width ‘W’ of texturing.

3.4 Pin on disk wear test
The test is done at ambient temperature. The density of Ti6Al4V is taken as 4.47 g/mm$^3$. For wear track diameter of 60 mm speed of the disk is kept at 637 rpm. During the test, samples are weighed before and after the test and mass loss is calculated. The wear rate and coefficient of friction is calculated as per Eqs. 1 and 2

\[
\text{Wear Rate (mm}^3/\text{m}) = \frac{\text{Volume Loss (mm}^3)}{\text{Sliding Distance (m)}}
\]

(1)

\[
\text{Coefficient of Friction} (\mu) = \frac{\text{Friction Force (F)}}{\text{Normal Load (N)}}
\]

(2)

Using pin on disk wear test, the tribological properties of single CuNiIn coating and duplex CuNiIn with MoS$_2$ are studied at 75 N load with 2000 m sliding distance. This study is done mainly to analyze and compare influence of surface preparation process and geometry of surface texture on coefficient of
friction and wear rate. The coating is applied on grit blasted as well as on laser textured samples. Table 6 shows the wear test results on 10 different samples with and without MoS$_2$ coating. Coefficient of friction tends to decrease almost in all surface textures after application of MoS$_2$ lubricant coating on top of CuNiIn coating. In elliptical pattern wear rate is decreasing after application of MoS$_2$ coating.

Table 6
Pin on disk wear test results

| Surface preparation method | Coating applied | Mass loss (g) | Wear rate (mm$^3$/m) | CoF ($\mu$) |
|---------------------------|-----------------|---------------|----------------------|-------------|
| Grit blasted              | CuNiIn          | 0.159         | 0.018                | 0.29        |
| Grit blasted              | CuNiIn + MoS$_2$| 0.2255        | 0.025                | 0.27        |
| LSP Ellipse-1             | CuNiIn          | 0.1878        | 0.021                | 0.29        |
| LSP Ellipse-1             | CuNiIn + MoS$_2$| 0.1549        | 0.017                | 0.26        |
| LSP Ellipse-2             | CuNiIn          | 0.1662        | 0.019                | 0.31        |
| LSP Ellipse-2             | CuNiIn + MoS$_2$| 0.1613        | 0.018                | 0.31        |
| LSP Square-1              | CuNiIn          | 0.2508        | 0.028                | 0.31        |
| LSP Square-1              | CuNiIn + MoS$_2$| 0.279         | 0.031                | 0.30        |
| LSP Square-2              | CuNiIn          | 0.2002        | 0.022                | 0.31        |
| LSP Square-2              | CuNiIn + MoS$_2$| 0.2512        | 0.028                | 0.30        |

But the wear rate is increasing in case of grit blasted and square pattern samples after application of MoS$_2$ coating. This is due to the removal of asperities in sliding from the top surface especially with high Rt and high Rz values (Table 4) of square pattern as compared to elliptical pattern. Hence, geometry of pattern has influence on wear rate and coefficient of friction.

4. Conclusion

In the present study, for application of CuNiIn and MoS2 coating on Ti6Al4V, surface preparation is carried out with grit blasting, a conventional method followed by industry and laser surface texturing with varied patterns. Two different types of elliptical and square patterns are created by varying laser surface texturing parameters. CuNiIn coating by APS and MoS$_2$ lubricant by painting and curing is applied on the samples. Analysis of different surfaces prepared by LST on coating substrate interface is studied. The effect of grit blasting surface and laser textured surface on tribological properties CuNiIn and MoS$_2$ coating is evaluated. The conclusions drawn from this study are:
• Entrapment of grit on the grit blasted surface and distortion in thin components is a major concern of grit blasting process. Grit between coating and prepared surface may affect the coating adherence with the Ti6Al4V surface.

• Laser surface texturing is a viable option to create a controlled surface modification with higher repeatability. LST will completely eliminate the effect of grit entrapment and distortion which is a major drawback of conventional grit blasting process.

• Same geometry of pattern created with different laser texturing parameters has different quality of coating substrate interface. The coating quality on four different textured surfaces is varying from better coating adherence to complete detachment of coating from the substrate.

• Geometry of pattern and spacing of the pattern (pitch) has influence on roughness created by LST. LST with higher pitch shows higher Wmax.

• Depth of texturing created by laser has more influence than width of texturing on mechanical interlocking of coating with substrate.

• In CuNiIn and MoS₂ coating, wear rate is increasing on grit blasted as well as LST square patterns. LST ellipse patterns shows decline in wear rate. Geometry of pattern has influence on coefficient of friction and wear rate.

• Pattern geometries and laser surface texturing parameters can be created and optimized to improve the coating adherence and tribological properties of the CuNiIn and MoS₂ coating. LST process can be explored as an alternative process for grit blasting for industrial application.

• LST process will lead to higher repeatability in surface preparation for application of thermal spray coating. Optimized LST will lead to higher productivity on small components like low pressure and high pressure compressor blades.

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Figures

Figure 1

Bladed disk assembly of Ti6Al4V low pressure compressor disk showing Ti6Al4V aerofoil assembled in disk
Figure 2

CuNiIn coating on First stage low pressure compressor blade

Figure 3

CuNiIn and MoS2 Coating Microstructure

Figure 4

Grit blasted surface 2D topography by WLI

Figure 5
Schematic of Laser surface texturing set up

Figure 6

Grit blasted surface a) WLI 3D topography and b) SEM morphology image

Figure 7

Ellipse-2 pattern a) WLI 3D topography and b) 2D topography

Figure 8
Morphology of elliptical pattern a. SEM overview image of elliptical pattern b. SEM-magnified image of elliptical pillar

**Figure 9**

Square 1 pattern a) WLI 3D topography and b) 2D topography

**Figure 10**

Morphology of square pattern a. SEM overview image of square pattern b. SEM- magnified image of a single square pillar
Figure 11

Coating substrate microstructure for a) Pattern Square - S1 b) Pattern Square - S2 c) Pattern Ellipse - E1 d) Pattern Ellipse - E2
Figure 12

Analysis of laser textured profile in coating microstructure