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INFLUENCE OF MATERIAL CHARACTERISTICS ON THE ABRASIVE WEAR RESPONSE OF SOME HARDFACING ALLOYS

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ABSTRACT

This study examines the abrasive wear behavior of two chromium based hardfacing alloys with different combinations of chromium and carbon on a mild steel substrate. Effects of welding parameters and material on the wear behavior of the specimens were studied. Operating material removal mechanisms also were analyzed through the scanning electron microscopy (SEM) examination of typical wear surfaces, sub surfaces regions and debris particles. The results suggest a significant improvement in the wear resistance of the hardfacing layers over that of the substrate. Further, the specimens overlaid with the material with low carbon and high chromium contents attained better wear resistance than the one consisting of more carbon but less chromium. The former specimen also attained superior hardness. Smoother abrasion grooves on the wear surfaces and finer debris formation during the abrasion of the hardfacing samples were consistent with wear resistance superior to that of the substrate.

Keywords: Hard Facing Alloys, Material Removal Mechanism, Microstructure Hardness, Abrasion Property Correlation, Surface Engineering, Wear.

I. INTRODUCTION

Hardfacing is a commonly employed method to improve the surface properties of agricultural tools, components for mining operations, soil preparation equipments and others.

An alloy is homogeneously deposited on to the surface of a soft material by welding with the purpose of increasing hardness and wear resistance without significant loss in ductility and toughness of the substrate. A wide variety of hardfacing alloy is commercially available for production against wear. Deposits with a microstructure composed by disperse carbides in austenite matrix are extensively used for abrasion applications and are typically classified according to the expected hardness. Nevertheless, the abrasion resistance of a hardfacing alloy depends on many other factors such as type, shape and distribution of hard phases, as well as the toughness and strain hardening behavior of the matrix [1]. Chromium rich electrodes are widely used due to low cost and availability, however more expensive tungsten or vanadium rich alloys offer better performance due to a good combination of hardness and toughness [4]. Complex carbides electrodes are also used especially when an abrasive wear is accompanied by other wear mechanism [2], [3]. Several welding techniques such as oxy-acetylene gas welding [OAW], gas metal arc welding [GMAW], shielded metal arc welding [SMAW] and submerged arc welding [SAW] can be used for hardfacing. The most important differences among these techniques lie in the welding efficiency, the weld plate dilution and the manufacturing cost of welding consumables. SMAW, for example, is commonly used due to the low cost of electrodes and easy applications. The present investigation aims to study two commercial electrodes in terms of their chemical composition, microstructure, hardness and abrasive wear resistance [5]. Wear related failure of machinery components counts as one of the major reasons for inefficient working of machines in a variety of engineering applications. Many such applications involve handling of abrasive materials or contact with the material in service. Abrasion is one of the important and commonly observed wear modes in these cases. Abrasive wear behavior of steels has been in earlier investigations. Fundaments of the mode of wear including operative wear mechanism, the nature of the debris particles formed, and the kind of surface and subsurface damage under a given set of experimental conditions have been evaluated. Other aspects studied include the extent and mode of damage caused to the abrasive particles during wear.

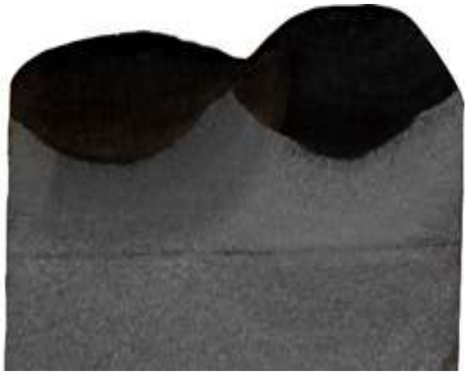

Figure1. schematic representation of hardfacing layer deposition is approximately 3mm in thickness.

II. EXPERIMENTAL PROCEDURE

A. Base Metal

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. Mild steel was selected as the base metal for the study which composes the main elements of carbon, silicon, manganese, sulphur, and phosphorous. The chemical composition is given in Table 1.

Table 1. Chemical composition of base metal (in weight percentage)

C	Si	Mn	S	p	Fe
0.18	0.32	1.47	0.013	0.029	Bal

B. Hardfacing Alloys

In the study, two different commercial hardfacing alloys were used for overlaying. These are basically iron –based alloys having varying amount of chromium, carbon, silicon and other alloying elements as they are more suitable for shielded metal arc welding process. Chemical compositions of two electrodes are presented in table 2.

Table 2: Chemical composition of hardfacing alloy (In weight percentages)

Electrode	C	Si	Mn	S	P	Cr	Mo	Ni	V	Fe
Hardfacing 1	0.33	0.28	1.15	0.014	0.025	2.22	-	-	-	Bal
Hardfacing 2	0.1	0.38	1.51	0.024	0.03	2.15	0.745	1.09	0.103	Bal

C. Welding Conditions

The standard size test specimens of 16 nos. with the dimensions of 250×100×12 mm were selected for the experiment. The following precautions are taken before hardfacing.

- The electrodes are perfectly dried in the furnace and baked at 250° C one hour before the use.
- Area of the weld is properly cleaned.
- Preheated the hardfacing area to a minimum of 200° C.

D. Machine Specifications

Name: TORNADO MIG 630 Arc welding machine
Current: 100-630 Amps
Input Voltage: 415 volts± 10% / 50-60 HZ / 3 Phase
Machine Capacity: 50 KVA.

III. METHODOLOGY

The experiment was carried out in three stages to investigate the effect of current, travel speed and voltage on hardfacing electrodes, and the corresponding hardness was determined.

(i) In first stage, voltage (V) and travel speed (S) were kept constant and current (A) was increased.
(ii) In second stage, voltage (V) and current (A) were kept constant and travel speed (S) was increased.
(iii) In third stage, current (A) and travel speed (S) were kept constant and voltage (V) was increased

The selected standard size of the test specimen is shown in figure 1.The results of hardfacing obtained by varying current, travel speed and current along with their hardness and the corresponding relationship between them are shown in figures 2, 3 and 4 respectively. From graphs, it is concluded that as current, travel speed & voltage increases the hardness of surface & the layer next to the surface decreases. Figure 2 shows that, as current increases the hardness of the bead & HAZ decreases. Figure 3 shows, hardness decreases with increase in travel speed. Figure 4 shows as voltage increases the hardness of the bead & HAZ decreases.

Table 3.Varying current

Current (A)	Voltage (V)	Travel Speed (cm/min)	Hardness (HV 0.5)
200	25	23.1	380
250	25	23.1	318
300	25	23.1	317

Table 4. Varying travel speed

Travel speed (cm/min)	Voltage (V)	Current (A)	Hardness (HV 0.5)
15.0	25	200	417
21.4	25	200	418
50.0	25	200	356

Table 5. Varying voltage

Voltage (V)	Current(A)	Travel Speed (cm/min)	Hardness(HV 0.5)
15	215	37.5	537
25	215	37.5	390

IV. RESULTS AND DISCUSSION

A. Hardness Test

The specimens were cut to a size of 100x30x12mm for hardness testing and were polished using standard metallographic procedure. Micro hardness surveys were made on these specimens using Vickers hardness tester along the direction of thickness from the top surface towards the base metal after every 0.5mm. These surface values are plotted in the form of a graph shown in figure 5. The hardness survey of heat affected zone (HAZ) samples for every 0.5mm depth was made. The results indicate that the hardness values are more on the welded surface and decrease towards the base metal and remain constant on the base metal.

B. Dry Sand Abrasive Wear Test

In the present study, sample of 75x26x6 mm size were used for testing as shown in figure 1 as per ASTMG65 standards. Specimens were ground using surface grinder to make the surface flat. Before the abrasive wear test all the specimens were cleaned with acetone and then weighed on an electronic balance with an accuracy of ± 0.1 mg. The three-body abrasive wear tests were conducted using a dry sand/rubber wheel abrasion tester as per ASTM G65-04 (2010) shown in figure 6a. The sand particles of AFS 60 grade (figure 6b) were used as abrasives and they were angular in shape with sharp edges. The sand particles were sieved (size200–250 µm), cleaned and dried in an oven for 6 hr at 40 ^{0}C. In this test, samples were held against a rotating rubber wheel under the constant flow of abrasives in between the sample and the rubber wheel under predetermined load. The actual photograph of the testing machine is shown in figure7.

C. Test Conditions

Speed: 200 ± 5 rpm
Sample test duration: 15 and 30 min.
Abrasive: loose silica sand having particle size 200 - 250µm.
Load is kept constant at 130.5 N for all the samples.

After each test, the samples were cleaned with acetone and then weighed on the electronic balance. The wear loss was calculated as weight losses in gms. Sample of 26x75x6 mm size were used for analysis. Specimens were ground using surface grinder to make the surface flat. Dry sand abrasive wear test was carried out as per ASTM G65 standards. In this test, samples were held against a rotating rubber wheel under the constant flow of abrasives in between the sample and the rubber wheel under predetermined load. The wear testing machine is shown in figure 3 and the test conditions are given here under:

Speed: 200±5rpm
Sample run duration: 30 minutes
Abrasive: loose silica sand having particle size 200 to 250 µm

Silica sand of size between 200 to 250µm was used as abrasive. Load is kept constant at 130.5N for all the specimens. The wear rate was calculated as weight loss in gms. Results indicate that as hardness increases, the loss of wear decreases. Electrode-I has less wear as compared to electrode-II as the percentage of chromium, carbon and silicon is more in electrode-I. However the composition of chromium, carbon & silicon in the weld deposit made with type-I electrode is higher than that of weld deposit made with type-II electrode. Higher amount of chromium, carbon, silicon and finer structure resulted in higher hardness where as lower hardness values were recorded in weld deposit with less amount of Cr, C & Si & coarser structure. From wear testing data under various conditions of the parameters, it can be stated that weld deposits made with type I electrode are more wear resistant than the weld deposits made with type II electrode.

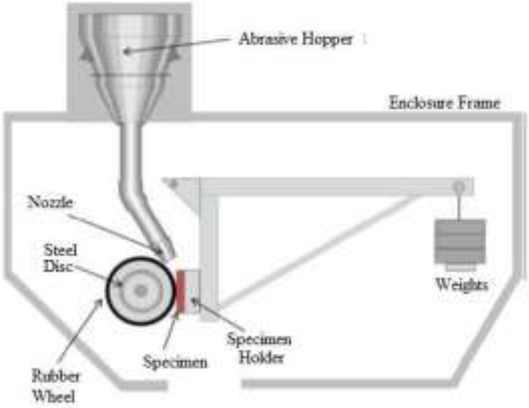

Figure 2(a): Dry Sand/Rubber Wheel Abrasion Tester

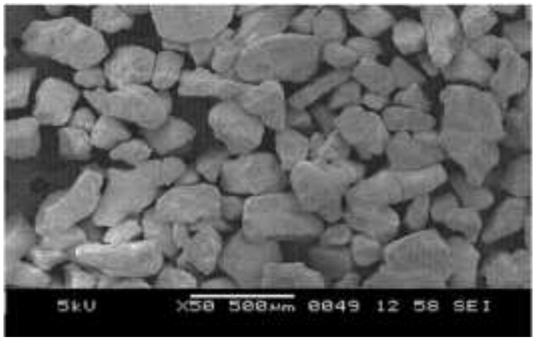

Figure 2(b): SEM Picture of Silica Sand (200-250 μm)

In three-body abrasion, the sand particles behaved in one of the following ways. From free fall, the sand particles gained energy from the rubber wheel (figure 4a) and then struck the sample surface, which would result in the formation of pits. Secondly, the abrasive particles were embedded in the rubber wheel, transforming the three-body abrasion into multi-pass two-body abrasion (figure 4b).

Figure 3: Dry sand abrasive wear testing machine

Thirdly, the particles roll at the interface causing plastic deformation to the hardfaced alloy (figure 4c). These stages are illustrated in figure 4a-4c respectively.

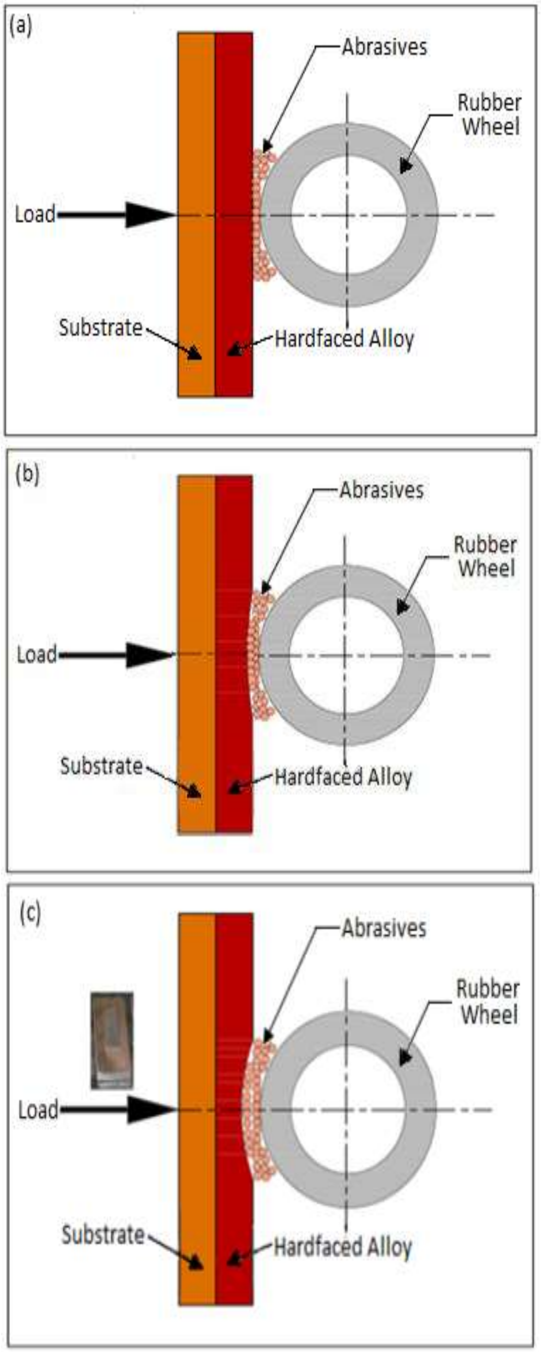

Figure 4: Stages of Abrasion: a) Initial, b) Middle and c) End of Tests

Wear is generally a complex process, which is influenced by the many system variables, such as materials properties, environment and mode of loading. In this study, two Fe-Cr-C hardfaced alloys of different composition and microstructure were investigated under three-body abrasion. Various researchers have been demonstrated that the application of hardfaced alloy on cast iron/mild steel significantly increases the surface hardness and results in increased resistance to abrasive wear [6-8], it has been shown in this work that the hardness of two hardfaced alloys were very different, their wear loss were dissimilar under the same test conditions. This indicates that the importance of microstructural parameters, such as the amount and size of the carbides, weld parameters, toughness and type of phases in determining the wear resistance [9-12].

The development of Fe-Cr-C hardfacings has been based around the understanding that good wear resistance is obtained with materials that have a high volume fraction of hard phases that are supported in a tough matrix. Both hardfacing 1 (type 1 electrode) and hardfacing 2 (type 2 electrode) are composed of similar phases; however, hardfacing 1 has a significantly larger amount of carbide phases than hardfacing 2.

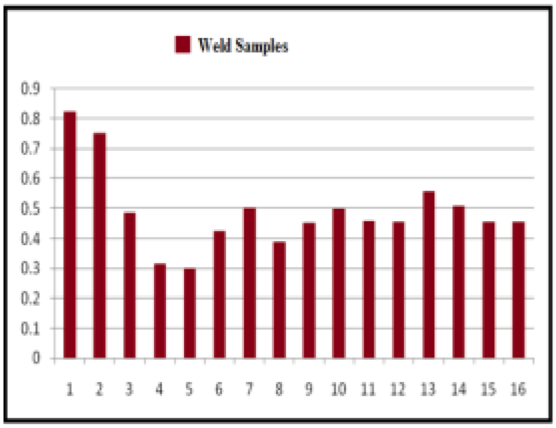

Figure 5: Wear Loss of Weld Sample 15 min

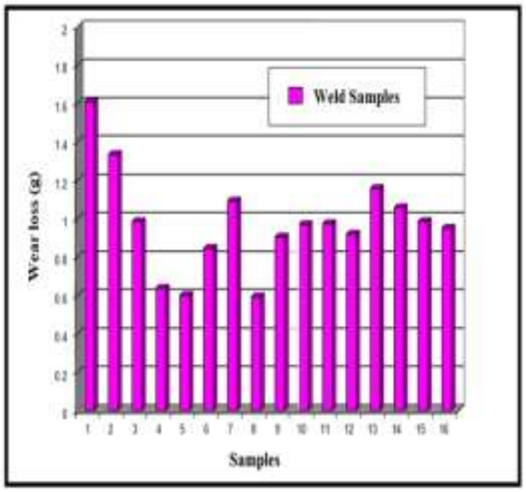

Figure 6: Wear Loss of Weld Samples 30 min

The results indicate that as hardness increases, the loss of wear decreases (figures 5 and 6). Electrode-I has less wear as compared to electrode- II as the percentage of chromium, carbon and silicon are more in electrode-I. However the composition of chromium, carbon and silicon in the weld deposit made with type-1 electrode is higher than that of weld deposit made with type-2 electrode. Higher amount of chromium, carbon, silicon and finer structure resulted in higher hardness whereas lower hardness values were recorded in weld deposit with less amount of Cr, C and Si and coarser structure.

The wear resistance increases with increase in chromium, carbon and silicon present in the hardfaced alloy 1. The experimental results are in agreement with those reported [9-11] on hardfacing alloys tested under low stress against a rubber wheel. Meanwhile, decrease in the wear resistance with decreasing chromium, carbon and silicon were observed in type 2 electrode and is in consistent with other published works. The reduction of the wear resistance with type 2 electrode could be due to the fact that the surface hardness was greatly reduced as compared to type 1 electrode. Higher hardness of samples increasing the apparent contact area allows a large number of sand particles to encounter the interface and share the stress. This, in turn, leads to a steady state or reduction in the wear rate.

The wear test results of the type 1 electrode deposited hardfaced alloy indicate that a better wear performance. In type 2 electrode deposited hardfaced alloy, the wear resistance is poor compared to those obtained for type 1 hardfacing alloys. In type 2 electrode deposited hardfaced alloys, the abrasion was simultaneously initiated on the hard and soft phases of the weld material. In this situation, soft surface was continuously exposed to the interface throughout the entire test. It can be clearly seen from figures 5 and 6 that the presence of lower chromium and silicon in the interface increases the wear rate. On the other hand, in the case of the rich chromium, and silicon, the abrasion started through contact with the hard phase.

Mechanical properties influence the abrasive wear performance of a material. When considering the properties individually, it has been found that the hardness played a main role in controlling the abrasive wear [13]. The compression strength could have a stronger influence on the abrasive wear property than the tensile strength thereby the load is applied in the form of compression thereby pressing the specimen towards the sand particles at the interface [14]. This attracted the attention to explore the possibility of a correlation between the selected mechanical properties and the wear loss of the hardfaced alloys. Table 6 and 7 shows the wear loss as well as the hardness of all the samples [Electrode I and Electrode II]. From the table it can be seen that when considering the hardness alone, the wear resistance of all the hardfaced alloys tested, a better correlation was obtained in the present work. The higher the hardness, the lower was the wear loss [15]. From wear testing data under various conditions of the parameters, it can be stated that type 1 electrode deposited hardfaced alloys are more wear resistant than the type 2 electrode deposited hardfaced alloys.

The work summarizes that type 1 electrode deposited by considering optimum weld parameters i.e., current 200 Amps, travel speed of 21.3 cm/min and potential difference of 15 volts of hardfaced alloys has beneficial effect on the three- body wear as well as on the hardness, thus re-emphasizing the fact that the introduction of rich Cr, C and Si in type 1 electrode has got the advantage of enhancing the properties.

Table 6: The Relation between Hardness and Abrasion Resistance for Hardfacing 1(Electrode 1)

Sample number	Load (N)	Weight loss (g)	Hardness (HV 0.5)
1	130.5	1.6075	377
2	130.5	1.3345	318
3	130.5	0.9861	380
4	130.5	0.638	417
5	130.5	0.6007	418
6	130.5	0.8454	356
7	130.5	1.0923	537
8	130.5	0.5934	390

Table 7: The Relation between Hardness and Abrasion Resistance for Hardfacing 2(Electrode 2)

Sample number	Load (N)	Weight loss (g)	Hardness (HV 0.5)
9	130.5	0.9051	330
10	130.5	0.9698	416
11	130.5	0.9746	370
12	130.5	0.9205	406

13	130.5	1.1571	388
14	130.5	1.0576	377
15	130.5	0.9852	357
16	130.5	0.9506	401

V. CONCLUSIONS

ASTM G-65 is a reliable low stress abrasion test to assess the performance of the hardfacing deposits used in actual service conditions.

Results reveal that weld metal chemistry, welding heat input and test duration have significant influence on abrasion resistance. Hardness can be used as a predictor of wear resistance only for weld deposits having similar micro structural characteristics. Wear resistance increases with increase in chromium, silicon and carbon content of weld deposit as well as with increase in heat input.

The hardness mainly depends on process parameters such as welding current, speed of arc travel and voltage.

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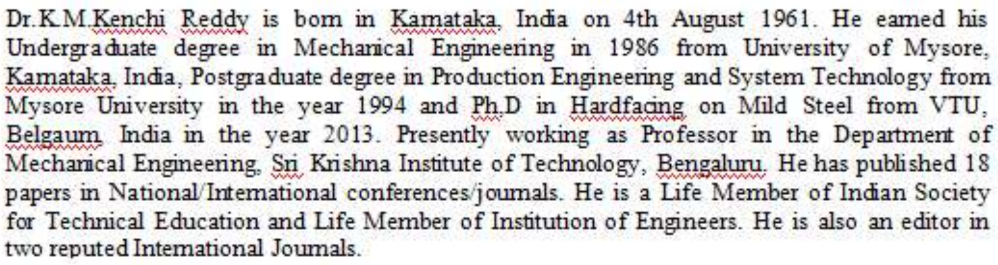

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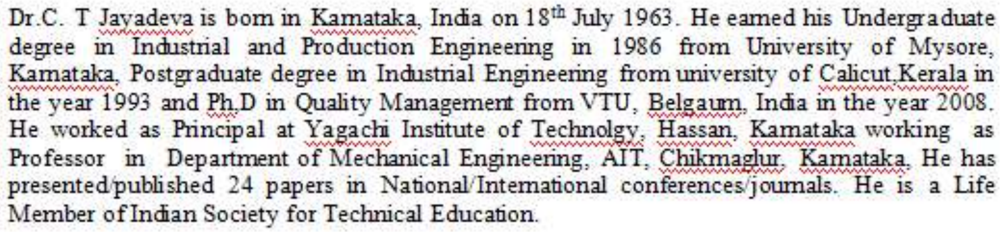

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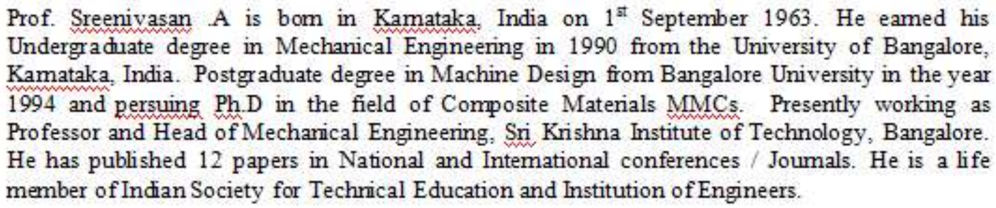

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