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Tribological behaviour of Fluorocarbon Coating under Dry and Lubricated Sliding Conditions

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Abstract: *Due to positive tribological performance, fluorocarbon coatings have established an importance in many applications, as a possible replacement to enhancement and substitute traditional liquid lubricants. The literature in this area is to a certain extent limited, especially on the Tribologicalbehaviour of fluorocarbon coated and fluorocarbon uncoated components in aggressive conditions. In this work, fluorocarbon coated on HSS M2 and fluorocarbon uncoated components were tribologically evaluated using Ducom friction and wear machine under specific conditions, which included rotating sliding conditions. The coatings showed good to excellent tribological performance, and in general fluorocarbon coating exhibited better friction and wear behaviour than uncoated specimen. The Fluorocarbon coating has ability to reduce the friction and wear along with this it also gives smooth and noise free running operation. Long-term durability experiments also showed the superiority and suitability of fluorocarbon coating for potential use in many applications. Fluorocarbon coatings are considered for their advantageous mixture of properties, in specific it has exceptional low friction as well as release capability and good chemical properties. As a result of experimentations, fluorocarbon coating shows the coefficient of friction as low as 0.196 which is much better than many other coatings in the fluorocarbon category and wear rate is also way better which is* $1.0610\times10^{-5} mm^3/Nm$.

Keywords: *Fluorocarbon coating, Friction, Wear, Wear rate, Coefficient of friction, Regression equation.*

I. Introduction

In different industries friction and wear are one of the intrinsic factors to increase energy consumption.According to [1] in the industrialized developed nations the energy losses and damaging of machine components because of friction as well as wear accounted for 5% to 7% of their GDP which is nearly about one third of the world's total energy sources in actual practice it appears as a friction or in the form of wear.Yearly thousands of machine campers in different industries become useless because of excessive wear. According to [2] in Europe and America 10% of total oil consumption is used to counter the damage caused by friction and wear. The side effect of increase of friction and wear in machine component is not only limited to damage of machine but it also dangerous for environmental point of view because the friction and wear factor also responsible for excessiveCO_2emission specifically in case of vehicles. It is a huge problem and it is also necessary to overcome the friction and limit the $CO_2$with the help of different engineering and typology ideas and principles which include appropriate use of surface modification and survey statement processes, proper use of lubricants, materials, coatings and special structural designs. Out of these all options surface modification and surface treatment, coatings which is collectively called as surface engineering is the best operational and flexible way out for tribology issues. This surface engineering more precisely coating modifies the tribological properties by introducing the compressive stresses which helps to minimize the coefficient of friction by maximizing the surface hardness. In this way coating develops and increases the wear resistance of surface and also helps to increase the life of machine components. From last few years different types of coating and their depositions method have been developed successfully to reduce the damage of machine from friction and wear. Now a days in industries greater performance is essential for components and different tools of machine which cannot be achieved only by selecting the proper materials or improving the mechanical structures of components. The final result of performance of components can be improved by effective use of coating which can positively replicate the results in terms of greater reduction in friction, improving the wear resistance ability, to withstand or survive under different environmental conditions, to reduce corrosion and improve other characteristics. Along with improving all these characteristics it is also important to keep original properties of main substrate which is responsible for strength and toughness. Besides all these points at present situation we are far away from actual scenario where the friction coefficient as well as rate of wear can be precisely calculated for specific an experimental, working condition which is totally based on theoretical evaluation and studies of calculation. Practically a harder component coated by soft thin coating shows the probability of decrease in sliding friction.But the main issue of soft thin coating is their wear out time and life span is critical and the coating on the substrate is not executed precisely and correctly then there is possibility of detachment of coating material from base material. Along with all these for soft coating the selection of parameter is also a considerable factor. These parameters may include sliding speed, applied load, deposition method of coating, thickness of coating substrate and environmental conditions. According to [3] when soft coating sliding against still the range of friction coefficient is 0.1 to 0.5 which is much less than that of uncoated steel sliding against still under dry conditions whose value is 0.6 or more [4].According to G.S. Senior [5] in the USA a three year time-consuming experiment held between 1973 and 1976 whose results are exciting. In the test a fluorocarbon coated Cummings NH230 diesel engine was used. All the parts of engine like the piston skirts, crankshaft, connecting rods, and big end bearings of the engine were coated by fluorocarbon and was installed in a motor vehicle and run with in service uncoated engine simultaneously. As a result it is observed that the fluorocarbon coated engine show a 14.8% improvement in fuel consumption after completing 170 000 miles, along with that two unexpected results are noticed. One of them is piston slap and resulting noise from the block was decreased by an estimated 3dBA and other was the coated engine uses fuel at a constant rate, while the control engine's fuel use varied to some extent, proposing that coating also decreases break-in irregularities. The wear resistance of soft coating like fluorocarbon coating is better under low and medium loaded conditions. A soft coating mainly the fluorocarbon coating has high resistance to chemical reaction such as acid and alkaline also different environmental conditions[6]. Further in this study the experimentation conducted on fluorocarbon coated samples under different parameters are tested. Perfluorocarbon or PFC is the other name by which Fluorocarbon is famous. Precisely it is compound of organofluorine having chemical formula C_xF_y and has a combination of different elements mainly carbon & graphite [7]. The fluorocarbon and it's by products can be used as solid lubricant, refrigerant, fluoropolymers and also for coating propose.

II. Material and Methods

2.1Base metal details

Engineering design is very tough job because in it one must select a suitable metal for certain application and this selection of metal is based on many factors like cost, availability of material, properties of material and functionality of material. Most of the machine elements specifically plate type cam follower which is made up of steelmore precisely HSS M2 grade steel because of its strength and toughness as well as ability to withstand at high loads. The HSS M2 steel used as a substrate of coating is basically tungsten molybdenum high speed steel with well-balanced composition of different materials.

The metal used as substrate for fluorocarbon coating is HSS M2 i.e. is molybdenum high speed steel which is mainly used as cutting tool in general purpose. These cutting tools may include drills, reamers, all kind of millers etc. But the use of HSS M2 metal for experimentation is based on practical situation i.e. from plate type cam follower mechanism which is manufactured with the help of different heat treatment processes. The result of chemical analysis of HSS M2 steel is tabulated below.

Table 1 Chemical composition of HSS M2 steel

Chemical Analysis			
Element	**Observed**	**Specified**	
%	%	Min	Max
C	0.83	0.78	1.05
Mn	0.38	0.15	0.40
Si	0.23	0.20	0.45
S	0.019	-	0.030
P	0.023	-	0.030
Cr	4.48	3.75	4.50
V	1.98	1.75	2.20
Mo	5.01	4.50	5.50
W	6.16	5.50	6.75

The heat treatment process includes following steps:

1. HSS M2 steel is heated before hardening at a temperature of2610°C.
2. Process of rapid heating carried out at temperature between2610°C to 3960°C.
3. The steel is allowed to cool naturally for 3 to 5 minutes and then quenching process is done with the help of air, salt bath and oil.
4. The process of annealing takes place at a temperature of 1204°C and then steel is allowed to coal at 72°C /hr.
5. The process of tempering takes place at a temperature of 552°C to achieve the Rockwell hardness of 65.
6. The steel is hardened by heat treatment and quenching processes.

2.2 Coating details

A fluorocarbon coating is well known for its low friction and wear resistance properties. It is also well known for corrosion resistance and ability to work under extreme environmental conditions. Fluorocarbon coating can also act as solid lubricants and at room temperature under 200 'c. In atmosphere like absence of non-oxidizing agents its lubricating quality makes it accountable for relevant environmental situations. The fluorocarbon coating used for the experimentation is a mixture of different elements like carbon, molybdenum, graphite, glass fibre, fluorine and other elements.

2.3 Coating properties

The properties of fluorocarbon coating are not same in all the forms and for all applications.

Table 2 Properties of fluorocarbon coating

Property	Value
Density	1080 kg/m^3
Melting point	600 K
Young's modulus	0.5 GPa
Coefficient of friction	0.02–0.30
Tensile Strength (ASTM D1708)	4000 - 5000 psi
Hardness (ASTM D2240)	60 - 90 HB (shore D)
Use Temperature	-100°F to 500°F max (-73.3°C to 260°C)
Chemical Resistance (ASTM D543)	Good
Salt Spray Resistance (ASTM B117)	Excellent
Water Absorption (ASTM D570)	< .03 %
Thickness of coating	30 Micron
Deposition pressure of coating	4kg/cm^2

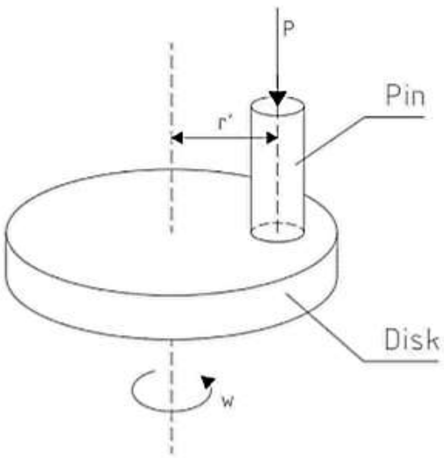

Fig. 1 Pin on disc assembly

If the fluorocarbon is made up different type of fluoropolymer, resin content and adding different percentage of elements while manufacturing and used for different applications then these factors may have significant effect on its properties and end results. The main advantage of fluorocarbon coating is that it creates a working surface tailored to on application the fluorocarbon coating comes or available in different forms and colour. The fluorocarbon coating has the ability of reduce the friction, prevent corrosion, offers excellent adhesion to metals, wood ceramics and plastics, even to itself, give resistance to sunlight, salt water and road chemicals. It can bend freely and can be applied repeatedly without breaking. Fluorocarbon coating is also available in different colours like black, green, blue, and red.

1. **Preparation of specimen**

A. Metals
1. Buying of metal rods of 10 mm diameter
2. Chemical composition testing
3. Cutting of rod into pieces having length 28±1 mm.
4. Chamfering of 1±0.5 mm and polishing.

B. Coating
1. Oil is removed from substrate by using seven oil tank process

2. Grid blasting process is done
3. Fluorocarbon is sprayed at rate of 4kg/cm^2
4. Specimen is baked in furnace at 250 °C.

The objectives of this study are to compare the results of fluorocarbon coated steel under dry and lubricated sliding conditions. The behaviour of fluorocarbon coating and effect of lubrication is also studied in this paper. This study also involves the observation made during experimentations which helps to determine a suitable condition under which fluorocarbon coating performs well.

2. Testing conditions

The testing carried out on Ducom friction and wear machine with the help of ASTM G99 procedure.

Table 3 Testing Parameters

Parameters	Value
Pin Material	Fluorocarbon coated HSS M2 steel
Pin Size	10 mm Diameter And 28±1 Height
Disc Material	Material 31 hardened to 60 HRC ground to 1.6 RA surface roughness.
Disc Size	165 mm diameter and 8 mm thick
Speed (Rpm)	300, 500, 700
Load (N)	10, 20, 30
Wear Track Diameter (Mm)	80, 90, 110
Temperature()	Room temperature
Coating Thickness (Micron)	30
Coating Color	Green
Machine Used	DUCOM friction and wear machine

III. Results

Case 1: Result and validation of Coefficient of friction

By using this result the Analysis of variance and regression equation found using minitab software from two equations are obtained separately for dry condition and lubricated condition.

$$coefficient\ of\ friction = 0.1167 - 0.000002\ sliding\ distance + 0.002550\ Load \quad \text{..................4.1}$$

$$coefficient\ of\ friction^2 = 0.000498 + 0.000000\ sliding\ distance + 0.000113\ Load \quad \text{................4.2}$$

It is determined that the value of coefficient of friction in lubricated condition is decreased by 65% to 75% than that of dry conditions in all testing conditions. During experiments it is also observed that in first seven cases the coefficient of friction settle down and gives constant reading after first few meters. But, in remaining the coefficient of friction is very low up to 900 meters but after that it varies a lot due to the coating partially wear out due to high load as well as high speed. In all low loading conditions as speed increases the coefficient of friction decreases. In lubricated conditions the coefficient of friction is much more less than that of dry conditions.

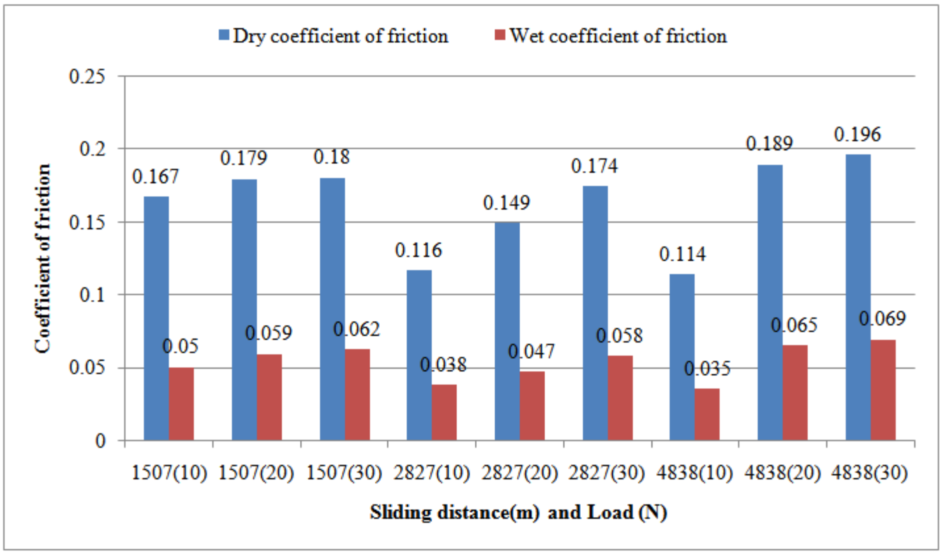

Fig. 2 Graphical representation coefficient of friction of fluorocarbon coating under dry and lubricated sliding condition

During lubricated testing it is observed that there is no damage to the coating and coating safely survived till the end of test. Also in the last two testing conditions when load and speed both are high coefficient of friction increases but there is no damage to the coating.
Case 2: Result and validation of wear rate
The conditions used for experiments and their results are enlisted in the table below:

Table 4 Results of wear rate

Sliding Distance(m) and Load (N)	Dry wear rate (Calculated) (mm^3/Nm)	Wet wear rate (Calculated) (mm^3/Nm)
1507 (10)	3.3178×10^{-5}	1.1054×10^{-5}
1507 (20)	2.8224×10^{-5}	0.9408×10^{-5}
1507 (30)	1.8801×10^{-5}	0.62671×10^{-5}
2827 (10)	1.4503×10^{-5}	0.48323×10^{-5}
2827 (20)	1.0610×10^{-5}	0.35373×10^{-5}
2827 (30)	1.7686×10^{-5}	0.58953×10^{-5}
4838 (10)	3.5101×10^{-5}	1.1707×10^{-5}
4838 (20)	3.3080×10^{-5}	1.1025×10^{-5}
4838 (30)	3.3776×10^{-5}	1.1263×10^{-5}

By using this results the Analysis of variance and regression equation found using minitab software from two equations are obtained separately for dry condition and lubricated condition. Equation 4.3 is obtained for dry conditions and equation 4.4 is obtained for lubricated conditions.

$$\text{Specific wear rate}^2 = 4.96 + 0.00149\ \text{Sliding Distance} - 0.124\ \text{Load} \ldots\ldots\ldots\ldots\ldots 4.3$$

$$\ln(\text{Specific wear rate}) = 1.636 - 0.000366\ \text{Sliding Distance} + 0.0267\ \text{Load} \ldots\ldots\ldots 4.4$$

After putting the values of sliding distance and load in the above equations the experimental results can be verified which are tabulated in the table given below:

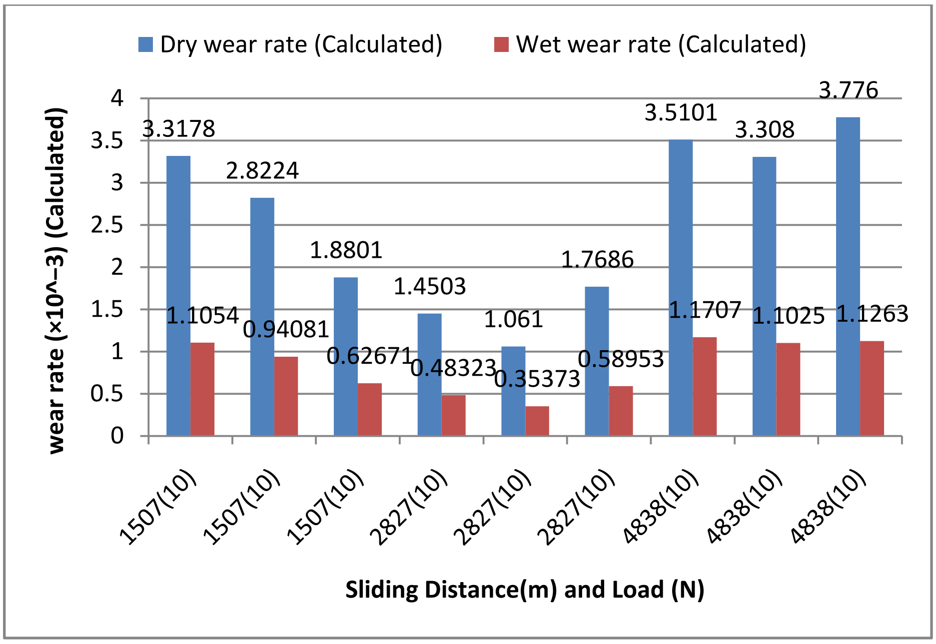

Fig.3 Graphical representation wear rates of fluorocarbon coating under dry and lubricated sliding condition

From above graph it can be concluded that the lubricated results for friction and wear of fluorocarbon coated are 50% to 70% less than the dry condition.

IV. Conclusion

After conducting the set of experiments and observing the graphs and behaviour of fluorocarbon coating following conclusions are made:

1. The fluorocarbon coating is better suited for maximum contact pressures up to 0.3 Mpa.
2. At contact pressure above 0.3 Mpa, the rate of wear fluorocarbon coatings on the substrate is not survived till the end of test due to increase in frictional force once coating wear out and in some cases partially wear out.

3. The fluorocarbon coating wear out in the form of black powder type material, but it doesn't create any wear debris or causes any damage and doesn't affect the sliding condition as well as material.
4. The fluorocarbon coating shows maximum coefficient of friction as 0.196 under tested conditions which results in with good wear life. Thus for components for which the good wear life is needed along with good coefficient of friction, fluorocarbon coating is better choice.
5. The lubricant reduces the friction force which results in reduction in coefficient of friction as well as wear rates

Conflict of interest The authors declare that there is no conflict of interests regarding the publication of this paper.

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