Tribological Study on Automotive Braking Using the Effect of Laser Surface Texturing

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Abstract

Most commercial vehicles use disc brake system for braking. Brake pads are usually worn out due to frictional force caused on the surface of the material. Increasing wear resistance enhances the life of the brake pad material. Hence, laser engraving method is used to improve the wear resistance of the braking material. The study of friction, wear is of enormous practical importance. The function of any mechanical system is depends on appropriate friction and wear characteristics. Improving the wear resistance of braking system by studying the wear properties of materials like Aluminium Alloy and Mild steel material is also of great importance. In this paper, different patterns of dimples are inscribed on the surface of the material and an experiment investigation carried out using pin on disc tribometer to study the wear characteristics and also to find the most efficient material-pattern combination.

Keywords: Pin-on-disc, COF, Surface Engraving, Sliding Friction, Wear.

I. Introduction

Tribology is the science and engineering of interacting surfaces in relative motion. It includes the study and application of the principles of friction, lubrication, and wear. The performance of many machines in our everyday life depends on contacting surfaces in movement. These surfaces often need to be lubricated for proper durability and energy efficiency. The knowledge needed to do all this is included in a specific branch of science known as tribology. The performance of many machines in our everyday life depends on contacting surfaces in movement. These surfaces often need to be lubricated for proper durability and energy efficiency. The knowledge needed to do all this is included in a specific branch of science known as Tribology. Tribology is, therefore, a multidisciplinary subject that draws upon a large section of the syllabus of a typical undergraduate science or engineering course. Tribology is particularly important in today's world because so much energy is lost to friction in mechanical components. A braking system may be defined as the machine element for applying a force to a moving surface to slow it down or bring it to rest in a controlled manner. Here, the kinetic energy is converted into heat energy which is then dissipated into atmosphere. Automotive brakes are disc type and generally are hydraulically operated. The basic principle behind any braking operation is to create a controlled friction process that increases the deceleration converts motion into heat energy.

One of the major advantages in disc brakes is the resistance to wear as the discs remain cool even after repeated brake application. Also, brake pads are easily replaceable. The brake disc is the rotating part of a wheel’s disc brake assembly, against which the brake pads are applied. The material is typically cast iron. Brake pads are designed for high friction with brake pad material embedded in the disc in the process of bedding while wearing evenly. The higher coefficient of friction for the pad, the more brake power will be generated. Coefficient of friction can vary depending upon the type of material used for brake rotor.

The force slowing the brake disc or rotor is

$$F=2C_{f.pad}F_{pad}$$

The braking system is a vital safety component hence the structural materials used in brakes should have combination of properties such as wear resistant, lighter weight, good thermal capacity.

2. **Material Selection and its properties**

2.1 En30B

EN30B is typically used in manufacturing Gears, shafts, high duty bolts, high duty spindles and other demanding maximum strength, toughness or wear resistance. This steel is shocked in the annealed condition, to render machining possible, and must be heat treated as follows: harden in air (or oil for larger sections over 2½"diameters) from a temperature of 810°C / 830°C. Temper, if desired, at a suitable temperature nor exceeding 250°C.

Melting point	: 1425°C
Density	: 8.08g/cm^3
Specific gravity	: 7.65
Modulus of elasticity in tension	: 365 Gpa
Tensile strength minimum	: 717 N/mm^2
Yield strength minimum	: 713 N/mm^2
Hardness	: Rockwell 233

2.2 Aluminuim Alloy 7075

Aluminum has a density around one third that of steel or copper making it one of the lightest commercially available metals. The resultant high strength to weight ratio makes it an important structural material allowing increased payloads or fuel savings for transport industries in particular. Pure aluminium doesn't have a high tensile strength. However, the addition of alloying elements like manganese, silicon, copper and magnesium can increase the strength properties of aluminium and produce an alloy with properties tailored to particular applications. Aluminum is well suited to cold environments. It has the advantage over steel in that its' tensile strength increases with decreasing temperature while retaining its toughness.

Melting point	: 477- 635 °C
Density	: 2.81 g/cc
Specific gravity	: 2.73
Modulus of elasticity in tension	: 71.7 Gpa
Tensile strength ultimate	: 572Mpa
Yield strength minimum	: 503Mpa
Hardness	: Rockwell 87HRB

2.3 Mild Steel

Even the pans and spoons of the kitchen are sometimes made of mild steel. The main target of this article is to discuss about different mild steel properties. The mild steel is very important in the manufacturing of metal items. Almost 90% steel products of the world is made up of mild steel because it is the cheapest form of steel.

Melting point	: 1350 to1530°C
Density	: 7900 kg/m^3
Specific gravity	: 7900kg/m^3
Modulus of elasticity in tension	: 210 Gpa
Tensile strength minimum	: 47 kgf/mm^2
Yield strength minimum	: 32 kgf/mm^2

2.4 Ceramic

Ceramic materials are usually ionic or covalent bonded materials, and can be crystalline or amorphous. A material held together by either type of bond will tend to fracture before any plastic deformation takes place, which results in poor toughness in these materials. Additionally, because these materials tend to be porous, the pores and other microscopic imperfections act as stress concentrators, decreasing the toughness further, and reducing the tensile strength. These combine to give catastrophic failures, as opposed to the more ductile failure modes of metals. These materials do show plastic deformation.

Melting point	: 2000°C
Density	: 2 to 6 gms/cm^3
Specific gravity	: 1.8 gms/cm^3
Modulus of elasticity in tension	: 393 Gpa
Tensile strength minimum	: 260 to 300 mpa
Yield strength minimum	: 4300mpa
Hardness	:Rockwell 30

3. Experimental Setup:

The Pin on Disc is used to determine the wear of the material during sliding. Here EN30B serves as disc, while Mild Steel, Aluminum Alloy, Ceramic acts as pin specimen. The experiment is conducted with 20% density. The Pin on disc experiment has sliding distance of 90m with a velocity of 2m/s. The coefficient of friction for each surface textured pin is determined and compared.

Mild steel, Aluminum Alloy, Ceramic are machined and polished into a cylindrical pin of diameter 8 mm and length 28 mm respectively. As said the different patterns such as circle, hexagon, Ellipse and the combination of these three were designed in AutoCAD software. The laser surface texturing is done on the pin using laser marking system supported by AutoCAD software. The laser is incorporated by a diode pumped Yttrium doped fiber source. The following laser parameters were followed for texturing the pins. Wavelength: 1064 nm; Power: 80W; Pulse: 20 kHz pulsating fiber laser beam. Speed: 200 rpm; Number of passes: Single.

Parameters:

Laser Type	Diode pumped Nd: YAG fiber laser
Laser Power	20 W
Laser Wavelength	1064 nm
Marking Field	200*200 mm
Maximum Scanning Speed	10000 mm/sec
Ambient Operating Temperature	40° C

3.1 Pin-On-Disc Test

In this study, Pin-on-Disc testing tribometer in Figure.1 was used for tribological characterization. The test procedure is as follows: Initially, pin surface was made flat such that it will support the load over its entire cross-section called first stage. This was achieved by the surfaces of the pin sample ground using emery paper (80 grit size) prior to testing Run-in-wear was performed in the next stage/ second stage. This stage avoids initial turbulent period associated with friction and wear curves Final stage/ third stage is the actual testing called constant/ steady state wear.

Fig. 1 Pin on Disc Machine

This stage is the dynamic competition between material transfer processes (transfer of material from pin onto the disc and formation of wear debris and their subsequent removal). Before the test, both the pin and disc were cleaned with ethanol soaked cotton. Before the start of each experiment, precautionary steps were taken to make sure that the load was applied in normal direction.

3.2 **Laser engraving method:**

Laser surface texturing (LST) is a surface engineering process as shown in Figure 2 used to improve tribological characteristics of materials. Using a laser to create patterned microstructures on the surface of the materials can improve load capacity, wear rates, lubrication lifetime, and reduce friction coefficients. Laser texturing or laser ablating is a process that creates a mark on a material by eliminating a section of the surface-coated layer on the material. Nd-YAG and CO_2 are more common than excimer lasers, as excimer lasers have comparatively low ablation rates and take excessive time for LST. In our case Nd-YAG laser is used to form dimple like pattern on the surface of the specimen. Using a laser to create patterned microstructures on the surface of the materials can improve load capacity, wear rates, lubrication lifetime, and reduce friction coefficients.

Fig. 2 Laser Marking Machine

3.3 **Surface texturing:**

The textured surfaces can have a beneficial effect on tribological performance but it is widely agreed that the optimization of textures should be carried out based on specific requirements of applications. The laser marking operation is depicted in Figure 3. Surface Texturing of Circular, Hexagonal, Ellipse dimple(major axis in horizontal direction), and a combination all these dimples (cir+hex, hex+ellipse, circle+ellipse) were made over the mirror finished surface over the pin as shown in Figure 4. The laser surface texturing was performed on the test specimen with a Nd:YAG laser beam. The dimple depth is 2.5 micron.

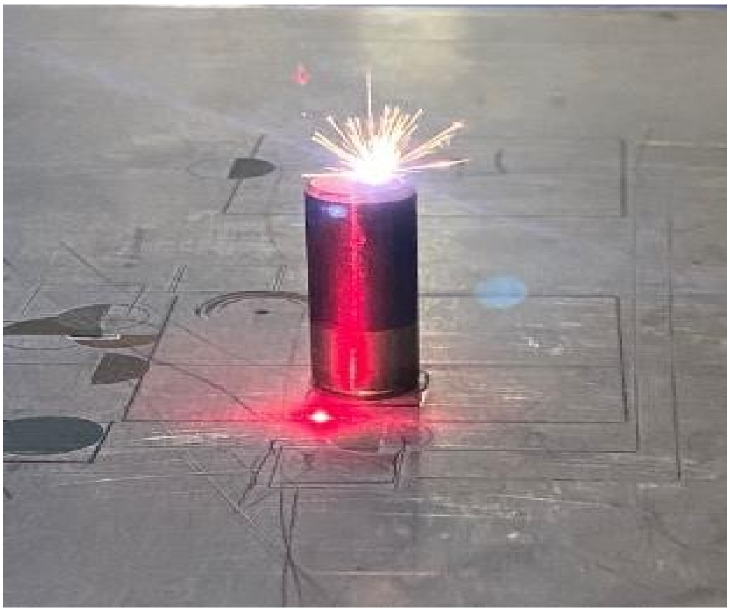

Fig. 3 Laser Marking Operation

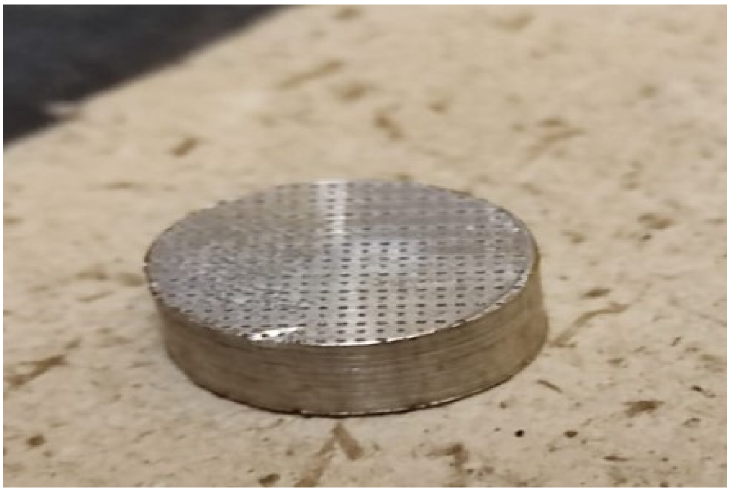

Fig. 4 Surface Texturing pattern on specimen

4. **Design Calculations of Brake pad**

Area of pin specimen, A = $\frac{\pi d^2}{4} = \frac{\pi d^2}{4}$ **= 78.53981** mm^2

For a Circular dimple:

1. Area of a circular dimple= $\frac{\pi d^2}{4} = \frac{\square \times 0.1^2}{4}$ = 7.85398x10^{-3} mm^2
2. Dimple density=> $\partial c = \frac{Ac}{Sc^2}$

   Where, ∂c-Dimple density (Taken as 20%)
   Ac- Area of circular dimple
   Sc- Distance between centre of two dimples

Dimple Density=>20/100=0.00785398/Sc^2

=>Sc^2= 0.039265

=>Sc= 0.198mm

3. No.of dimples = A x ∂c/Ac

$= 78.53981\times\frac{0.2}{7.85398\times10^{-3}}$ = 2000 dimples

For a Hexagonal dimple:

1. Area of hexagonal dimple= $3\sqrt[2]{3}\ \frac{a^2}{2}$

Where, a= side length of the hexagon

Area of hexagonal dimple =>7.85398x10^{-3}= $3\sqrt[2]{3}\ \frac{a^2}{2}$

=>3.0229983=a^2

=>a=0.005498mm^2

For a Elliptical dimple:

1. Area of elliptical dimple= $2(1+\sqrt{2}\,)(a^2)$

Where, a= side length of the ellipse

Area of elliptical dimple => 7.85398x10^{-3} = π x a x b = 2.4999 x 10^{-3}= a x b

=>2.4999 x 10^{-3}/0.07= a

=>A=0.0357mm

4.1. Weight Loss

The alloy and composite samples are cleaned thoroughly with acetone. Each sample is then weighed using a digital balance having an accuracy of ± 0.1 mg. After that, the sample is mounted on the pin holder of the tribometer ready for wear test. The specific wear rates of the materials were obtained by

W = w where W denotes specific wear rates in mm^3/N

W is the weight loss measured in grams, density of the worn material in g/mm3 and

F is the applied load in N.

4.2. Wear and Coefficient of friction:

Friction coefficient and wear rate can be defined as the responses of a tribo- system. Co-efficient friction and wear rate define the state of contact of bodies not the material properties of the bodies. Although in some special cases of contact, they can be treated as the material properties of the bodies. Both friction and wear can be treated as two kinds of responses from one tribo-system and are related with each other in each and every state of contact. Now days in addition to traditional method of lubrication methods like soft or hard film coating, multi-phase alloying and composite structuring have been developed to control the friction and wear. To study the tribo-characteristics of materials we should first understand the wear mechanisms in which roughness, hardness, ductility, oxide film, reaction layer and adhesive transfer play a significant role. Friction is the force that occurs between two contact surfaces in relative motion, whereas wear is the phenomenon of mechanical and/or chemical damage that affects the quality of the materials in contact with each other.

4.3. Wear Calculation

1. **Coefficient of friction,** μ = Frictional Force (N) / Normal Load (N)

2. **Sliding Velocity, U** = πDN (m/s) / 60 x 1000

D is the Wear track diameter (mm)

N is the Disc Speed (rpm)

3. **Sliding Distance, D** = πDNT (m/s) / 60000
   T is the Testing Time (seconds)

4. **Mass Loss, M** = $m_1 - m_2$ (g)
   m_1 is the mass of the pin specimen before test (g)
   m_2 is the mass of the pin specimen after test (g)

5. **Volume Loss (Wear Volume), V** =Mass Loss (M) x 1000 (mm^3) / Density of the Pin Specimen (ρ)
   M is the Mass loss in g
   ρ is the Density of the Pin Specimen in g/cm^3

6. **Specific Wear Rate (SWR)** =Volume Loss (V) (mm^3/Nm) / Load x Sliding Distance (D)

4.4. Specific wear rate for pin specimen

Material	Dimple shape	Weight (W1) grams	Weight (W2) grams	Mass oss, M (g)	Volume Loss, V (g)	Specific Wear Rate, (SWR) $\frac{mm^3}{Nm}$
Aluminum Alloy	Circle	6.175	6.102	0.073	36.5	8.11×10^{-3}
	Circle+ Hexagon	6.723	6.15	0.073	36.5	8.11×10^{-3}
	Circle+ Ellipse	6.193	6.134	0.059	29.5	6.55×10^{-3}
	Hexagon	6.235	6.0162	0.072	36	8×10^{-3}
	Ellipse	6.163	6.112	0.051	28.5	5.66×10^{-3}
	Hexagon +Ellipse	6.203	6.144	0.059	29.5	6.55×10^{-3}
Mild Steel	Circle	17.169	17.080	0.089	44.5	9.88×10^{-3}
	Circle+ Hexagon	17.200	17.098	0.102	51	11.33×10^{-3}
	Circle+ Ellipse	17.204	17.183	0.101	50.5	12.2×10^{-3}
	Hexagon	17.258	17.047	0.161	80.5	17.88×10^{-3}
	Ellipse	17.216	17.118	0.098	49	10.86×10^{-3}
	Hexagon +Ellipse	17.197	17.015	0.182	91	20.2×10^{-3}

5. **Results and Discussions**

The following graphs shown in Figures. 5 and 6 depicts the different values of coefficient of friction for various dimple structures and untextured pin vs Sliding Distance. From the following graphs we can evidently prove that which dimple structure has less wear rate in terms of coefficient of friction. Plot between COF and sliding distance are plotted, major inference analyzed from most of the graphs is as time goes the wear also increases this is because temperature goes on increasing which softens the material.

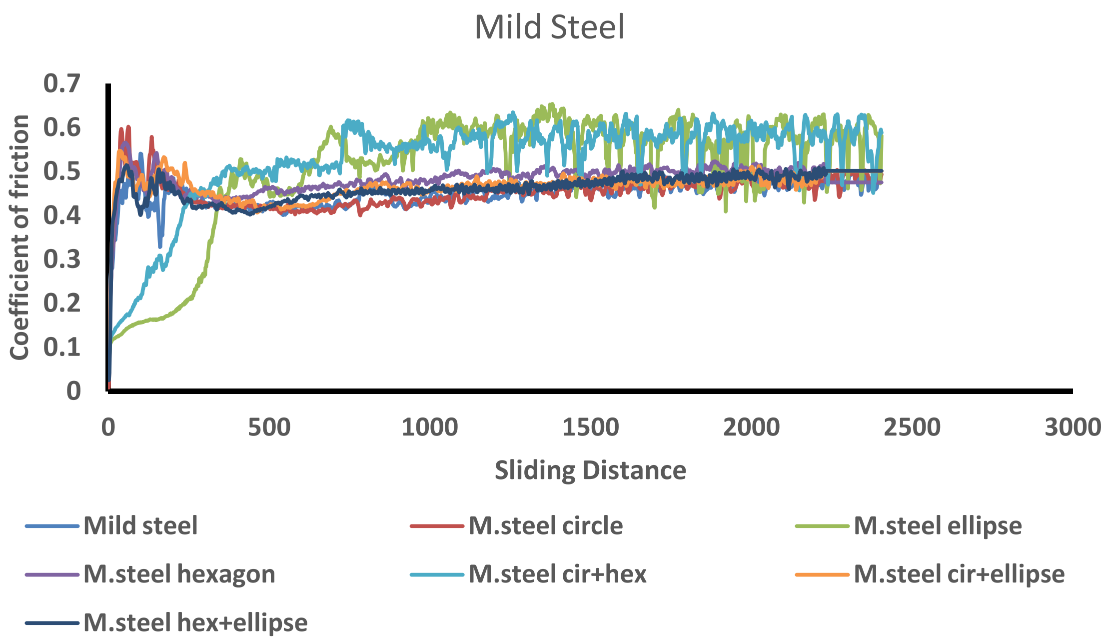

Fig. 5 Coefficient of Friction Vs Sliding Distance of Mild steel

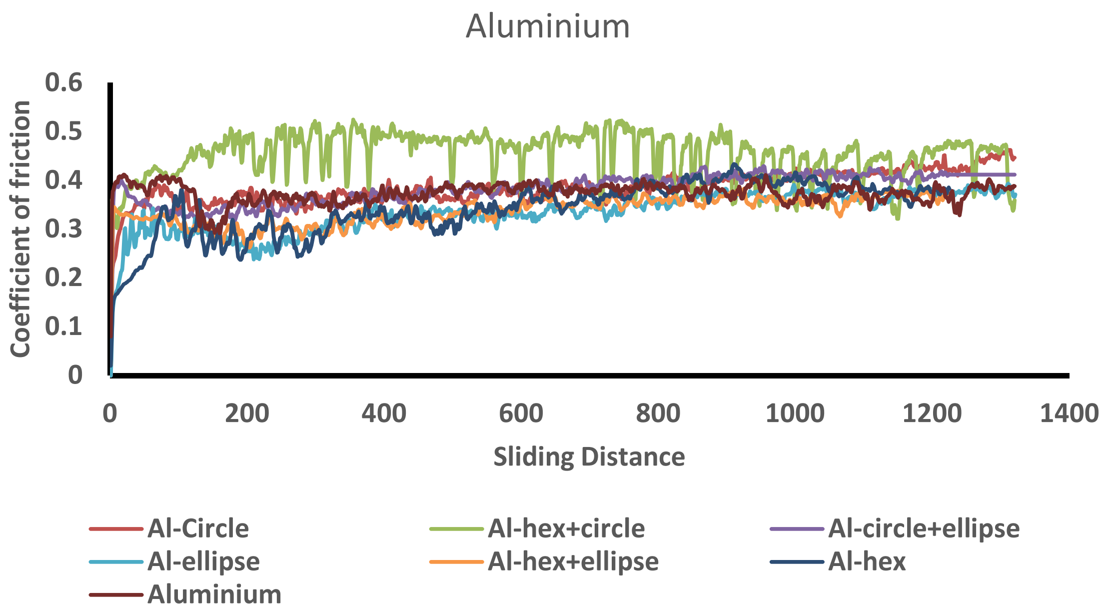

Fig. 6 Coefficient of Friction Vs Sliding Distance of Aluminium Alloy

Initial sudden contact rise the value of Coefficient of friction against frictional force because there occurs an adhered contact between the two materials which makes it to remain constant. At the final stage the adhered layer gets removed and sticks to the disc surface thereby increasing the coefficient of friction again.

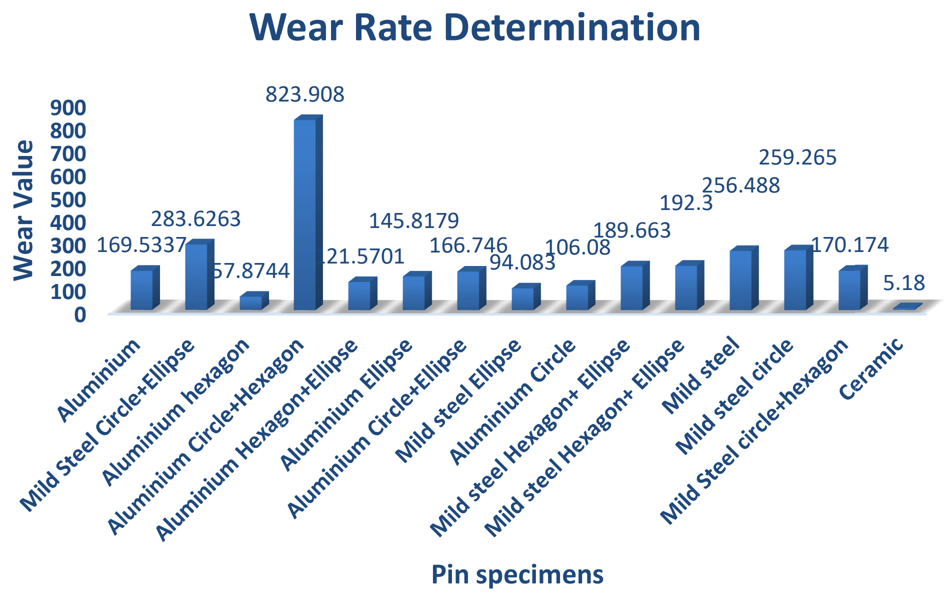

Fig. 7 Wear Vs Different combinations of Texturing and Materials

As we can clearly see from the graphs shapes like hexagon tends to increase wear in most of the cases while the shapes like ellipse and circle tends to decrease the wear rate this trend is attributed due to sharp nature of edges in hexagon while there is slightly curved edges in ellipse and circle which majorly decreases the wear rate as shown in Figure. 7. A clear trend is also observed in case of the combination of circle and ellipse dimple where wear rates are decreasing to a large level than in other cases.

Dimples tend to reduce the wear rate because of lower surface contact between the two wearing surfaces and those wear debris will be filling the dimple without falling making it less polluting and environmental friendly in brake pad application. Ceramic has the least wear value this is because of its less wear ability and strong adhesion between the surface material and fillers. Mild steel has the higher wear rate this is because of it has a good adherence property with the disc which makes it more comfortable for larger adherence wear so the wear is greater in mild steel.

6. **Conclusions**

Using Laser engraving method different dimples where made on the surface of the specimen and with the help of pin-on-disk tribometer, the wear characteristics were examined and determined. The following bar graph shows the wear rate determination.

- From the bar graph above we are able to see that Aluminum circle + Hexagon has the highest wear rate while, ceramic has the lowest wear rate.
- Among Aluminum, Aluminum with hexagonal dimple has the lowest wear rate of $57.874\frac{mm^3}{Nm}$.

- Among steel, Steel with elliptical dimple has the lowest wear rate of $94.083\frac{mm^3}{Nm}$.

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