Archard Wear Constant Experimental Validation for Dry Sliding Wear

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Abstract: The relations for hardness and wear were studied, then these relations were combined to form the wear equation, which is called Archards wear law. This law was then modified to be applicable for the soft and pseudo-elastic materials by considering the deformation load and indentation load. Experimental process of wear was conducted over steel and the wear constant was generated using the machining, hardness characteristics of steel and the machining process. Thus generated wear constant was validated by comparing with the standard wear constants. This comparison has given that archard wear relations give out good wear constants when predicted experimentally.

1. Introduction

Archard wear equation was proposed in the year 1960, this law is also called as Reye Archard Krushchov wear law. This law is used to calculate the wear caused by the sliding motion in the workpiece. This equation operates on the principles of surface contact and forces generated due to the unevenness of the surfaces. This law states that the volume of wear loss is proportional to sliding/stroke distance, volume of wear loss is proportional to normal load and volume of wear loss is inversely proportional to the hardness of the material. Wear loss is only related to hardness in Archard's equation, and such calculated wear loss is also compatible with experimental findings. This equation has also been used to calculate the wear caused by rolling sliding contact. The proportionality constant for this equation depends on the medium where the materials are being operated.

The constants of a material which influence the wear behavior are hardness, elasticity, yield & tensile strength, fracture strain and strain hardening. But among the most discussed constants in a sliding wear of a material, archards wear law deals with only a few constants like sliding distance, normal load and hardness of the material. The given relation shows that, according to archard we have the fallowing assumptions for the wear loss

2. Numerical analysis

As per the governing equation-

Wear loss ∝ Sliding/Stroke distance,

Wear loss ∝ Normal load,

Wear loss ∝ 1⁄(Hardness of material)

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By considering the above equations, we can deduce that,

Wear loss ∝ (Sliding distance) x (Normal load) ⁄ (Hardness of material)

$$V \propto {(S)x(L)}/{H} \Rightarrow V = K\, x\, {(S)x(L)}/{H}$$

(S), Sliding distance is the length over which the tool moves over the workpiece, to remove the material. This length is usually in mm and the rate sliding tool operates is given as rotations per minute. (L), Normal loading is the load that is being applied to the workpiece in the perpendicular direction. (H), The hardness of the material, which is the ability of the material to resist deformation. We have the hardness of a material-

$$H \propto 1/d^2$$

where the ‘d’ is the depth of indentation created by the tool. (K), Wear Constant is a dimensionless quantity used to equate the linear proportionality and this constant value varies from material to material.

The equation we have formed is for most of the elastic materials, but in the case of the soft metals and pseudo-elastic materials, the current equation needs to be modified.

3. Modified Wear Law

In modifying the wear law, we consider two other material properties, which are recoverable deformation energy (Wrc) i.e. the potential energy which is transformed into strain energy where material undergoes elastic transformation. Where total deformation energy (Wt) is the strain energy that effects the material with a plastic deformation. Along with these energy properties, we also take pseudo-elasticity (PE) into consideration. The relation between these material properties is as follows.

$$\frac{Wrc}{Wt} = \eta, \text{ (where } \eta \text{ is the hardness ratio)}$$

$$PE \propto Wrc$$

$$\text{and } Wt \propto d$$

Where, d is the depth of indentation

We get a relation

$PE \propto d\eta$ and also have hardness as

$H \propto 1/_{d^2}$.

Now we can write our modified equation as-

$$V \propto [\eta (\tfrac{1}{PE}) + (1-\eta)\tfrac{1}{H}]\ LS$$

Table 1: Wear and time data

Wear on rough specimen(mm^3)	Wear on Finished specimen(mm^3)	Load (N)	Stroke Length (mm)	Frequency(Hz)	Time Operated(min)
0.007826	0.006253	25	15	10	3.0
0.022864	0.018581	25	15	15	4.5
0.020818	0.017494	25	15	20	6.0
0.012046	0.009629	35	15	15	3.0
0.030895	0.02532	35	15	20	4.5
0.009885	0.008376	35	15	10	6.0
0.033043	0.026432	45	15	20	3.0
0.026061	0.021189	45	15	10	4.5
0.0439	0.037212	45	15	15	6.0

From table 1, considering the wearing load (L1), the load which causes the material removal, indentation wearing load (L2), the load which is in normal direction to the work piece which creates a notch on the material surface and considering the relations for pseudo-elasticity, deformation energies, we can write the wear relation as

$$V \propto [(K1)\ (\tfrac{1}{d}) + (K2)\ (1-\eta)\ d2]\ (^{L1}/_{L2})\ S$$

Where η lies between 0 to 1.

4. Wear Constant

In the above-said equations, the wear loss proportionality was equated with a constant value 'K', which is considered as wear constant. This constant is used to measure and correlate the wear of materials, while this being a dimensionless value. The wear constant for various materials are given by table 2.

Table2: Material and material constant

Material	Wear Constant
Mild Steel	7.024×10^{-3}
Various brass	6.025×10^{-4}
Tool grade steel	1.312×10^{-4}
Copper	3.701×10^{-5}
Stain less Steel	1.701×10^{-5}

4.1. Experimental Analysis of Wear Constant

To experimentally analyse the wear constant we will conduct a dry sliding wear process over the medium carbon steel with different loads and sliding frequencies. The properties of steel are Given by table 3.

Table 3: Steel properties.

	Density (gm/cc)	Hardness (Mpa)
Medium Carbon Steel	7.82	200

Now the materials of rough steel and smoothly finished steel will be subjected to loads ranging from 25N to 45N with a stroke length of 15mm and varying frequencies from 10Hz to 20Hz. The time of machining will vary from 3min to 6min for different materials. The data of volume of wear occurred to the respective machining given by table 1.

With the mentioned data given by table 4 the wear constant will be calculated using the archard wear relation.

$$V = K \times {}^{(S)x(L)}/_{H} \Rightarrow K = \frac{V \times H}{S \times L}$$

Table 4: Constants derived for Medium carbon steel

Volume Of wear - Rough	Volume Of wear – Finished	K1	K2	Total Sliding Distance
0.007826	0.006253	0.00417387	0.00333493	54000
0.022864	0.018581	0.01219413	0.00990987	121500
0.020818	0.017494	0.01110293	0.00933013	216000
0.012046	0.009629	0.00458895	0.00366819	81000
0.030895	0.02532	0.01176952	0.00964571	162000
0.009885	0.008376	0.00376571	0.00319086	108000
0.033043	0.026432	0.00979052	0.0078317	108000
0.026061	0.021189	0.00772178	0.00627822	81000
0.0439	0.037212	0.01300741	0.01102578	162000

The result of constants obtained from the relation and the data are as fallows. These details are of constants obtained from relation and total sliding distance in machining process. Let us assume K1 wear constant for rough finished specimen and K2 wear constant for smooth finished specimen.

The total sliding distance is taken by considering the sliding distance, frequency and time operated. The calculation is as follows.

Frequency 1Hz = 1 cycle operation in one second = 2 x 15mm = 30mm Sliding distance.

For 10Hz in 3min = 10 x 30 x 3 x 60 = 54000 mm total sliding distance of the machining process. The similar data is calculated for different combinations of time and frequency in the table 4.

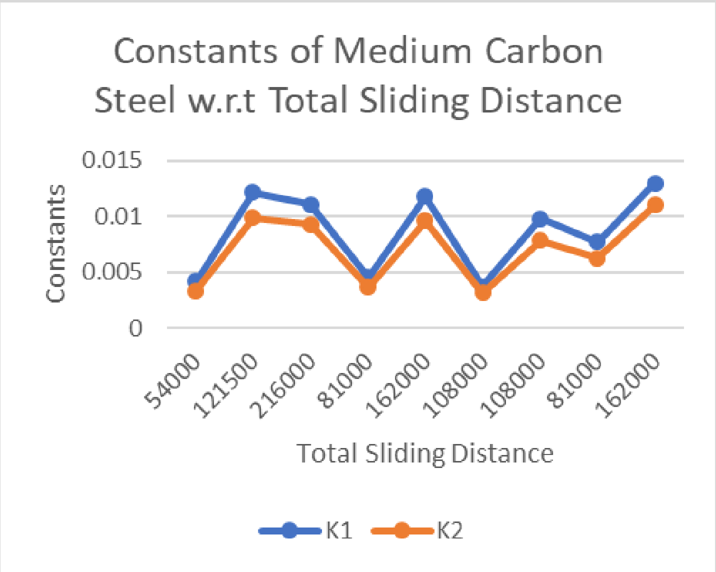

Fig. 1: Total sliding distance for mild carbon steel

The mean of the constant value obtained from the experimental operation is tabulated as follows for the rough finish specimen and smooth finish specimen.

Table 5: Wear constant of medium carbon steel

	Wear Constant of rough specimen (K1)	Wear constant of Finished specimen (K2)
Medium Carbon Steel	0.008679	0.007135

4.2. Limitations of the Wear Equation

The wear equation can be used in areas where there is wear occurring due to adhesive wear and forces are being projected in the normal direction for the wear to occur. The basic limitations for the wear equation are

1. The hardness posts the wearing is not considered
2. The temperature is not taken into consideration
3. The wear calculated for only linear tool motion
4. The equation is not accurate when there is micro cracking present in the workpiece.
5. The equation deals with only the wear loss but not the residue formed from the wear.

5. Conclusions

The wear equation is most appropriate for the basic metals undergoing sliding wear but in the case of the soft materials and the pseudo-elastic materials the equation needs to be modified with different additions of input to the equation such as deformation energy (Wrc), total deformation energy (Wt), wearing load (L1), indentation wearing load (L2) and hardness ratio. The relation formed with these constants deals with a low error rate in estimating the wear loss.

The specimens of different finishes of steel were machined to study the wear constants. This proved that experimental values were similar to theoretical values with minute error. These errors might be because of the external factors that were affecting in the operating environment. These factors can be stated as temperature, humidity and dust particle in the air. The wear equation though helpful in prediction but it still has its limitations to temperature and direction of wear in some cases.

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