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# Some Aspects Of Sliding Velocities And Applied Normal Loads On The Accelerated Wear Behaviour Of Sintered Fe-16%Cu-2.50%Mn-0.95%Cr-3.25%C P/M Steels

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***Abstract: -*** The present investigation is aimed to generate experimental data on the wear behaviour of sintered Fe-16%Cu-2.50%Mn-0.95%Cr-3.25%C preforms under furnace cooled and oil quenched condition on a pin-on-disc machine at two different sliding velocities: 2.09 and 4.19 m/s with three different loads, 1.10, 1.55 and 1.90 Kg respectively. Preforms were made from thoroughly blended iron, copper, manganese, chromium and graphite elemental powders in the required proportion to attain the above composition for 30 hours in a pot mill. Compacts of blended powders were prepared on a 1.0MN capacity UTM using a suitable die set assembly and controlling the densities in the range of 90±1 per cent of theoretical with 1.32±0.01 initial aspect ratio. Preforms were coated with the indigenously developed ceramic coating, sintered at $1050^0 \pm 10^0$C for a period of 100 minutes, half were oil quenched and half were furnace cooled. These were separately machined to required dimensions and then subjected to an accelerated wear test on a pin-on-disc machine. Experimental data and calculated parameters revealed that wear resistance was improved when the specimens were oil quenched. Higher, loads and higher sliding velocities resulted in higher wear rates. Several empirical relations were established to describe the wear behaviour.

***Keywords: -*** *behaviour, experimental, generate, sliding, velocity, wears*

## I. INTRODUCTION

Loss of mechanical performance and material loss control can be successful, if and only if, substantial reduction in wear is achieved which would cause considerable savings. Basically, friction is the major cause of wear and high energy dissipation. Tribology derived from Greek word ‘tribos’ meaning rubbing or sliding [1] is defined as the “science and technology of interacting surfaces in relative motion and of related subjects and practices”. Tribologies in fact deals with the technology of lubrication, friction control and wear prevention of surfaces having relative motion under applied load. Thus, the surface interaction controls the functioning of practically every mechanical device that was and is designed by man. Every thing that the man makes out wears out, almost always as a result of relative motion between surfaces and hence , most of the machine break – downs are due to failures and stoppages associated with interfacing moving parts such as gears, bearings, couplings, sealings, cams, clutches etc. It has been reported [2] that sweating on palms of hands or soles of feet of humans and dogs, has the ability to raise friction between the palm or feet and a solid surface. Thus, the practical objective of Tribology is to minimize the two main disadvantages of solid to solid contacts, i.e., friction and wear, but this is not always the case. However, in certain situations, minimizing friction and maximizing both friction and wear is desirable. For instance, reduction of wear but not the friction is most desirable in brakes and lubricated clutches, reduction of friction but not wear is desirable in pencils, increase in both friction and wear is most desirable in erasers.

Wear predominantly occurs in components like gears, piston rings sleeves etc. Metallic tribological components have been manufactured by casting or forging followed by machining to required dimensions. Once the machining operation is completed the mating surfaces are subjected to special finishing such as plating and chemical treatment processes. However, Powder Metallurgy (PM) is an alternative method of shaping components. PM is a highly developed technology of manufacturing ferrous and non ferrous parts. Many components are being produced by following PM route because the properties obtained are unique and quite often superior to conventionally produced parts. Main advantages of PM routes are achievements of high dimensional accuracy and minimal material wastage since the powder blends obtained are uniform and homogeneous. PM parts, generally, weigh from less than an ounce to nearly 1000, i.e., around 450 Kg. However, most P/M parts weigh less than 5lb (2.3 Kg) [3]. Micro-wave sintering of PM Green compacts comprising of various metal alloys such as Fe – Cu – C, Fe – Ni – C, WC – Co systems produced is highly improved sintered bodies in a very short duration of time with 20 to 30 per cent increase in wear performance when compared to conventionally produced parts [4].

Wear resistance of high speed tool steels, among the most wear resistant alloys produced by conventional metallurgical processes is due to the composite microstructure of a martensitic matrix and reinforcement of various metal carbides. But, the hot workability considerations limit the carbide content to the ranges associated with conventional alloy compositions. However, PM techniques allow these steels to be loaded with extra reinforcements via co-blended alloy steel and carbide powders. Further in addition to reinforcements such as alumina are effectively used as they pose no dissolution difficulties, as might the carbides. Twenty per cent volume fraction of reinforcements with alumina has been reported to enhance the wear resistance of M2 steel by an order of magnitude [5]. Apart from the above, new anti – friction materials based on iron – copper powders with several additional elements such as tin, lead and molybdenum di – sulphide have been developed via PM technique in order to exhibit improved anti – friction and mechanical properties. It has been reported [6] that the linear wear rates and gravimetric wear rates were reduced as the lead contents was decreased. It is also reported [7] that the optimum amount of copper added to Fe – Cu – C sintered bearing materials for high contact pressure ranges varied between 14 to 18 per cent by mass. Similarly, the addition of hard particles though improve the wear resistance, but, in excess cause damage to the shaft. Therefore, an optimum limit has been adopted which ranged in between 10 – 15 per cent by mass.

Around 215 years ago, it was proposed by Jacobs Rowe that by the application of the rolling element, i.e., bearings to the carriages in U.K. could save one million pounds per annum in early 18th century [8]. In 1966, Peter Jost reported [9] that by the application of the basic principles of tribology, the economy of U.K. could save approximately 515 million pounds per annum at 1965 values. A similar report published in West Germany in 1976 revealed that the economic losses by friction and wear cost about 10 billion per annum at 1975 values which equals to the 1 per cent gross national product. However, 50 per cent of these losses were attributed to wear. In U.S.A. it has been estimated that about 11% of the total energy annually can be saved in four major areas of transportation, turbo machinery, power generation and industrial process through technical progress in tribology [10].

In order to understand the wear mechanism, it is important to know the basics of molecular theory of wear and also wear rate.

### I.1 Molecular Theory of Wear

The degree of proximity of two surfaces that is their compliance mainly depends upon the statistical chance as the surfaces separate in the horizontal plane during sliding and trying to make due to the attractive force between their atoms. Once sufficiently close, the atoms will be repelled and its natural tendency is to return back to its original position. However, it is plausible hypothesis that an atom can be dislodged and moves for enough to come within the field of another atom in the opposite surface where it finds a new equilibrium position. Thus, this means that atoms from one body can be plucked by other in the opposite surface. According to Tomlinson [11], this is the mechanism of wear. Energy dissipated by an atomic couple is $F_oL$, where $F_o$ is the inter atomic force of cohesion and L is the distance of separation. If ρ is the density of the metal which is wearing, the mass of an atom is $m= \rho E^{3,}$ where E is the distance between successive row of atoms. If E is the total energy dissipated, the number of atomic junction 'N' is given by

$$N = E_t/F_o \qquad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Total mass of the atom being removed from the surface is,

$$M = N \qquad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$M = E_t\, \rho E3 / F_oL \qquad \ldots\ldots\ldots\ldots (3)$$

$$F_oL = \mu E \rho_o / \alpha \qquad \ldots\ldots\ldots\ldots\ldots (4)$$

$$M = \alpha\, E_{t\, \rho E2} / \mu\, \rho_o \qquad \ldots\ldots\ldots (5)$$

Flow stress $\sigma_y$ is the limiting force that the space lattice can withstand and, i.e. given by

$$\sigma_y = \rho_{max} / E^2 \qquad \ldots\ldots\ldots\ldots (6)$$

Where, $\rho_{max} = 2P_{o,}$ the mean repulsive force and, therefore, M is given by:

$$M = 2\, \alpha\, E + \rho / \mu\, \sigma_y \qquad \ldots\ldots (7)$$

Total mass of the metal removed is inversely proportional to the applied pressure.

### I.2 Wear Rate

Holm [12] proposed that as sliding commences, atom to atom contact removes surface atoms at favorable encounters so that the loss of volume, V for sliding distance, S is given by:

$$V = ZA_tS \qquad \ldots\ldots\ldots\ldots (8)$$

Where, $A_t$ is the true contact area, Z is the number of atoms removed per encounter. But, according to the friction laws, $A_t$ is given by:

$$A_t = W/\sigma_y \qquad \ldots\ldots\ldots(9)$$

Where, W is the applied load and $\sigma_y$ is the flow pressure of the softer metal.
Substituting for $A_t$, equation (8) can be rearranged as:

$$V/S = ZW/\sigma_y \qquad \ldots\ldots\ldots \ (10)$$

The term V/S is the volume rate of wear per unit sliding distance and it is inversely proportional to the flow stress. Thus, it is clear that the total volume of material removed due to sliding is proportional to the applied normal load, the sliding distance and inversely proportional to the flow pressure of the material. Some important investigations are reported elsewhere [13-25].

Present investigation is aimed to generate experimental data on the accelerated wear behaviour of sintered Fe-16% Cu-2.50%Mn-0.95Cr-3.25%C preforms under furnace cooled and oil quenched conditions on a pin-on –disc machine. Data were obtained and analyzed under three loading conditions and two different sliding velocities.

## II. EXPERIMENTAL DETAILS

Experimental details include the materials required and their procurements, instruments and equipment that are essentially required are identified and ensured for their availability. Further, powder charact erization such as chemical analysis and sieve size analysis needed to be carried out. Apart from these, the preparations of homogeneous powder blends are required to be experimentally carried out. Compact preparation and application of indigenously developed ceramic coating on the compact surfaces are detailed followed by sintering and subsequent treatments are highlighted. Standard specimens for accelerated wear tests were then prepared and tested.

### II.1 Materials Required

Commercially pure atomized iron powder of -180µm was procured from Sundaram Fasteners Limited Hyderabad, India and electrolytic grade of copper powder of -63 µm, manganese and chromium powder were obtained from Ghrishma Specialty Materials, Mumbai and Maharashtra, India. However, the graphite powder of 3-5 µm was provided by courtsy Ashbury Mills Inc., New Jersey. USA

### II.2 Instruments and Equipment Required

Sieve Shaker, pot mill for powder mix blending, stainless steel pots and porcelain balls in the diameter range of 10-20 mm, Hall flow meter for measuring apparent density and flow rates, die set assembly for compaction. Hydraulic press of 1.0MN capacity, sintering furnace which is capable of operating upto 1250±10ºC and an electronic balance capable of measuring 0.0001gm are required.

### II.3 Powder and Powder Blend Characterization

The sieve size analysis of iron powder is given in Table-1. Flow rate, apparent density and compressibilities are listed in Table-2. Atomized iron powder of -180 µm has been analyzed for chemical purity and it was found to be 99.67 per cent of pure with 0.33 per cent being insoluble impurities.

**Table: 1. Sieve Size Analysis of Iron Powder**

| **Sieve size, µm** | **Powder Size Distribution** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Wt % retained | -180<br>+ 150 | -150<br>+125 | -125<br>+106 | -106<br>+90 | -90<br>+75 | -75<br>+63 | -63<br>+53 | -53<br>+37 | -37 |
| Wt% powder retained | 1.52 | 1.83 | 23.12 | 1.11 | 21.86 | 2.21 | 18.60 | 13.62 | 16.11 |
| Cum, Wt% powder Ret. | 1.52 | 3.35 | 26.47 | 27.58 | 49.44 | 51.65 | 70.25 | 83.87 | 99.98 |

### II.4 Blending of Iron, Copper, Manganese Chromium and Graphite Powder

Powder blend of iron, copper, manganese and graphite elemental powders was prepared by blending the required amount of each of the above powders so as to yield the final sintered composition of the alloy as Fe-16%Cu 2.50%Mn-0.95%Cr-3.25%C. the powder mix was taken in a stainless steel pot with a powder to porcelain ball weight ratio of 1:1.1. Blending operation was carried out for a period of 36 hours so as to obtain homogeneous powder blend. During blending operation 100 g of powder mix was taken at an interval of every one hour to measure the apparent density and flow rates. Immediately after measuring the apparent density and flow rate, the powder mix was returned back to the pot and the blending operation was continued till consistency in apparent densities and flow rates were obtained.

**Table: 2. Characteristics of Iron Powder and Powder Blends**

| Property | Systems | |
|---|---|---|
| The density, g/cc | Iron | Fe -16%Cu-2.50%Mn-0.95%Cr-3.25%C |
| Flow rate, Sec/100g | 48.35 | 46 |
| Compressibility g/cc at a pressure of 480±10 M Pa. | 6.667 | 6.711 |
| Apparent density, g/cc. | 3.352 | 3.257 |
| Theoretical density | 7.850 | 7.461 |

### II.5 Cold Compaction

The cold compaction of the above elemental powders blend was carried out on a 1.0 MN capacity Universal Testing machine by using suitable die; punch and bottom insert assembly. Graphite paste in acetone was used as lubricant during compaction of the powder blend on the inner surfaces of the die, the outer surfaces of the punch and the bottom insert. Compact density was maintained in the range of 90±1 per cent of theoretical by applying the pressure in the range of 590±1 MPa and by taking controlled amount of powder blend. The compact dimensions were as 28.5mm diameter and 31.5mm height.

### II.6 Application of Indigenously Developed and Modified Ceramic Coating

Indigenously developed modified ceramic Coating [26] was applied on to the entire surfaces of all the compacts as a thin film and this coating was allowed to dry for a period of twelve hours under ambient conditions. Recoating was done 90° to the previous coating and re- allowed to dry for a further period of twelve hours under the aforesaid conditions.

### II.7 Sintering and Treatment

Ceramic coated compacts were sintered in the temperature range of 1050±10°C in an electric muffle furnace in the uniform temperature zone for a period of 100 minutes. Equal number of sintered compacts were cooled inside the furnace and oil quenched. A total of eight were oil quenched and eight were furnace cooled. Ceramic coated compacts were protected against oxidation during sintering as this coating has been impermeable upto 1300± 10° C which was tested prior to using the same in the present investigation.

### II.8 Specimen Preparation for Wear Test

Immediately after the removal of residual ceramic coatings after sintering and treatments were machined to 26.5 mm diameter and 24 mm height. Precaution has been exercised to obtain smooth and scratch free surface during machining and final surface finishing operations.

### II.9 Accelerated Wear Test

Pin-on-disc machine is a popular wear testing apparatus where the pin is loaded normally. The variable which can be changed as desired are the normal load, sliding contact velocity, specimen surface finish and wheel surface. However the amount of wear can be established by weighing the weared specimen on an electronic balance at each interval of time, say, 30 minutes. A complete wear test involves plotting weight loss/area against the sliding intervals to obtain steady state wear pin-on–disc machine. This machine consists of an abrasive wheel (carboraundum) which is made to rotate in the horizontal plane by an electric motor. A pin holder with a groove of dimension 27mm diameter and 12mm depth is placed vertically on the top of the wheel at certain height with a provision to vary its height. It also consists of a through hole in order to give access to apply loads on the pin. Pin is loaded using a rod to which various weights can be attached to its head. Specimen can be subjected to loads of 1.10, 1.55 and 1.90 kg respectively by means of a specimen holder. Two sliding velocities at all three loads were used during the wear test. These speeds were 2.09m/s and 4.19m/s respectively. Specimens were placed at 80 mm away from the centre of the wheel disc.

## III. RESULTS AND DISCUSSION

Accelerated wear test data and calculated parameters wear utilized to draw various plots to establish empirical relations between weight loss per unit area (g/m$^2$) and the sliding distance (Km) and also between wear volumes (cc) with the sliding time in minutes. Further plots were also drawn to assess the effects of applied loads, sliding velocities and the type's treatments given to the specimens prior to the accelerated wear test.

### III.1 Characteristic Plots between Weight Loss per Unit Area (g/m$^2$) and the Sliding Distance (Km)

Figs.-1(a) and 1(b) have been drawn between the Weight loss per unit area (g/m$^2$) and the sliding distance (Km) showing the effects of applied loads and the sliding velocities for furnace cooled and oil quenched specimens respectively. Observing the curves in these figures, it is observed that the characteristic nature of the curves drawn in these figs. -1(a) and 1(b) are quite similar to each other and, therefore, these curves must be governed by a similar mathematical expression. It is found that these curves conformed to a third order polynomial of the form:

$$W_g = A_0 + A_1 S + A_2 S^2 + A_3 S^3 \ldots\ldots\ldots\ldots (11)$$

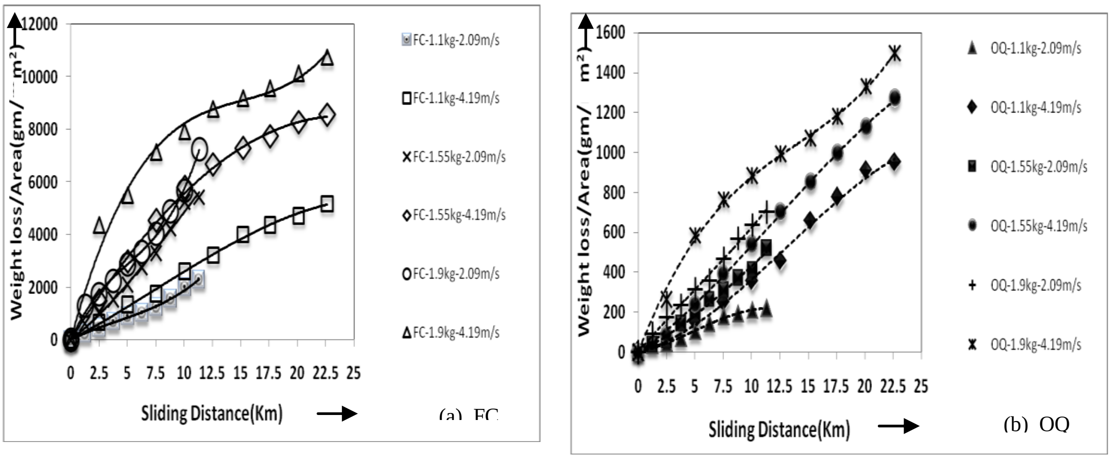


**Figure 1: Plots Loss/Area (g/m$^2$) and between Weight Sliding Distance (Km); (a) Furnace cooled and (b) Oil Quenched Specimens under Accelerated wear Test.**

Where, ‘$A_0$’, ‘$A_1$’, ‘$A_2$’ and ‘$A_3$’ are empirically determined constants which depend upon the applied loads and the sliding velocities. But, ‘$W_g$’ represents the weight loss per unit area(g/m$^2$) and ‘S’ being the sliding distance in Km. the values of these constants are listed in Table-3. It is further observed that, in general, the curves exhibited the tendency to exhibit higher wear rate at higher applied loads at a constant sliding velocity. However, at constant sliding velocity, the wear rate was higher for 1.90 Kg normal load applied and decreased successively for 1.55 Kg and 1.10 Kg normal loads. Once the normal load acting on the specimen was raised, the number of contact points also increased resulting into cold welding taking place locally and the relative, motion between the disc and specimen break the junction and thus incurring weight loss. However, at constant load, the wear rate was found to be higher at a greater sliding velocity. Now, therefore, it can be conclusively inferred from these figures that the wear rate increased with increase in either load or by increase in sliding velocity or both. Further for all curves it is observed that the wear rate is higher at initial stages of the test compared to the later stages of each curve (for a given load and a given sliding velocity). However, the wear rate remained virtually constant after certain sliding distance and this is attributed to the change in roughness of the specimen and the grinding disc. The constant ‘$A_0$’ is always remained zero because at no wear no weight loss principle being valid. Therefore, $A_0$ is not listed in this table. The coefficient ‘$A_1$’of S increases with increase in normal load at both sliding velocities, namely 4.19 m/s and 2.09 m/s respectively. Therefore, this certainly reflects higher wear rates at higher applied normal loads. But, the coefficient of ‘$A_2$’ of $S^2$ for sliding velocity of 4.19 m/s at 1.90 Kg and 1.55 Kg loads was found to be negative, thus, showing the tendency to decrease the wear rate. But, the magnitude of ‘$A_2$’is more in this case for (1.90 Kg at 4.19 m/s), and, hence, the wear rate. ‘$A_3$’the coefficient of $S^3$ increased with an increase in the applied loads, thus, showing an increase in the wear rate reduction which was more in this case. However, at (1.10 Kg and 4.19 m/s velocity), ‘$A_2$’ is a positive value showing the steady increase in wear rate. Same explanation holds good for all the other curves corresponding to sliding velocity of 2.09 m/s with the respective loads of 1.10, 1.55 and 1.90 kg. Since,

**TABLE: 3 Coefficient of Second Order Polynomial of the Form: Wg = $A_0 + A_1S + A_2S^2 + A_3S^3$ for Fe-16.0%Cu- 2.50% Mn-0.95% Cr-3.25%C Under Furnace cooled and Oil Quenched Between Wt. Loss (g/mm$^2$) and the Sliding Distance in km.**

| Sliding velocity, m/s | Treatment | Applied Load, Kg | $A_1$ | $A_2$ | $A_3$ | $R^2$ |
|---|---|---|---|---|---|---|
| 4.9 | FC | 1.10 | 230.69 | 5.2718 | -0.2389 | 0.9977 |
| | | 1.55 | 695.79 | -13.487 | -0.0294 | 0.9981 |
| | | 1.90 | 1577.3 | -96.964 | 2.1465 | 0.9872 |
| 2.09 | FC | 1.10 | 217.35 | -16.364 | 1.3537 | 0.9958 |
| | | 1.55 | 328.48 | 23.123 | -0.731 | 0.9932 |
| | | 1.90 | 950.71 | -112.99 | 7.5553 | 0.9969 |
| 4.19 | OQ | 1.10 | 14.575 | 2.914 | -0.0735 | 0.9948 |
| | | 1.55 | 39.617 | 1.8706 | -0.0512 | 0.9995 |
| | | 1.90 | 146.75 | -7.7838 | 0.1866 | 0.9976 |
| 2.09 | OQ | 1.10 | 11.711 | 2.9547 | -0.2029 | 0.9933 |
| | | 1.55 | 28.099 | 2.0429 | -0.053 | 0.9929 |
| | | 1.90 | 67.394 | -1.4046 | 0.0911 | 0.9960 |

the values of Regression coefficient '$R^2$' in all these cases was found to be almost unity and hence the third order polynomial arrived at, stands justified.

### III.2 Logarithmic Plots between Weigh Loss (g/m$^2$) Per Unit Area and the Sliding Distance (Km)

Figs.-2(a) and 2(b) have been drawn between log (weight loss (g/m$^2$)) and the log sliding distance in km for sintered furnace cooled and oil quenched specimens respectively. The plots shown in these figs. were found to be represented by a straight line equation of the form:

$$\text{Log } (W_g\ (g/m^2)) = M \log (S) + N \ldots\ldots\ldots.. (12)$$

Where, 'M' and 'N' are empirically determined constants. Values of these constant are given in Table -4.The above expression can also be expressed as under:

$$W_g = NS^M \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (13)$$

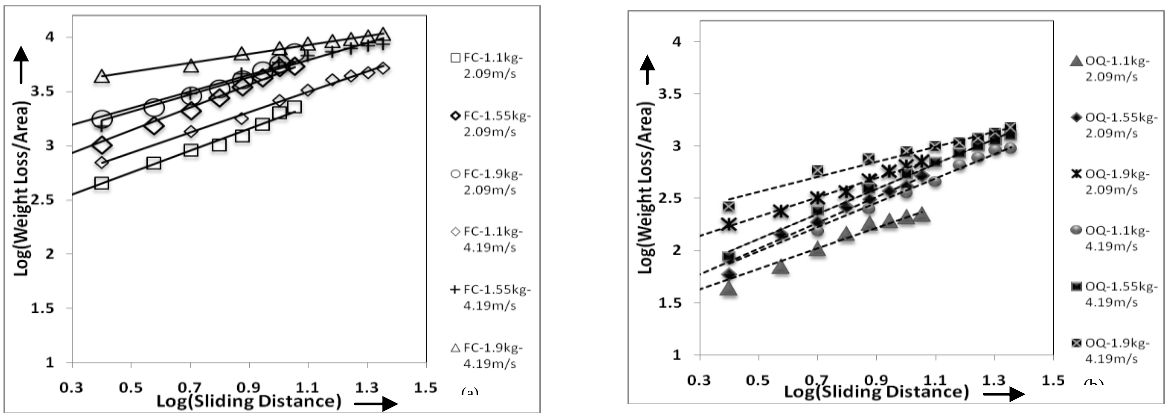


**Figure 2: Log-Log Plots Between Weight Loss (g/m$^2$) and the Sliding Distance (Km) for (a) Furnace Cooled and (b) Oil Quenched Specimens during Accelerated Wear Te**

**Table: 4 Coefficients and Exponents of Equation: $W_g = NS^m$ for Fe -16.0% Cu – 2.50%Mn – 0.95 Cr – 3.0% C**

| Treatment | Sliding velocity, m/s | Applied Load, Kg | M | N | $R^2$ |
|---|---|---|---|---|---|
| FC | 4.29 | 1.10 | 0.9366 | 2.4677 | 0.9957 |
| | | 1.55 | 0.7936 | 2.9143 | 0.9726 |
| | | 1.90 | 0.4155 | 3.4723 | 0.9896 |
| | 2.09 | 1.10 | 1.0145 | 2.2458 | 0.9895 |
| | | 1.55 | 1.0514 | 2.6185 | 0.9895 |
| | | 1.90 | 0.7112 | 2.9881 | 0.9653 |
| OQ | 4.29 | 1.10 | 1.1659 | 1.4608 | 0.9903 |
| | | 1.55 | 1.2164 | 1.4974 | 0.9946 |
| | | 1.90 | 0.7228 | 2.1992 | 0.970 |
| | 2.09 | 1.10 | 0.9822 | 1.3317 | 0.9693 |
| | | 1.55 | 1.2387 | 1.3966 | 0.9823 |
| | | 1.90 | 0.9216 | 1.8635 | 0.9943 |

Since the regression coefficients are in close proximity to unity, and, hence, the power law equation is justified.

### III.3 Effect of Sliding Velocity at Constant Loads

Figs.-3(a) and 3(b) are drawn between weight loss per unit area (g/m$^2$) and the sliding distance (Km) showing the effect of sliding velocity for sintered, but, furnace cooled and oil quenched specimen respectively. Both of these figures clearly show that the wear rate is quite high when the sliding velocity has been to 4.19 m/s from 2.09 m/s at the constant load of 1.10 Kg.

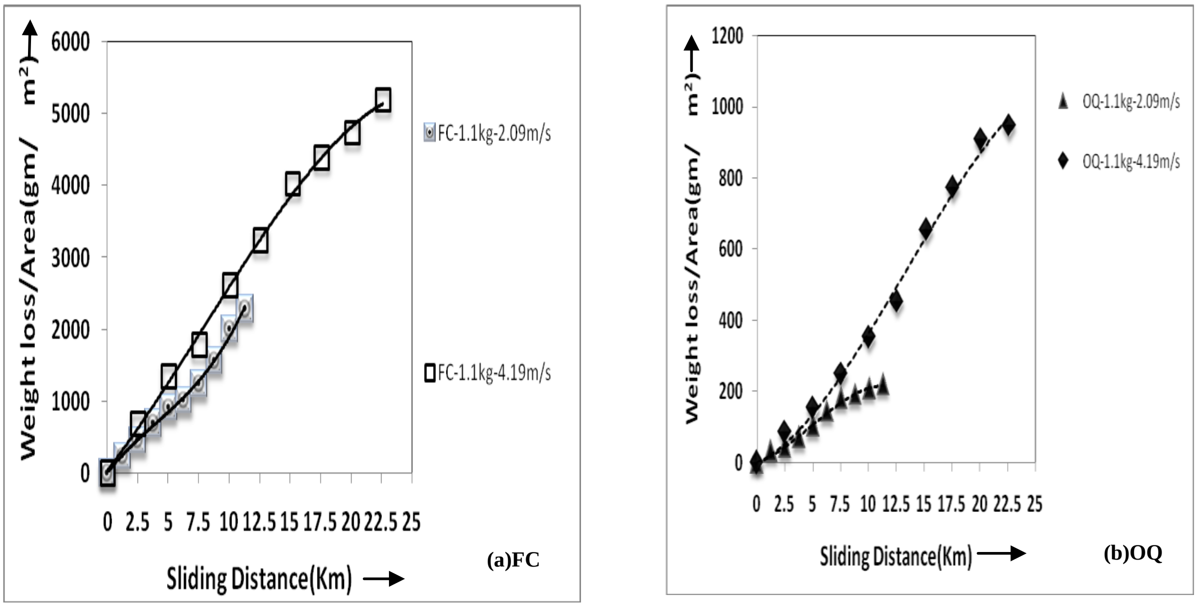


**Figure 3: Effect of Sliding Velocity on Weight Loss per Unit Area against Sliding Distance for Sintered (a) Furnace Cooled (FC), and, (b) Oil Quenched (OQ) at Constant Load.**

### III.4 Effect of Applied Loads on Weight Loss for Unit Area (g/m$^2$) and the Sliding Distance in (km)

Figs.-4(a) and 4 (b) have been plotted between weight loss per unit area (g/m$^2$) and the sliding distance (Km) exhibiting the effect of applied normal. It is, quite clear from these two figures that higher has been normal applied loads higher has been the wear rate and vice - versa is also true. This is true irrespective of the treatment given to the specimen prior to the wear test.

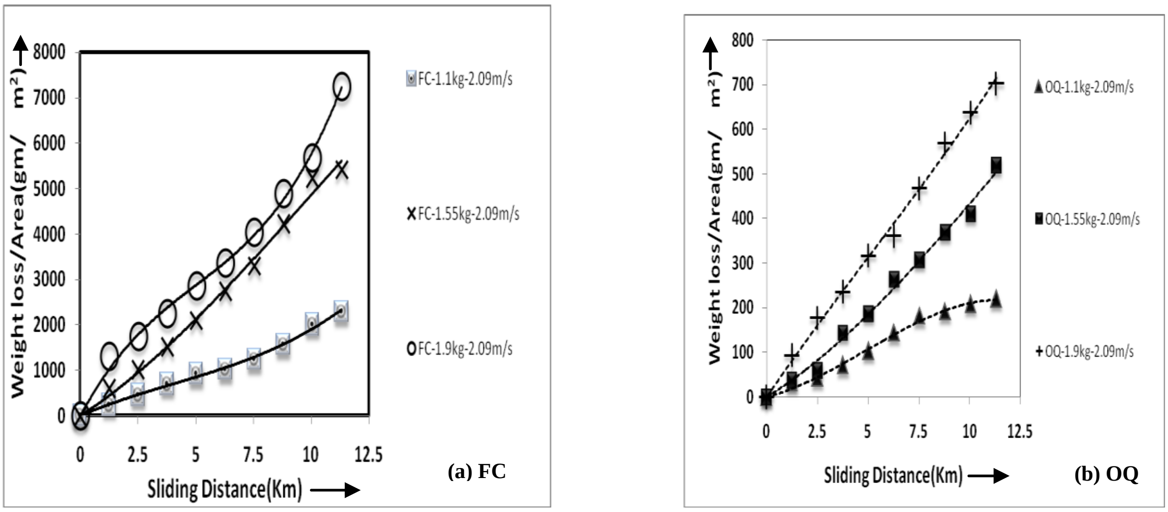
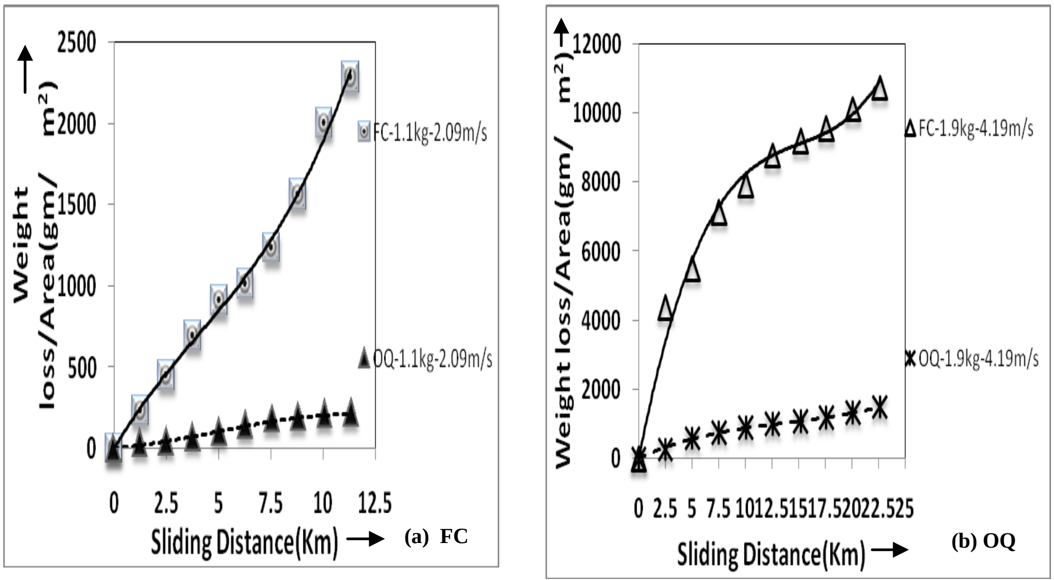


**Figure 4: Effect of Applied Loads on the Plots Drawn between Weight Loss and Sliding Distance at Constant & Sliding Velocity for Sintered (a) Furnace Cooled and (b) Oil Quenched Specimens During Accelerated Wear Test**

### III.5 Effect of Treatments on the Relationship between Weight Loss (g/m$^2$) and the Sliding Distance

Figs.–5(a) and 5(b) exhibit the effect of treatment given to the sintered specimens prior to the conduction of accelerated wear test on the relationship between weight loss (g/m$^2$) and the sliding distance (Km).Fig. – 5(a) corresponds to the constant applied load of 1.10 Kg whereas figure -5(b) represents the constant load of 1.90 Kg. both of these figures clearly indicate that the sintered but, furnace cooled specimen worn out at higher wear rates compared to the specimen sintered but oil quenched because of impregnation of 2-3 per cent coolant oil which provided improved lubrication during the wear test.

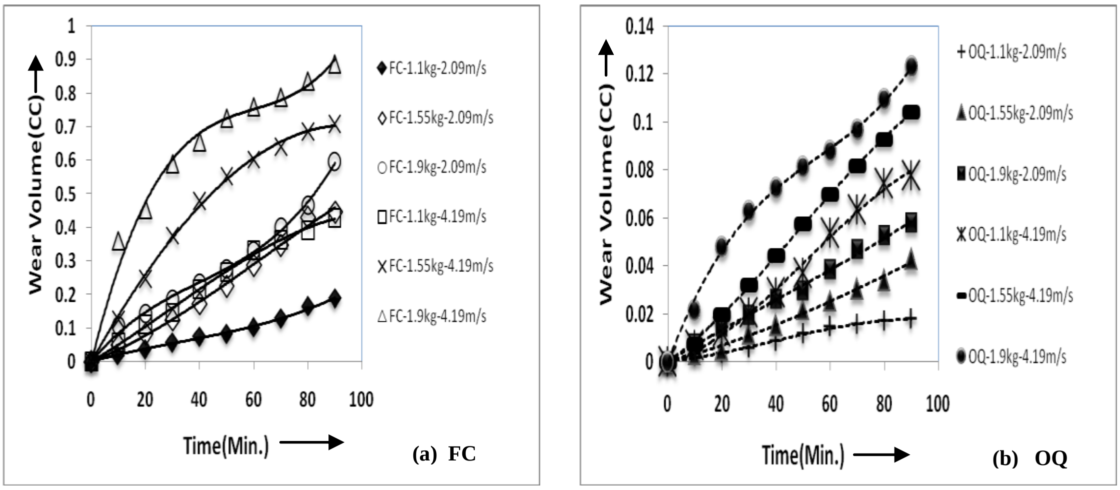


**(a) FC** **(b) OQ**

**Figure 5: Effect of Cooling Media on the Plots between Weight Loss per Unit Area (g/m$^2$) and the Sliding Distance at Constant Load for Sintered at (a) 1.1 Kg load &2.09 m/s Sliding Velocity and (b) 1.9 Kg Load &4.19 m/s Sliding Velocity during Accelerated Wear Test.**

### III.6 Wear Volume and the Time (min.) of Sliding

Figs.-6(a) and 6(b) have been drawn between the wear volume (cc) and the time (minutes) of sliding for sintered and (a) furnace cooled and (b) sintered but oil quenched specimen during accelerated wear test respectively at two different sliding velocities (4.19m/s & 2.09 m/s) and three different applied loads, namely, 1.10 Kg, 1.55 Kg and 1.90 Kg respectively. The characteristic nature of curves in these figs.– 6(a) & 6(b) are found to be quite similar



**(a) FC** **(b) OQ**

**Figure 6: Characteristic Plots Between Wear Volume (cc) and Time (Minutes) of Sliding at Given Sliding Velocities and Applied Loads for Sintered (a) Furnace Cooled and (b) Oil Quenched Specimens During Accelerated Wear Test.**

**Table: 4 Coefficients of the Third Order polynomial of the Form: $V_w = B_1T + B_2T^2 + B_3T^3$ between Wear Volume (cc) V/S Time (T) in Minutes**

| Sliding velocity, m/s | Treatment | Applied Load, Kg | $B_1$ | $B_2$ | $B_3$ | $R^2$ |
|---|---|---|---|---|---|---|
| 4.19 | FC | 1.10 | 0.0048 | 3.00E05 | -5.00E-07 | 0.9973 |
| | | 1.55 | 0.0144 | -7.00E05 | -5.00E-08 | 0.9981 |
| | | 1.90 | 0.0327 | -0.005 | 3.00E-06 | 0.9872 |
| 2.09 | FC | 1.10 | 0.0022 | -200E05 | 2.00E-07 | 0.9958 |
| | | 1.55 | 0.0032 | 400E05 | -2.00E-07 | 0.9946 |
| | | 1.90 | 0.0098 | -0.0001 | 1.00E-06 | 0.9969 |
| 4.19 | OQ | 1.10 | 0.0007 | 2.00E-05 | -1.00E-07 | 0.9945 |
| | | 1.55 | 0.0008 | 1.00E-05 | -7.00E-08 | 0.9982 |
| | | 1.90 | 0.003 | -4.00E-05 | 2.00E-07 | 0.9976 |
| 2.09 | OQ | 1.10 | 0.0001 | 4.00E-06 | -3.00E-08 | 0.9938 |
| | | 1.55 | 0.0003 | 3.00E-06 | -9.00E-09 | 0.9929 |
| | | 1.90 | 0.0007 | -2.00E-06 | 2.00E-08 | 0.9961 |

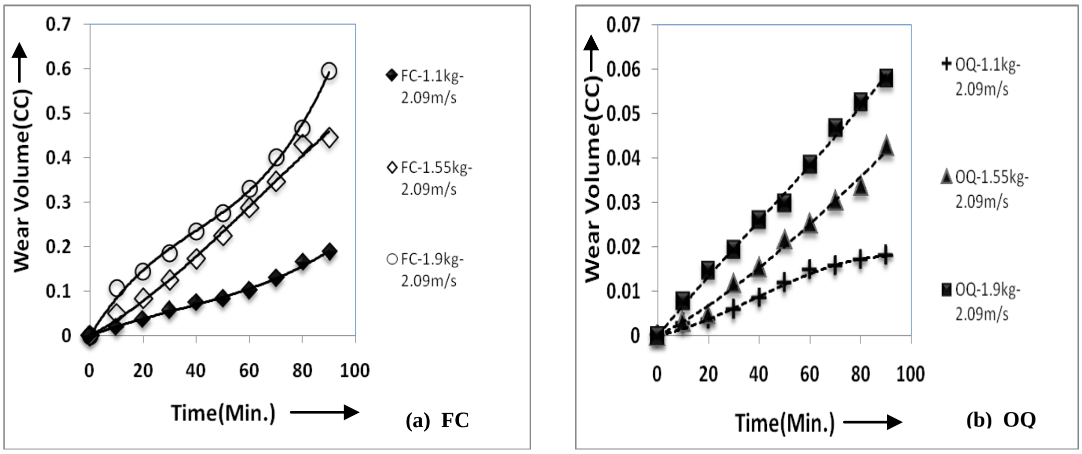
to each other and therefore, they must be governed by a similar mathematical expression. The curves corresponding to both heat treatment conditions conform to a third order polynomial of the form:

$$V_w = B_0+B_1T+B_2T^2+B_3T^3 \ldots\ldots\ldots\ldots\ldots (14)$$

Where ‘$B_0$’, ‘$B_1$’, ‘$B_2$’ and ‘$B_3$’ are empirically determined constants and are found to depend upon the sliding velocity and the applied normal load. ‘$V_w$’ represents the wear volume in cc and ‘T’ represents time in minutes. These constants are listed in Table -4. The constant ‘$A_0$’ has no influence on the curve as it is zero because at no wear no volume loss is there at starting time T =0. From these equations it is inferred that the wear is a function of time and wear volume increases with the increase in the applied normal load and the sliding velocity or both.

### III.7 Effect of Applied Loads on the Wear Behaviour Keeping Treatment and Velocity Constant

Figs.-7(a) and 7(b) are drawn between the wear volume (cc) and the time ‘T’ in minutes for sintered (a) furnace cooled and sintered, but (b) oil quenched conditions showing the influence of the applied normal loads. These figures clearly indicate that the higher values of applied normal loads result in enhanced wear volumes at a constant sliding velocity. Meaning thereby, that mainly the material is worn out at enhanced applied normal loads, and, the same is true irrespective of the heat treatments given to the sintered specimen prior to the condition accelerated wear test. These two plots are constructed at a constant sliding velocity of 2.09m/sec.



(a) FC (b) OQ

**Figure 7: Effect of Applied Loads on the Plots Between Wear Volume (cc) and Time (Minutes) of Sliding at Constant Velocity of 2.09m/s for Sintered (a) Furnace Cooled and (b) Oil Quenched Specimens During Accelerated Wear Test**

### III 8 Effect of Sliding Velocity on the Relation between Wear Volume and Time of Wear Test

Figure -8(a) and 8(b) are drawn between the wear volume (cc) and time of accelerated wear test ‘T’ in minutes at constant load but two different sliding velocities , namely , 2.09m/sec and 4.19m/sec respectively for sintered , but (b) oil quenched specimens. It is observed that higher is the sliding velocity higher is the wear volume worn out mechanism is already established earlier. Both figures 8(a) and 8(b) respectively exhibit similar pattern but changed wear rates.

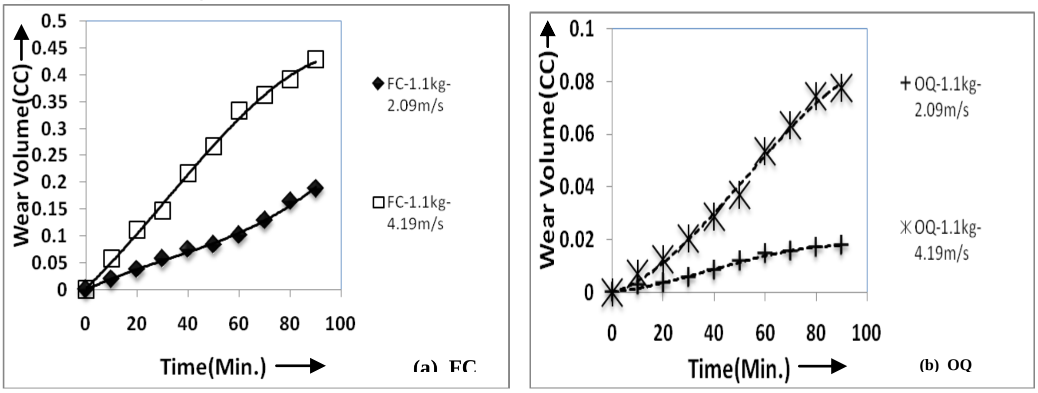


**Figure 8: Effect of Sliding Velocity on the Plots between Wear Volume (cc) and Time (Minutes) for Sliding at Constant Applied Load of 1.1 Kg for Sintered (a) Furnace Cooled and (b) Oil Quenched During Accelerated Wear Test.**

### III.9 Effect of Treatment on the Relationship between Wear Volume (in cc) and Time of Sliding (in minutes) at Constant Sliding Velocity

Figs.-9(a) and 9(b) are the plots drawn between the wear volume and the time in minutes showing the effect of cooling media at constant sliding velocities of 2.09m/s and 4.19m/s respectively. Visual observation of these figs. clearly asserts that irrespective of sliding velocity, the rate at which the wear volume for furnace cooled specimen rises up is comparatively much more than encountered by specimens which were sintered and oil quenched. Fig-9(a) was drawn for a normal applied load of 1.1 Kg and sliding velocity of 2.09m/s. whereas, fig.–9(b) corresponded to an applied normal load of 1.9Kg at a sliding velocity of 4.19m/s. Thus, the present investigation has comprehensively established the wear behaviour of sintered Fe-16% Cu-2.50%Mn-0.95%Cr – 3%C alloy of around 90% of its theoretical density value under sintered, but, oil quenched condition is far superior in performance compared to the specimens which were sintered and furnace cooled condition. In general, the wear behaviour of sintered oil quenched specimens was comparatively low as the absorbed oil has acted as lubricant. Hence, oil quenched material can be preferred for industrial applications.

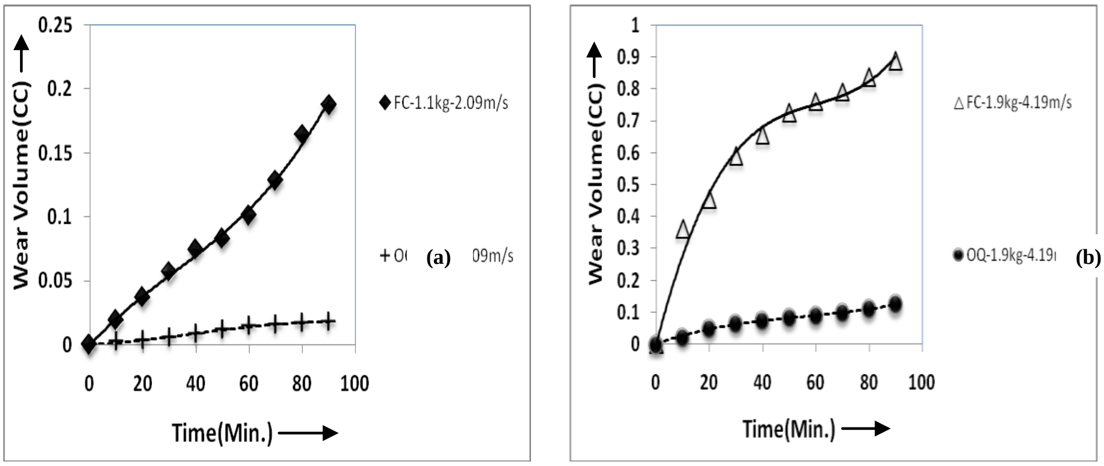


**Figure 9: Effect of Cooling Media on the Plots Between Wear Volume (cc) and Time (Minutes) for Sliding at Constant Load and Constant Velocity for Sintered (a) 1.1 Kg Load & 2.09 m/s Sliding Velocity and (b) 1.9 Kg Load &4.19 m/s Sliding Velocity**

## IV. CONCLUSIONS

Based on the critical analysis of the experimental data, calculated parameters and various plots drawn led to arrive at the following major conclusions:

1. Characteristic nature of all the curves drawn between weight loss / area ($g/m^2$) and the sliding velocity (m/sec) are found to be similar to each other irrespective of sliding velocity and the applied normal loads and the heat treatment given to the specimens. Mathematical analysis revealed that these characteristic curves corresponded to a third order polynomial of the form: $W_g = A_0+A_1S+A_2S^2+A_3S^3$; where, '$A_0$', '$A_1$', '$A_2$' and '$A_3$'are empirically determined constants and they are found to depend upon the sliding velocity and the normal applied loads. $W_g$ represents the weight loss per unit area ($g/m^2$) and 'S' is the sliding distance in Km,

2. The wear rate is found to increase with the increase in either load or in sliding velocity or both,

3. The wear rate is comparatively much higher for furnace cooled specimens compared to oil the quenched specimen,

4. All curves have revealed that the wear rate is much higher in the initial stages and comparatively slowed down in the final stages of wear which is attributed to the change in roughness of the specimen and the abrasive wheel,

5. Log- Log plots were drawn between weight loss per unit area and the sliding velocity (S/m) to obtain an improved and an accurate mathematical expression to explain the wear mechanism. Since, these plots yielded straight lines in two segments with two different slopes and two different intercepts. Therefore these lines, in general, can be expressed at a given normal load. The equation in general can be expressed in the form as : $\text{Log}(W_g) = M \log(S) + N$; where, M and N are empirically determined constants and S represents the sliding distance and thus the power law equation of the form: $W_g = NS^M$ is arrived at which is quite handy apply while interpreting the wear data, and,

6. Relationship between wear volume and time of wear test for both sintered furnace cooled and oil quenched specimens were established to be of the third order polynomial of the form :

$$V_w = B_o+B_1T+B_2T^2+B_3T^3$$

Where , '$B_o$', '$B_1$', '$B_2$' and '$B_3$'are found to be empirically determined constants and are found to be functions of sliding velocity and the applied normal loads . '$V_w$' represents the wear volume in cc and 'T' represents time in minutes

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