Sliding Wear Resistance of Hardfacing Alloys and their Material Removal Mechanism

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***Abstract*— The sliding wear behaviour of different iron based hardfacing electrodes with varying chromium and carbon content deposited on mild steel unit was studied using pin on disc wear test to simulate the high stress abrasion. The results showed that different hardfacing electrodes containing different chemical composition had large effects on high stress abrasion resistance of the deposit. Such effects on the abrasion resistance are mainly attributed to the variation in deposit chemistry and microstructures. Carbon and chromium content is an important factor determining microstructure of such hardfacing electrodes and therefore wear resistance. Furthermore, the wear behaviour also indicated that the abrasive wear resistance is not simply related to the hardness of the deposit but is determined by the carbides and matrix structure of the deposits. Scanning electron microscopy was done to ascertain the operating material removal mechanism.**

Keywords—Hardfacing welding, Pin-on-disc wear test, Scanning Electron Microscopy

I. INTRODUCTION

Wear related failure of machinery components counts as one of the major reasons for inefficient working of machines in a variety of engineering applications [1, 2]. The phenomenon of wear is not only responsible for material removal but also leads to premature failure of engineering components. The monetary loss due to wear also includes cost involved in replacement and downtime cost. Abrasive wear is the most common mode of failure in industrial applications, near about 50% occurs due to this wear of total wear. Cost due to abrasive wear has been estimated to fall within range of 2-4 % of the gross national product for all nations [3]. Wear resistance of materials can be improved through bulk treatment and surface modification [4, 5]. While bulk treatment has been practiced for a long time, surface treatment is fairly recent and gaining importance [5]. Improvement in surface properties of materials can be achieved through a number of surface engineering techniques and a proper choice has to be made between cost effectiveness and application before choosing a particular method or material [6]. One important aim of modifying a surface is to attain a wear or corrosion resistant material only on the surface without affecting the bulk characteristics. Because wear is a surface phenomenon, it is possible to use a relatively inferior bulk material for a specific (wear related) application by modifying the surface characteristics of the material economically.

One of the least expensive methods of modifying the surface of engineering components is by overlaying or hardfacing. Hardfacing can be broadly defined as the application of wear resistant material on the surface of the components by weld overlay or thermal spray [7]. The conventional methods of hardfacing include oxyacetylene gas welding, tungsten inert gas welding, submerge arc welding, and plasma transferred welding. Hardfacing by any open arc welding process is less expensive and can be applied to the critical part of the machine components prone to severe wear and where dimensional tolerances are not very stringent [8-9]. In the present study four types of hardfacing electrodes have been used to carry out welding on a mild steel specimen, and the sliding wear characteristics of mild steel overlayed with hardfacing material have been compared with each other.

II. EXPERIMENTAL

1. Base Metal and Hardfacing Alloys

The selection of base metal is very essential in deciding what alloy to use for hardfacing deposit. Since welding procedure differs according to the base metal. Carbon steels and low alloy steels are by far the most commonly used base metals. The base metal selected for this study is Mild steel which composes the main elements of carbon, silicon, manganese, sulphur, and phosphorous and ferrous. The chemical composition is shown in Table 1. Mild steel material was cut in the dimensions of 25mm x 25 mm x 35 mm. Four types of commercially available hardfacing electrodes (Iron based with Cr %age varying from 2.43 % to 26.77 %) were used for overlaying using manual metal arc (MMA) welding process. The chemical composition of the hardfacing electrodes are shown in Table 2.

2. Deposition of Hardfacing Aloys

Mild steel material was cut in the form of 25mm × 25 mm cross section with 35 mm length and oxide layers were removed from their surfaces by grinding and cleaning them thoroughly to provide good bonding between the substrate and hardfacing material. Hardfacing was carried out by the open arc welding process using a welding machine. Before welding, the electrodes were dried at 100˚C for 2 hours. An overlay of 4mm was deposited using welding electrode. The welding was performed using direct current electrode positive conditions (DCEP) for all samples without preheat or post-heat, using settings recommended by the manufacturer. On completion of weld deposits, each test piece was allowed to cool in air. Welding parameters are given in Table 3. These parameters were kept within the range as specified by the manufacturers.

Table 1: Chemical Composition of Base metal

S.No.	Elements	Wt.%age
1.	C	0.114
2.	Mn	0.69
3.	P	0.02
4.	S	0.008
5.	Si	0.175
6.	Cu	0.014
7.	Cr	0.049
8.	V	0.018
9.	Fe	Balance

Table 2: Chemical Composition of Hardfacing electrodes

S. No.	Elements	HE1	HE2	HE3	HE4
1.	C	0.777	0.537	3.39	4.25
2.	Mn	0.748	13.71	0.761	0.331
3.	P	0.0257	0.0202	0.0335	0.0381
4.	S	0.0135	0.0038	0.0193	0.0407
5.	Si	0.133	0.337	1.58	1.60
6.	Cu	0.013	0.010	0.189	0.132
7.	Ni	0.0506	2.94	0.0412	0.108
8.	Cr	5.434	2.43	6.71	26.77
9.	V	0.0229	0.0527	0.0283	0.0433
10.	Mo	—	0.014	—	—
11.	Co	0.278	0.0050	—	0.0277
12.	Fe	Balance	Balance	Balance	Balance

3 *Chemical Composition And Micro Hardness Test*

The composition of base metal and the deposited weld overlay was found by using spectrometer (AAS). Microhardness measurement of specimen was done on the welding bead on FIE M50Vickers hardness tester having a 136^0 diamond pyramid indenter. The hardness was taken on the welding bead and the load was kept constant for all specimens that is 20 kgf with a dwell time of 20s. Before microhardness testing all specimens were polished on belt grinder. Hardness of the deposited layers was determined by using the average of five measurements taken on the surface.

Table 3: Parameters used in deposition of Hardfacing Electrodes

Parameters	HE1	HE2	HE3	HE4
Electrode diameter	4 mm	4 mm	4 mm	4 mm
Voltage	20-23	22-25	20-23	20-23
Welding Current	125-150	160-190	150-170	150-190
Electrode Polarity	Positive	Positive	Positive	Positive
Welding speed	190-210 mm/min	180-200 mm/min	180-200 mm/min	160-180 mm/min
Power Supply	AC	AC	AC	AC

4. *Wear Test*

After conducting the spectroscopic and harness tests, the test specimens were cut from each sample using Wire EDM machine to have a control over the shape and size of specimens for the tests as per standards. The cylindrical pins of diameter 6 mm and length 30 mm were prepared for wear test to be performed on pin-on-disk tribometer as per ASTM G99-95 standards. These specimens were hardfaced at their cross-section on one side. The pin-on-disk test apparatus (TR-201, Ducom, India) used in this study is shown in Figure 1 (b).The wear tests were performed at atmospheric temperature and under dry sliding conditions. The pin slides against the hardened disk (62-65 HRC) made of hardened steel as shown in Figure 1 (c). Before and after the test, all the specimens taken for analysis were cleaned and then weighed using an electronic balance as shown in Figure 1 (d) with a least count of ± 0.0001 g. During the wear test, the sliding velocity of pin against the hardened disk was maintained at 4.4 m/s for different cycle time (i.e. 5 minutes, 10 minutes, 15 minutes and 20 minutes) at constant normal loads 10 Kg and 20 Kg. The abrasive wear resistance was determined from the mass loss results, which were measured with 0.1 mg resolution, converted to volume losses. The loss in mass was calculated as the difference of initial and final weight of the specimen. In addition, wear volume loss was also determined. The wear rate was calculated as follows:

Wear Rate = Wear Volume/ Sliding Distance
Sliding distance = $\pi DNT/60$
D = Wear track diameter (m)
T = Time (Sec)
Wear resistance =1/wear rate

Fig. 1 (a) Schematic of hardfaced specimen (b) Pin-on-disk wear test apparatus as per ASTM G99-95 standards (c) Specimen slide against hardened disk (d) Electronic balance

5. *Worn Surface Studies*

Samples were cut from the worn surface and observed under a scanning electron microscope to study the features. Such studies helped in assessing the effects of material compositional features and the load in the material removal mechanism.

III. RESULTS AND DISCUSSIONS

Micro Hardness Analysis

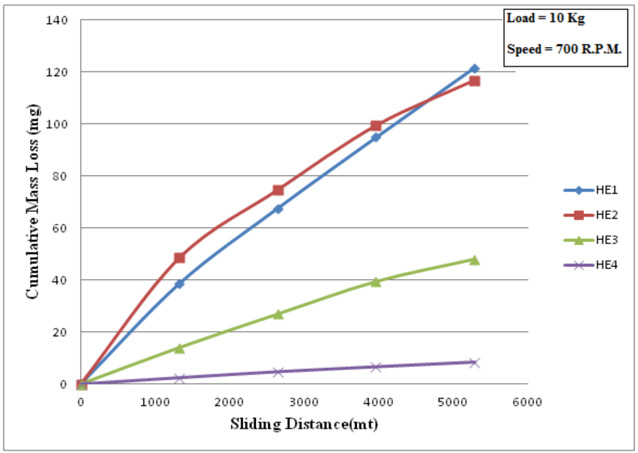
It can be seen from Table 4 that hardness values varied between range of 375 HV – 655 HV and it is highest for HE4 which has Cr- 26.77% & C- 4.25 % i.e. the highest contents of chromium and carbon among the tested hardfacing alloys. This reveals that addition chromium and carbon (as both forms carbides) induces microstructure changes in Fe-based alloys, which results in increase of the hardness drastically. The hardness was lowest for the HE2 which has least chromium content (Cr-2.43%).But hardness does not depend only the amount of chromium content it also depends upon the microstructure of the deposited alloy. The little variation between the manufacturer claimed hardness and the obtained hardness can be attributed to effects of dilution.

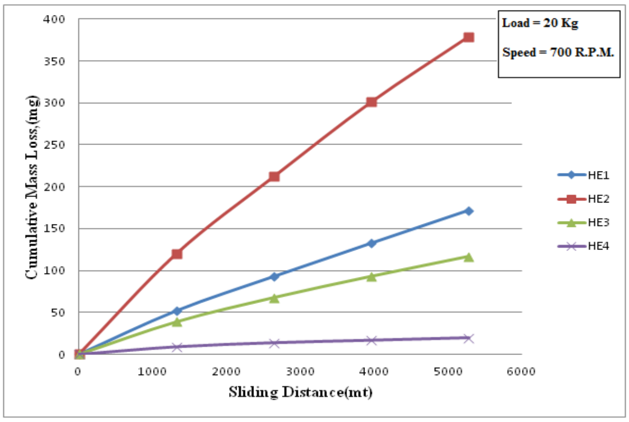
Table 4: Micro Hardness Measurements

Sr. No.	Hardness Value (VHN)
HE1	545
HE2	375
HE3	628
HE4	655

Wear Test Analysis

The organisation for Economic Cooperation and Development (OECD) defined wear as: “The progressive loss of substance from the operating surface of a body occurring as result of relative motion at the surface. Also it is damage to a surface as a result of relative motion with respect to another surface under load in dry conditions. The wear tests were conducted in normal atmospheric conditions. Figure 2 shows the cumulative mass loss as a function of sliding distance for different specimens at constant loads 10 Kg and 20 Kg respectively at fixed linear sliding velocity of 4.4 m/s.



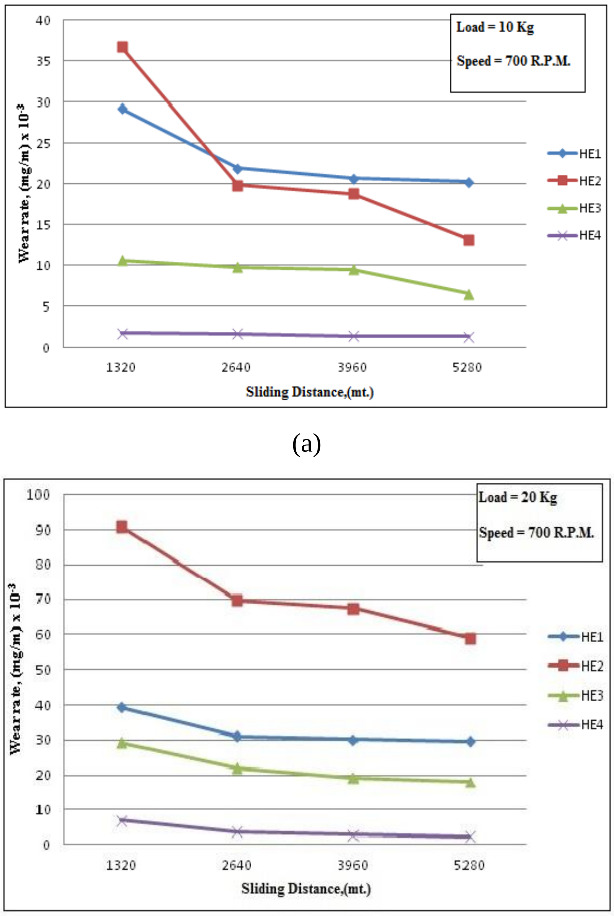


(b)

Fig. 2 Cumulative mass loss as a function of sliding distance at load (a) 10 Kg and (b) 20 Kg

The variation in mass loss for different hardfacing alloys is primarily due to the variation in their microstructure, chemistry and hardness. The mass loss for all the materials increases linearly with an increase in sliding distance. It is evident from Fig. 2 that the alloy HE4 being the hardest, exhibits a minimum mass loss among all materials throughout the range of sliding distance at all loads. The alloy HE2 being the softest, exhibits a maximum mass loss among all materials but appears to have better wear resistance than that of HE1 at higher sliding distances at the load of 10Kg. But again at higher load i.e. 20 Kg alloy HE2 shows the maximum mass loss at all ranges of sliding distance. Hardness, as demonstrated by previous investigators [11] and reinforced in this study, is not always a reliable indicator of the sliding wear performance of a material, particularly when comparing materials of high hardness as attained in this study. As it can be confirmed by comparing the hardness of alloy HE1 (545HV) and HE2 (375HV) with the mass losses the former had more mass loss than that of the later after the sliding distance of 5000 mt. It can also be confirmed by comparing the characteristics of alloys HE3 (628HV) and HE4 (655HV). As relative difference between the hardness of the two alloys was approximately 4 % but the mass loss for the alloy HE3 was five to seven times (for 10 Kg load) and six to nine times (for 20 Kg load) more than that of HE4 for every sliding distance. This can be attributed to the formation of a larger volume fraction of carbides as the alloy HE4 contains high chromium (26.77%) and relatively more carbon (4.25%) as compared to HE3 which contains chromium (3.39%) and carbon (6.71%) both being the carbide forming elements. This signifies that microstructural features of the hardfacing material play more important role than the hardness to control their wear behavior.

Wear rate of the specimens is plotted as a function of sliding distance at a constant speed of 700 R.P.M. at constant loads of (a) 10 Kg (b) 20 Kg in Fig. 3. The wear rate was observed to decrease with increase in sliding distance but wear rate increases with increase in load. However, within that, higher wear rate was noted initially while a decrease in wear rate with sliding distance was observed in later stage. This could be attributed to a practically counterbalancing effect of the subsurface hardening and the microcracking tendency of the specimens (Ref 6). Higher wear rate at the initial stage indicates the predominance of the microcracking tendency over subsurface hardening. However, the subsurface hardening became more effective with the increase in sliding distance. Thus, strain hardening causes the local hardness of the matrix to increase, leading to a lower wear rate. By observing the wear rate of other alloys we see that effect of distance traversed on wear characteristics of the specimens did not follow a definite trend has a mixed influence on the same.



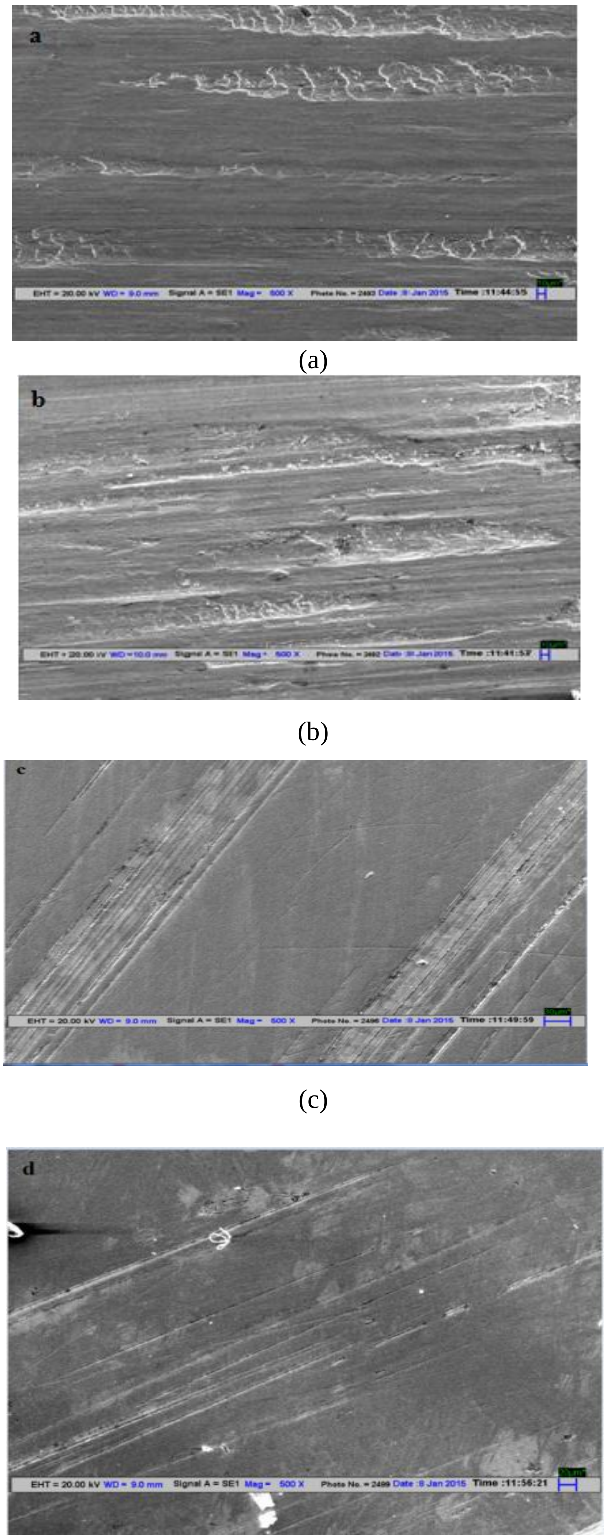
(a)

(b)

Fig.3 Variation of wear rate with sliding distance at loads of (a) 10 Kg (b) 20 Kg

Analysis Of Worn Surfaces

For a deeper understanding of the interacting mechanisms detailed SEM investigations were carried out. The micrograph of HE1 specimen in Fig. 4 (b) shows much deeper and wider grooves which resulted into severe plastic deformation of the material. This specifies the ploughing type of wear mechanism is prevailing in alloy HE1.Fig. 4(a) i.e. the micrograph of alloy HE2 shows comparatively less deep and narrower grooves than HE1, which also indicates a ploughing type wear mechanism. In comparison to this, as shown in Fig. 4(c), significantly fine and continuous wear grooves indicate that micro-cutting was the dominating wear mechanism in the alloy HE3. Discontinuous and the finest grooves among all alloys were found on the alloy HE4 and these can be attributed to its high hardness value.



(a)

(b)

(c)

(d)

Fig. 6 Micrograph of the worn surface of (a) HE1 (b) HE2 (c) HE3 (d) HE4 at 500x

CONCLUSION

The following conclusions can be drawn:

- The four different iron based alloys(HE1,HE2,HE3 & HE4) with different amount chromium(varying from 2.43% to 26.77%) and carbon(varying from 0.54% to 4.25%) were tested in terms of their chemical composition, hardness and sliding wear resistance.
- Among the four alloys the HE2 (375HV) showed the least hardness and the HE4 (655HV) showed highest hardness owing to their chromium content which was 2.43% and 26.77% respectively.
- The mass loss varies linearly with sliding distance. It was maximum for HE2 for entire range of sliding distances at 20 Kg load. But at 10 Kg load HE1 showed the comparable mass loss with HE2.After 5000 mt of sliding distance cumulative mass loss of HE1 was more than that of HE2. Cumulative mass loss was minimum for HE4 for entire range of sliding distances at all loads. It should be noted that the hardness was minimum for HE2 but its mass loss was not the maximum in every case. This again emphasizes that hardness is not the criteria to determine the wear resistance of hardfacing alloy but microstructure is more important which depends upon the chemical composition of the material and the welding parameters.
- Wear rate was observed to be affected by distance traversed.Higher wear rate at initial stage shows predominance of microcracking/ploughing over subsurface hardening and a reduction in wear rate with distance suggests the reverse to be effective.
- The material removing mechanism was studied using scanning electron microscopy.It was observed that ploughing mechanism dominated in the case of HE1 and HE2 when hardness was relatively lower.In the case of HE3 and HE4 when the alloys were relatively harder the microcutting mechanism was prevalent.

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