Effect of Frictional Force and Wear Rate on Hadfield Steel

Ravindra.G.Tikotkar
Professor
Department of Mechanical Engineering
BLDEA'S College of Engineering and Technology
Bijapur. Karnataka State. India

Abstract

Hadfield's Manganese steel is a very useful engineering material due to its high toughness, ductility, high work-hardening capacity and good resistance to wear. The original austenitic manganese steel, containing about 1.2% C and 12% Mn, was invented by Sir Robert Hadfield in 1882. In the present study slight chromium was added for better work hardening effects, especially used in rail road crossings. Wear characteristics of Hadfield steel under different operational conditions were monitored with a standard pin-on-disc wear testing machine under the wear pressures of 0.063, 0.125, 0.449 and 0.874 MPa and sliding speeds of 0.5, 1, 4 and 7 m/s. Weight loss of the specimen was measured after the wear tests to obtain wear rate. The variations were observed in wear rate and frictional force with wear pressure under different sliding speeds for the fixed sliding distance of 20,000 meters. The results indicated almost steady frictional force under the low wear pressures. The wear mechanism was found to be primarily abrasive wear followed by oxidative and laminative wear. The results indicated low wear rate at the sliding speed of 4 m/s.

Keywords: *Austenite, Hadfield steel, Work hardening, Abrasive wear*

1 Introduction

Tribology deals with friction, wear and lubrication of interacting surfaces in relative motion (or in a state of rest).Wear is one of the important subjects under tribology which is a complex phenomenon. Wear is the major cause of material wastage and loss of mechanical performance and reduction in wear can result in considerable savings which can be made by improved friction control. The one third of the world's energy resources in present use is needed to overcome friction in one or another form. Lubrication is an effective means of controlling wear and reducing friction. Wear can be defined by the American Society for Testing and Materials (ASTM) as 'damage to a solid surface' generally involving the progressive loss of material due to relative motion between that surface and a contacting substance or substances. The process of wear can be defined as the volume loss per unit sliding distance. Wear of machine parts means a loss of precision with resultant sacrifice in efficiency and cost of replacement.

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

$$W_r = f\ (W/A,\ S,\ \text{Material Properties, Geometry})$$

M.F.Ashby and S. C. Lim reported the wear mechanism map and further they studied on wear under unlubricated sliding wear, but not much study was made on microstructure [1]. Friction and wear are not the intrinsic material properties. They are dependent on both the working conditions and the properties of materials. Small changes of load, speed, frictional temperature or properties of materials including microstructures cause remarkable changes in the wear of contact surfaces.

Almost all the railway tracks at the junctions Fig.1, the commonly used material is Hadfield's Austenitic Manganese steel (AMS) a very useful engineering material due to its high toughness, ductility, high work-hardening capacity and good resistance to wear. It is particularly useful for severe service that combines abrasion and heavy impact as in railway frogs and crossings, in power shovel loader, bucket teeth, rock crusher etc [2]. The industrial application of hadfield is proposed by few authors.(R.W Smith, A.DeMonte, WBF.Mackay) [3], And study of work-hardening behaviour of austenitic manganese steels was made by S.B. Sant, R.W. Smith [4].

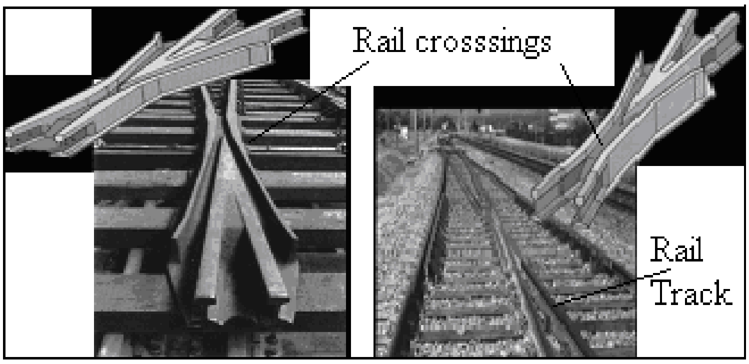


Fig.1 Photographic view of rail crossings

The original austenitic manganese steel, containing about 1.2% Carbon and 12% Manganese, was invented by Sir Robert Hadfield in 1882. Many variations of the original austenitic manganese steel have been proposed. These usually involve variations of carbon and manganese with or without additional alloys such as chromium, nickel, molybdenum, vanadium, titanium and bismuth. In the present study, the high manganese austenitic steel has 1%C and 12.5% Mn and slight chromium 0.09% was added for better work hardening effects, especially used in rail road crossings. The material was heat treated at temperature 1040^0C. Researchers experimented and observed the effect of solution treatment on the carbide dissolution during solutionising at austenitiging temperature of 1040^0C [5].

The wear behavior of metals (austenitic manganese steel) depends on various factors such as wear pressure, sliding speed, frictional force, microstructure etc.

2. Experimental procedures

Wear tests were conducted with a pin on disc type 'Wear and Friction Monitor' machine Fig.2. The disc Fig.3 is made up of AISI 316 Stainless Steel Austenitic (supplied by Ducom Bangalore. as per International standards and G-99). Dry sliding wear tests were carried out against the counter face of the hardened polished disc. Pin losses its weight during wearing at different wear pressures of 0.063, 0.125, 0.449 and 0.874 MPa and sliding speeds of 0.5,1,4 & 7m/s and the loss of weight due to wear were measured in grams by an electronic balance having an accuracy of 10^{-7} kg. Weight loss was converted in to volume loss by considering the density of the pin material (Hadfield steel).The disc smoothness was maintained for each set of reading. The worn out surfaces of the specimen were characterized by a wide range of experimental techniques like SEM and XRD.

Fig.2 Photographic view of wear testing machine

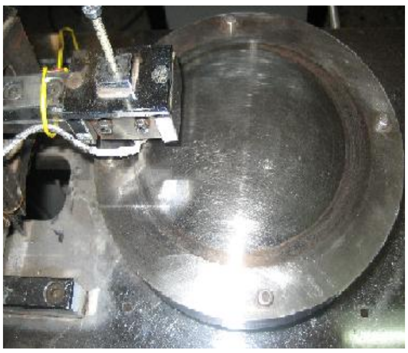


Fig.3 Photographic view for pin on disc

2.1 Heat treatment of Hadfield steel

The castings were properly fettled, dressed and all surfaces were thoroughly cleaned. The castings were heat treated in a properly constructed furnace having adequate means of temperature control, permitting uniform heating of the castings to the necessary temperature of $1040^{0}C$. Solution annealing consists of re-heating the steel to a high enough austenitizing temperature to complete the solution of carbon for a sufficient time period. Quenching was accomplished by immersion of castings in a water bath agitated by air, as agitation reduces the tendency for the formation of a vapour known as the Lieidenfrost effect on the casting surfaces and more uniform rate of cooling was obtained to get the final mechanical properties [6].

2.2 Fabrication of Wear Test Specimen

Manganese Steel castings were obtained from Electric Induction Furnace from a single crucible. The chemical composition were maintained as per (IS 228) A128/A, 128M-86 ASTM (American Society of Testing of Materials).Standard specimens of 10mm diameter and 32 mm length were prepared as per G 99 for wear test.

2.3 Metallographic studies of Hadfield Steel

For metallographic studies specimen was machined, polished and buffed according to the standard metallographic technique. A 2% nital (2 ml HNO3 + 98 ml ethanol) solution was used as an etchant to reveal microstructures.

The X-ray diffraction pattern by X-ray diffractometer (XRD) using CoKa radiation Fig.4 confirms that the microstructure consists of austenite, α-ferrite and (Fe, Mn)3C carbides. Dissolution of this (Fe, Mn)3C carbide is the primary reason of heat-treatment of austenitic manganese steel [7].

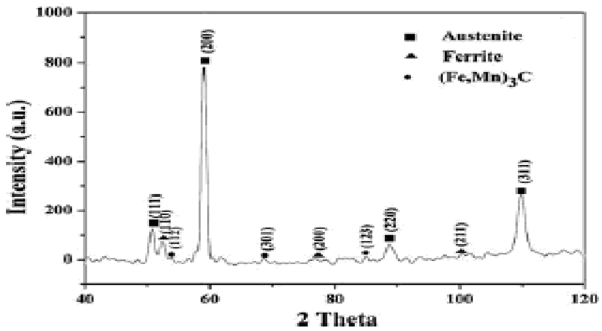


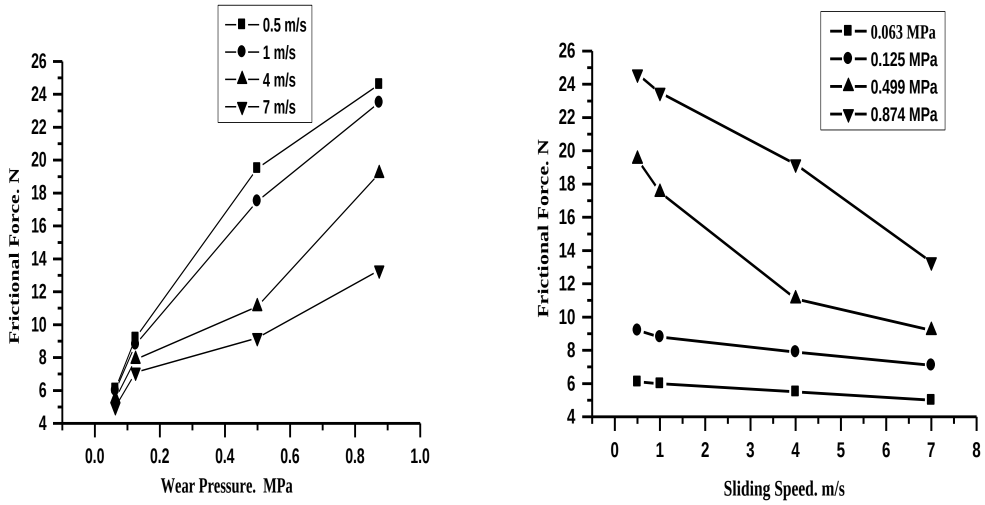
Fig. 4.XRD of Hadfield steel

3. Results and discussion

The experiments were carried out with pin on disc wear testing machine for Hadfield steel under the operational conditions like sliding speeds of 0.5, 1, 4 and 7 m/sec and the wear pressures of 0.063, 0.125, 0.449 and 0.874 MPa for a fixed sliding distance of 20,000 meters.

The Fig 5a.shows the effects of wear pressure for a sliding distance of 20,000 meters on frictional forces for the different sliding speeds and the same are increased almost directly with wear pressure for different sliding speeds.

The Fig 5b.shows the effects of for a sliding distance of 20,000 meters on frictional force developed under the increase in wear pressure. The general trend indicates that the frictional force is decreased with sliding speeds under different wear pressure and corresponding rates vary directly with the wear pressure. The frictional force generated during sliding is reduced steadily with sliding speeds due to the generation of frictional heating and hence softening the wearing surface for the wear pressures of 0.784 & 0.449 MPa, Fig 5b.



(a) **(b)**

Fig.5.Graphs showing variation in Frictional Force with Wear Pressure and Sliding speed

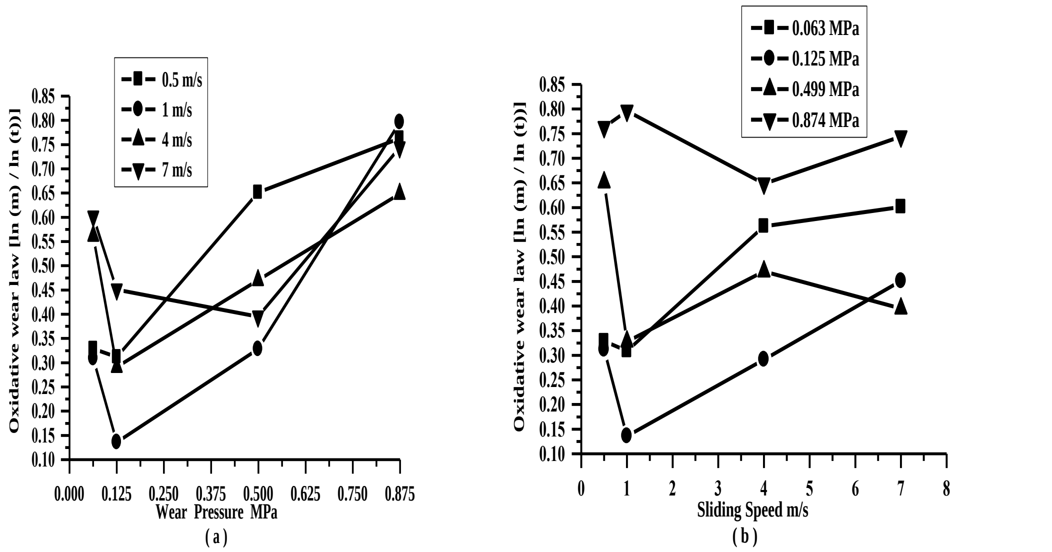


Fig.6 (a) & (b).Effect of wear pressure on oxidative wear law for different sliding speed and wear pressure

Sliding under high wear pressures generates high frictional temperatures, which is responsible for two important metallurgical effects. Firstly, there is thermal softening lowering the yield stress of the surface layer. As the sliding speed increases the rate of growth of micro weld will decrease at the junction. At higher speeds the contact regions are sheared so rapidly that heat is generated at a rate which is much faster than the rate at which it can be conducted away. Secondly, the oxidation of the interface is facilitated. Due to low yield stress facilitated the asperity and the presence of oxide films minimizes the surface interactions during sliding and thus lowering frictional force**.** The corresponding value of ln(m)/ln(t) becomes nearly equal to 0.5, Fig.6 a&b. and hence confirms to oxidative wear conditions.

However, the corresponding surface hardness is increased with sliding speeds under low wear pressure [8]. (H.So, 'The mechanisms of oxidational wear').

It is observed that under the sliding speed of 4 m/s for the wear pressure of 0.063, 0.125 and 0.449 MPa, the minimum wear rate is recorded Fig. 7(a). This minimum wear is due to the formation of oxide at the wearing surface.

The Fig. 7 (b).shows the wear rate is decreased with the increase in the sliding speed from 0.5 to 1 m/s for all the wear pressures. With increase in the sliding speed the residential time between the pin and disc is decreased hence the wear rate is decreased [9]. When sliding takes place between the pin and with the disc, the micro weld takes place between the wearing surfaces and breaks during sliding. The growth of micro weld depends on the residential time between the pin and disc. As the sliding speed increases the residential time will decrease hence the wear rate is decreased.

Fig.8. shows the SEM topography of the worn surface of the Hadfield steel under the operational conditions for the wear pressure of 0.125 MPa and 1 m/s.

However, it has been observed that the wear rate is slightly more for the sliding speed of 0.5 m/s than the sliding speed of 1 m/s under the wear pressure of 0.063 and 0.125 MPa Fig.7 (a&b).The wear rate is more due the abrasive wear mechanism. Under low sliding speed the frictional temperature may not be sufficient to form the oxide layer over the worn surface. This is due to the formation of micro weld on the disc and behaves as two body abrasive wear Fig.9.

The worn surface has been characterized by long continuous grooves, which are because of SiC abrasive particles ploughing across the surface.

Also it has been observed that the wear rate is considerably more for the same sliding speed of 0.5 m/s than the sliding speed of 1 m/s under the wear pressures of 0.449 and 0.874 MPa Fig. 7 (a). The wear rate is more due the abrasive wear mechanism. Under low sliding speed and high pressure, the formation of micro weld with the disc is more hence; the abrasive wear is characterized by deep valley, which is observed in Fig.10

For the sliding speed of 7 m/s under the load of 0.449 MPa Fig.7 (b) the wear rate falls down. This is due to the smooth surface formed on the wearing surface.

The smooth surface is formed due to the formation of laminates on the wearing surface but the laminates are not separated from the parent material Fig.11.

The subject of this paper has been the effect of frictional force and the estimation of wear rate under different wear pressure and sliding speed and also to study the wear mechanisms

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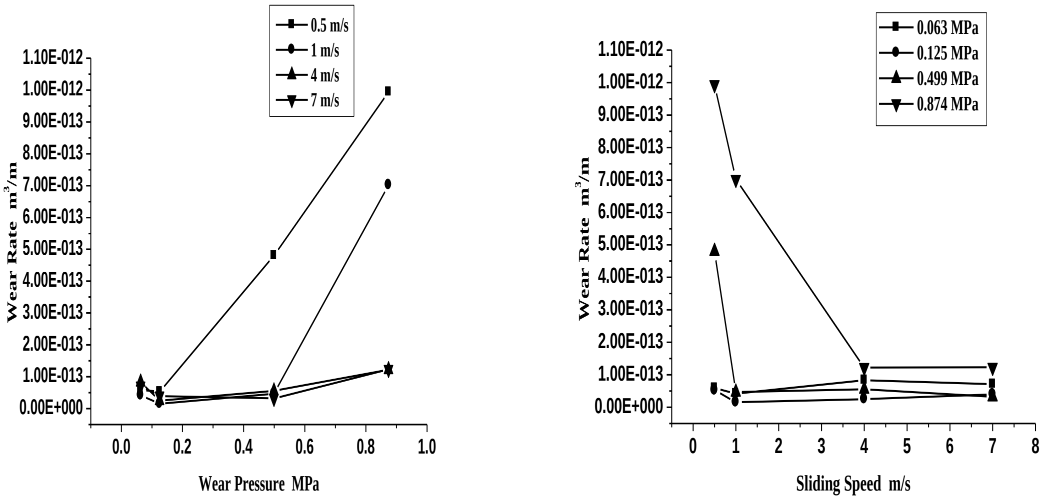


(a) **(b)**

Fig.7. Graphs showing variations in Wear rate with Wear Pressure and sliding speed.

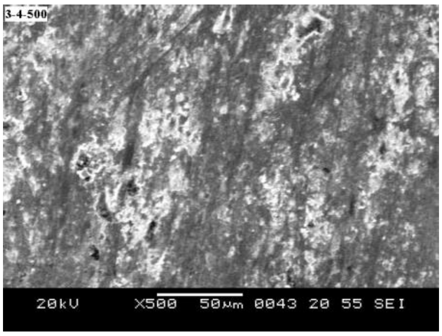


Fig.8 SEM for 0.125MPa,1m/s.Oxidative wear

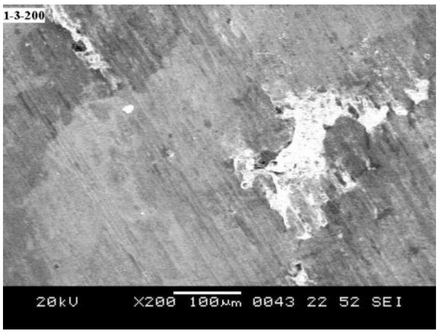
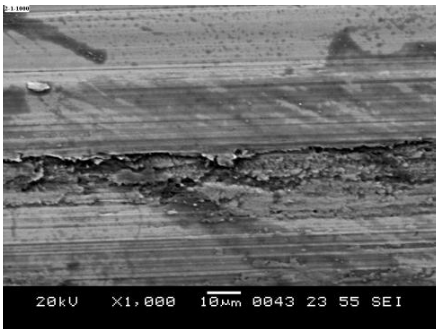


Fig.9 SEM for 0.063MPa, 0.5m/s.Abrasive wear



Figs 10.SEM for 0.784MPa, 0.5 m/s.Abrasive wear

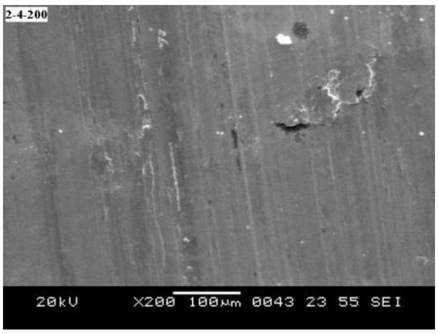


Fig 11. SEM for 0.499MPa, 7 m/s.Laminative wear

4. Conclusions

1. Frictional force, the same is increased almost directly with wear pressure for different sliding speeds.
2. Oxidative wear mechanism is observed for the sliding speed of 4 m/s.
3. The wear rate is almost the same under high operational conditions.
4. Under low sliding speed of 0.5 m/s the wear rate is increased with the wear pressure.
5. Frictional force is more under high operational conditions.

5. References

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