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Depositing Fe-C-Cr based Hardfacing Alloys on Steel Substrate for Enhancement in Wear Resistance

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Abstract—**Hardfacing is a surface alteration method mostly utilized for the deposition of superior and hard materials on the surface of a substrate with the help of some suitable welding process. This technique is generally used for improving the desirable surface characteristics, for example, erosion resistance, corrosion resistance, etc. of several engineering parts. In the present investigation three dissimilar Fe-C-Cr based hardfacing electrodes were deposited on the surface of ASTM A36 steel by using manual metal arc welding process for improving its wear resistance. Sliding wear behavior of bare ASTM A36 steel specimens and hardfaced ASTM A36 steel samples was studied on a pin-on-disc wear tester. It was observed that the sliding wear behavior and performance of all the hardfaced specimens was observed to be superior to that of bare ASTM A36 steel samples. The effect of the different hardfacings on the wear characteristics, behavior, performance and the extent of wear on ASTM A36 steel were thoroughly examined. The impact of the diverse hardfacing alloys on the wear characteristics, behavior, performance and the degree of wear on ASTM A36 steel were thoroughly examined.The effect of varying the percentage composition of chromium from 23% to 33% and carbon from 3.5% to 4.5% in the diverse Fe-C-Cr based hardfacing electrodes on the resultant microstructure and also the wear behavior of the deposited layers was studied. The comparison of cumulative wear rate (in Bowden) of all the hardfaced specimens with that of the bare ASTM A36 samples exhibited a considerable advancement in the wear resistance imparted by Fe-C-Cr based hardfacings over the ASTM A36 steel.**

Keyword - Cumulative Wear Rate (CWR), Hardfacing, Manual Metal Arc Welding (MMAW), Pin-on-Disc Wear Tester.

I. INTRODUCTION

The economic condition of individuals and industry is significantly affected by losses due to wear, hence they tend to focus on the causes of wear and methods that can improve wear resistance. All types of industries such as manufacturing, assembly, construction, automobiles, etc. face the problem of wear on components in service. Due to wear the components need frequent repair and replacement, which costs money and causes downtime of the equipment. Degradation of materials due to wear ultimately results in very high losses that affects the economic situation of all the countries as well as defames their reputation [1]. Erosive wear has been a persistent problem faced by boiler components such as boiler tubes, super-heater tubes and blades of induced draft fans, etc. especially in coal fired power plants.Commonly used surface alteration method is hardfacing in which hard and superior materials is meld onthe surface of the inferior base material by welding for improving its wear resistance [2]. Wear is the degradation of material from either of two surfaces in contact due to relative motion between them [3].Wear is generally a very slow process, but it goes on very steadily and continuously [4].

Although due consideration has been paid by the researchers to develop diverse and most recent techniques to prevent and control wear, but still there is a need for further research in this area. These wear and corrosion associatedissues can be reduced primarily by utilizing costly wear resistant materials,superior than the existing low cost ones or by employment of certain surface alteration methods on the existing materials in order to improve its wear resistance [5]. Generallywear takes place on the surfaces in contact, subsequently the utilization of the surface alteration techniques on existing materials is more reasonable and inexpensive than utilizing costly or superior wear resistant materials.During the design of an engineering component the properties of the materials from which it is fabricated should not be ignored as they have a considerable effect on its functioning as well as the service life[6]. For the manufacturing of components with requisite surface characteristics, surface engineering is commonly utilized which is comparatively inexpensive technique[7]. Surface engineering improves the service life of a component due to improvement in its performance. However, the impact of surface engineering on the performance and service life of a part depends upon a number of factors such as base material orsurface material, alloy, operationalenvironment and the application process used [8]. Hardfacing is a standout amongst the most flexible methods which can create surfaces possessing tremendous hardness and wear resistant characteristics of several materials on base metal [9]. Hardfacing material is uniformlyfused to the base metal by welding keeping in mind the end goal to increase the hardness and wear resistance of its surface without considerable loss in ductility and toughness [10]. The most general welding techniques are oxyacetylene welding, shielded metal arc welding and submerged arc welding [11]. Various welding processes can be utilized in applying hardfacing materials ranging from the conventional techniques, like oxyacetylene torch to new and modern processes, for example, laser techniques [12]. Hardfacing processes are broadly classified as: hardfacing by arc welding, hardfacing by gas welding, powder spraying and laser hardfacing [13]. MMAW technique is frequentlychosen for hardfacing applications due to its adaptability and cost-effectiveness [14].

In the present investigation weld overlays of three different hardfacing alloys are deposited on ASTM A36 steel by using MMAW process. The objective of this research was to identify the sliding wear behavior, characteristics and performance of hardfaced ASTM A36 steel along with bare ASTM A36 steel. The data created through this study will be of much use in the selection of a suitable hardfacing alloys.

II. MATERIALS AND METHODS

A. Selection of the Substrateor Base Material

Selection of the substrateor base material for the present investigation had been made after consultation with Pressure and Process Boilers, Saharanpur (India). The nominal and actual chemical composition of the substrate material, i.e. ASTM A36 (IS 2062) steel is mentioned in Table I.

TABLE I. Nominal and Actual Composition (WeightPercentage) of ASTM A36 Steel

	% C	% Si	% Mn	% P	% S	% Al	% Cu	% Cr	% Mo	% Ni	% Pb	% Ti	% V	% W	% Fe
Nominal	0.16	0.17	0.46	0.026	0.019	0.007	0.048	0.084	0.018	0.039	0.007	< 0.001	0.003	< 0.001	98.89
Actual	0.19	0.18	0.92	0.019	0.022	0.01	0.01	0.01	0.002	0.01	--	--	0.001	--	98.626

B. Selection of the hardfacing electrodes

Three dissimilar commercially available Fe-C-Cr based hardfacing electrodes had been chosen and were designated as hardfacing 1, hardfacing 2 and hardfacing 3 respectively in this study. These electrodes were available in the market at reasonable prices. The chemical composition of the three dissimilar hardfacing alloys is mentioned in Table II.

TABLE II. Chemical Composition (Weight Percentage) of Hardfacing Electrodes

Hardfacing Electrode Type	% C	% Mn	% Si	% Cr	% Mo	% V	% Ti	% Fe
Hardfacing electrode 1(HF1)	3.5	1.0	--	23.0	--	1.0	0.5	Rem.
Hardfacing electrode 2 (HF2)	4.0	1.2	1.0	30.0	1.9	--	--	Rem.
Hardfacing electrode 3 (HF3)	4.5	1.2	1.0	33.0	--	--	--	Rem.

C. Welding parameters employed

MMAW process with direct current (DC) constant current type power source was utilized to deposit the hardfaced layers of uniform quality. Most of the arc heat was concentrated on the electrode by utilizing electrode negative (straight polarity) for MMAW process. Three layers of hardfaced material were deposited on the surface of the specimen to achieve a thickness of about 4 to 5 mm andso as to limit the impact of dilution with base material. The welding parameters employed are mentioned in Table III. The hardfacing electrodes with varying percentage composition of chromium and carbon were chosen because it is quoted by Kumar and Mondal [15] that high chromium content in the hardfacing alloy displays the minimum wear rate. In order to avoid cracking in the hardfaced layers inter-pass temperature control was maintained as discussed by Kang et al. [16]. Adequate care was employed to refrain any transverse oscillation of the hardfacing electrode during the whole MMAW process to deposit stringer beads that restricts the dilution rate within defined limits as reported by Selvi et al. [17].

TABLE III. Welding Parameters Employed

Parameters	Hardfacing Alloys		
	Hardfacing 1	Hardfacing 2	Hardfacing 3
Electrode Diameter (mm)	4.0	6.3	6.3
Electrode Length (mm)	350	450	450
Welding Current (A)	125	125	125
Welding Speed (mm/min)	100-120	100-120	100-120
Preheating for 1 hour (ºC)	200	200	200

D. Preparation of test samples from the substrate

Small cylindrical specimen pins were manufactured on lathe machine for the sliding wear test. They have a circular cross-section of 8 mm diameter and definite length of 30 mm. These pins were needed to perform the sliding wear tests at room temperature on a pin-on-disc wear tester in accordance with ASTM G99 standards [18]. Further, the specimen pins were hardfaced on one end of the circular cross-section and consequentlyfabricated to proper dimension as illustrated in Fig. 1 and discussed by Kang et al. [16].

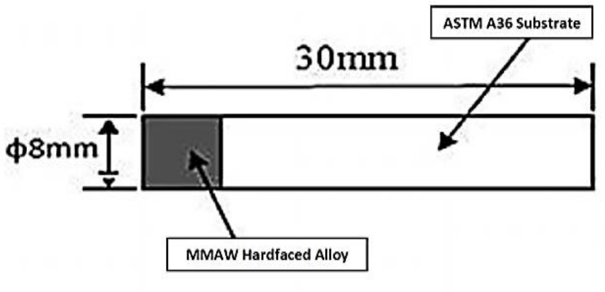


Fig. 1. Hardfaced pin (test specimen) prepared for the sliding wear testing

E. Sliding wear testing using pin-on-disc wear tester

Dry sliding wear tests for the hardfaced and bare (unhardfaced) ASTM A36 steel specimens were performed using a pin-on-disc tester of the following specifications: wear and friction monitor tester (Model: TR-20-PHM-CHM-6000) of make Ducom Instruments Pvt. Ltd., Bangalore, India that conforms to ASTM G 99 standard. The wear tests were performed in air with relative humidity of 51.5 % at a room temperature. The test specimen was held stationary against the opposite face of a rotating disc made of EN-31 steel at a track diameter of 80 mm as shown in Fig. 2.

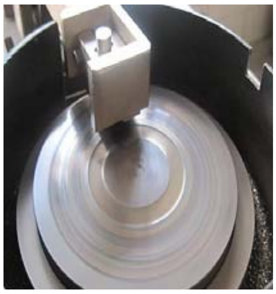


Fig. 2. Snapshot of a pin-on-disc wear tester

EN-31 steel is an alloy steel that is case hardened to 63-65 HRC. The chemical composition by weight percentage of the material of the steel disc, i.e. EN-31steel is mentioned in Table IV.

TABLE IV. Chemical Composition (WeightPercentage) of EN-31 Steel

C	Si	Mn	Cr	Ni	S	P
0.90-1.20	0.10-0.35	0.30-0.75	1.00-1.60	1.46	0.04	0.04

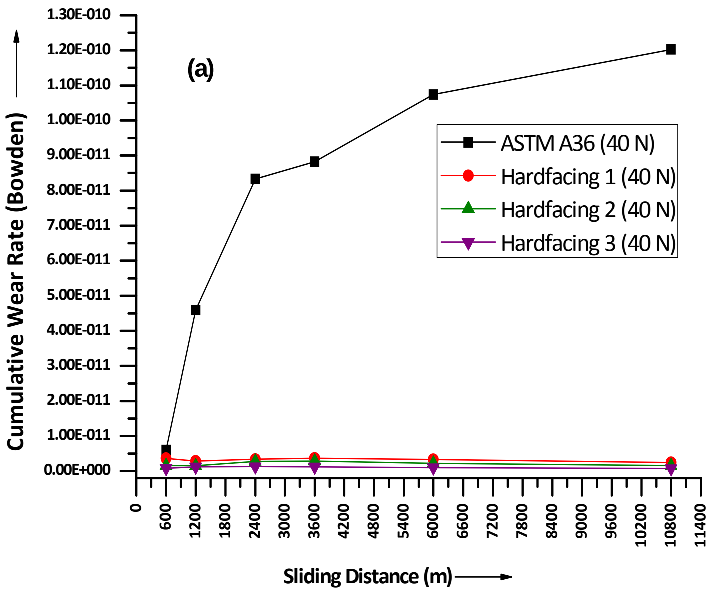
The specimen pins were polished with emery paper. Both steel disc and the pins were cleaned and dried before the sliding wear tests. The pin was loaded against the steel disc through a dead weight loading arrangement. The sliding wear tests for hardfaced as well as unhardfaced or bare ASTM A36 steel specimens were performed at a uniform velocity of 2 ms^{-1} and at normal or applied loads of 40N, 50N and 60N. The track radii for the specimen pins were taken as 40 mm. The rotational speed of the steel disc was about 477 RPM for all the cases. The rotational speed of the disc was adjusted in such a manner that a uniform linear sliding velocity of 2 ms^{-1} can be maintained. A variation of ± 5 RPM was observed in the rotational speed of the steel disc. Sliding wear tests were performed for a total sliding distance of 10800 m, so that only top coated surface was exposed for each hardfaced sample. The weight loss of each sample was measured after 5, 5, 10, 10, 20, 40 minutes in order to find the wear loss. The specimen pin was taken out from the holder after each run and cooled to room temperature. Further, it is brushed lightly to evacuate the loose wear debris, weighed and settled again in the very same position in the holder so that the orientation of the sliding surface remains unaltered. The weight of the specimen was measured by using a micro balance to an accuracy of 0.001g as displayed in Fig. 3. Weight loss for every test pin was measured after each cycle to find the wear loss.

Fig. 3. Image of control unit with computer interface and weighing apparatus

The wear rate data for bare ASTM A36 steel specimens and all the different types of hardfaced specimens was plotted with respect to the sliding distance to establish the wear kinetics.

III. RESULTS AND DISCUSSION

The variation of the cumulative wear rate (CWR) with the sliding distance for the three different hardfaced ASTM A36 steel specimens and bare ASTM A36 specimens at a normal load of 40N, 50N and 60N have been plotted in Fig. 4. It is apparent from Fig. 4 that the hardfacing 3 has shown considerable wear resistance in comparison withbare ASTM A36 steel and other hardfacings at all loads of 40N, 50N and 60N.



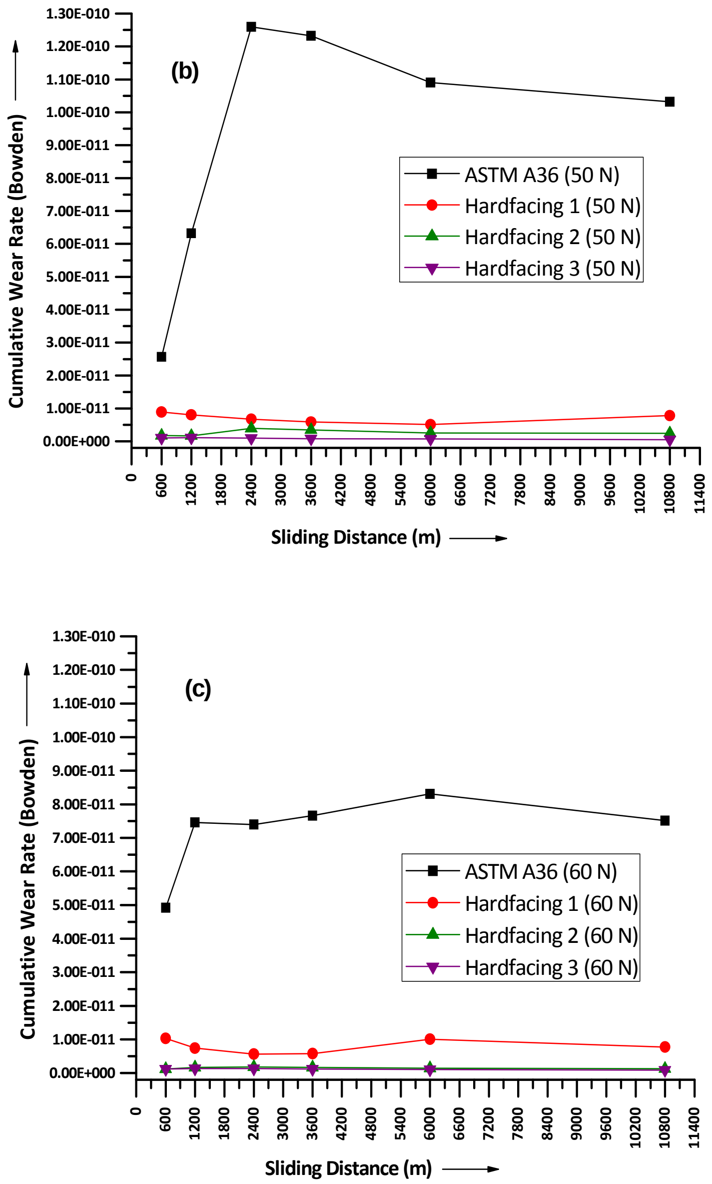


Fig. 4. Variation of cumulative wear rate (in Bowden) with sliding distance for bare (ASTM A36 steel) and hardfaced specimens at normal applied loads of (a) 40N, (b) 50N and (c) 60N and sliding velocity of 2 ms^{-1}

Bar Chart as shown in Fig. 5 clearly depicts the cumulative wear rates for the different hardfaced ASTM A36 steel specimens and bare ASTM A36 steel specimens at normal applied loads of 40N, 50N and 60N and sliding velocity of 2 ms^{-1}, after a sliding distance of 10800 m. These bar charts revealed that the CWR for bare ASTM A36 steel specimen at 40N, 50N and 60N shows significant wear, whereas it has been decreased significantly after the deposition of hardfacings alloys. Hence, from these plots and bar charts it is quite clear that the bare ASTM A36 steel specimen had shown much higher CWRs in comparison with its hardfaced counterparts.

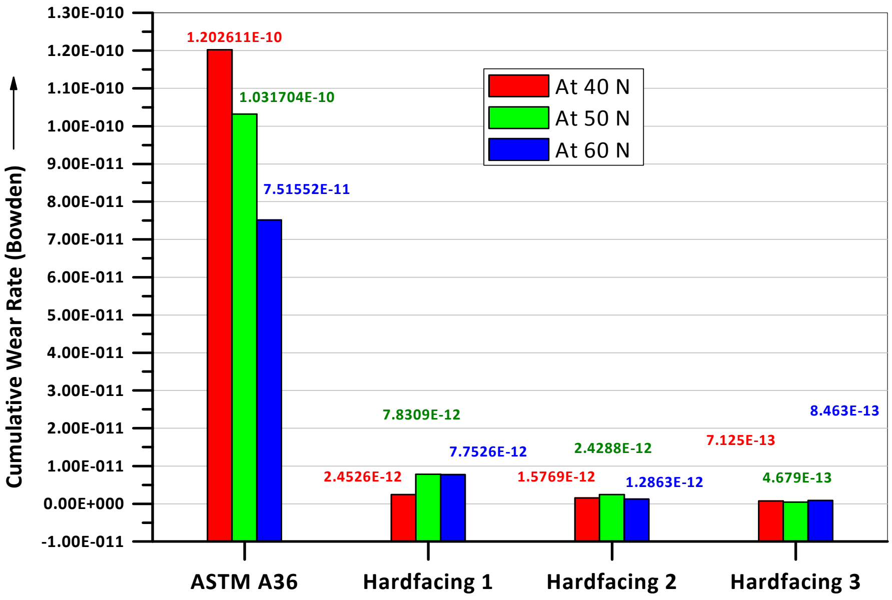


Fig. 5. Cumulative wear rate (in Bowden) for bare ASTM A36 steel and all the hardfaced specimens at normal applied loads of 40N, 50N and 60N and sliding velocity of 2 ms^{-1} after a sliding distance of 10800 m

The C.W.R. in all the cases under investigation at normal applied loads of 40N, 50N and 60N and at a sliding velocity of 2 ms^{-1} after a sliding distance of 10800 m followed the trend given below:

Hardfacing 3 (HF3) on ASTM A36 steel < Hardfacing 2 (HF2) on ASTM A36 steel < Hardfacing 1 (HF1) on ASTM A36 steel < bare ASTM A36 steel (substrate)

It exhibits that with an increase in the percentage of chromium and carbon in the hardfacing alloys the wear resistance of hardfacing welds had improvedwhich is in agreement with the findings of Kang et al. [16]. This enhancement in the wear resistance is primarily due to the creation of greaterquantities of primary and secondary carbides in the ferrite matrix which isin agreement with the findings of Kang et al. [16], Amirsadeghi and Sohi [19] and Kumar et al. [20]. Therefore, it is anticipated that the variation in the CWR in the hardfacing alloys and base material is mainly due to the variation in their microstructure, chemistry and hardness as suggested by Kang et al. [16]. These details may also lead to diverse wear mechanisms for dissimilar hardfacing materials. The trend of sliding wear exhibits that the cumulative wear rate of the hardfacing materials decreases with an increase in the percentage of carbon and chromium. This wear behavior is associated with the chromium surface alloying that results in the creation of hard chromium carbides, which increased higher load bearing capacity of the material, which is almost in agreement with the findings of Kang et al. [16], Selvi et al. [17] and Amirsadeghi and Sohi [19].

IV. CONCLUSION

The following inferences were made based on experimental results obtained in the present investigation:

(1) All the three different types of Fe-C-Cr based hardfacing electrodes were successfully deposited on ASTM A36 steel by using MMAW process.
(2) Bare ASTM steel specimens had shown much higher cumulative wear rate (C.W.R.) at normal applied loads of 40N, 50N and 60N as compared to its hardfaced counterparts.
(3) The C.W.R. had been decreased considerably after the deposition of hardfacing alloys.
(4) The C.W.R. for hardfacing material 3 (HF3) was found to be least in the present study.
(5) The C.W.R. for all the cases under investigation at normal applied loads of 40N, 50N and 60N and at a sliding velocity of 2 ms^{-1} after a sliding distance of 10800 m followed the trend given below:
Hardfacing 3 (HF3) on ASTM A36 steel < Hardfacing 2 (HF2) on ASTM A36 steel < Hardfacing 1 (HF1) on ASTM A36 steel < bare ASTM A36 steel (substrate)
(6) The sliding wear resistance of hardfacing-substrate combinations in their decreasing order is:
Hardfacing 3 (HF3) on ASTM A36 steel > Hardfacing 2 (HF2) on ASTM A36 steel > Hardfacing 1 (HF1) on ASTM A36 steel > bare ASTM A36 steel (substrate)
(7) Therefore, out of these hardfacing-substrate combinations the hardfacing 3 (HF3) on ASTM A36 steel is the best combination.

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