

STUDIES OF HIGH TEMPERATURE SLIDING WEAR OF LOW CARBON NICKEL-CHROMIUM BASED ALLOY STEEL

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ABSTRACT

In order to explore the tribological potential of the low carbon Ni-Cr based alloy steel as a wear-resistant material, the friction and wear characteristics have been investigated for room temperature and high temperature condition. Dry sliding wear tests have been conducted on steel using a pin-on-disk machine under different loads of 9.81, 29.43 & 49.05 N, sliding speeds of 1, 3 & 5 m/s and ambient temperatures of room temperature, 200, 400 & 600°C. Weight loss has been measured at the end of the experiment. With increasing the load and sliding speed the hardness of the worn out surface is increased due to work hardening at room temperature. Under low operational conditions, two body abrasive, under high operational conditions oxidative and under moderate operational conditions adhesive wear mechanisms are observed.

The wear behaviour of metallic material is influenced by the frictional force, which is turn, is governed by the hardness & oxidation kinetics of the mating surface. Keeping in view the present investigation was undertaken to find the influence of mating surface on the high temperature wear. Understanding the behaviour of metals and alloys at elevated temperature, Nickel Chromium based alloy have been reported to be widely used as they combine several advantages such as abrasion, erosion & resistance to high temperature corrosive atmospheres. In this article a brief review of the performance of Nickel Chromium based alloy at different speeds, loads and temperatures has been made and compared with the room temperature. It is observed that the sliding speed of 3 m/s is critical sliding speed.

Key words : Ni, Cr, High temperature wear, surface roughness

INTRODUCTION

Wear is one of the major phenomena of reducing the effectiveness of mechanical components, directly or indirectly impact the nation financially in terms of material loss, associated equipment down time for repairing and finally the replacement of worn and corroded components. The interactions among wear and corrosion could significantly increase total weight losses and reduction of either wear or corrosion could considerably decrease the total weight loss. for any particular applications, sufficient information will be necessary [1, 2].

Wear is inevitable for machine part sliding in contact. The amount of wear depends on material pair, surface topography, working condition, and chemical effects of the environment. It is impossible

to completely prevent wearing. Any empirical relation is difficult to be developed, because the factors are not predictable. Abrasive wear is the dominant mechanism causing the material losses. The most severe wear occurs on the cylinder surfaces in internal combustion engines. On the upper portions of the cylinders, lubrication is poorer comparing to other regions, because the lubricant that reaches here is then burnt partly. Pistons, valves, and piston rings are the other elements that are subjected to severe wear.

The deterioration of surfaces is a very real common problem in many industries. Wear is the result of impact, erosion, metal-to-metal contact, abrasion, oxidation and corrosion, or a combination of these. Industries have long been involved in the development of processing technique to overcome

this problem. So far the wear behavior of steel has been studied in detail under the different operational conditions like load and sliding speed in ambient temperature. But under elevated operational conditions, the detailed literature is insufficient. So it is necessary to study the wear behavior of steel under elevated temperature because, the basic concepts of elevated-temperature in wear is plastic deformation and fracture of wearing surface. At elevated temperatures it is one of the most challenging engineering problems faced by materials engineers. In order to study the wear behavior at high temperatures, several key concepts must be taken into consideration :

- Plastic behavior of wearing surface at elevated temperatures
- Wear mechanisms with under different operational conditions
- Stress and temperature dependence
- Fracture at elevated temperatures
- Work hardening and softening effects

Nickel based alloys has good high temperature wear & corrosion resistance. This alloy is widely used in the chemical industry, petrol industry, glass mould, Aircraft and Automobile industries, hot working punches, fan blades, mud purging elements in cement factories & engines.

High temperature alloys have high degree of heat resisting properties. Nickel is the most favorable choice for the wide structural application because nickel has no allotropic phase transformation below its melting point. The densities of iron, nickel and cobalt-base super alloys are 7-8.5 gm/cm³, which are quite moderate when compared with alloys containing heaviest alloying elements, like molybdenum, tantalum and tungsten. Ni base alloys tend to increase the thermal conductivity resulting in reduced thermal stresses.

Nickel increases the strength of steel by dissolving in ferrite. Its main effect is to increase toughness by limiting grain-growth during heat-treatment process, for this reason, up to 5.0% nickel

is present in some of the better quality steels used for case hardening. Unfortunately, nickel does not combine chemically with carbon, & worse still, tends to make iron carbide (cementite) decompose & so release free graphite. Consequently, nickel steels are always low-carbon steels or alternatively, medium carbon steels with very small amounts of nickel. However, because of their shortcomings in respect of carbide instability, they have been almost entirely replaced in recent years by other low-alloy steels. Chromium is added to steel; some of it dissolves in the ferrite (which is strengthened as a result), but the remainder forms chromium carbide. Since chromium is harder than ordinary iron carbide (cementite), the hardness of the steel is increased. Because chromium stabilizes carbides, these steels may contain 1.0% or even more of carbon. The main disadvantage of chromium as an alloying element is that, unlike nickel, it increases grain growth during heat treatment. Thus unless care is taken to limit both the temperature & the time of such treatment, brittleness may arise from the coarse grain produced.

Nickel & chromium steels have opposite effects on the properties of steel. Nickel is a grain refiner & chromium tends to cause grain-growth, on the other hand, whilst chromium is the carbide stabilizer, nickel tends to cause carbides to break down, releasing graphite. Fortunately the beneficial effects of one metal are stronger than the adverse effects of the other, and so it is advantageous to add these metals together to steel. Unfortunately, these straight nickel chromium steels suffer from a defect known as temper brittleness & for this reason straight nickel chromium steels have been almost entirely replaced by nickel-chromium-molybdenum steels.

Nickel-based alloys are the most frequently employed materials for components subjected to high dynamic stresses at working temperatures of up to 1100°C. They are used mainly to make blades, disks, and housing components for the hot sections of stationary gas turbines and jet engines. Hence, research work has been carried out on Nickel – Chromium based alloy under different operational conditions.

Experimental details

Considering all the above advantages, AISI-SAE 8630 steel was selected for further investigation. The composition of steel is provided in Table 1. In the present invention one of the common and simplest methods to test for wear rate was by using a pin-on-disc wear tester. Weight loss of the pin was measured after the wear test. Wear is usually expressed as worn volume per unit sliding distance. The wear volume of the pin specimen was determined from weight loss measurements.

In general, the wear rate ‘ W_r ’ depends on the bearing pressure W/A (Where W is the load carried by the contact A is its nominal area), on the sliding speed, S & on the material properties & geometry of the surface.

$$W_r = f(W/A, S, \text{Mat. Properties, Geometry}) \text{ [3].}$$

Table: 1 Alloy composition of steels

Composition in %	8630
C	0.28
Ni	0.395
Si	0.241
Mn	0.471
S	0.010
P	0.017
Cr	12.345
Mo	0.005
Cu	0.024
Co	0.004
Ti	0.002
V	0.011
Al	0.000
Nb	0.000
Fe	86.070
W	—
Pb	—

The photographic view of high temperature wear-testing machine is shown in Figure. 1.



Figure 1 : Photographic view of high temperature wear-testing machine

In the Figure.1 element A is a disc and element B a pin AISI-SAE 8630 steel specimen. The pin specimen was installed in holder with set screws. The pin specimen was then pressed against the disc under a calibrated constant vertical load. The vertical load acting between the pin & disc was measured. This wear-testing machine is equipped with a 1 kW electrical resistance heater divided into three sectors to produce ambient temperatures of up to 600°C for elevated temperature work. The pin specimen was made from a bar, 10 mm in diameter x 32 mm length. The wear test conditions were as follows. The Three vertical loads (9.81, 29.43 & 49.05 N), Three different sliding speeds (1.0, 3.0 & 5.0 m/s), all within the speed range in which there is smooth sliding contact between the pin specimen & the disc without any unstable vibration & ambient temperatures of room temperature, 200, 400 & 600°C were used. The mass loss of the pin specimen was measured by a precise electro balance, with a least count of 0.1 mg. When the sliding distance reached the 10,000 m, the pin specimens were thoroughly cleaned & degreased in acetone & removed the wear lips carefully taken.

RESULTS AND DISCUSSIONS

While conducting the wear test weight loss was recorded. The volumetric wear rate was estimated on

the basis of volume loss after converting weight loss into volume loss by considering the density of the material. Hardness after wear was measured by micro hardness under 100gm load. Roughness of the worn-out surface along the parallel & perpendicular were measured by roughness instrument.

For the material AISI SAE 8630, from the Figure 2 (a) it is observed that the volumetric wear rate is decreased with the sliding speed for the lower load of 9.81 N at room temperature. Also the volumetric wear rate is decreased with the load for the lower sliding speed of 1 m/s.

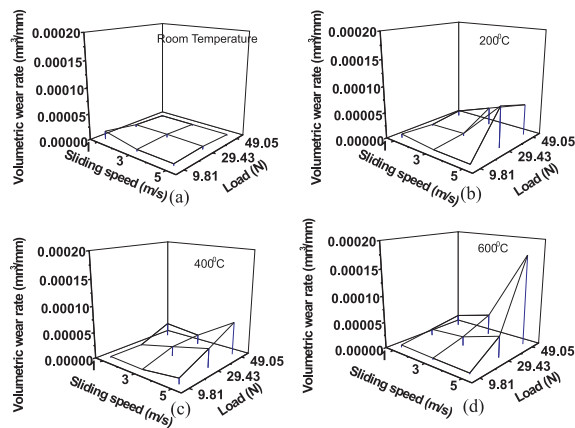


Figure 2 : Effect of sliding speed and load on volumetric wear rate for AISI SAE 8630 under differential operational temperature

Under low sliding speed the generation of frictional temperature is low hence; the wearing surface may tend to produced the work hardening effect. Under the sliding speed of 1 m/s, with increase in the load, the surface contact between the wearing pin & with the disc is increased. Due to this increase in the surface contact, & due to the low frictional temperature, the work hardening effect takes place. The work hardening effect may be noted on the basis of hardness after the wear. The hardness after the wear for the sliding speed of 1 m/s with increase in the load, values of hardness after the wear is increased Fig.2 (a). Hence, the volumetric wear rate is decreased with the load for the sliding speed of 1 m/s. For other operational conditions at room temperature the values of volumetric wear rate is almost the same.

With the increase in sliding speed, the residential time is decreased between the wearing pin with the disc. At lower sliding speed the sufficient residential time is available between the wearing pin and the disc. Wear of metals takes place whenever two solid surfaces are in dry rubbing contact. No matter how smoothly these surface are finished, they will only touch with a relatively few isolated points, often referred to as asperities. All these small contact areas carry together the entire load between the two surfaces. Therefore, the localized pressures generated are very high usually exceeding the yield strength of the softer material involved. During this time it is possible to get micro welds & also increase in the size of the micro welds due to this more residential time. As a result of high local pressures combined with increase in the sliding speed, the residential time between wearing pin & the disc is reduced which results in less growth of micro welds & rupturing of micro welds or junctions formed at these localized contact areas[4] & result in wear loss. It is usually observed for metals that the coefficient of friction decrease as the sliding speed is increased. So, at low & moderate sliding speeds friction is largely due to local adhesion & shearing at the region of contact. Almost the same feature is observed under the ambient temperature of 400°C for the sliding speed of 1 m/s & load of 49.05 N Fig.3. At high sliding speeds metal surfaces are subjected to very intense frictional heating which profoundly changes the state of the surface layers on which the sliding takes place.



Figure 3 : SEM photograph at moderate operational conditions of load 49.05 N, sliding speed 1 m/s & temperature 400oC Three body abrasive

Friction & wear is governed largely by the interaction of asperities of the two sliding surfaces. Energy is dissipated due to mechanical work & inevitably causes a rise of temperature but it happens intermittently in so far as the points of actual contact are concerned due to sticking & slipping of the junctions. These high temperature flashes are short lived in the order of 10^{-4} second. The heat evolved in friction is dissipated to the surrounding with the result that the asperities tips are at a high temperature but the bulk of the component remains relatively cool [5].

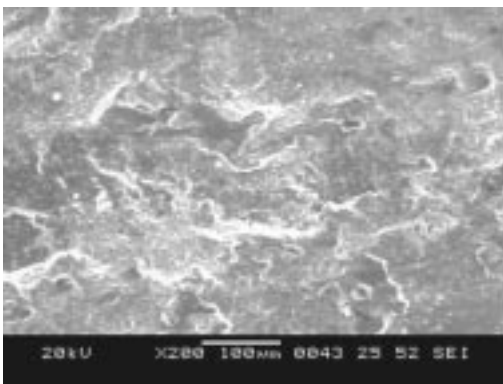


Figure 4 : SEM photograph at moderate operational conditions Oxidative wear

Welsh [6] has studied extensively the wear of plain carbon & low alloy steels with a pin sliding under various loads on the periphery of a revolving ring of identical material, without lubricant. He confirmed the existence of transitions from mild to severe & severe to mild wear & they were dependent on both load & sliding speed. From the Figure. 2 (a), (b), (c) & (d) it is observed that transitions from mild to severe wear at the sliding speed of 3 m/s. Mild wear involves relatively the slow removal of the tips of the highest contacting asperities with little substrate distortion, together with building up of an oxide film on the sliding surface Fig.4. The white patches have been observed on the topography of the worn out surface, which indicates oxidation of the wearing surface.

It is observed that long grooves appeared on the wearing surface. These long grooves are due to tearing of the micro welds on the wearing surface of the pin. These types of grooves occur usually under high load and high speed.

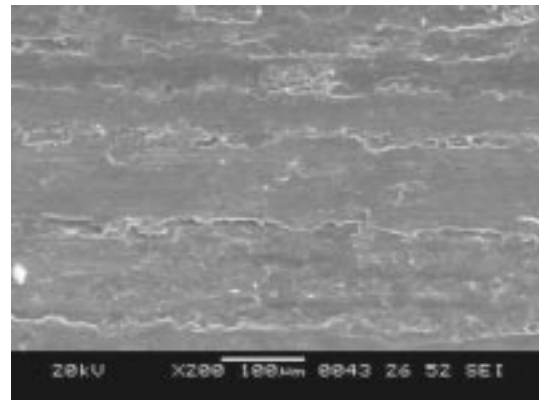


Figure 5 : SEM photograph at moderate operational conditions of load 49.05 N, sliding speed 5 m/s & temperature 400°C Adhesive wear

In case of severe wear i.e. for higher sliding speed 3 and 5 m/s and the load 29.43 and 49.05 N, the scale of surface damage is high, the wear rate is increased by some two orders of magnitude of that of mild wear [7]. Fig.5. Under the ambient temperature of 400°C and under the high load of 49.05 N and high Sliding speed of 5 m/s, the adherences between the wearing surface and with the disc is more hence the adhesive wear is predominant. Since the effect of increasing speed is to cause an increase of the temperature of the sliding interface, oxide formation in air should be facilitated. An increase in temperature also means that the hardness of the metal will decrease so that an increase in the rate of wear can be expected Fig.2 (d). However, from the Figure. 2 (b) the general effect of increasing sliding speed under low load is to cause a reduction in the rate of wear because during wearing the metal is first transferred to the disc from the wear pin. The size of the transformed fragment decreases as the speed is increased, as sufficient time is not available for the junction growth. This means that the frequency of metal transfer will decrease with the increase of sliding speed resulting in a progressive fall in the rate of wear [5].

The wear loss is a function of load, hardness & sliding distance. In this research work a fixed sliding distance of 10,000 meters is taken. So the wear loss is directly proportional to the load & inversely

proportional to the hardness. This hardness is actually before the wear test. But during the sliding, the frictional temperature is generated due to the friction between the wearing pin and with the disc. Due to this frictional temperature the wearing surface may soften or if sufficient frictional temperature is not available to soften the wearing surface then the wearing surface may work hardened due to the plastic deformation of the wearing surface.

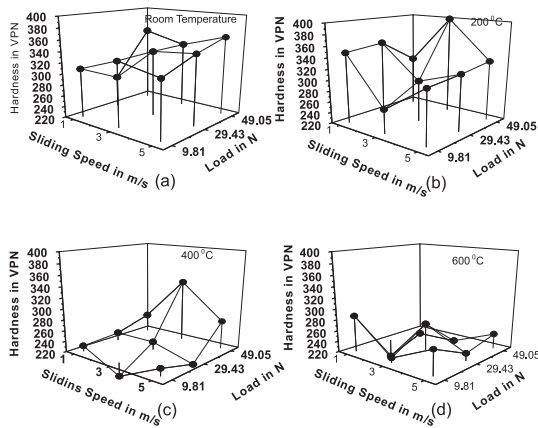


Figure 6 : Effect of sliding speed and load on Hardness for AISI SAE 8630 under differential operational temperature

From the Fig.6, it is observed that the hardness after wear, the values of surface hardness is increased with the increase in sliding speed & load under room temperature Fig.6 (a). The same is reduced under 600°C Fig. 6 (d).

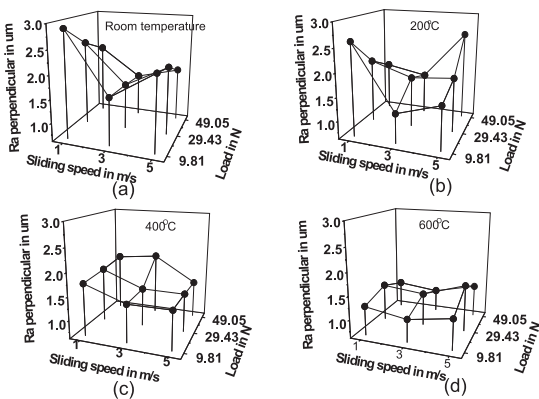


Figure 7 : Effect of sliding speed and load on Ra perpendicular for AISI SAE 8630 under differential operational temperature

Surface roughness values are least for the sliding speed of 3 m/s, for the sliding speed of 3 m/s, the wear mechanism is almost oxidative and the smooth compacted oxide layers on the surfaces. Hence, the surface roughness is minimum for the sliding speed of 3 m/s. Fig.7. The values of surface roughness are more for perpendicular and are less for parallel. Because the roughness along with the direction of abrasion is minimum and the same is more for transverse direction.

The studies of Quinn on the sliding wear of different steels [8,9], the predominance of one wear mechanism, as well as the wear mechanism transition in metals or alloys, are dependent on load, sliding speed and sliding distance [8,10]. The plasticity dominated sliding wear prevails at lower sliding speed [8,11]. However, at very low sliding speeds, oxidation of metallic particles can compete with plastic deformation, material transference, mechanical mixture and adhesion events that characterize the plasticity dominated wear mechanism & adhesive wear.

In the case of austenitic stainless steels, it has been reported that wear is reduced at different levels of load and sliding distance [8,12]. This wear reduction was associated with oxidation effects. The transition and the sliding behavior in general were also attributed to the subsurface strain hardening & to the formation of a tribological layer, consistent with previous studies developed by Yang et al. [8,13]. Under the condition of high sliding speed & high contact pressure, the temperature rises for the sliding materials induced by the friction are intense and the changes of properties of sliding materials by the temperature rise have strong influences on their friction & wear characteristics. Moreover, it is known that the surface oxide film and the temperature rise by the frictional heat affect the friction and wear characteristics of metals. Especially, under the severe condition of high sliding speed and high contact pressure accompanied by a violent wear, they are strongly influenced by the two body abrasive wear. From Figure. 8 under moderate operational condition of load 49.05 N & sliding speed of 5 m/s at 200°C the wear mechanism is fully abrasive. No oxide formation is developed on the wearing surface. The sizes of the

pits are more hence the wear rate is quite high under this operational condition.

From the Fig 2 (b) the effect of load and sliding speed on Volumetric wear rate for AISI-SAE 8630 steel, it is observed that with increasing the load, Volumetric wear rate is increased and with further increase in the load Volumetric wear rate is decreased for the sliding speeds of 5m/s for the ambient temperature of 200°C. The wear rate is increased from the load of 9.81 to 29.43 N. the effect of softening is more predominant than the effect of work hardening. The wear rate is decreased form the load of 29.43 to 49.05 N; in this situation the effect of work hardening is more predominant than the softening effect due to the frictional temperature. Where as, under same operational conditions for the ambient temperature of 600°C, the wear rate is increased with the load. Due to this high ambient temperature the effect of work hardening is nil. The corresponding surface hardness is more for the ambient temperature of 200°C and the same is reduced for the ambient temperature of 600°C Fig.6.

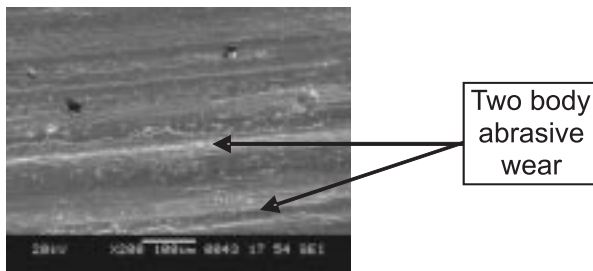


Figure 8 : SEM photograph at moderate operational conditions of load 49.05 N, sliding speed 5 m/s & temperature 200°C

During wearing due to rubbing action between wearing surface of the pin and with the track of the disc, the effect of work hardening takes place and this can be understood by knowing the surface hardness of the wearing surface of the pin. This surface hardness is measured under VPN hardness machine for the load of 100gm. The VPN is preferred because it covers more area and less indentation into the material hence it is possible to measure the surface hardness.

From the Fig.5 it is observed that the surface topography for the worn out surface under the load of 49.05 N and 5m/s sliding speed and at 400°C, the wearing mechanism is adhesive wear mechanism. Adhesive wear mechanism is the breaking of the micro welds. After breaking the micro weld a small pit occurs on the wearing surface and the fresh black surface appears in the picture.

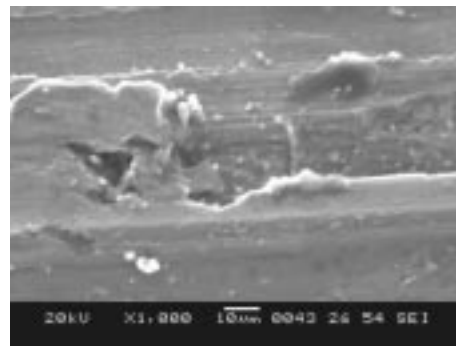


Figure 9 : SEM photograph at moderate operational conditions of load 49.05 N, sliding speed 5 m/s & temperature 200°C Delaminative wear

Fig.9. Shows Microphotographs of 8630 steel wear at the load of 49.05 N and sliding Speed of 5 m/s at 600°C that the wear is laminative and it is plastically deformed during wearing and separated from the parent material.

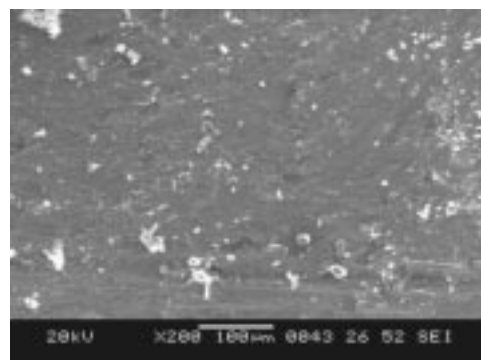


Figure 10 : SEM photograph at moderate operational conditions of 9.81 N & sliding speed of 5m/s at 600°C Adhesive wear

Fig.10. Shows Microphotographs of 8630 steel wear at constant load of 9.81 N & sliding speed of 5m/s at 600°C, the metal deforms plastically and separated from a parent material it seems like an adhesive wear mechanism.

SUMMARY AND CONCLUSION

- It is observed that under low operational conditions of load and sliding speed the wear rate is minimum, under moderate operational conditions, the wear rate is moderate and under high operational conditions the wear rate is maximum
- With increasing the load and sliding speed the surface hardness of the worn out surface is increased due to work hardening at room temperature under the low ambient temperature and the same is decreased under the higher ambient temperature.
- Under low operational conditions two body abrasive, under high operational conditions oxidative and under moderate operational conditions adhesive wear mechanisms are observed.
- It is observed that at 3 m/s is oxidative minimum wear rate.
- Below the speed of 3 m/s, the mild wear and above the 3 m/s, the severe wear observed.
- The hardness values are lowered with increase in the working temperature.

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