Tribological Analysis of Etched Mild Steel Surface

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Abstract

The technological age has complex machines used in the industries as well as in daily life. The problem of wear is likely to occur whenever there is relative motion between two mating surfaces resulting the dimensions of machine component are lost leading and finally failure of components. This causes hazardous effect on surfaces and breakdown of machine. Micro machined smooth and rough parts have high coefficient of friction in elasto hydrodynamic area. It requires micro level of roughness. It contains fluid which reduces friction. Through chemical etching the micro dimples are produced on the components which reduce the metal to metal contact and thus decreasing wear rate. In this research work hexagonal micro dimples have been produced on mild steel disc through chemical etching and subjected to tribological analysis through pin on disc test and found the significant improvement in the wear resistance. Wear test is performed by varying load and velocity of disc. The study shows that the wear rate first decreases and then increases. Coefficient of friction and friction force is determined andappropriate graph is obtained during relative motion between mating surfaces.

1. Introduction

Surface texturing as a means for enhancing tribological properties of mechanical components is well known for many years. Perhaps the most familiar and earliest commercial application of surface texturing is that of cylinder liner honing. Today surfaces of modern magnetic storage devices are commonly textured and surface texturing is also considered as a means for overcoming adhesion and stiction in devices. Fundamental research work on various forms and shapes of surface texturing for tribological applications is carried out by several research groups worldwide and various texturing techniques are employed in these studies including machining, ion beam texturing, etching techniques and laser texturing. Interestingly almost all these fundamental works are experimental in nature and most of them are motivated by the idea that the surface texturing provides micro reservoirs to enhance lubricant retention or micro-traps to capture wear debris. Usually, optimization of the texturing dimensions is done by a trial and error approach.

Surface texturing has emerged in the last decade as a viable option of surface engineering resulting in significant improvement in load capacity, wear resistance, friction coefficient etc. of tribological mechanical components. Various techniques can be employed for surface texturing but chemical etching is probably the most advanced so far. Chemical etching produces a very large number of micro-dimples on the surface and each of these micro dimples can serve either as a micro-hydrodynamic bearing in cases of full or mixed lubrication, a micro-reservoir for lubricant in cases of starved lubrication conditions, or a micro-trap for wear debris in either lubricated or dry sliding.

2. Consequences of Friction and Wear

The consequences of friction and wear are many. Friction and wear usually cost money, in the form of energy loss and materialloss, as well as in the social system using the mechanical devices

A. Friction and wear can decrease national productivity
B. Friction and wear can affect national security
C. Friction and wear can affect quality of life
D. Wear causes accident

3. Types of wear

A. Adhesive wear

Adhesive wear is defined as the transfer of material from one surface to another during relative motion by a process of solid-phase welding or as a result of localized bonding between contacting surfaces. Particles that are removed from one surface are either permanently or temporarily attached to the other surface [1]. Adhesive wear occurs when two body slides over each other, or are pressed into one another, which promote material transfer between the two surfaces. When either one of two surfaces of tribo-elements in sliding or rolling contact has thin soft surface layer that can partly transfer to the counter surface by adhesion, relative displacement takes place at the interface between the surfaces of coating and transfer layer with smaller shear strength of the soft material than that of the underlying element material.

B. Abrasive wear

The abrasive wear of a material is defined as the progressive loss of material due to abrasive action of hard particles present between the counter surfaces. The abrasive wear depends on various factors like abrasive size, rake angle of abrasives, applied load and shape, size, volume fraction of the dispersed phases. In addition to these factors the abrasive wear rate of a material also depends on the surface hardness and materials properties like fracture toughness [3]. Abrasive wear occurs when a hard rough surface slides across a softer surface. ASTM (American Society for Testing and Materials) defines it as the loss of material due to hard particles or hard protuberances that are forced against and move along a solid surface.

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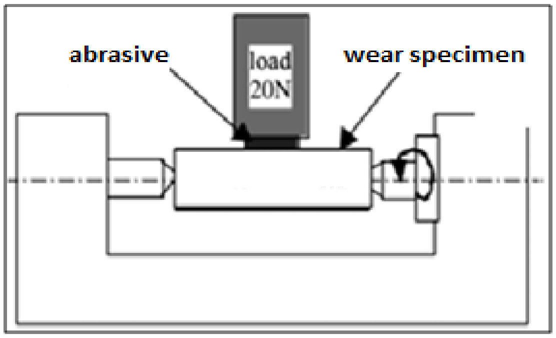

Fig: 1. Abrasive Wear of Etched Mild Surface (4)

There are a number of factors which influence abrasive wear and hence the manner of material removal. Several different mechanisms have been proposed to describe the manner in which the material is removed. Three commonly identified mechanisms of abrasive wear of coatings are:

1. Plowing
2. Cutting
3. Fragmentation

C. Surface fatigue wear

Surface fatigue wear of the surface is a process by which the surface is weakened by cyclic loading, which is one type of general material fatigue. Fatigue wear is produced when the wear particles are detached by cyclic crack growth of micro cracks on the surface. These micro cracks are either superficial cracks or subsurface cracks. It is extremely important to improve the resistance of the material against fracture in aerospace applications.

D. Fretting wear

Fretting wear of the surface is the repeated cyclical rubbing between disc and another surface, which is known as fretting, over a period of time which will remove material from one or both surfaces in contact. It occurs typically in bearings, although most bearings have their surfaces hardened to resist the problem. Another problem occurs when cracks in either surface are created, known as fretting fatigue [6].

A plate specimen (1) was fixed on the upper holder (2) to link a six-axis torque/force sensor (3) (three loads of x, y and z direction; three torques of x, y and z direction) through a spring suspension (4). A ball specimen (5) was mounted on the lower holder (6), which fixed on the low-speed reciprocating rotary motor system (7). The flat specimen rotated following the motion of the motor at a constant rotary velocity (in the range of 0.01–5◦/s).

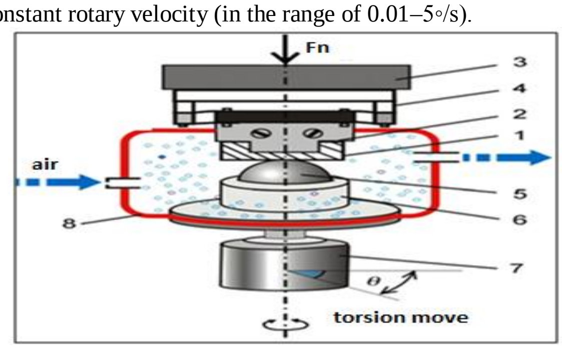

Fig: 2. Fretting Wear (7)

E. Erosive wear

Erosive wear of the etched disc is caused by the impact of particles of solid or liquid against the surface of coating [8]. The impacting particles gradually remove material from the surface through repeated deformations and cutting actions. It is a widely encountered mechanism in industry. A common example is the erosive wear associated with the movement of slurries through piping and pumping equipment (fig.3).

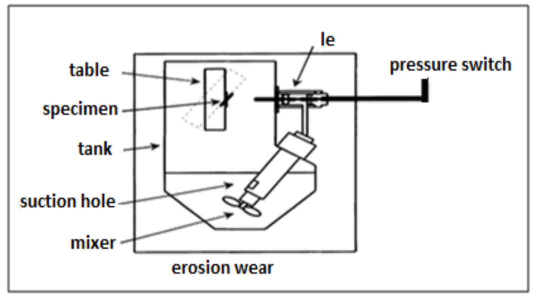

Fig: 3. Erosion Wear (8)

The rate of erosive wear is dependent upon a number of factors. The material characteristics of the particles, such as their shape, hardness, and impact velocity and impingement angle are primary factors along with the properties of the surface of the coating [8, 28]. The impingement angle is one of the most important factors and is widely recognized in literature. For ductile coating materials the maximum wear rate is found when the impingement angle is approximately 30°, whilst for non ductile coating materials the maximum wear rate occurs when the impingement angle is normal to the surface.

4. Types of Wear Test:

A. Scratch test

The scratch tester is used to test the scratch resistance of flat solid surfaces such as coatings, metals, ceramics, composites, polymers, and other material surfaces. The test is performed by sliding a stylus over the surface of the test specimen. The normal load, sliding speed, direction, stylus geometry, and stylus material can be varied. The resultant tangential force at the contact interface can be monitored using tribo data, the supplied windows-based data acquisition Software. The onset of scratch or adhesion failure of coatings can be inferred from this data. A CMOS camera is built-in to capture the scratch scar image.

B. Slurry Abrasion Test

The Slurry Abrasion Test is used to test the abrasive resistance of solid materials to slurry compositions. Slurry erosion problems are especially important during rainy seasons in hydroelectric power plants due to the increase in the number of solid particles impacting the surfaces, especially in systems where the installation of an exhaustive filtration process is not possible [10]. Various materials such as metals, minerals, polymers, composites, ceramics, coatings, and heat-treated materials can be tested with this instrument. The test is performed by rotating a rectangular test sample within a cup filled with abrasive slurry (fig. 4). The mass of the test sample is recorded before and after conducting a test and the difference between the two values is the resultant mass loss due to slurry abrasion [10].

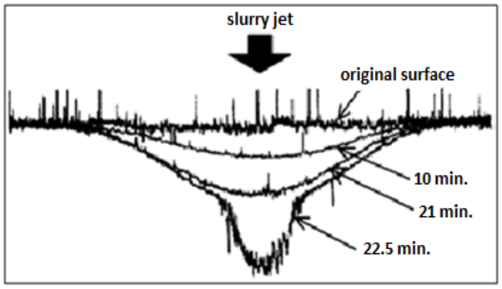

Fig: 4. Slurry Abrasion Wear

C. Friction Test

The Friction Tester is used to test the frictional characteristics of materials in dry or lubricated reciprocating motion contact. A wide variety of materials including fluid lubricants, greases, cutting fluids, metals, composites, ceramics, polymers, and coatings can be tested. The test is performed by loading the test specimen against a ball, pin, or cylinder undergoing reciprocating linear motion. The frictional force developed at the contact interface is measured by a force transducer. The output signal can be captured by a storage oscilloscope or tribo data, Koehler's data acquisition software, for evaluation.

D. Air Jet Erosion Test

The Air Jet Erosion Tester is used to test the erosion resistance of solid materials to a stream of gas containing abrasive particulate. The test is performed by propelling a stream of abrasive particulate gas through a small nozzle of known orifice diameter toward the test sample. Material loss, in this case, is achieved via the impingement of small abrasive particles upon the surface of the test sample. Materials such as metals, ceramics, minerals, polymers, composites, abrasives, and coatings can be tested with this instrument [12]. The test specimen, temperature, angle of incidence of the jet stream, abrasive particulate speed and flux density, can be varied to best simulate actual conditions. Special adapters are available to test various geometries and components for user-specified testing applications.

E. Pin on Disc Test

The Pin-On-Disc Tester is used to test the friction and wear characteristics of dry or lubricated sliding contact of a wide variety of materials including metals, polymers, composites, ceramics, lubricants, cutting fluids, abrasive slurries, coatings, and heat-treated samples. The test is performed by rotating a counter-face test disc against a stationary test specimen pin. The advantage of a wear test, when compared to indentation or scratch testing, is that it can give a measure of the lifetime of a particular system.

5. Experimental Procedure: Material

Mild steel is the most common form of steel because its price is relatively low while it provides material properties that are acceptable for many applications. Low carbon steel contains approximately 0.05–0.15% carbon and mild steel contains 0.16–0.29%carbon; making it malleable and ductile, but it cannot be hardened by heat treatment. Mild steel has a relatively low tensile strength, but it is cheap and malleable; surface hardness can be increased through carburizing. It is often used when large quantities of steel are needed, for example as structural steel. The density of mild steel is approximately 7.85 g/cm3 and the Young's modulus is 210 Gap.Low carbon steels suffer from yield-point run out where the material has two yield points. The first yield point (or upper yield point) is higher than the second and the yield drops dramatically after the upper yield point. If low carbon steel is only stressed to some point between the upper and lower yield point then the surface may develop Luder bands Low carbon steels contain less carbon that other steels and are easier to cold-form, making them easier to handle.

Fig: 5. Mild Steel Disc Before Etching

6. Sample Preparation

A. Etching

Image analysis work is facilitated if the etchant chosen improves the contrast between the feature of interest and everything else. Thousands of etchants have been developed over the years, but only a small number of these are selective in nature. Although the selection of the best etchant, and its proper use, is a very critical phase of the image analysis process, only a few publications have addressed this problem. Stansbury [15] has described how potentiostatic etching works and has listed many preferential potentiostatic etching methods. The potentiostatic offers the ultimate in control over the etching process and is an outstanding tool for this purpose. Many tint etchants act selectively in that they color either the anodic or cathodic constituent in a microstructure. tint etchants are listed and illustrated in several publications .

A classic example of the different behavior of etchants where low-carbon steel has been etched with the standard nital and picral etchants, and also a color tint etch. development of color image analyzers, this image can now be used quite effectively to provide accurate grain size measurements since all of the grains are colored. etching with 2% nital reveals the ferrite grain boundaries and cementite. Note that many of the ferrite grain boundaries are missing or quite faint, a problem that degrades the accuracy of grain size ratings.

B. Steps to etch mild steel

i. Choose the type of steel you want to etch. You can etch stainless steel, mild steel, or high-carbon steel. Which type of steel you etch will determine the best acid or chemical to use to etch it with.
ii. Remove any burrs on the edges of the steel. File away any burrs on the side of the steel you plan to etch with

acid. You can leave the burrs on the other side if you're etching a steel plate.

iii. Scrub the steel. Use a chlorine cleanser on an abrasive sponge, a wire brush, fine steel wool, wet number 600 emery paper, or corundum paper, scrubbing in a circular motion. You want to leave the surface just gritty enough to grip the resist material, but not so scratched that you end up etching extra lines that aren't part of your design.

iv. Rinse the steel with water. The water should sheet off the steel surface. Clean the steel a second time with isopropyl alcohol.

v. Choose the image you want to etch into the steel. You can either draw a freehand image or replicate an existing image onto the steel surface. Depending on which transfer method you use, you can have a fairly simple design or a complex one.

vi. Remove and clean the steel plate. Wash the plate with water to remove the acid. If you used a particularly strong acid, you may also need to use baking soda to neutralize it. You then need to remove the resist; depending on the resist material, use one of the following methods

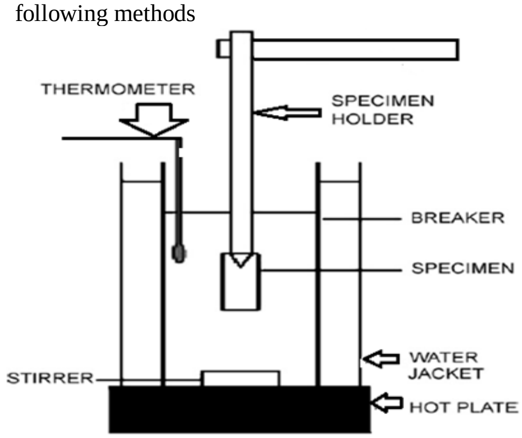

Fig: 6. Experimental set up for Etching

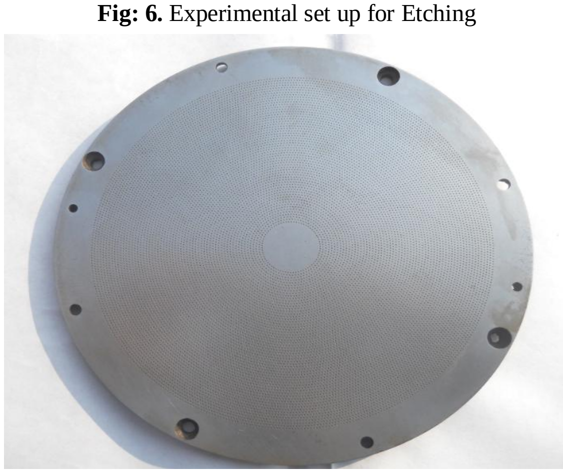

Fig: 7. Hexagonal Micro Holes on Disc by Chemical Etching

7. Design of experiment

Statistical methods are commonly used to improve the quality of a product or process. Such methods enable the user to define and study the effect of every single condition possible in an experiment where numerous factors (load and sliding speed) were involved in present work to study the wear behavior of the etched mild steel surface. There were two parameters which were taken into consideration to determine the wear rate and coefficient of friction. The design of experiment was made on the software design ease 7.1. There are several methods to design the experiment in this software but we have chosen general factorial design because it can be design the experimental variable when there are more than three levels. The both of the two variables have three levels. It was sliding speed (150, 200 and 250 rpm) and loads (29.9, 44.1 and 58.8 N) as shown in Table 1.

Table: 1. Variables for Wear Test

Variables	Level 1	Level 2	Level 3	Level 4
Velocity(m/sec)	6.28	5.23	4.186	3.14
Load (kg)	2kg	3 kg	4 kg	5 kg

Table 1 shows the two variables used to determine the response such as wear rate, coefficient of friction. The significant variables on which the wear rate and the coefficient of friction depend were directly given by the software with the help of F-test

Table: 2. Specifications of the Pin on Disk Wear and Friction Monitor

Parameter	Unit	Minimum	Maximum
Disk speed	rpm	200	2000
Pin diameter	mm	3	12
Wear track dia	mm	50	100
Normal load	N	1	200
Frictional force	N	0	200

7.1 Pin on Disc Test

Pin on disc type wear monitor (DUCOM, TL-20, Bangalore, India) with data acquisition system was used to evaluate the wear behavior of mild steel against two pin of different materials. Load was applied on pin by dead weight through pulley string arrangement. The system had maximum loading capacity of 200 N. The test was performed under dry and wet condition. The wear test can be performed on any wear tester, but for etched mild steel surface, pin on disc wear test is most commonly used (fig. 8).

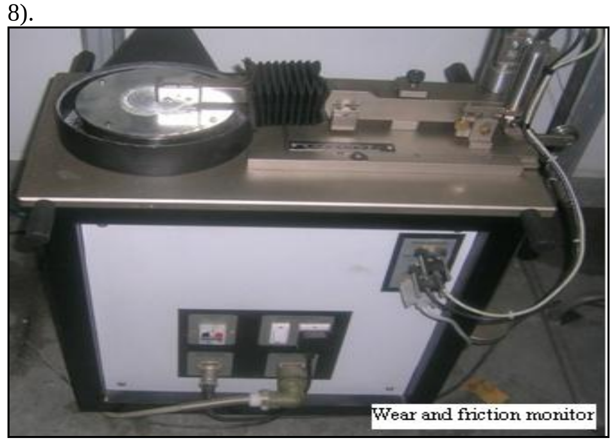

Fig: 8 Wear and Friction Monitor Machine for Pin on Disc Test

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The mass loss was measured on weight balance (accuracy) and after that specific wear rate has been calculated by using the given formula

K = Vw / L × S

Here Vw is the wear volume, Lthe applied load and s the total sliding distance and K is specific wear ratecare has been taken to clean up the sample before and after each test to prevent any form of corrosion on the surface [33].

Fig: 9 Etched Mild Disc before Wear Test

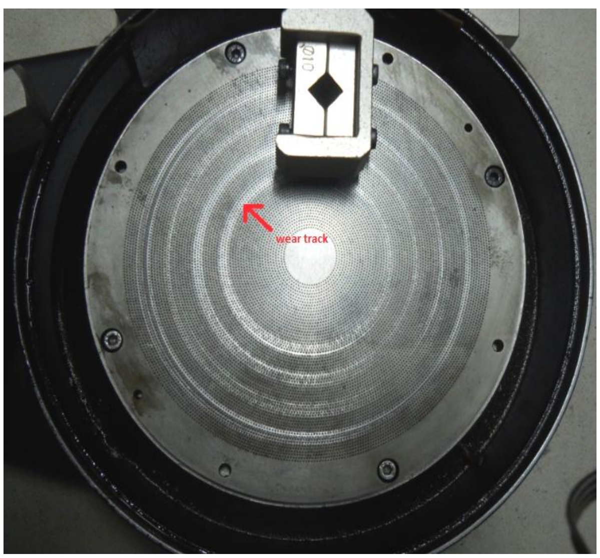

Fig: 10 Etched Mild Disc during Wear Test

Fig: 11 Pins of Brass and Mild st

8. Results and Discussions: Wear rate with mild steel pin in wet condition

The mild steel pin taken for experiment has dimension of diameter of 9 mmand length is about 30 mm. The initial mass of pin was 19.5102 gm. The projected length beyond gripping in the clamp of the test rig is 4 mm. The mild steel disc of diameter 165 mm is taken for testing having hexagonal etched holes with the distance 420 microns across the corners.The experiment carried shows the variables and the results obtained during pin on disc test in table 3. Column 1 shows velocities (m/s) for different loads (kg). Column 2 shows the load applied during each run. The mean value of friction force for each run is taken from the graph showing on computer monitor attached with wear testing machine and then coefficient of friction is obtained. Coefficient of friction is shown in column 3. Disc rpm is shown in column 5.Tracking distance is taken in decreasing order from 120 to 60.

Table: 3. Variables and Result Obtained in Wet Condition with Mild Steel Pin

Velocity (m/sec.)	Load (kg)	Coeff.of friction	Friction force (N)	Disc rpm	Tracking distance	Sliding Distance (km)	Time (sec.)	Mass After wear (gm)	Mass loss (gm)	Specific wear $(m^2/n)\times 10^5$
3.14	2	.08154	1.6	1000	120	2	318	19.5101	.0001	3.98
4.186	3	.0645	1.8	1000	100	2	382.16	19.5100	.0002	7.07
5.234	4	.0739	2.9	1000	80	2	477.70	19.5099	.0003	6.58
6.28	5	.0672	3.3	1000	60	2	636.44	19.5098	.0004	7.72

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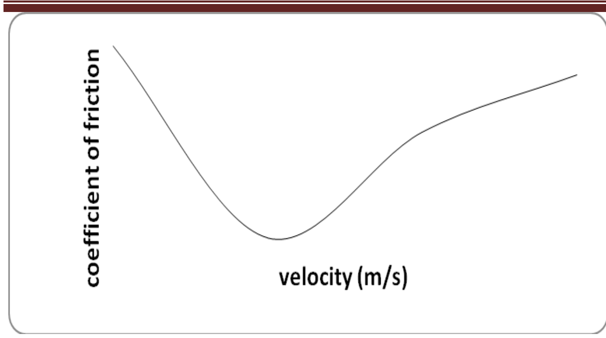

Fig: 12. Coefficient of Friction vs. Velocity

The variation of coefficient of friction with the velocity is shown in Figure 12. Figure has 3 zones. First zone is boundry or mixed zone. In first zone, coefficient of friction decreases with velocity. In second zone, elasto hydrodynamic film is produced. Coefficient of friction decreases up to its minimum value of 0.0645 at 5.23 m/s velocity of disc. In third zone hydrodynamic condition exists. In third zone coefficient of friction increases rapidly due to debris present between pin and disc. Slope of curve in velocity range of 3.1 to 5.1 m/s. should be continuously increasing but due to insufficient lubrication and debris sticking in wear area, it is not continuously increasing. Maximum value of coefficient of friction is 0.08154.

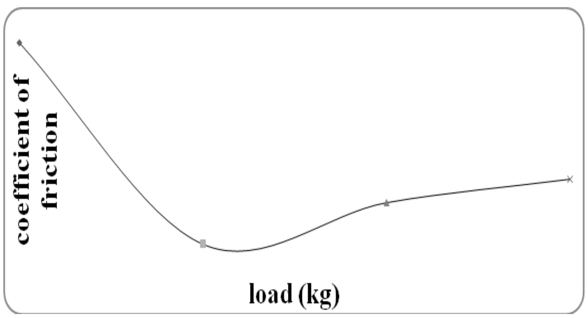

Fig: 13. Coefficient of Friction vs. Load

The variation of coefficient of friction with the load is shown in Figure 13. Figure 13 has 3 zones. First zone is boundry or mixed zone. In first zone, coefficient of friction decreases continuously with load. In second zone, elasto hydrodynamic film is produced. In this zone, coefficient of friction attains its lowest value of 0.0645 at 3 kg. In third zone hydrodynamic condition exists. In zone 3 coefficient of friction increases slowly compare to zone 2 due to less debris present in wear area. Maximum value of Coefficient of friction is 0.08154.

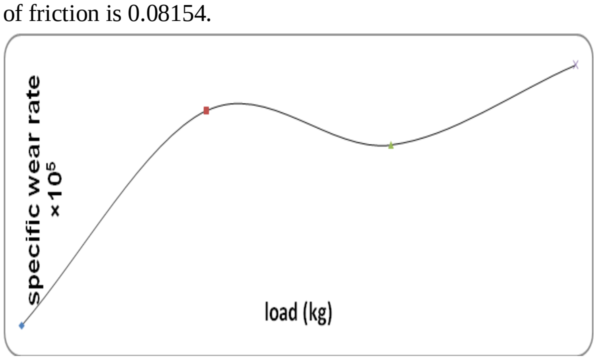

Fig: 14 Specific Wear Rate vs. Load

The variation of specific wear rate with the load is shown in Figure 14. Figure 14 shows specific wear rate is increasing up to the load of 3 kg attains the value of 7.07 and then decreases beyond this load. This may be due to formation of debris of mild steel pin which reduces the area of contact between pin and disc and finally the wear rate again increases beyond 4 kg load. Maximum value of specific wear rate is 7.72 obtained at 5 kg load.

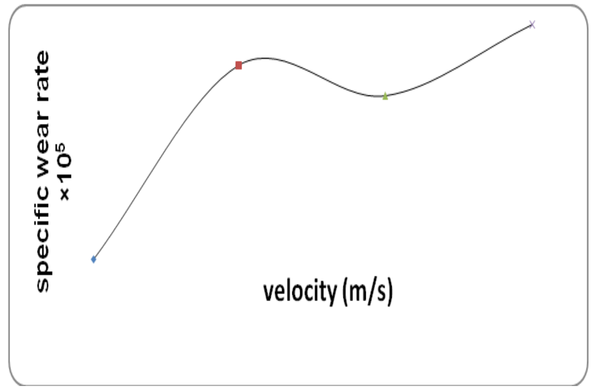

Fig: 15. Specific Wear Rate vs. Velocity

8.1 Wear Rate with Steel Pin in Dry Condition

The brass pin taken for experiment has dimension of diameter of 89 mm and length is about 30 mm. The initial mass of pin was 19.5098 gm. The projected length beyond gripping in the clamp of the test rig is 4 mm.

Table: 4. Variables and Result Obtained in Dry Condition with Mild Steel Pin

Velocity (M/sec.)	**Load (Kg.)**	**Friction force (N)**	**Disc rpm**	**Tracking distance**	**Sliding Distance (km)**	**Mass After wear Loss (gm)**	**Mass loss (gm)**
6.28	1	5.6	1000	120	2	19.5094	.0004

Friction force started from zero then rose up to 7 after that it decreased and curve become stable, its mean value 5.6 was observed. After 260 sec. again friction force rose to 7.6 and then decreased.

8.2 Wear Rate with Brass Pin

The brass pin taken for experiment has dimension of diameter of 9 mm and length is about 30 mm. The initial mass of pin was 20.7986 gm. The projected length beyond gripping in the clamp of the test rig is 4 mm.

Table 5 shows variables and the results obtained during pin on disc test. Column 1 shows velocities (m/s) for different loads (kg).column 2 shows load applied in each run. Column 3 shows coefficient of friction. Mean value of friction force for each run is taken from the figure showing on computer monitor attached with wear testing machine and then coefficient of friction is obtained disc rpm is shown in column 5. Column 6 shows tracking distance taken in each run. Tracking distance is taken in decreasing order from 120 to 60. Column 8 shows time for each run. Column 9 shows mass after wear of pin by by weighing in weighing machine. Last column shows specific wear rate.

Table: 5. Variables and Result Obtained in Wet Condition with Brass Pin

Velocity (M/s)	Load (kg)	Coeff. of friction	Friction force(N)	Disc rpm	Tracking distance	Sliding Distance (km)	Time (s)	Final Mass (gm)	Mass loss (gm)	Specific wear (m^2/n)× 10^5
6.28	2	.04587	0.9	1000	120	2	318	20.7979	.ooo7	4.57
5.23	3	.0339	1	1000	100	2	382.16	20.7973	.0013	7.64
4.186	4	.0280	1.1	1000	80	2	477.70	20.7966	.0020	10.69
3.14	5	.0387	1.8	1000	60	2	637	20.7961	.0025	8.16

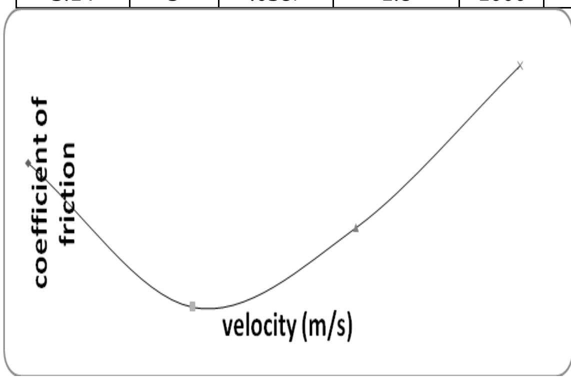

Fig: 16. Coefficient of Friction vs. Velocity

The variation of coefficient of friction with the velocity is shown in Figure 16. The figure has 3 zones. First zone is boundry or mixed zone. In first zone Coefficient of friction decreases with velocity. In second zone, elasto hydrodynamic film is produced. In this zone Coefficient of friction decreases up to its lowest value of 0.0280 at 4.186 m/s. In zone 3, Coefficient of friction increases up to 0.04587. The reason for increasing coefficient of friction is the presence of debris between pin and disc. Curve is uniform and shows actual stribeck curve.

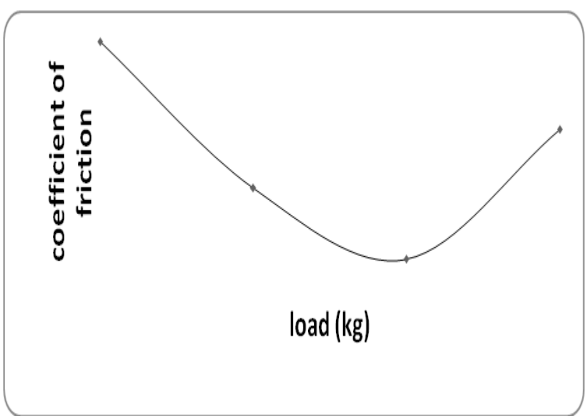

Fig: 17. Coefficient of Friction vs. Load

The variation of coefficient of friction with the load is shown in Figure 17. The figure has 3 zones. First zone is boundry or mixed zone. In first zone, the coefficient of friction decreases with load. In second zone, elasto hydrodynamic film is produced. Coefficient of friction obtained its lowest value of 0.0280 at 4 kg. In third zone hydrodynamic condition exist. In zone 3, coefficient of friction continuously increases and attained its maximum value of 0.04587. In zone 3, coefficient of friction is increasing because of debris presence between pin and disc.

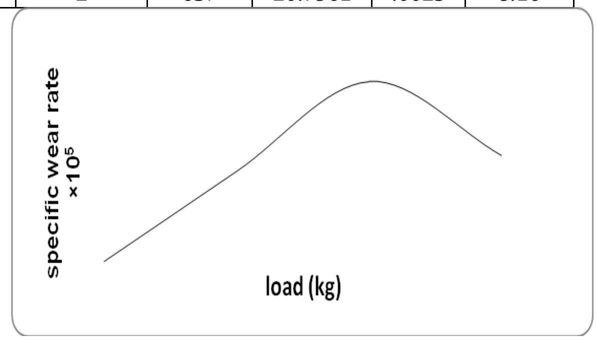

Fig: 18 Specific Wear Rate vs. Load

The variation of Specific wear rate with load is shown in Figure 18. Figure has 2 zones. In first zone, Specific wear rate continuously increases and obtained its maximum value of 10.69 at the load of 4 kg. In zone 2 Specific wear rate decreases up to 8.16 due to insufficient lubrication and debris present between pin and disc.

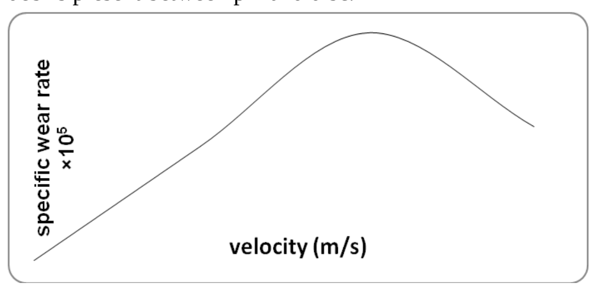

Fig: 19 Specific Wear Rate vs. Velocity

The variation of Specific wear rate with the velocity is shown in Figure 19. Figure has 2 zones. In zone 1 specific wear rate is increasing up to 5.3 m/s velocity of disc and attained it maximum value of 10.69. In zone 2 specific wear rate decreases because of thick layer of lubricant and also formation of debris. Specific wear rate decreases up to 8.16.

Wear rate with brass pin in dry condition

The brass pin taken for experiment has dimension of diameter of 9 mm and length is about 30 mm. The initial mass of pin was 20.7950 gm. The projected length beyond gripping in the clamp of the test rig is 4 mm.Table 6 shows variables and the results obtained during pin on disc test. Column 1 shows velocity (m/s) for load (kg). Column 2 shows load applied in wear test run. Column 3 shows friction force. Mean value of friction force for each run is taken from the figure showing on computer monitor attached with wear testing machine and then coefficient of friction is obtained disc rpm is shown in column 4. Column 5 shows tracking distance taken in wear test run. Tracking distance is taken 100. Column 7 shows mass after wear of pin by weighing in weighing machine.

Table: 6. Variables and Result Obtained in Dry Condition with Brass Pin

Velocity (M/sec.)	Load (Kg.)	Friction force (N)	Disc rpm	Tracking distance	Sliding Distance (km)	Mass After wear Loss (gm)	Mass loss (gm)
5.23	1	0.7	1000	100	2	20.7938	.0012

Friction force started from zero then raised up to 0.7 after that it decreased and curve become stable, mean value 5.6 was observed. After 260 sec. again friction force rose to 7.6 and then decreased.

9. Conclusions

This research work presents that optimized and well-controlled micro-craters were successfully produced on the common carbon steel substrates. Microstructure and mechanical properties of the textured dimples were characterized and analyzed. The etched-dimpled hard craters present a strong metallurgical bonding with the substrate. Microstructure of the deposited regions mainly consists of fine and defect-free hard grained structures. Compositions distributed in the texturing layers are rather uniform. The comprehensive mechanical properties of the texturing layers are greatly enhanced. The hard crater on the roll surface results in substantial reductions in friction. The chemical etched work piece is demonstrated to have excellent abrasion resistance and a much longer service life.

The abrasive wear resistance was 10 times higher than that of the substrates. In wet condition with mild steel pin, coefficient of friction decreases up to 0.0645 at 5.23 m/sec. velocity of disc. Maximum value of coefficient of friction is 0.08154.The same phenomenon also occurs with load. Coefficient of friction decreases up to 0.0645 at 3 kg load. Specific wear rate also increases up to velocity of 4.2 m/sec. of disc. With brass pin coefficient of friction decreases up to 0.0280 at 4.186 m/sec. velocity of disc and then increases up to 0.04587. With load, coefficient of friction decreases up to 0.0280 at 4 kg and then increases up to 0.04587. Specific wear rate is increasing up to 4.5 kg then decreases. With brass and mild steel pins, specific wear rate increases first with velocity and load and then decreases, after this it also increases. Since specific wear rate should increased uniformly but due to debris present between pin and disc the area of contact reduces and due to this wear also reduced. One more reason is insufficient lubrication in wear area during wear testing.

10. Future Scope

This study showed further research opportunities in the chemical etching of mild steel such as investigating various etchant concentrations on etching parameters, some chemical additives to main etchant and examining other possible etchants. Moreover, environmentally acceptable mild steel etching process should be investigated including economical regeneration of waste etchant and recovery of etch material. Depth of etch and surface finish is greatly influenced with concentration of etchant and time of application of etchant. So for future prospects these variables can be varied and result can be observed. In this research work hexagonal micro dimples is created but circular, triangular and various other shape can be generated on disc and effect can be analyzed. Pin of mild steel and brass is used in this work but pin of other material can also be tested.

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