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## A Study on Wear Behaviour and Mechanical Properties of Ferrous Based Chilled Castings

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**ABSTRACT:** The ferrous metals are iron base metals which include all varieties of iron and steel. Most common engineering materials are ferrous materials which are alloys of iron. Iron is the name given to pure ferrite Fe. The fused mixtures of this ferrite with varying amount of carbon yields steel and cast iron upon processing. Iron most widely used of all metals as base metal in steel and cast iron.

The tribological and mechanical properties of these ferrous based materials can be controlled or modified by various means either varying the alloying elements or by heat treatment process.

The properties of these ferrous based materials steel and/or cast iron can also be controlled by varying solidification rate by employing different methods. Solidification is a phase transformation process in which liquid is transformed into solid phase upon cooling by liberating the super heat and latent heat of fusion. The properties can also be controlled by controlling the microstructure obtained after solidification of liquid metal.

Microstructures play a key role in assessing the properties of engineering materials and alloys. They are the important link between materials processing and materials behavior. Microstructure control is therefore essential for any processing activity. One of the most important processing routes for many materials, especially metals and alloys is solidification. Steel is an alloy of iron with definite percentage of Carbon ranging from 0.15% - 2.08 %. These plain Carbon steels are classified on the basis of their Carbon content, as their major alloying element is Carbon, steel with low Carbon content has the same properties as iron i.e. soft but easily formed. As the Carbon content rises, the metal becomes harder and stronger by compromising ductility.

Although the number of steel specifications runs into thousands, plain carbon steel accounts for more than 90% of the total steel output. The reason to focus on plain carbon steel group material is that, it is a tough, ductile and cheap material with reasonable casting, working and machining properties and also heat treatable to many properties. An attempt has been made to review various literatures from many researchers related to varying the cooling rate of a liquid metal during solidification and effort to study the different heat treatment processes of steel group materials which are responsible for modifying and improving the tribological and other mechanical properties by phase transformations.

**KEYWORDS:** chilled castings, wear behaviour, mechanical properties, Ferrous alloys.

### I. INTRODUCTION

Steel with least percentage of carbon is generally will not responded to the heat treatment concerning to its properties variations and has nearly the same properties as iron. It has formable easily as they are quite softer and malleable. As the carbon content increases becomes stronger and harder at the cost of losing its ductility. The steel and cast iron can be classified based on the carbon content in it. Various techniques through which the characteristics/properties of these ferrous based materials can be modified either by controlling rate of cooling during solidification of the liquid metal, or by the addition of alloying elements or also through different heat treatment

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processes. The properties of iron and steels are linked to the chemical composition, processing path and resulting microstructure of the material.

Plain carbon steel consist of about four-fifth of the total tonnage of steel produced, are economical as compared to alloy steels and find adequate application in many general engineering applications include shafts stud, bolts connecting rods piston rods, flanges, motor casings rollers for crushing ores and fittings of high temperature services.. Of the many failure modes associated with the steel components, wear presents a unique challenge to the designer and developer of mechanical components. Steel may wear out in different modes such as abrasion, adhesive, erosion, surface fatigue and erosion-corrosion. Out of these modes, adhesive and abrasive wear are commonly observed in steel components. Wear characteristics of steel components and their real life performance in different working conditions have been the subject of numerous investigations. With large number of variables like Frictional force, sliding velocity, test geometry, composition, strength and hardness, etc.,

Wear is the removal of material from one or both of two solid surfaces in a solid-state contact. It occurs when solid surfaces are in a sliding, rolling, or impact motion relative to one another. Wear occurs through surface interactions at asperities, and components may need replacement after a relatively small amount of material has been removed or if the surface is unduly roughened [2]. In well-designed tribological systems, the removal of material is usually a very slow process but it is very steady and continuous [3]. Actually wear refers to the progressive removal of material from a surface and plastic deformation of material on a surface due to the mechanical action of the other surface. The necessity for relative motion between the operating surfaces and initial mechanical contact between asperities leads an important role between mechanical wear compared to other processes with similar outcomes [4]. The sliding wear behavior of various steels is a vast subject which has received much attention in recent years. Tribological behavior of metals which are in sliding contact depends on the many variables such as normal Load applied on the material, sliding speed, sliding distance, surface geometry, surface hardness, roughness of operating surface, working environment, etc., which affect the wear mechanism and results in change of wear rate [5]. For most of the cases wear rate is proportional to the normal load applied [6]. The sliding speed and normal load indeed affects the friction force and wear rate considerably. The values of friction coefficient decrease with the increase of sliding speed and normal load. The wear rates, on the other hand, increase with the increase of sliding speed [7].

It is observed from several investigations that the understanding of wear mechanism is remain unclear and still exist with some ambiguities and controversies. Apart from these variables like sliding speed, frictional force etc., the type of microstructure also influences on the wear behaviour of steels.

## II. EXPERIMENTAL DETAILS AND DISCUSSIONS

V. K.Gupta[1] studied on plain carbon steel of nearly eutectoid composition shown in table 1

**Table 1 Composition of Plain Carbon Steel**

Elements	C	Mn	P	S	Si
Composition%	0.86	0.56	0.02	0.04	0.06

Three set of specimens consisting five numbers in each set are subjected different heat treatment process. First set subjected to normalizing process with temperature 840°C temperature with soaking period of 45 minutes followed by air cooling, 2nd and 3rd also heated to same temperature and same soaking period. 2nd set subjected to oil quenching followed by tempering process and 3rd set subjected to annealing treatment by furnace cooling to room temperature. Micro hardness test conducted for all the samples by using diamond indenter and found to be annealed 350, normalized 450 and tempered 550HV.

The heat treated samples examined under SEM and revealed that the test specimen undergone annealing treatment yields coarse pearlite structure and specimens undergone normalizing process shows fine pearlite structure and specimens subjected to quenching followed by tempering process showing round shaped cementite in a matrix of ferrite called tempered martensite structure.

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Wear test conducted for the samples for 3 different loads 2.5kgs, 3.5kgs and 4.5kgs discussed about wear rate, wear volume with respect to load. All the 3 types of specimens shows the similar behavior about wear rate for different applied loads as specified above.

Observed variation, linearly increased with increasing load in all the 3 types of specimens viz., annealed, normalized, quenched and tempered. Similarly volume loss also increases linearly with increase in sliding distance in all the 3 different types of specimens. All the 3 different types of samples show the similar nature with respect to volume loss against loads.

Wear test conducted for the same three different loads at a constant sliding velocity of 1m/sec. The worn surfaces of the samples were also examined under SEM to know the wear mode of the worn-out surfaces.

This investigation[1] deals with the influence of microstructure and the morphology of faces in heat treated 0.86% C steel under dry sliding condition against the counter face of hardened steel. The volume loss in wear has been found to increase with sliding distance and can be described in terms of two linear segments.

The wear rate in the first linear segment is higher than that in the second linear segment which has been attributed to run-in period in the first segment and progressive development of oxide cover in the second linear segment. The wear rate in both the linear segment has been found to vary with load over a limited range and does not even change significantly between certain intervals of load.

At low load, oxidative wear mechanism is predominant where as at higher load metallic wear mechanism dominates. The wear debris generated at higher loads contain larger amounts of oxide compared to those generated at lower load which may be due to higher frictional heating at high load increasing the temperature at the sliding surface. On the basis of wear co-efficient, both in the first and the second linear segments, the coarse pearlite, fine pearlite and tempered martensite structure in 0.86% C steel show the wear resistance in decreasing order.

Amit K. Gupta et al [3] studied on the effect of carbon content on the wear behavior of plane carbon steel. Wear test conducted for three test specimens A, B, C are having different carbon content 0.131%, 0.246% and 0.358% respectively. The size of the specimens prepared of diameter 6mm and length of 30mm. The chemical composition shown in table 2

**Table 2 Composition of Plain Carbon Steel**

Mark	C%	Si%	Mn%	P%	S%
A	0.131	0.215	0.457	0.008	0.028
B	0.246	0.170	0.514	0.008	0.031
C	0.358	0.339	0.583	0.010	0.061

Pin-on-dish equipment used to study the wear characteristics of these different specimens subjected to different loads from 0.5 kg to 2.5 kg in steps of 0.5 kg with a wear track diameter was fixed at 50mm; the rotational speed of the disc was fixed at 480 rpm. Timer was set to 3 minutes for each set of loads. The apparatus was set for 3 minutes and readings were recorded from digital display and observed the effect of carbon content and load on wear of materials.

The researcher found that wear of the materials increases with the increase in load. Also noticed that the test specimen which contains low carbon content (0.131%), the slope of the curve steeper. As the carbon content increases, observed lesser the steep in slope of this curve. But the wear of the material was not much in the specimens when the load was increased from 0.5 kg to 0.1 kg that is the slope of the curve is linear.

Investigator also studied the effect of carbon content on wear behavior of plane carbon steel and stated that the tendency of wear curve has been found to be decreasing with the increase in carbon content. Wear falls rapidly with the increase in carbon content from 0.131% to 0.246 % and follows the trend for further increase in carbon content to 0.358%.

Also recorded the amount of wear in microns at highest load (2.5 kgs) for all the three specimens having 0.131%, 0.246% and 0.358% are 35, 28 and 24 respectively. Investigator concluded that wear resistance of steel is affected by the load. Wear of steel is linearly related to the load. Steel with the higher carbon content experiences better friction and wear characteristics.

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Senthur et al[4] investigated the wear characteristics of a sintered Fe-C-W powder metallurgy low alloy steel. Prepared 3 test specimens of low alloy steel (Fe-1%C, 1%W) by powder metallurgy technique with different densities 85%, 90% and 95%. The wear behavior of the as sintered performs were studied under dry conditions on pin-on-disc arrangement with a sliding speed of 2m/sec and at a normal loads of 30, 50, 70n respectively. Wear regimes of p/m metallurgy steels have been characterized using optical microscopy. From the microstructure of wear pattern it is evident that, presence of carbides of the carbide forming element tungsten offers greater wear resistance. The elements get embedded as hard particles in a soft matrix of Fe-C, resulting in non-uniform wear pattern in higher density preforms (95%), whereas uniform wear was observed in low density performs (85%) even at higher loads during the test. Delamination is a common wear mechanism found in both p/m alloy steels with an increase in applied load, but oxidation wear was observed in all the preforms at low levels of applied load.

The microstructures of the sintered p/m alloy steels used for the wear test basically containing ferrite-pearlite microstructure and reveals that the uniform distribution of tungsten particles. Tungsten is known carbide former. In higher density performs 95% the carbide phase due to tungsten embedded in between the ferrite grains is bigger in size. The carbides of alloying element embedded along the grain boundaries leads to enhance the wear resistance of the alloy steel. Investigator [4] reported on morphological features of wear pattern of maximum worn out pin surfaces of p/m alloy steels. Non-uniform wear pattern was observed due to the presence of high dense tungsten carbides because of the addition of alloying element tungsten is known carbide former.

At higher load and higher density (95%) extent of grooves, craters formed at the worn surfaces of the preforms indicate that delamination is a main mechanism responsible for removal of material. failure by a delamination process is clearly indicated by the shape of the debris particles. The wear debris mechanism of wear may include oxidative wear, micro-cutting and delamination wear because of some oxide particles, microchips, delamination flakes. Heat generated at high load causes more oxidation but that is counteracted by continuous fracture under those conditions.

Researcher summarizes that, the wear rate gradually increases with increase in applied load for all the density p/m alloy steels and in higher load wear rate increases abruptly due to delamination wear. In high density performs (95%) due to hard phase of the tungsten carbide results in high hardness leads to higher wear loss during the test. Heat generated at high load causes more oxidation and the continuous fracture of oxide film formed the metal to metal contact results in delamination wear. The uniform wear loss was observed in 85% density performs irrespective of loads compared with other density performs. But the frictional coefficient slightly increases due to oxide layer formed. The basic microstructure of all density Fe-C-W p/m alloy steel is ferrite-pearlite. Distribution of the tungsten (carbide) particles embedded in Fe-C matrix is uniform in the 85% density sintered p/m steel preforms results in uniform wear and also observed the least wear loss. So the density plays the vital role in the p/m alloy steels to ensure the wear resistance.

Kiran Deore et al[7] reported on wear behavior of 6 different materials namely SS316, SS304, SS410 and aluminium copper and brass with the same parameters of load 3kg, disc rotational speed 700 rpm and time 5 minutes with pin size 10mm diameter. The test conducted on pin-on-disc apparatus with a spherical pin with flat circular disc placed perpendicular to the surface of the spherical pin end.

**Table 3 Test results**

Material	Frictional Force (N)	Wear ( $\mu\text{m}$ )	Coefficient of friction
SS316	11.5	1290	0.4407
SS304	11.7	1467	0.4480
SS410	5.9	1200	0.3293
Al	8.4	1146	0.6544
Cu	10.9	432	0.5043
Brass	4.5	1467	0.1698

Researcher shown the wear characteristics of all different materials through graphical representation by plotting wear rate, COF and frictional force with respect to time and concluded as follows: (1) The wear rate of all the

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3 types of steels was comparatively higher. (2) Aluminium has wear 1146 $\mu$ m and frictional force 8.4N while COF was 0.6544. (3) Wear resistance of copper was highest with intermediate frictional force and COF. (4) Graph of a brass for wear rate was smooth curve in nature. (5) SS304 and brass shown same wear rate but different frictional force and COF. (6) Aluminium has maximum COF while brass shows lowest among the specimens. But the researcher not reported the reason for higher wear rate of all 3 types of steels experiences than the other metals aluminium, copper and brass.

B.Vasudeva[9] studied the effect of nickel addition on mechanical properties and wear behavior of chilled ASTM A216 Grade WCB steel. Prepared the test specimens by using sand mold with CO<sub>2</sub> process and provided different chills. Result of the investigation reveal that addition of nickel has no effect on mechanical properties and wear resistance but increases elongation significantly. Out of all chilled steels sub zero chilled steel was found to be good in enhancing hardness and hence better wear resistance. In addition tensile strength is also found to be enhanced in sub-zero chilled steel. Investigator observed that the wear rate increases as load increases. Sub-zero chilled steel has the least wear rate; whereas graphite and silicon carbide chilled steel has the highest. The steel chilled using other type of metallic and non-metallic chills fall in between them two. Researcher[9] concluded that, the least wear rate for sub-zero chilled steel is because of highest rate of heat removed during solidification (VHC), whereas graphite and silicon carbide chills has least specific heat capacity and hence has the highest wear rate.

SEM analysis of sub-zero chilled and unchilled WCB steels reveals that, subzero chilled steel has very minute debris on the surface with minimum ploughing of the abrasive of the wear testing machine. The low wear rate is confirmed with the presence of large carbide particles in pearlite matrix of the microstructure of the steel casted.

SEM analysis for unchilled reveals that large number of debris and ploughing was seen. It is shown that it has large number of ferrite which is soft in pearlite matrix. The soft ferrite only has undergone deformation during wear test.

Vemuri lakshminarayana[5] studied the influence of varying load on EN8 alloy steel when it is sliding against EN31 steel alloy. The wear test was carried out by using pin-on –disc apparatus. The test was carried at low loads and high loads. Variations of frictions coefficient and the wear rate at different normal loads and high load were investigated. The result shows that the wear rate increases when the load increases. An interesting result showed that the coefficient of friction decreases at normal loading conditions and when the load increases from 125N, the coefficient of friction increases till 175N. The scanning electron microscopy (SEM) image of the worn out specimen reveals that the formation of groove lines on the sliding surface due to adhesion strength of the material is very less when it subjected to higher loads.

The test was conducted at a constant speed of 450rpm at 20 minutes time for each specimen. the load has a significant influence on the wear loss of the material. The wear loss increases when the load increases. Wear loss increases gradually till the load reaches 150N. At load 175N, wear loss is suddenly increased and once it reaches 200N, much worn out takes place. This indicates that wear of EN8 steel against EN31 attains a new phase of transformation at high load (200N).this leads to increase in temperature and the material becomes ductile.

Further when the load increases the COF gradually decreases until it reaches the load 125N, once it reaches 125N, dramatic increase in COF takes place till it reaches 175N, then after it decreases gradually. This clearly indicates that the high load conditions, the change of phase takes place and the material becomes more ductile.

For various loading conditions, the wear losses and the wear rates have been calculated and tabulated as shown below table 4.

**Table 4 Loading conditions**

Load (N)	Weight loss (gm)	Volume (mm <sup>3</sup> )	Wear rate (mm <sup>3</sup> /N-m)
20	0.0239	29.8750	0.000417
30	0.076	95.0000	0.000884
40	0.1128	141.0000	0.000984
100	0.3033	379.1250	0.001059
125	0.422	527.5000	0.001178
150	0.6658	832.2500	0.001549
175	1.1515	1439.3750	0.002297
200	4.3836	5479.5000	0.007650

Investigator stating that when the load increases on the specimen the friction also increases this leads to increase in temperature and the material becomes ductile. So, wear particles get adhered to the surface and leads less wear rate. The wear rate it increases gradually upto 50N. The wear particles get adhered to the surface and layer called smeared layer is formed. Further there is sudden increase in wear rate due to normalization at higher loads. The increase in temperature increases the ductility.

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Investigator examined the worn surface under SEM stating that worn out specimen at the load of 150N is consisting of more groove linings which indicates adhesion strength of the material is very less when it is subjected to higher loads. Thus, it might be reasonable to conclude that at higher sliding speeds, an increased plastic deformation of the matrix leads to a transition from cutting or ploughing or wedge formation during abrasion. Material is displaced on either side of the abrasion groove without being removed. While in wedge forming, tiny wedge shaped fragments or worn only during the initial contact with an abrasive particle.

L.N.Karadi et al[6] studied the tribological characteristics of the two different mild steel specimens containing 0.2% and 0.45% carbon steels. Wear test was carried out before and after the high temperature tempering heat treatment. Specimens are subjected to high temperature tempering after quench hardening. It is done by reheating the hardened steel to a temperature below 550°C followed by slow cooling. Tribological and mechanical test conducted and reported that there is an improvement in tensile strength, compression strength and percentage of elongation with slight reduction in hardness.

Wear test conducted for varying loads from 10N to 50N insteps of 10N with a constant sliding distance and sliding speed. graphical representation with respect to 3 parameters normal pressure (N/mm<sup>2</sup>), sliding speed (m/sec) and sliding distance (m) plotted by keeping two parameters constant. Plot depicts that volume loss increases as the normal pressure increases. As the sliding speed of the disc increases there is a decrease in the volume loss of the specimen. Another graphical representation shows that volume loss increases with the sliding distance. The test specimen without subjected to high temperature tempering experiences the higher volume loss compared to the specimen undergone high temperature tempering after hardening.

Researcher[6] reported that volume loss (wear rate) decreases with the increase in sliding velocity, as the sliding velocity increases there is an increase in interface temperature. This may lead to the formation of oxide layer at higher interface temperatures. Wear rate of the tempered specimen relatively lesser than the specimen without tempering.

The investigator[2] conducted the experiment to study the wear characteristics of plain carbon steel was used as shown in table1. Wear characteristics of these samples were investigated after the heat treatment process. These samples heated to 840°C and soaked to 60 minutes followed by slow cooling in furnace itself. Then hardening was done by heating again 840°C soaked for 1 hour for homogenization and quenched in water. This hardening process led to the formation of martensite.

**Table 5 Composition of Plain Carbon Steel**

Composition	Grade	%C	%Si	%Mn	%P	%S
Sample	EDDIS1079	0.87	0.251	0.342	0.007	0.005

Wear test were carried out at loads 1,3,5 and 7kgs and sliding speeds 1,3,5 and 7m/s, by pin-on-disc apparatus. Operating conditions shown in table 6.

**Table 6 Operating conditions**

Sl No	Speed (m/s)	RPM	Time (minutes)	Normal Pressure(MPa)	Sliding Distance (meters)
1	1	212	167	0.1249	10,005
2	3	636	56	0.3747	10,065
3	5	1060	34	0.6245	10,185
4	7	1484	24	0.8743	10,065

Figure4a shows that volumetric wear rate decreases with increasing sliding speed. This may be due to frictional temperature, which causes recrystallisation of brittle work hardened layers and therefore inhibit severe surface spalling. At high at very high loads and or speeds frictional heating produces more intensive form of hardening based on structural strain transformation bringing about mild wear condition. The changes in mechanical and frictional properties of the surface layer produce due to heat evolution are difficult to control the process of wear [P.L Hurricks(1973)].this decreases drastically to a very low value and continues to remain at that level with increase in

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sliding speed, is due to the hard asperities of martensite that gets removed easily in the initial stages. Later very few asperities are present that gets locked easily in large numbers. Martensites being a hard phase offers wear resistance to further wear when the sliding speed increases. At this stage frictional force increases slightly. This increase in the frictional force causes frictional heating by structural transformation leading to mild wear reducing the volumetric wear rate. With further increase in the sliding speed, friction temperature increases, further softening the hard martensitic phase. Figure4b [P L Hurricks 1973].

At still higher speed the effect of high temperature leads to martensitic phase transformation into tempered structure forming ferrite and precipitating carbide particles. This resists the wear hence, the volumetric wear rate decreases slowly as seen from the figure 5a. As seen from the figure 5b the values of frictional force decreases with increasing sliding speed for all the normal pressures. With increasing sliding speed the frictional force decreases along with decrease in the residential time which results in the restriction on growth of micro-welds.

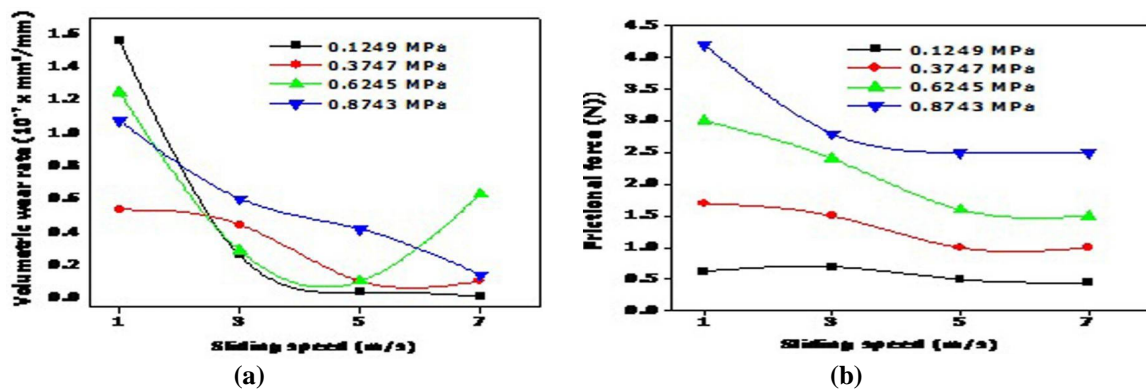


Fig 4 (a) Effect of sliding speed on the volumetric wear rate: (b) Effect of sliding speed on the frictional force

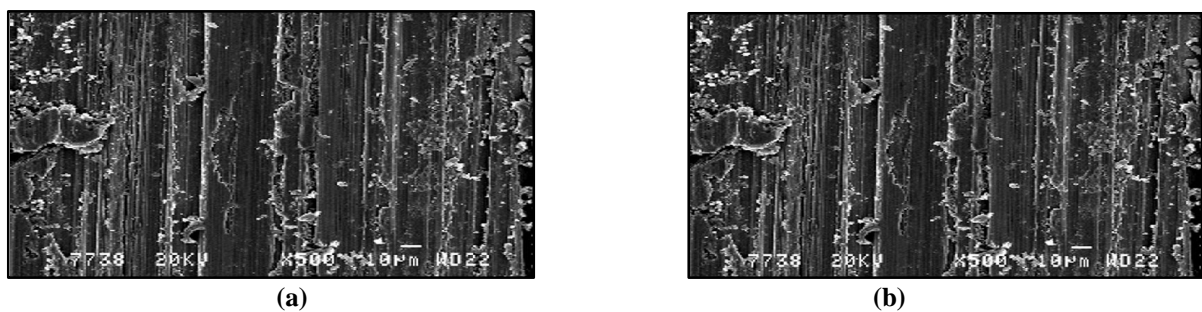


Fig 5 Micrograph for (a) sliding speed 1m/sec and load 0.1249MPa, (b) Sliding speed 7m/sec and load 0.1249MPa

As the speed increases these asperities are broken and the surface roughness values are reduced. This reduces the frictional force values also. With further increase in the sliding speed friction temperature soften the hard martensitic phase reducing the friction force.

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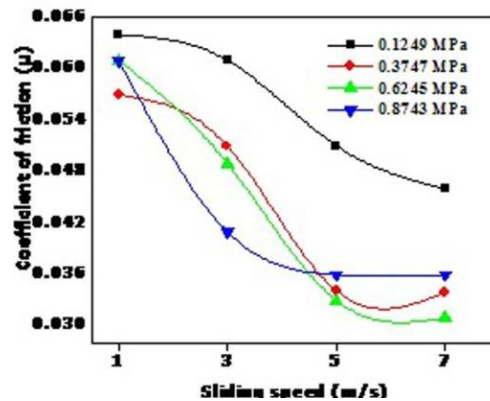


Fig 6 Effect of sliding speed on COF at constant normal wear pressure

As seen from figure 6 higher friction coefficient prevails at the low sliding speed condition. Increased wear rate is observed at these values of friction coefficients because thicker wear particles are formed and also faster rate of crack propagation takes place. This ultimately increases the volumetric wear rate. At higher speeds due to more number of asperities in contact the inter locking between the asperities reduces. Therefore the coefficient of friction is low. Also at higher speed frictional heating reduces the hardness of the hard martensitic structure.

Researcher [2] reported that in order to find the traces of oxides energy dispersion spectroscopy (EDS) test conducted and observed that oxide formation is almost negligible at lower normal pressure and lower sliding speed. Traces of oxides found at higher normal pressure and higher sliding speed.

Hesham [13] investigated on wear behavior of carburized mild steel specimen prepared to a size for abrasive wear and hardness test of dimensions (40x25x5mm). The chemical composition of the mild steel specimen is shown in table 7.

Table 7 Chemical composition

Element	C	Si	Mn	S	P	Ni	Cu	Cr	Fe
Composition %	0.16	0.03	0.32	0.05	0.02	0.01	0.01	0.01	Balance

Specimens were heat treated namely carburizing, quenching and tempering, carburized to a temperature range of 850°C to 950°C with a soaking period of 30 minutes followed by quenching in industrial engine oil which was maintained at ambient atmospheric temperature then the specimen subjected to wear test after tempering to 200°C for 30 minutes.

Test conducted under different loads from 10N to 100N with a speed of 0.65m/sec for a period of 60 minutes. Investigator[13] observed that wear resistance is higher for carburized mild steel and lowest for uncarburized mild steel. Weight loss during abrasion is higher for uncarburized steel sample. Also reported that, as the carburization temperature increases the weight loss during abrasion is decreases. Further, the weight loss is higher for the load of 49N and lower for the load of 14.7N. This is because the increase in force, the friction increases which causes weight loss. The mild steel carburized at the temperature of 950°C gives the best results for the mechanical and wear properties. Researcher stated wear resistance is directly proportional to the carburizing temperature and is linked as higher the carburization temperature better the hardness and consequently higher the hardness better the wear resistance.

### III. SUMMARY

Many of the researchers [1, 2 and 6] carried out the investigation to study the effect of heat treatment on tribological characteristics of low, medium carbon steel group materials and some of the researchers [13] put their effort to evaluate the properties of mild steel by subjecting the test specimens to carburizing process. Some studies [2] reveal the



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influence of martensitic phase of plain carbon steel on wear resistance. Some investigators [3, 6] studied the effect of carbon content and the effect of high temperature tempering on wear behavior of plain carbon steel group material. In another research [4] effort has been made to study the dry sliding wear behavior of sintered low alloy steel and reported through SEM analysis.

Research [5] conducted and reported on wear resistance of EN8 steel which is widely used for many general engineering applications include shafts, studs, bolts, connecting rods and screws etc., reported wear behavior for various applied loads. Studied [7] the properties by conducting experiments to the six different specimens and revealed the wear characteristics of all these test specimens. In another study [9] attempt has been made to investigate the mechanical and wear properties of chilled steels also reported the addition of nickel has no effect on mechanical and tribological properties.

## IV. CONCLUSION

Most of the researchers made an attempt to modify or to improve the tribological behavior of ferrous based materials either by altering the chemical composition particularly carbon or through phase transformation by heat treatment process. Also investigator made an attempt to induce carbon atoms on the surface of the test specimen by surface heat treatment process for better wear performance.

Many researchers put their effort to improve the tribological properties by subjecting them to different rates of cooling in solid to solid phase transformation. Another study [9] reported on the mechanical and wear characteristics of a chilled steel group material also revealed that the addition of nickel has no effect on mechanical and tribological properties.

Very few investigators [9] reported on the effect of different rates of cooling during solidification by the application of different chills and observation made during liquid to solid phase transformation. Hence further investigation is required to study the liquid to solid phase transformation during solidification of steel material by using chills to regulating the cooling rate and due attention is also required to study the effect of addition of alloying elements on strength and wear properties of ASTM grade steel used for mining industries.

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