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Friction and Wear Properties of Hardfacing Alloys

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***Abstract*—This study was initiated for the purpose of understanding the tribological behavior of three commercially available iron based hardfacing electrodes with varying chromium, tungsten and carbon content. These electrodes were deposited on mild steel using manual metal arc welding (MMAW) and the influence of added alloy elements on the friction and wear properties of the hardfacing layers was investigated. The results showed that different hardfacing electrodes containing different chemical composition had large effects on high stress abrasion (Wear) resistance and friction properties of the deposit. The Friction and wear tests were performed using a pin-on-disc (POD) machine.**

***Index Terms*— Hardfacing welding, Wear, Pin-on-Disc, Friction.**

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

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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 three 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

A. Base Metal and Hardfacing Alloys

TABLE I: CHEMICAL COMPOSITION OF BASE METAL

Elements	C	Mn	P	S	Si	Cu	Cr	V	Fe
Wt. %age	0.114	0.69	0.02	0.008	0.175	0.014	0.049	0.018	Balance

TABLE II: CHEMICAL COMPOSITION OF HARDFACING ELECTRODES

Elements	C	Mn	S	Si	Ni	Cr	V	Mo	Co	Al	W	Ti	Fe
HE1	5.44	1.65	0.003	2.21	0.139	27.33	0.0446	*3.15*	0.469	0.0742	4.77	0.199	Balance
HE2	4.77	1.56	0.003	2.62	0.151	24.61	0.0454	*2.88*	0.646	0.0291	3.49	0.191	Balance
HE3	3.09	0.678	0.004	1.63	2.85	0.679	0.0283	----	3.05	0.0877	18.1	0.364	Balance

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 I. Mild steel material was cut in the dimensions of 25mm x 25 mm x 35 mm. Three types of commercially available hardfacing electrodes were used for overlaying using manual metal arc (MMA) welding process. The chemical composition of the hardfacing electrodes are shown in Table II.

B. 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^{0}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 III: PARAMETERS USED IN DEPOSITION OF HARDFACING ELECTRODES

Parameters	Electrode Diameter (mm)	Voltage (Volt)	Welding Current (A)	Electrode Polarity	Welding speed (mm/min)	Power Supply
HE1	4	20-23	125-150	Positive	190-210	DC
HE2	4	22-25	160-190	Positive	180-200	DC
HE3	4	20-23	150-170	Positive	180-200	DC

C. 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.

D. Wear Test

After conducting the spectroscopic and hardness 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 1.57 m/s for fixed cycle time (i.e. 5 minutes) at constant normal loads 5 Kg and 10 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:

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

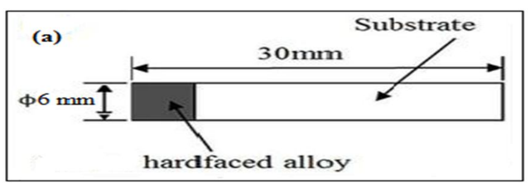


Fig. 1 (a) Schematic of hardfaced specimen (b) Pin-on-disk wear test apparatus as per ASTM G99-95 standards (c) Specimen slide against hardened disk (d) Electronic balance

III. RESULTS AND DISCUSSIONS

A. Micro Hardness Analysis

It can be seen from Table 4 that hardness values varied between range of 832 HV – 1076 HV and it is highest for HE1 which has Cr- 27.33% & C- 5.44 % 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 HE3 which has least chromium content (Cr-0.679%).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 IV: MICRO HARDNESS MEASUREMENTS

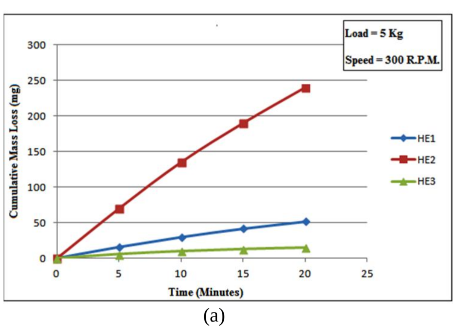
Electrode Type	HE1	HE2	HE3
Hardness Value (VHN)	1076	940	832

B. Wear Test Analysis

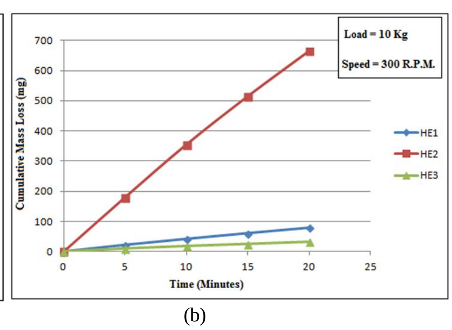
The organisation for Economic Cooperation and Development (OECD) defined wear as: "The progressive loss of substance from the operating surface of a body occurring as result of relative motion at the surface. Also it is damage to a surface as a result of relative motion with respect to another surface 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 5 Kg and 10 Kg respectively at fixed linear sliding velocity of 1.57 m/s. 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 HE3 having the maximum W content (18.1%), exhibits a minimum mass loss among all materials throughout the range of sliding distance at all loads. The alloy HE2 having the least W content (3.49%), exhibits a maximum mass loss among all materials.

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 (1076HV) and HE2 (940HV).As relative difference between the hardness of the two alloys was approximately 12 % but the mass loss for the alloy HE2 was four to five times (for 5 Kg load) and six to seven times (for 10 Kg load) more than that of HE1 for every sliding distance. This can be attributed to the formation of a larger volume fraction of carbides as the alloy HE1contains high chromium (27.33%), high tungsten (4.77%) and relatively more carbon (4.25%) as compared to HE2 which contains chromium (24.61%), tungsten (3.49%) and carbon (4.77%) all being the carbide forming elements. The wear behavior of HE2 (940HV) and HE3(832HV) can also be compared as the former showed more mass loss than later despite having more hardness. 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 300 R.P.M. at constant loads of (a) 5 Kg (b) 10 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 [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.

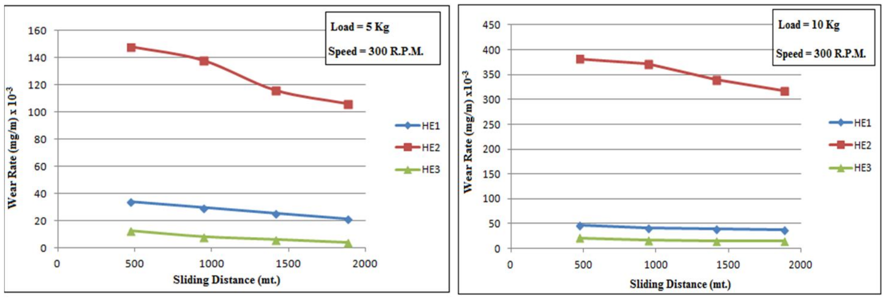


(a)



(b)

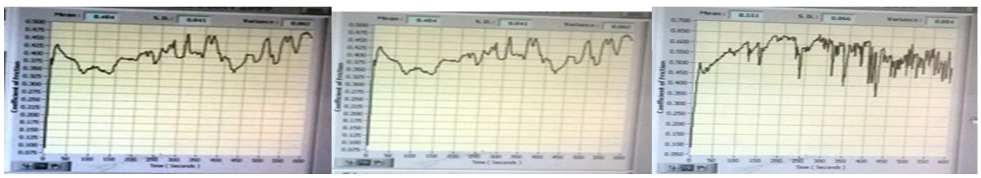
Fig. 2 Cumulative mass loss as a function of sliding distance at load (a) 5 Kg and (b) 10 Kg



(a) (b)

Fig.3 Variation of wear rate with sliding distance at loads of (a)5 Kg (b) 10 Kg

C. Friction Coefficient Analysis



(a) (b) (c)

Fig.4 Variation of friction coefficients with sliding time at 5 Kg load for (a) HE1 (b) HE2 (c) HE3

Fig. 4 displays a typical evolution of the friction coefficients versus time. The friction coefficient of the hardfacing layer was recorded in real time by a computerized data acquisition system equipped with an analog/digital converter. For HE1 and HE2, the observed decreasing of friction coefficients after the initial break-in can be attributed to crushing and aggregation of the debris due to fragmentation of mating asperities, producing a "third" body acting as a solid lubricant [14]. But this phenomenon did not happen in the HE3 which can be attributed to different chemical composition of the hardfacing alloys. It is found that there exist few of fluctuation in the values of the friction coefficient which is more or less in all graphs. A possible explanation for such fluctuations in the friction coefficient values has been suggested on the basis of a 'stick and slip' mechanism. As the asperities adhere during the wear, the moving parts stick, leading to a high friction values. The junction ruptures under the applied load the friction tends to zero.

IV. CONCLUSION

In this paper, the focus has been to evaluate the effect of different alloying elements on the wear and friction behavior of hardfacing alloys. The following conclusions can be drawn:

- Three different iron based alloys (HE1, HE2 & HE3) with different amount chromium(varying from 0.679% to 27.33%), different amount of tungsten(varying from 3.49% to 18.1%) 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 HE3 (832HV) showed the least hardness and the HE1 (1076HV) showed highest hardness owing to their chromium content which was 0.679% and 27.33% respectively.
- 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.
- By comparing the hardness and sliding wear behavior of alloy HE1 (1076HV) and HE2 (940HV) it was confirmed that hardness is not always a reliable indicator of the sliding wear performance of a material.
- By comparing the wear behavior of HE2 (940HV) and HE3(832HV) it was again verified that chemical composition not hardness defines the actual sliding wear resistance of hardfacing alloys. As the former showed more mass loss than later despite having more hardness.
- Tungsten had the large effects on the sliding wear behavior of the tested alloys. As content of tungsten increases the wear resistance also increases.

- Friction coefficient analysis showed that there exist few of fluctuation in the values of the friction coefficient which is more or less in all hardfacing alloys possibly due to ‘stick and slip mechanism’.

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