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TRIBOLOGICAL ANALYSIS OF STEEL WITH DIFFERENT GRADES UNDER WET CONDITION USING PIN ON DISC

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ABSTRACT
Steel, being the most essential and frequently used metal has many applications. This material is been classified by various grade one of which is European grade i.e. EN7 (Mild steel), EN8, EN24, EN31 etc. This classification is based basically on the percentage composition and particularly carbon percentage which is responsible for strength and hardness of any steel material. Different grades steel has been tested in the laboratory and analyzed them with respect to different parameter like sliding speed, time & load. The same experiment is done even after heat treatment which includes both hardening (quenching in water bath) and annealing process , taken place at 830 ^{0}C.
After experiment, that is before heat treatment it has been observed that initially the wear increases with time but slightly reduces and becomes constant after sometime. Also with the increase in sliding distance, wear volume also increases but wear rate decreases after covering some distance. So overall conclusion is that the wear of mild steel is more than EN8. Heat treatment by quenching make the surface harder and annealing is just opposite, as it makes the material more ductile. Quenching is the technique which is good if concerning surface hardness and less wear and there are various cooling medium for quenching that is water bath and oil bath of different grades

I. INTRODUCTION
The science and technology of interacting surfaces in relative motion & of associated subjects and practice is called tribology. Name was coined after the Greek word "tribos" which means "rubbing". Tribology ranges from fundamental research to industrial applications. Nanotechnology and surface sciences are some examples of fundamental or academic research in Tribology. With the advancement of engineering applications, it is important to understand the properties of new materials which can sustain the various working conditions. The tribological properties play an important role in the application of engineering materials. The parametric study and analysis of tribological properties of any materials are important. Tribological properties of materials are determined by either measuring of friction force in contact area or by measuring wear of one element of tribo-mechanical system with or without heat treatment. Behavior of engineering material with respect to wear and friction also depends on the type of heat treatment [1].

It is important to design new materials with desired tribological properties to withstand various working conditions and environments, from car engines to joints in human body. Tribological studies of various materials such as metals, composites, bio and dental materials, and Nano-materials are conducted in laboratory.
While concerning metals, steel has many applications in engineering. It has been classified in different grades and is basically differentiated on the basis of composition and preferably carbon percentage as it is the main cause of hardness and strength of material. EN which stands for European standard has discovered various grades for steel on the basis of composition. For example EN8 is material having carbon percentage of 0.30 % and EN31 having carbon percentage of 0.43%.

Other composition i.e., manganese, silicon, nickel, phosphorous, sulphur almost are in same percentage. + Heat treatment is the phenomenon of varying the properties of any material by supplying thermal energy to the material. Different mechanisms have been developed to get different desired properties like ductility &

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brittleness. Also used to increase the strength, toughness and sometimes hardness. So all this basically depends upon the technique which we are using. Example of different techniques are annealing, quenching (oil or water quenching) etc.

The tribological properties under study are-
1 Friction
2 Wear

Friction
There is continuously some resistance once an object slides over a surface. This is often as a result of a resistive force also known as frictional force, and is often aimed opposite to the projected direction of motion on the surface. The dimension of this force depends on the exacting object and surface irregularity. A body is sited on level. The body is pushed with a minute horizontal force F. If the force F is sufficiently minute, the body doesn't move [3].

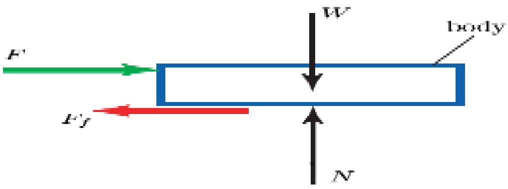

Figure 1Schematic of friction concept

Figure 1 indicates the free-body diagram of the body, where the force W is the weight force of the body and N is that normal load exerts by the surface on the body. The force F is the horizontal force, and F_f is the friction force created by the surface.

Friction force arises partly from the contacts of the roughness of the contacting surfaces ie, peaks and valleys at the surface. The body is in stability and F_f = F. The force F is slowly increased as long because the body remains in stability, the friction force F_f should increase likewise, since it equals the force F. The body slips on the surface. The friction force, once obtaining the utmost value, cannot continue the body in stability. The smaller quantity of force is needed to keep body moving on the surface whereas the force for cause of slip is more.

The assumption of dry friction, or Coulomb friction, predicts:
- The max. friction forces that may be imposed by dry, contacting surfaces that are stationary relative to each other;
- The friction forces produced by the surfaces once they are in relation motion, or sliding.

Wear
Wear is the slow removal of material obtained at contacting surfaces in the form of debris during relative motion of two body or sometimes three body. Whereas friction results in very important energy losses wear is expounded with increased maintenance costs and expensive machine downtimes. Wear phenomena are closely coupled to frictional processes. Recall that friction forces are the result of two contributions [3].
- Shearing
- Ploughing

A detailed, mechanistically- based classification of wear :
- Adhesion and transfer- Wear takes place by gradual removal of adhered fragments of particles picked up by the contacting surfaces throughout resistance interaction.
- Corrosion film wear- Wear is linked to the removal of fragments of protective corrosion/ passivating layers from the surface of the worn material.
- Cutting wear is the results of intermittent or continuous chip formation within the soft material due to cutting action by a harder tool.

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- Plastic deformation- Wear being related to the removal of sheared layers ensuing from excessive plastic deformation.
- Surface jetting- Wear resulting from surface instabilities associated with localized softening at the contact interface.

II. METHODOLOGY

Pin on Disk
The test set-up used in this experiment is widely used pin-on-disc type set up as shown in the fig below. The test samples are of rectangular cross sections of size 10×10 mm their initial weight is recorded using the electronic balance of accuracy 0.1mg after cleaning. The counter face rotating disc used is made of EN 31 steel hardened to 60 HRC of 120 mm diameter and 8 mm thick. The sample is dead weighted loaded through a string to which a pan assembly is attached.

The test was conducted by selecting the testing parameters such as time duration, load, velocity and working track of 120, 80 & 40 mm diameter. The surface of samples and the disc are cleaned with acetone before the test. After fixing the disc and the sample inside the sample holder in there, respective positions, the normal load to the rectangular sample was applied through a pivoted loading lever with a help of automatic reciprocating piston as per require load.

As the test time is finished, the test was stopped automatically with the help of timer mechanism set in the machine (tribometer). After the completion of the test weight of the sample is measured. The tests are carried out on the selected parameters by varying the load for all the three samples and weight loss is noted after the completion of the test. The result of the experiment were listed and discussed.

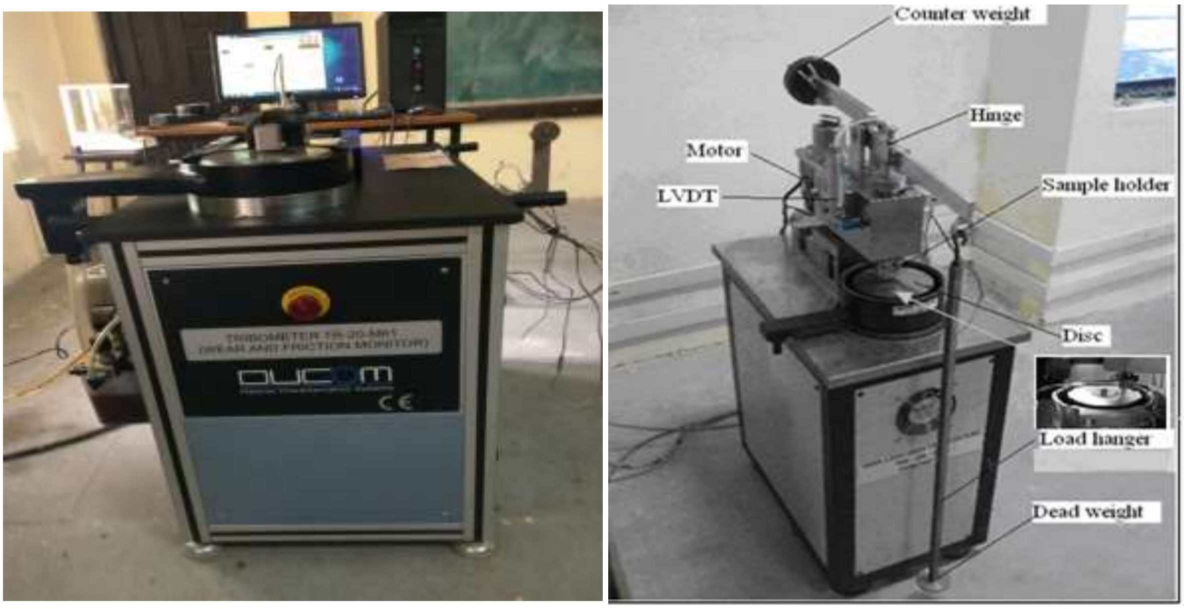

Figure 2 Schematic of Tribometer

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Figure 3 Furnace

This technique works on following principle:

1. Archard's equation: The Archard's wear equation is a simple model employed to describe sliding wear and works around the theory of asperity contact. It concludes that the volume of the removed debris due to wear is proportional to the work done by friction forces.
   $Q = \frac{KWL}{H}$
   Where:
   Q is the total volume of wear debris formed
   K is a dimensionless constant
   W is the total normal load
   L is the sliding distance
   H is the hardness of the softest contacting surfaces
   WL is proportional to the work done by the friction forces as explained by Reye's hypothesis.

2. Amontons' First Law: The force of friction is directly proportional to the applied load.
   $F_F \alpha N$
   Where N is Normal applied load
3. Amontons' Second Law: The force of friction is not dependent on the apparent area of contact.
4. Coulomb's Law of Friction: Kinetic friction is free from the sliding velocity.
5. Euler's law: the buckling of pin is said to what proportion axial load is applied:

Axial force on pin causing the pin to buckle = (Pin material modulus of elasticity * Pin Dia.^{4})/ Pin Length^2

III. RESULTS

Results before heat treatment

The variation of accumulative wear volume with sliding distance under different loads and at fixed sliding velocity of 2m/s, also at different wear track. It is discovered that the wear rate will increase linearly with increasing sliding distance initially but after covering some distance wear rate becomes constant. But on the other hand coefficient of friction decreases with increase in sliding distance.

The variation of coefficient of friction with sliding distance, friction coefficients fluctuates around the mean level and reduces as the sliding progresses. This trend is same in all the materials. The fluctuations within the coefficient of friction could also be due to variation involved contact between sample and disk.The variation of average coefficient of friction with increasing load. It is ascertained that average coefficient of friction decreases linearly with increasing load. A transfer layer of compacted wear debris besides the wear tracks may be ascertained over the sliding surface. This layer reaches a important thickness before being detached resulting eventually in generation of wear debris. The extent of cover provided by this transfer layer is set by the load,

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sliding speed and it increases with increasing load because of the increased frictional heating and hence better compaction. The various results are shown which shows the behavior of bright bar , mild steel and EN8 at loads of 50,75 and 100N. The friction and wear nature of engineering materials are shown on following graph.

Results of coefficent of friction

Material which are tested are differentiated on the basis of carbon content and EN8 is having more carbon content then mild steel. And it has been found that more the carbon percentage more will be the COF. EN8 is possessing highest COF then mild steel on any load.

It has also been experimentally found that COF decrease as load on the specimen increases. Due to the fact that on higher load, asperities from the specimen gets wear out readily.

Peaks and valleys gets destroyed and make the surface smooth on further sliding. So from the above, conclusion is that more the load, less is the coefficient of friction. Similar observation is done with respect to sliding distance that more the sliding distance, the surface gets smoother on removal of asperities, and thus COF get decreases after some distance.

At 2000 m Sliding distance and different load

Table 1 - COF for different material at 100 N & 2000m

Time (sec)	COF		
	EN8	Mild Steel	Bright Bar (Low carbon)
50	0.124	**0.123**	**0.105**
100	0.121	0.119	0.103
150	0.121	0.119	0.101
200	0.115	0.118	0.101
250	0.117	0.117	0.099
300	0.117	0.116	0.098
350	0.116	0.114	0.094
400	0.115	0.111	0.093
450	0.115	0.109	0.091
500	0.114	0.105	0.091

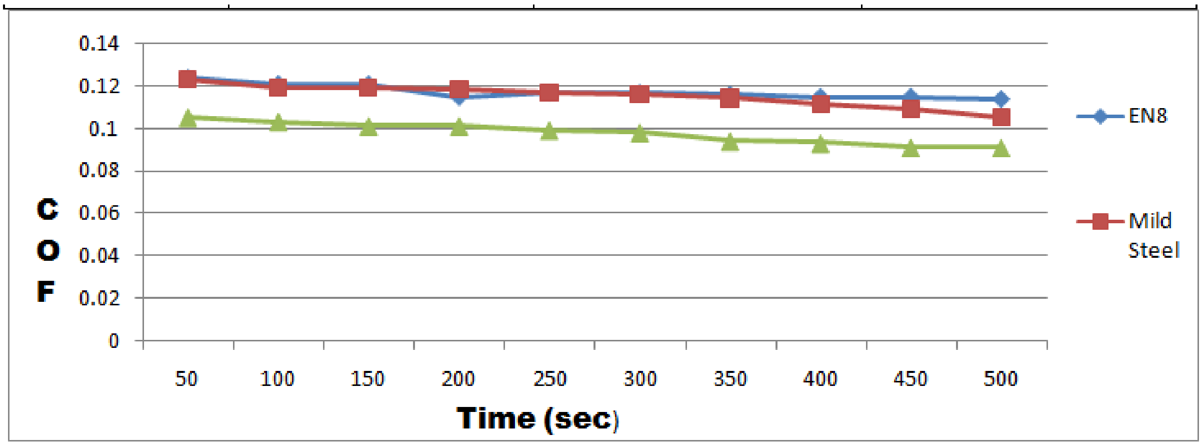

Figure 4 Variation of COF with respect to time at 100N & 2000m

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Table 2 –COF for different material at 75 N and 2000m

Time (sec)	COF		
	EN8	Mild steel	Bright bar (low carbon)
50	0.169	0.136	0.129
100	0.162	0.129	0.129
150	0.157	0.13	0.128
200	0.158	0.128	0.127
250	0.154	0.123	0.122
300	0.147	0.122	0.119
350	0.141	0.135	0.118
400	0.139	0.122	0.116
450	0.133	0.122	0.116
500	0.126	0.121	0.115

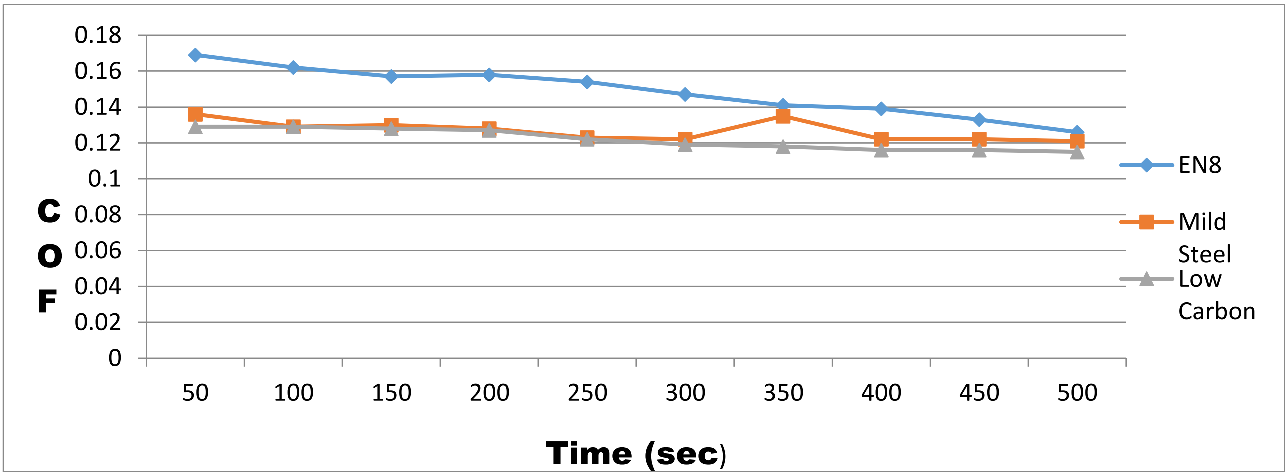

Figure 5 Variation of COF with respect to time at 75N & 2000m

Table 3 -COF for different material at 50 N and 2000m

Time (sec)	COF		
	EN8	Mild steel	Bright bar (low carbon)
50	0.219	0.177	0.144
100	0.221	0.173	0.145
150	0.22	0.172	0.141
200	0.218	0.171	0.139
250	0.205	0.17	0.142
300	0.205	0.169	0.14
350	0.204	0.169	0.139
400	0.199	0.169	0.137
450	0.197	0.167	0.135

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500	0.193	0.167	0.135

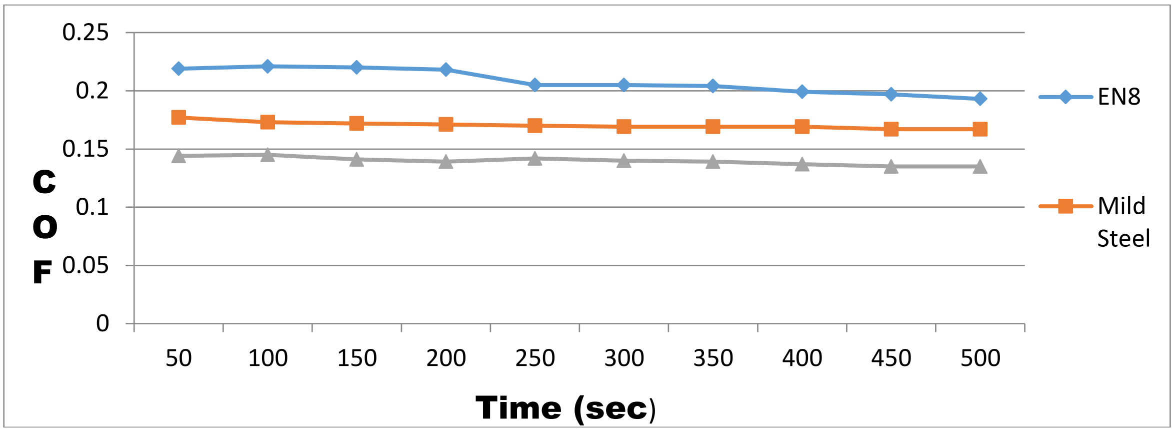

Figure 6 Variation of COF with respect to time at 50N & 2000m

So from the above graph's conclusion is that coefficient of friction reduces with the increase in sliding distance. Also coefficient of friction of EN8 is more than the remaining two as it posses more carbon content. More the carbon, harder will be the surface and thus coefficient of friction is higher. Asperities required more efforts to wear out because carbon makes them to resist up to great extent. We can even increase carbon percentage if require less wear.

Other then surface roughness, carbon content, sliding distance and load plays a vital role to define coefficient of friction of any material.

IV. RESULTS OF WEAR

It has been experimentally found that on increasing the load the wear rate was found to be increased initially but later it decreases and rate of wear becomes constant.

Wear somehow depends upon load as well as material's property and preferably carbon percentage. More the carbon percentage less is the reduction in weight. Secondly it also depends upon the sliding distance that more the sliding distance more the wear.

EN8 posses least wear whereas bright bar posses highest wear at different load and sliding distance. Also more the load applied more will be wear but less will be COF.

Table 4- Wear of different material at 100N/2000m

Material	Carbon %	Weight Before	Weight After	Reduction in weight
EN8	0.35%	21.1653gm	21.1626 gm	**0.0027 gm**
Mild steel	0.30%	53.1536 gm	53.1467 gm	**0.0069gm**
Bright Bar	0.25%	41.9145gm	41.9061gm	**0.0084gm**

Table 5- Wear of different material at 75N/2000m

Material	Carbon %	Weight Before	Weight After	Reduction in weight
EN8	0.35%	21.1677 gm	21.16459gm	**0.0018 gm**
Mild steel	0.30%	53.2094 gm	53.2034 gm	**0.0060gm**
Bright Bar	0.25%	41.8521gm	41.8450gm	**0.0071gm**

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Table 6- Wear of different material at 50N/2000m

Material	Carbon %	Weight Before	Weight After	Reduction in weight
EN8	0.35%	21.1512 gm	21.1505 gm	**0.0007 gm**
Mild steel	0.30%	53.1251gm	53.1199gm	**0.0052gm**
Bright Bar	0.25%	42.4188gm	42.4134gm	**0.0054gm**

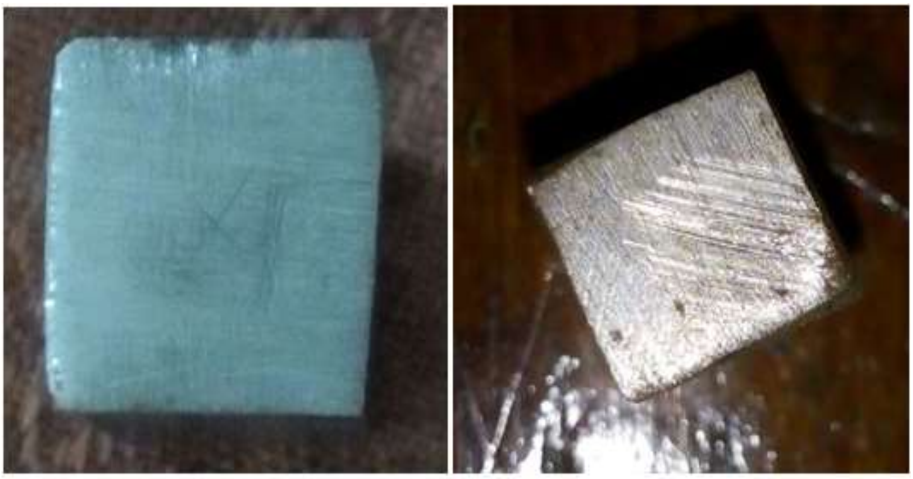

Figure 7 – Worn-out Surfaces of EN8 and Mild steel

The result shown above is basically concerning with the carbon percentage and sliding distance and it has been observed that wear rate decreases on increasing carbon percentage. Similarly it has also been observed as well that more the sliding distance more will be the wear. Interestingly with sliding distance, wear rate increases initially but then remains constant and this is due to the reason that surface become regular after covering some distance, and thus wear rate decreases and then it will wear out at very low rate.

Carbon content, load and sliding distance are mainly responsible for wear rate other then surface roughness. Wear rate can be decreased by increasing carbon content according to load application. High carbon content material can be used for heavy load conditions.

V. CONCLUSION

Engineering materials like bright bar (Low Carbon), EN-8, and mild steel have been widely used for many industrial applications. In order to subjecting the material into action, it is essential to look into their characteristics property which includes friction and wear. Hence it has become objective of the present work. Based on trials on the variation of load the properties like friction and wear vary, the following conclusions are made

It has been experimentally found that coefficient of friction decrease as load on the specimen increases due to the fact that at higher load asperities from the specimen gets wear out readily. Peaks and valleys get destroyed and make the surface smooth on further sliding. So the conclusion is that more the load less is the coefficient of friction. And among the three material EN8 posses highest COF where as bright bar posses the least. So application where friction is required we can se EN8 instead of mild steel.

Similar observation is done with respect to sliding distance that more the sliding distance, the surface gets smoother on removal of asperities, and thus coefficient of friction get decreases. So for more durability with respect to the sliding distance and less wear , go for EN8.

It has been noticed that when we increase the load the wear was found to be increased. Well wear somehow depends upon load as well as material's property and preferably carbon percentage. More the carbon percentage less is the reduction in weight.

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After studying the mechanical friction and wear properties of this different material's sample under the different loading conditions, the following works are suggested to be carried out in the future.

1. The similar studies can be made for other types of widely used materials such as EN9, EN24, EN43etc
2. The studies on friction and wear properties of sample can also be performed at variable speed.
3. The studies can be further extended for considering the effect of change in microstructure of the material with or without heat treatment.

Future scope

In the future, comparative study of same material will be done after heat treatment by taking the same parameter. Also the microstructural change in the specimen will be examined. Heat treatment by water quenching as well as oil quenching will be done. So that we can even compare between the best lubrication oil so as to reduce the wear rate up to some extent. Comparative study under dry condition of will also be done with some more EN grade material so as to get more and more exposure with respect to material selection

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