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Realistic Approach to Pin-on-Disc Wear Testing Measurement

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Abstract : *Wear means, a loss of material during sliding of the matting surfaces, when they are in contact. Many researchers have estimated the wear loss in terms of weight loss, volume loss, weight loss per unit time, volume loss per rpm etc. It is very difficult to compare their results among one another and to bring in a common wear results. To understand the wear measurement, wear experiments have been conducted for different diameter specimens, under different operational conditions on pin-on-disc testing machine. From the various types of results, it is observed that volumetric wear rate i.e., volume loss per unit sliding distance gives a better understanding of the wear measurement. Also it is observed that instead of normal load, normal pressure is better variable to understand the wear. Further this wear equation can be improved by considering sliding speed and frictional temperature.*

Keywords: Wear measurement, volumetric wear rate, specific, Normalized.

INTRODUCTION

Wear is defined by American society for testing and materials (ASTM) as a “damage” to a solid surface, generally it represents a loss of materials due to relative motion between that surface and contacting substance [1]. Wear is not only produced between the two rubbing surfaces of solids, also presents in liquid, gas and stream, in the sense of the particle.

Wear is based on a Archard’s equation [2]. Archard equation is totally based upon the model of sliding wear & based on the theory of asperity. Archard’s states that the volume of removed debris due to wear directly proportional to the normal load, distance covered and indirectly proportional to the hardness.

Archard Equation:

$$Q = \frac{k*W*L}{H} \text{-----------------------(1)}$$

Where,

k: dimensionless constant.

Q: is the total volume of wear debris (mm^3).

W: normal load (gm).

L: sliding distance (mm).

H: hardness (gm/mm^2).

Wear test is carried out to determine the amount of materials removed after a wear test. The loss of material can be expressed as in weight loss, volume loss or height loss

Wear testing or quantification

There are many methods and improvements for wear testing, they are called *tribotester* and *tribometer*. The tribo-stands for the wear, friction, and lubrication. All the instruments consists two main parts, which are loaded against and relatively moving to each other. The movement is given by motor and electromagnetic device.

Wear measurements:

1. Height measurement (µm).
2. Weight loss measurement (mg).
3. Height loss / time measurement (µm/min).
4. Weight loss / time measurement (mg/min).
5. Volume loss measurement (mm^3).
6. Volume loss / time measurement (mm^3/min).
7. Volume loss /area measurement (mm^3/mm^2).
8. Weight loss / distance measurement (mg/m).
9. Volume loss / distance measurement (mm^3/m).
10. Energy wear measurement (mm^3/N-m).
11. Wear coefficient measurement (dimensionless).
12. Specific wear measurement (mm^3/N-m).
13. Normalized wear measurement (dimensional less).

Wear is in terms of height loss with respective of time. Initially a small wearing surface will come in contact with the sliding disc. For the same load the stress on the small area is considerably high. Due to this high stress, initially rate of height loss is more later with increase in the contact area the rate of height loss decreased. Authors have considered the fixed time to all the wearing tests. So, height loss will vary depending upon the initial area of wearing contact. Hence, the results may not be true [3]. Niko Ojala et.at., have considered the volume loss for different hardness and TiO_2 content. Authors have considered their own time and track diameter for their wear tests. Track diameter is not mentioned in the research paper. Only time is considered to compare the results among the different specimens. These results are comparable themselves but it is not possible to compare their results among the other researchers. Because track diameter is not mentioned and the rpm is also not mentioned to estimate the distance traveled to wear the specimen [4].

L.J.Yang has conducted experiments on pin on disc for the speed of 4.58 m/s, track radius of 87.7 mm at a constant 500 rpm and measured the weight and estimated the volume loss for the constant load of 7.5 Kg. Actually wear loss is nothing but volume loss per unit sliding distance. From his data it is possible to estimate the volume loss per unit sliding distance hence; his results can be compared with the other researchers. Author has also estimated the values of wear coefficient 'K'. Wear coefficient K is directly proportional to volume loss and hardness of the specimen but inversely proportional to normal load and sliding distance. For the same operational conditions with increase in sliding distance the values of wear coefficient decreases [5]. T.Sudaprasert has considered gm/s as a wear rate but has not mentioned the distance covered during the wear. Weight loss can be converted into volume loss by considering its density. But to convert the time into distance, author has not mentioned the distance cover therefore these results are not useful to other researchers [6]. M.M.Stack & K.Chi have studied his wear test by considering the mass loss per unit hour with the speed. Authors have selected four speeds and ran the test for one hour. It is known that with increasing in the speed the distance covered per hour will be more. Hence, the wear rate is not an appropriate to considered for comparison. But they have not mentioned the track diameter hence it puts the readers in confusion [7]. S.F.Wayne & S.L.Rice The authors have considered weight loss for the sliding speed of 1 m/s for 100 cycles, Authors have considered the weight loss as a wear rate. Authors have selected two speeds but maintained the number of cycles same. Hence, this will not give the clear picture of the wear rate [8]. R.Ward has considered equilibrium wear rate (gm/cm), with respect to load (gms), he has considered gm/cm to estimate the wear. It is possible to compare his results with other researchers by converting gm into volume loss by considering the density of the material [9]. F.Garnhm & J.H.Beynon have considered gm/m^3 as a wear rate hence this type of wear rate is not useful to common researchers, and it has no scope for future reports [10]. P.Clayton has considered height loss with respect to rpm, in his research paper has not mentioned the track diameter, hence it is not possible to estimate the volumetric wear rate [11].

Many researchers have considered their own wear measurements, some of them it is possible to convert into volume loss per unit sliding distance. Some of them are not possible because not availability of detailed parameters of operation conditions. Some of them are not at all possible to convert it into volumetric wear rate.

Hence it is required to follow a generalised common wear rate, for the research work so as to compare their results with other researchers to understand the matter. The main objective of this paper is to understand the realistic approach to pin-on-disc wear measurement .

EXPERIMENTAL PROCEDURE

The wear tests were carried out on pin-on-disc apparatus (DUCOM TR-20LE, model, India). The test–specimens were used as a ASTM standard of Diameter Ø 6 mm & Ø 10 mm and length of 30 mm to 35 mm, which is called as a G99. Then initial and final weight of the each specimen noted before and after the wear test respectively. After the wear test, weight loss is estimated for the further calculations. During the wear test, height measurement, frictional force and coefficient of frictional were observed [12].

Fixed Variables: Material: Aluminium 6063 grade, Track diameter : Ø 130 mm, Sliding distance: 2500 m, Density of the Al : ρ=2.68 gm/cm^3. Variables: Specimen size : Ø 6 mm & Ø 10 mm, Load: 0.5, 1.0, 1.5, 2.0 & 2.5 Kg, Speed: 0.5, 1.0, 2.0, 3.0 & 4.0 m/s

Estimation of time for 0.5m/s speed.

Velocity=$\frac{\pi * D * N}{60*1000}$ ---(1.1)

Where 1000 is conversion factor

0.5=$\frac{\pi*130*N}{60*1000}$ -- (1.2)

N=73.456 rpm

w.k.t 1rev=π*D

1rev= π*130=408.40rev ------------------------------------ (1.3)

Time for above rotation

Time=$\frac{2500*1000}{408.40*73.456}$ -- (1.4)

Time=82.60 ≅ 83min.

WEAR RATE FORMULAE

1. Linear wear rate (µm/m).

K1= [thickness of layer removed] / [sliding distance].

2. Volumetric wear rate (mm^3/m).

Kv= [height loss * cross section area of the pin] / [sliding distance].

Kv= [weight loss / density] / [sliding distance]

3. Wear coefficient (dimensional less).

V=kWL / H

k=[volume of the material removed* hardness] / [load applied*sliding distance].

4. Specific wear rate (mm^3/N-m).

Ws= [volume of material removed] / [normal load * sliding distance]

5. Energy wear rate (mm^3/N-m).

Ke= [volume of layer removed] / [work of friction].

6. Volume loss (mm^3).

V= [weight loss] / [density of the material].

7. Normalized wear rate (dimensional less).

Wn= [volume loss] / [sliding distance * cross section area].

RESULTS AND DISCUSSION

Many researchers have measured the wear in different ways like weight loss per unit time, weight loss per unit distance, volume loss per unit time, volume loss per unit sliding distance, height loss per unit time, height loss per unit sliding distance, weight loss per unit rpm, volume loss per unit rpm, height loss per unit rpm like this. So it is very difficult to understand their results and also it is almost impossible to compare their results with the other researches.

So it is very essential to make a one standard measurement, so that it should be easy to understand and possible comparable with the other researchers results.

So wear is nothing but the loss of material per unit sliding distance. Because as per Archard's wear equation

Volume loss(mm^3) α $\frac{Normal\ Load(N)/(L)*Sliding\ distance(m)/(D)}{Hardness\ of\ the\ wearing\ surface(\frac{N}{mm^2})/(H)}$------(1.5)

V α $\frac{L*D}{H}$---(1.6)

V= $\frac{k*L*D}{H}$--(1.7)

Where k is wear coefficient which is dimensionless.

Archard's has defined this equation on the basis of the volume loss. But many researchers have considered the weight loss method for their research work

From the below figure 4.1 it can be said as, if the height loss of the material under same operation conditions for different density material is same then if weight is considered, weight loss is more for higher density material and weight loss is less for low density material. Even though, the volume loss is same for two materials. Because the cross sectional and height loss is same for two materials. Hence, it is better to consider the volume loss method for research work.

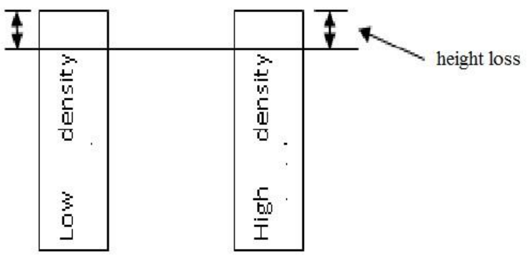

Fig. 4.1 Densities of a material

Usually wear test will be conducted on Pin-on-Disc wear testing machine. While conducting the wear test, track diameter on the disc, rpm of the disc and normal load will be selected to conduct the wear test. Many researchers have considered the rpm as a specific sliding speed for their research work and discussed upon the rpm itself. Rpm is the revolution per minute. If the track diameter is small then sliding distance per unit time is low whereas if the track diameter is more then sliding distance is more for a particular fixed rpm.

v = $\frac{\pi * D * N}{1000}$ ----------------(1.8)

v – speed (m/minute).

D – Track diameter (mm).

N – rpm (Revolution per time).

1000 – Conversion factor to convert mm into meter.

Speed is a function of rpm and track diameter. If the track diameter is less then more rpm is required for the same speed. Whereas if the track diameter is more, then low rpm is required of the same speed. Hence, rpm (N) should not be considered but speed (v) should be considered for the research work.

Many researchers have considered height loss for their research work. During wearing initially specimen will not completely contact with the sliding disc. Initially it is a point contact then later slowly as specimen wear's, increase in surface contact takes place then later almost 100% apparent contact wear takes place.

While conducting the experiments rpm, time and track distance will be adjusted before start the experiment. Many researchers discussed their results on the basis of the time. If the track distance and rpm not decided properly then it is of no use to discuss with time factor. Because for same time if the track diameter is low then sliding distance is less for same time and if the track diameter is high then sliding distance is more for the same time. Hence time factor should not be considered for the research work and it is not possible to compare their results with the other researcher's results.

Hence, before start the experiment, sliding distance, speed and normal load should be selected. To cover the selected fixed sliding distance time should be estimated. Before that track diameter and rpm should be estimated.

For a particular speed, for a fixed track diameter D, rpm will be estimated using the below mentioned formulae

v = $\frac{\pi * D * N}{1000*60}$ ---------------------------(1.9)

Then the track diameter should be selected. If the speed and track diameter are fixed then estimate the rpm.

N = $\frac{v * 1000 * 60}{\pi * D}$ -----------------------(2)

After estimating the N, time to be estimated for selected sliding distance.

For one revolution $\pi * D$ distance will be covered. For one minute N * $\pi * D$ distance will be covered, so to cover the selected total distance.

Time (Min) = Distance to be covered / (N* π * D) --(2.1)

Experiments should be conducted for this time to cover the required distance. For different sliding speeds the time will change to cover the same distance. With raise in the sliding speed the time required to cover the same distance is lessening

During wearing, initially a small portion of the specimen will come in touch with the sliding disc. Later slowly the area of contact will increase with the sliding distance. Hence initially due to low contact area for a fixed normal load the stress is high. Hence the wear loss in height is more. With increase in contact area the wear loss in height is decreased. Once the almost 100% apparent contact will come then the steady state wear will occurs. During this time the slope of the curve is almost the constant as shown in figure 4.2, & 4.3.

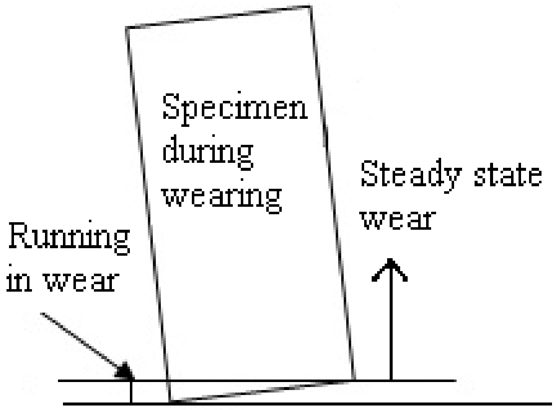

Fig. 4.2 Position of the pin during wearing.

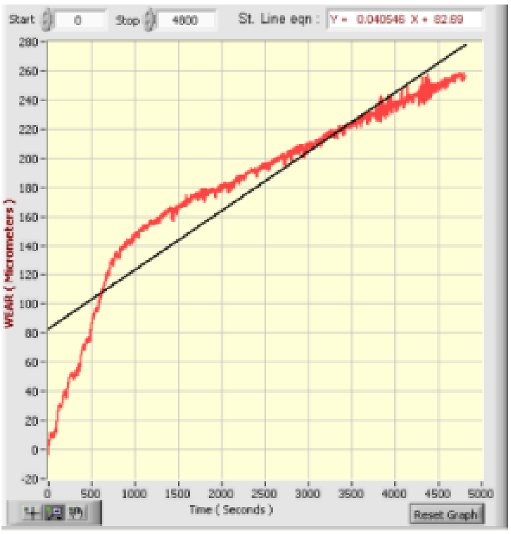

Fig. 4.3 Effect of time on height loss of the wearing pin.

Hence wear rate is to be estimated during this period. The wear rate is height loss per unit time. Then the time should be converted in terms of distance. Then this height loss will be converted into volume loss by multiplying with the cross sectional area of the specimen. Hence, wear rate can be estimated in terms of volume loss per unit sliding distance.

Height loss measurement: Usually almost all researchers have considered the height loss method for their research work. During pin on disc wear testing, initially the pin is in not almost apparent contact with the sliding disc. This is called running in wear. During running in wear the wearing surface of the pin goes on increases till it reaches almost 100% apparent contact area of the pin. Once the almost 100% apparent contact area occurs, then the height loss will almost in the same slope and this is called the steady state wear. So, the height loss should be considered during the steady state only.

Hence, volume loss should be considered for the estimation of the wear rate.

A. Volumetric Wear Rate

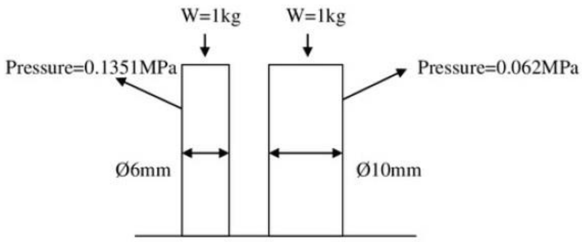

Fig. 4.4 Different wearing size pins.

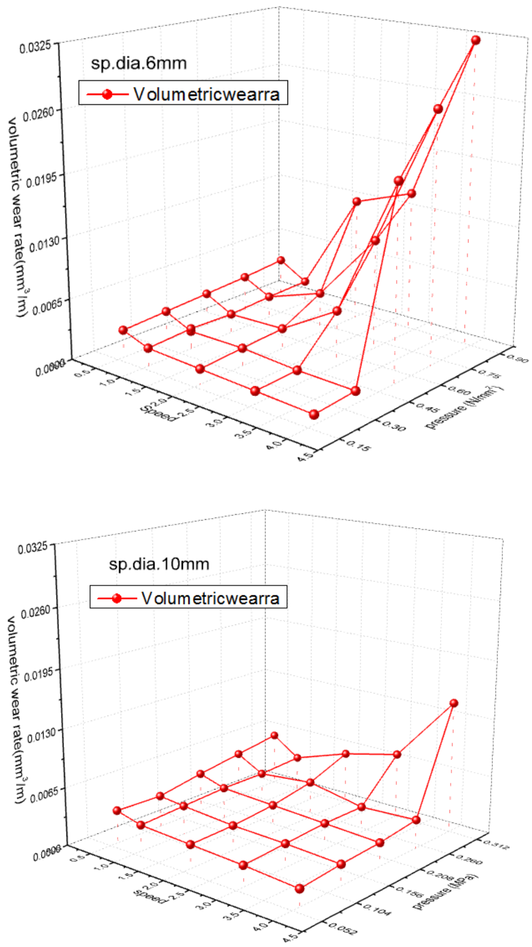

Fig. 4.5 Effect of Pressure and Speed on Volumetric wear rate for 6 & 10 mm diameter specimens.

Volumetric wear rate is volume loss per unit sliding distance; volume loss is the more appropriate one than weight loss. Sliding distance is more appropriate one than time and rpm. Hence volumetric wear rate is better than all wear measurements. The Archard equation, that is volume loss provides an array of magnitude for estimation and is true estimation of wear.

The normal load will be applied on specimen and during the wear. Even though the load is same on the different cross sectional area of the specimen, then the corresponding pressure on each specimen varies. As the diameter of the pin decreases, the normal pressure on the wearing surface increases. Hence, it is better to consider the normal pressure than the normal weight. As shown in above fig 4.4 & 4.5.

B. Specific Wear Rate

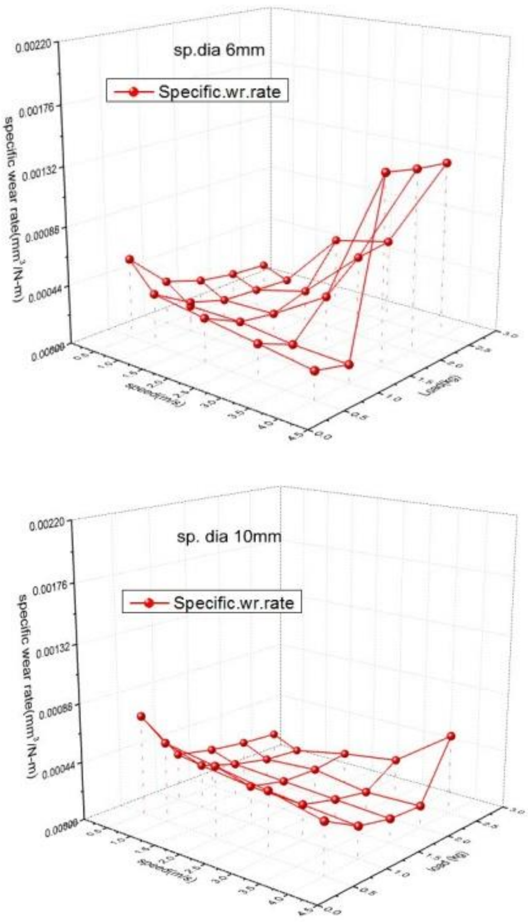

Fig.4.6 Effect of Load and speed on Specific wear rate for 6 & 10 mm diameter specimens

Figure 4.6 represents a Specific wear rate is the ratio of volumetric wear rate to the normal load. When this is the ratio, then the Specific wear rate remains the same when volumetric wear rate increases in multiple of normal load. Then the Specific wear rate remains the same with increase in the normal load, even though the actual volumetric wear rate is increase with the normal load. The specific wear rate increases with the normal load, if the specific wear rate is more than the multiple of normal load and the same is decreases with normal load if the specific wear rate is multiple of less than the normal load. So even though volumetric wear rate goes high, some of the researchers have concluded that specific ware rate is falling off with increasing in the normal load which may gives not correct information to the readers.

This will happen when the rate of work hardening due to the plastic deformation of the wearing surface during wearing and rate of softening effect takes place when wearing surface becomes soft due the frictional temperature.

Initially with increase in the operational conditions like sliding speed and normal load, work hardening and frictional temperature generates at the wearing surface. Initially under low normal load and sliding speed the rate of generation of frictional temperature is very low hence, work hardening effect is prominent at the wearing surface. So, wearing face becomes hard due to work hardening. Hence, as per Archard's wear law, the volume loss is inversely proportional to hardness. Hence, volumetric wear rate is reduced with increase in the operational conditions.

Table.4.1 Estimation of specific wear rate.

Load(X)	Volume loss(Y)	Volumetric wear rate	Specific Wear Rate
kg	mm^3	mm^3/m	m^3/Nm
1	10	0.004	0.004
2	20	0.008	0.004
3	30	0.012	0.004
4	40	0.016	0.004
5	50	0.02	0.004
6	60	0.024	0.004

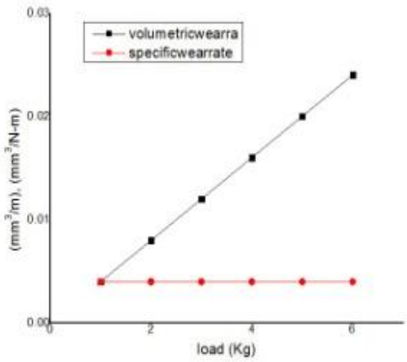

Fig.4.7 Effect of load on volumetric and specific wear rate.

With further increase in the operational conditions i.e., increase in the normal load and sliding speed, again the rate of work hardening and generation of frictional temperature takes place at the wearing surface. But under high frictional operational conditions, the rate of generation of frictional temperature is quite high. Due to this increase in the frictional temperature, work hardening will not take place because the asperity temperature is quite higher than the hot working temperature of the material. Also due to this high temperature the softening effect takes place and the wearing surface becomes soft and loosens its hardness. Due to reduction in the surface hardness, the corresponding volume loss will increase and result in increase in the volumetric wear rate

It is observed that, volumetric wear rate increase with the normal load whereas specific wear rate remains the same with the load. Because, volume loss is multiple of load, hence volume loss is i.e., volumetric wear rate is increased. Whereas specific wear rate is ratio of volumetric wear rate to the load therefore the specific wear rate remains the same. It is observed that if the volume loss is more than the multiple of load then specific wear rate is increases. If the volume loss in less than the multiple of load then specific wear rate is decreased. In all this case, volumetric wear rate is raises the irrespective of specific wear rate. As shown in figure 4.7.

C. Wear coefficient

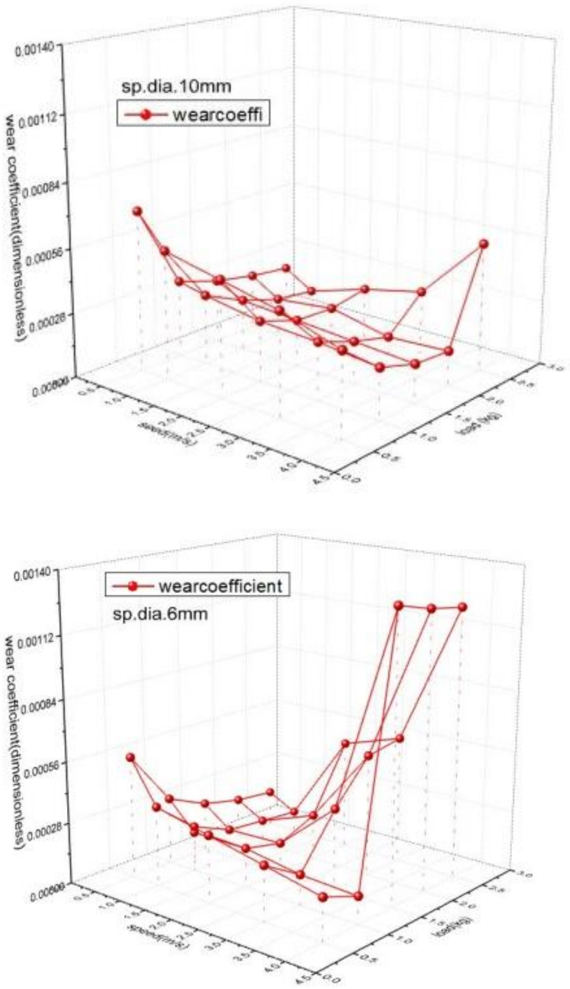

Fig.4.7 Effect of Load and speed on Specific wear rate for 6 & 10 mm diameter specimens

Figure 4.7 represents Wear coefficient is a dimensionless unit which is directly proportional to the volume loss and hardness of the material during wear and inversely proportional to the normal load and sliding distance. It means it's an almost volume loss per unit load, if the constant hardness and fixed distance are considered. Usually fixed distance is considered for the estimation of the wear. But hardness values goes on changes with the wearing conditions. Initially under low operational conditions under low frictional temperature conditions, the work hardening is predominant and the hardness value of the wearing surface increase. Whereas under high operational conditions, i.e. under high frictional temperature conditions the wearing surface becomes soft and hardness values decreased.

But during wearing it is not possible to measure the hardness of the wearing surface under high temperature conditions, so almost all researchers consider the original hardness of the material to estimate the wear coefficient and gives not correct idea of the wear measurement. Hence, wear coefficient can't be considered to estimate the wear rate.

D. Normalised wear rate:

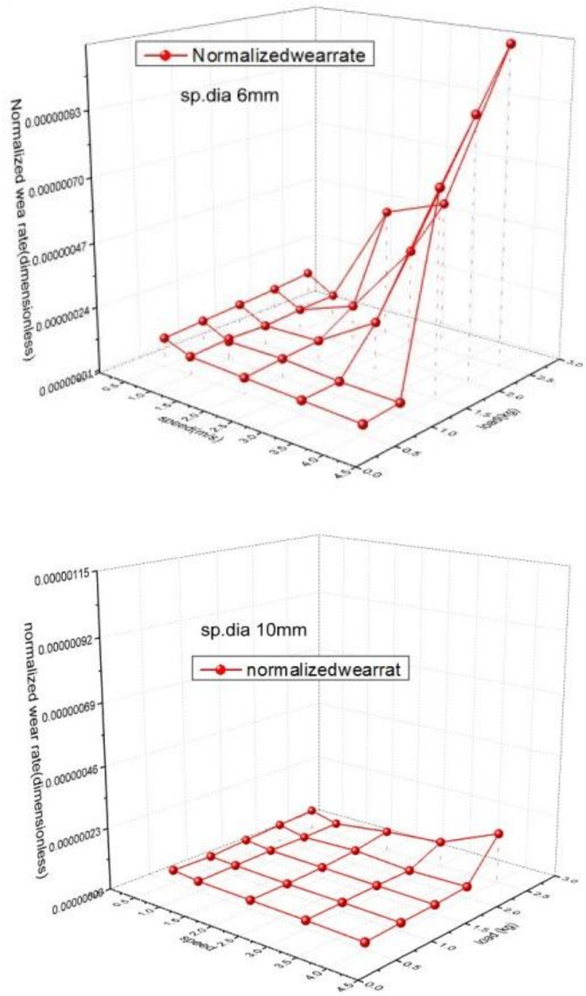

Fig.4.8 Effect of Load and speed on normalised wear rate for 6 & 10 mm diameter specimens

Figure 4.8 represents Normalized wear rate is the ratio of volume loss per unit sliding distance to the cross sectional area of the specimen. Normalized wear rate can be considered because it will consider the corresponding cross sectional area of the pin

CONCLUSIONS

A. Total height loss should not be considered for the estimation of the wear loss.
B. Height loss should be considered only during the steady state.
C. If the short sliding distance considered for the wear then height loss is not the correct wear measurement but weight loss is the correct wear measurement, later it should be estimated to the volume loss by considering it's density.
D. If the long sliding distance is considered for the estimation of wear, then height loss during steady states only it to be considered and the same should be estimated to the volume loss by considering its cross sectional area.

E. Rpm should not be considered for the wear measurement, because for the same rpm, more the track diameter more the sliding distance and lesser the track diameter lesser the sliding distance for the same speed.
F. Normal load should not be in Kg but it should be in normal pressure (MPa), because for the same normal load, if the small cross sectional area of the pin is used, the stress on the pin is more whereas if the large diameter pin is used then the stress is low on the wearing pin.
G. Weight loss should not be considered, because for same volume loss, low density material shows low wear, whereas high density material shows high wear.
H. Specific wear rate should not be considered for the wear measurement, because specific wear rate is the ratio of volumetric wear rate to the normal load.
I. Volume loss per unit time should not be considered.
J. Volume loss per unit sliding distance should be considered.

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