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"EXPERIMENTAL STUDIES ON TRIBOLOGICAL STUDIES OF CHROMIUM AND MANGANESE BASED HARDFACINGS"

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ABSTRACT

Surfacing is a process which is used for deposition of a layer over a base material to improve the surface quality of the base material. Hardfacing is surfacing technique in which hard layer is deposited over soft material to improve the wear resistance. There are so many techniques used in the industry to deposit these hard layers. Welding is also used in the industry to produce these harfacing layer as it has so many advantages including high deposition rate, low dilution and high productivity. In this project iron based hardfacing has been successfully developed with the help of submerged arc welding. Since iron based alloy associates with low cost and better metallurgical property it has chosen for final experiment in this study. Three hardfacing layer with different carbon content has been successfully developed without any defect. Mechanical and metallurgical characterization of developed hardfacing alloy has been studied and it shows significant improvement in the property as compared to the base material. Microstructures of deposited layer show mixture of hard carbides and austenite in which carbides are embedded in the matrix of soft austenite. Microstructure also shows increment of carbide volume fraction as the amount of alloying element is increasing. Hardness of hardfacing layer has been also improved as compared to the base material and it is also increasing with increment of carbon and chromium percentage.

Keyword*:* Iron based hardfacing, Submerged arc welding, Fe-Cr-C, Hardness.

I. INTRODUCTION

Wear in machine elements is a common and inevitable phenomenon that occurs when two or more mechanical components interact with each other. It is a gradual process of material loss from the surface of these components due to friction, abrasion, erosion, or other mechanical actions. Understanding wear is crucial in engineering and manufacturing because it directly impacts the lifespan, efficiency, and reliability of machines and mechanical systems.

Erosive wear is a type of mechanical wear that occurs when solid particles suspended in a fluid, such as sand, grit, or other abrasive materials, collide with and gradually erode the surface of a material. This wear mechanism is particularly relevant in industrial and natural environments where solid particles are present in fluids or gases. Erosive wear can lead to significant material loss over time and has important implications for the durability and performance of various engineering components and structures. Key characteristics and aspects of erosive wear include:

Erosive wear can affect a wide range of industrial equipment and components, including pipelines, turbine blades, agricultural machinery and mining equipment. Managing erosive wear is crucial for maintaining the longevity and efficiency of affected components.

Depositing another layer of material over a base metal or substrate to improve its surface quality is known a surfacing. In other word, For improving the wear resisting properties like resistance to abrasion, corrosion, friction of any metal i.e. base metal, an or multi- layer of another metal or alloy is depositing over it. This process is known as Surfacing.

Initially surfacing was developed for the needs of oil-well drilling industry but now it is widely used on all types of equipment, implements, and containers to enhance their lives against wear and chemical action. It extends the service life of the product and saves expensive material.

It can maintain certain dimension, lower production and parts costs.

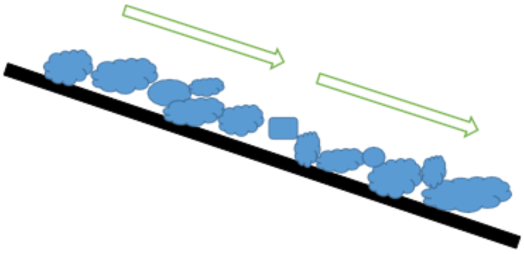

Figure 1 Low and moderate stress abrasion

II. LITERATURE REVIEW

Semih Ates et al. (2023) Impact-sliding wear failures mostly occur in complex tribological contact systems such as working parts of combustion engines, metal-forming dies, etc. The impact-sliding test method allows for examining both the effect of cyclic impact and sliding contacts. In this study, the impact-sliding wear test was conducted on Stellite 6 and Stellite 12 hardfacings produced by using Tungsten Inert Gas welding was investigated at room and high temperatures. Microstructural examinations and impact-sliding wear tests revealed that even though examined hardfacings exhibited almost similar microstructural features, the impact-sliding wear loss of the Stellite 12 hardfacing was relatively higher when compared to Stellite 6 hardfacing both at room temperature and 600 °C.

Pavlo et al. (2022) Structure formation and impact-abrasion wear resistance of the hardfaced layers deposited by flux-cored arc welding with powder wires of a high-manganese austenitic steel – (Ti, Nb, Mo, V)C high-entropy(-like) carbide system, were investigated and compared to the impact-abrasion resistance of the commercially available high-manganese steel-based hardfacing as well as with high-speed and mild carbon steels. Flux for the flux-cored wires was prepared by adding the equimolar mixture of TiC, NbC, VC and Mo2C powders to the Si-alloyed ferromanganese and arc shielding components. Microstructure investigations of the hardfaced layers show, that its structure consists of an austenitic matrix and complex carbide reinforcements, in form of uniformly distributed fine-grained particles. Its impact-abrasion wear resistance is more than three times higher than that for hardfacing, deposited with commercially available high-manganese steel-based electrodes and almost equal to the high-speed steel samples tested under the same conditions.

Liu et al. (2021) Superior hardfacing materials, such as Ni-WC blends, are commonly applied to rock-engaging regions of oil & gas drill bits and other downhole tools to provide sufficient wear protection. In this work, it was found that drill bits were subjected to severe high-stress abrasive wear while rubbing against rock formations. The wear behavior of drill bits could be appropriately evaluated by the wear test in accordance with ASTM standard B611 rather than ASTM standard G65. This work also found that the toughness of tungsten carbides was a predominant factor determining high-stress abrasion resistance of Ni-WC hardfacing. Any choices from various types, sizes, and shapes of tungsten carbides would contribute to the improvements of wear resistance as long as this choice delivered better toughness, such as cemented tungsten carbide and spherical tungsten carbide. Large particle size was also beneficial for reinforcing wear resistance, but played a secondary role as compared to carbide toughness. Therefore, large-sized cemented tungsten carbide pellets provided the best high-stress abrasion resistance for drill bits, with large-sized spherical tungsten carbide being a close second. In addition, the comprehensive hardness of Ni-WC composite could be well represented using a linearly additive approach. The calculated hardness established a strong positive correlation with the wear behavior of Ni-WC hardfacing.

Buntoeng Srikarun (2020) Coal crusher is an important piece of equipment in the production of coal, but its abrasive wear remains a troublesome problem. A worn coal crusher damaged by abrasive wear is usually repaired by hardfacing weld deposit to prolong its lifespan. Currently, submerged arc welding with added metal powder is gaining interest as a hardfacing process. This study aimed to find alternative materials for hardfacing a coal crusher by submerged arc welding, possibly with powder added into the weld pool. Five samples were welded with a single hardfacing layer. Metal powders were added to some samples. The macroscopic structure and dilution of the deposited layer were examined using a stereo camera, across the cases. The chemical composition of the weld metal was investigated using an optical emission spectrometer. The worn surface layers, as well as the metallurgical structure of the hardfaced surfaces, were characterized optical microscopy, scanning electron microscopy, and energy dispersive X-ray diffraction. Mechanical properties were assessed from micro hardness testing and abrasive wear testing. The results showed a variety of chemical compositions in the hard faced deposit, depending on the type of wire used, the dilution of the weld metal, and the type of metal powder added. There are advantages and disadvantages to welding dilution of hard faced metal, and the degree of dilution depends on the type of wire and added powder used. Carbon, chromium, manganese and nickel contents in the dilution layer and in the added powder with the welded metal lead to structures that are mixtures of martensite and austenite, and this combination greatly improves hardness and wear resistance. The addition of ferro-carbon-chromium produced intergranular carbides, which were a major cause of decreasing wear resistance of the martensite structure. The worn surfaces of hardfacing layer showed micro cutting, micro ploughing, and micro fracture.

III. METHODOLOGY

3.1. Selection of base metal

Mild steel was selected as a Base metal for the final experiment as it is widely used in the industry for machine and structural application. These plates were cut in 280x50x12 mm size by power hacksaw. Plates were pre cleaned with the acetone to remove any oil or grease before the welding. The chemical composition of base material was given in the Table 1.

Table: 1 Chemical composition of base material

Element	C	Si	Mn	Cr	S
Weight Percentage (%)	0.176	0.16	0.52	0.08	0.039

3.2. Powder selection for hard facing

Ferro-chrome metal powder was selected for development of hard-faced layer over the base material. The reason behind selection of Fe-Cr powder is its low cost and better metallurgical compatibility with other materials. Apart from Fe-Cr some other metal powders were also used to enhance the property of the deposited layer. Chemical composition of metal powders was given in the following below table 2.

Table: 2(a) Chemical composition of Fe-Cr metal powder

Element	Cr	C	S	P	Si	Fe
Weight Percentage (%)	72.56	0.068	0.01	0.024	0.67	Balance

Table: 2(b) Chemical composition of Fe-Mn metal powder

Element	Mn	C	S	P	Si	Fe
Weight Percentage (%)	84.28	0.71	0.012	0.14	0.92	Balance

Table: 2(c) Chemical composition of Fe-Si metal powder						
Element	**Si**	**C**	**S**	**P**	**Mn**	**Fe**
Weight Percentage (%)	48.76	0.072	0.01	0.022	0.4	Balance

3.3. Hard facing methodology

Metal powder was sprayed over the base material in the form of paste; paste was made up of pre- defined amount of powder mixture with silicate binder. Coated Plates were left for 24 hours to dry and baked in oven at 200^{o}C so that no moisture remains. Submerged arc welding procedure was used to melt and fix this metal powder over the substrate. Baked plates were kept over the table of welding machine. DC electrode positive was used during the welding. An arc was formed over the paste to melt the metal powder. After solidification the slag was removed and a hardfacing layer was formed over the surface. The weld bead was cleaned with chipping hammer and later with acetone for further processes. As trial runs were started, too many defects were observed initially because the suitable welding parameters and proper material composition was not known. Some defects produced during trial runs are projected in figure 2, 3 and 4.

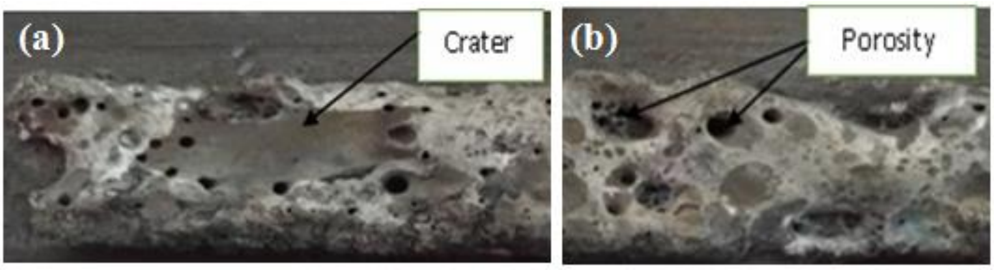

Figure 2 Defect-1

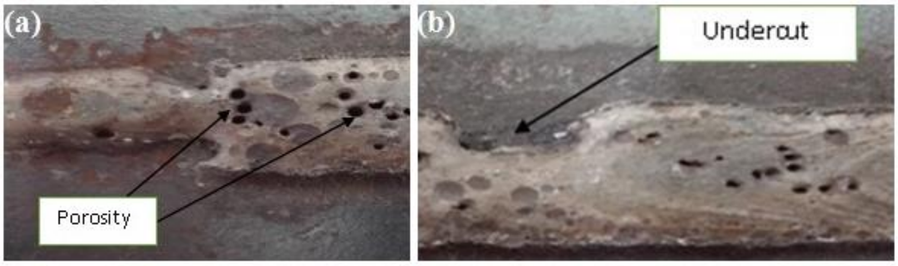

Figure 3 Defect-2

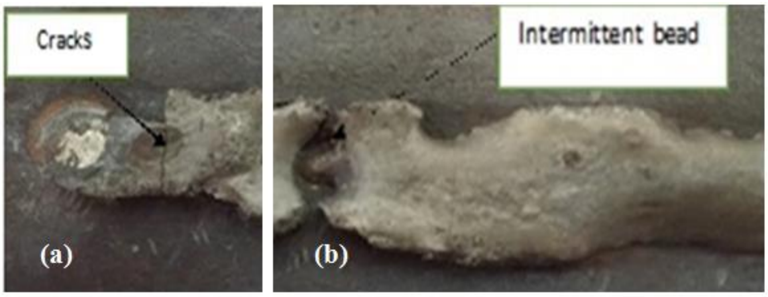

Figure 4 Defect-3

Table: 3 Final welding parameters

Voltage (V)	40
Current (Amp)	390
Speed (mm/s)	6
Nozzle to Plate Distance (mm)	16
Wire feed (mm/s)	12

Table: 4 Final metal powder composition

Sample	Fe-Cr (wt%)	Fe-Mn (wt%)	Fe-Si (wt%)	Graphite (wt%)
Sample-1	85	2.5	2.5	10
Sample-2	80	2.5	2.5	15
Sample-3	75	2.5	2.5	20

After finalizing welding parameters & metal powder composition final three hard faced layer was developed with different graphite percentage as per the Table 4. Graphite percentage was varied intentionally for producing three hardface layer with different carbon percentage. These experiments were planned to study the effect of carbon percentage in the developed hardfaced layer. Figure 5 (a, b and c) shows the three different hardface layer with different carbon percentage.

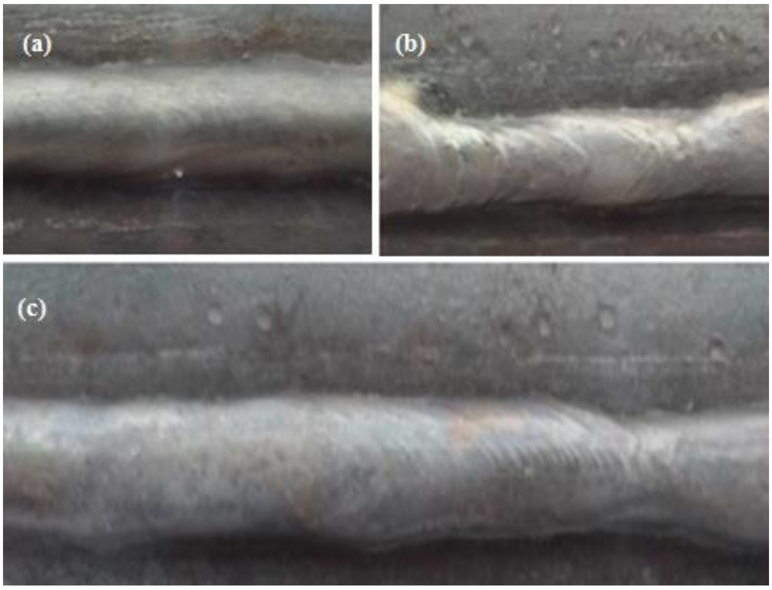

Figure 4 Hardfaced layer (a) Sample-1 (b) Sample-2 (c) Sample-3

3.4. Erosive wear Test

To check the wear behavior of developed hardfaced layer, erosive wear test was done as shown in figure 5. 20x25x5 mm (LxWxT) dimension was taken for erosive wear test specimen.

Figure 51 Erosive wear testing machine

Table: 5 Parameters used for erosive wear testing	
Parameters	**Particulars**
Erodent Material	Alumina particles
Feed rate	8g/min
Impact angle	30°
Particle size	35 microns
Pressure	2.18 bar
Air jet velocity	70 m/s
Nozzle diameter	3.5 mm
Test Temperature	Room Temperature
Test Time	60 min

In erosive wear hard particles (Alumina) with compressed air was impinged on the surface of a specimen for a particular time and after the test weight of the specimen is recorded. Based on the final weight, weight loss was calculated and this data was used to predict the wear behavior of hardfaced layer. The process parameter used for erosive wear was tabulated in table 5.

IV. RESULTS & DISCUSSION

4.1. Chemical Composition Analysis

Chemical composition analysis was done to determine the chemical composition of the developed hardfaced layer. The specific focus of this study was on the transfer behavior of Chromium, Carbon and other metals. Table 6 shows the chemical composition in developed hard faced layer.

Table: 6 Chemical composition of hardfaced layer				
Element	**Base Metal**	**Sample 1**	**Sample 2**	**Sample 3**
Carbon	0.178	1.18	1.31	1.38
Chromium	0.081	1.42	1.32	1.49
Manganese	0.49	1.19	1.08	1.12
Silicon	0.162	1.19	1.16	1.1

This shows technique used in this project is very useful for developing a hardface layer with high amount of alloying elements. Table 6 shows as the graphite content in the paste is increasing, the amount of carbon is increasing but when we are using more than 10 % graphite there is very less amount of increase in carbon content. Since the thermal conductivity of graphite is very high so after a certain percentage it takes more heat and it doesn't a low heat flow towards the base metal so less amount of alloying elements transferred in the developed hardface layer.

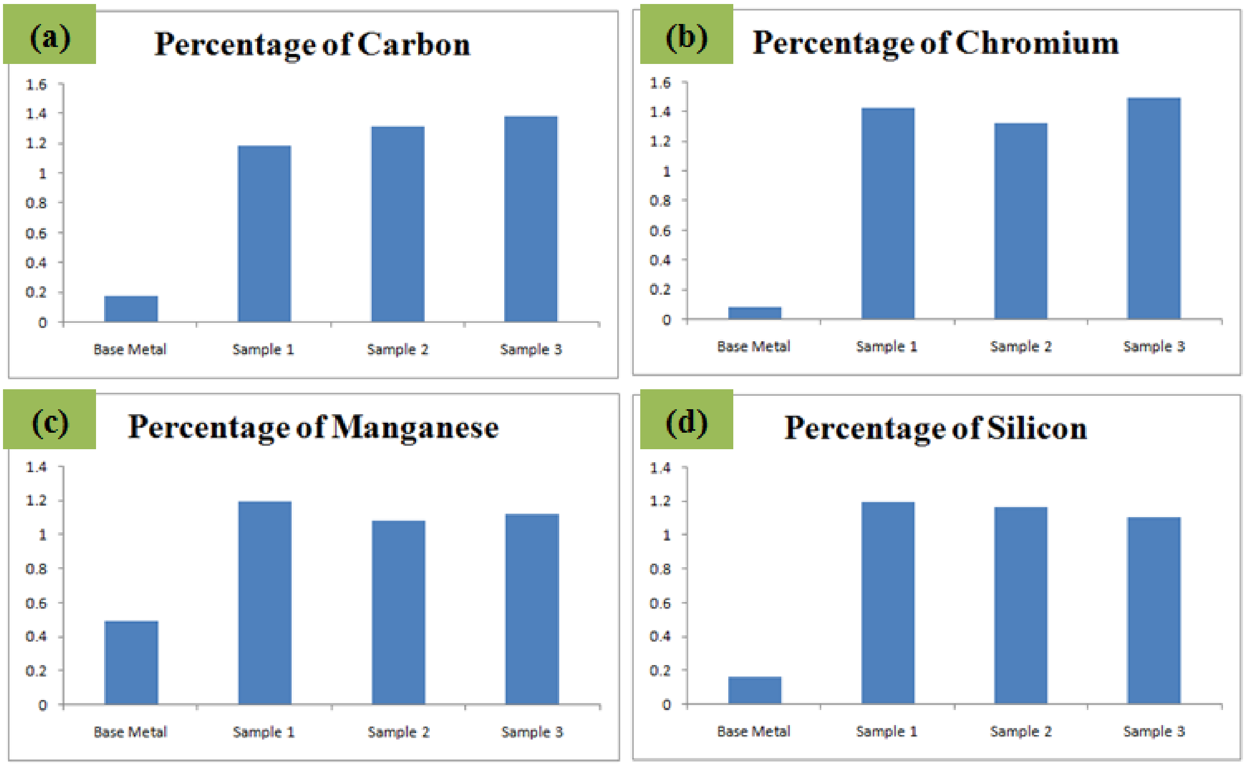

Figure 6 Distribution of element in chemical composition

4.2. Erosive Wear Analysis

Erosive wear of hardface layer was studies at an angle of 30 degree as it is proven that maximum erosion of metallic material occurs at this angle only. Initial weight of all samples were taken before the test and after test also weight was taken. Mass loss of all samples were calculated and tabulated in the table 7.

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Table: 7 Mass loss of all samples

Sample	Initial Weight (gm)	Final Weight (gm)	Mass Loss (gm)
Base Metal	11.168	11.568	0.400
Sample-1	9.739	9.988	0.249
Sample-2	9.384	9.502	0.118
Sample-3	10.661	10.752	0.091

From Table 7, it is clear that maximum erosion has been occurred at base metal and minim um erosion has been found in the sample which has higher amount of alloying elements.

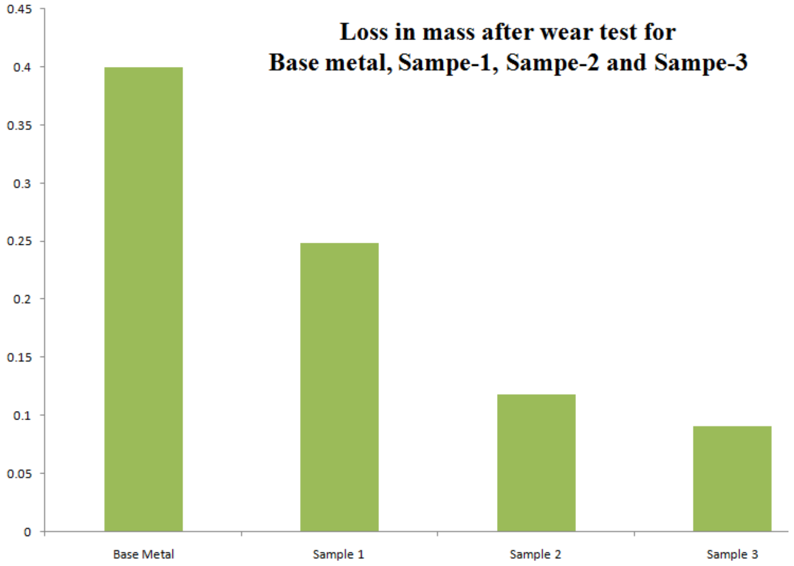

Figure 72 Mass loss of all samples

This shows that when amount of carbides are more in the hardface layer it offer resistance to the erosion because it has high hardness value as compared the low carbon steel which was used as a base material in this study.

V. CONCLUSION REMARK

Following the completion of the final set of experiments and comprehensive mechanical and metallurgical testing, the following conclusions have been drawn:

- A successful development of an iron-based hardfacing layer has been achieved through the submerged arc welding process. Visual inspection of the final alloy reveals a defect-free hardfacing layer.
- The desired chemical composition within the hardfacing layer has been effectively achieved using the paste technique employed in this process.
- The hardfaced layer exhibits significant enhancements in both mechanical and metallurgical properties in

comparison to the base material.

- The microstructure of the final alloy exhibits a combination of metallic carbides and austenite. Within this structure, hard carbides are embedded in a matrix of relatively soft austenite, and as the carbon content within the alloy increases, the quantity of metallic carbides within the matrix also increases.
- The resistance to erosion has been notably enhanced within the hardfacing layer when compared to the base material. Additionally, there is an observable improvement in erosion resistance with an increase in the carbide volume fraction within the alloy.

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