



Effect Of Welding Process Parameters On The Microstructure And Hardness Of Chromium-Boron Hardfacing Using SMAW And FCAW

Chowda Reddy C ¹, K. M. Kenchi Reddy ², C. T. Jayadeva ³

¹Research Scholar, Department of Mechanical Engineering, Adichunchanagiri Institute of Technology, Chikkamagaluru, Karnataka, India

² Professor, Department of Mechanical Engineering, Srikrishna Institute of Technology, Bengaluru, Karnataka, India

³Principal, Department of Mechanical Engineering, Adichunchanagiri Institute of Technology, Chikkamagaluru, Karnataka, India

Abstract: Chromium-boron hard facing can be applied on mild steel to increase its service life in areas of high wear applications in industries. The influence of welding process factors such as current, voltage and travel speed on the microstructure and hardness of the chromium-boron hardfacing deposited by Shielded Metal Arc Welding (SMAW) and Flux-Cored Arc Welding (FCAW) is the subject of this research. By modifying these four parameters the work investigates the dependence of the formation of hard phases like martensite and chromium borides and hardness of the deposited layers on heat input. The results revealed that microstructure improvement depends upon the use of minimum welding current and voltage and increased welding speed. On the other hand, large currents, voltage, and slow speed result into coarser microstructure and low hardness due to high rates of cooling and grain formation.

Comparison between SMAW and FCAW indicated that FCAW and its continuous wire feed and comparatively stable arc gives better control of deposition process to produce more uniform surface layers to hardface with higher hardness. The results indicate that selecting appropriate technological factors; low current, low voltage, and high travel speed, can lead to improved hardfacing with better wear resistance and surface hardness. From this research, a wealth of potential practical applications is presented to enhance the effectiveness of chromium-boron hardfacing other in several industrial fields; highlighting specific welding conditions to attain the proper material characteristics.

Keywords: Chromium-Boron, Hardfacing, SMAW, FCAW.

1. INTRODUCTION

Hardfacing is a critical technique employed to enhance the lifespan of components subjected to significant wear, abrasive, and impact forces. Among the diverse range of hardfacing materials, chromium-boron alloys are particularly noteworthy due to their excellent wear properties, such as high hardness and the formation of hard chromium boride phases that provide superior protection in demanding operating conditions. These chromium-boron alloys are frequently applied to the surfaces of mechanical equipment, agricultural gear, and mining tools where durability is crucial. The effectiveness of the hard-faced layer is largely dependent on the hardfacing method selection. Due to their cost-effectiveness, flexibility, and relative ease of handling, flux-cored arc welding and shielded metal arc welding are the most popular hardfacing techniques in the world.

SMAW commonly known as Stick welding, is one of the most often used techniques for hardfacing because it is simple to use, particularly in the field. However, a significant portion of the extended period results in increased heat input and decreased cooling rates, which affect the hardness and general performance of the hard-faced layer as well as the grain structures. Better control over heat input and deposition is possible with flux-cored arc welding when shielding gas is continually injected into the flux-cored wire. The hardfaced surface's hardness and abrasion resistance are increased by FCAW's better control over grain size and more even coating material distribution.

Investigating how welding process parameters affect the microstructure and hardness of chromium-boron hardfacing weldments made using SMAW and FCAW procedures is the goal of this study. The goal of this study is to enhance the mechanical and microstructural qualities of the welded joints by optimizing critical welding parameters like current, voltage, and welding speed. By comparing these two popular welding techniques, the study seeks to pinpoint each one's main benefits and drawbacks while figuring out the best circumstances for creating superior hardfaced layers. To determine the relationship between welding parameters and elements such the production of hard phases, grain size, and hardness in chromium-boron hardfacing, the emphasis will be on microstructure characterization and hardness testing. The results will reveal relationships between welding parameters and material attributes and offer important insights into choosing suitable welding circumstances and procedures.

2. MATERIALS AND METHODS

2.1 Materials

Mild steel plates measuring **150 mm x 100mm x 12 mm** were selected as the substrate material. These plates were cleaned thoroughly using a wire brush and acetone to remove surface contaminants such as oil, grease, rust, and scale. This cleaning ensured good adhesion between the hardfacing layer and the substrate.

A commercially available chromium-boron alloy electrode was selected as the hardfacing material in both SMAW and FCAW processes. A chemical composition of the chromium-boron alloy is presented in Table 1.

Table 1: Chemical composition of the hardfacing electrode

Element	Cr	Br	C	Mg	Fe
Weight (%)	18	2.8	0.9	0.6	Bal.

2.2 Hardfacing method

Hardfacing involves depositing a wear resistant material on a component surface in order to increase its service life. The SMAW and FCAW types of equipment are required for the hardfacing operations. vary significantly depending on the material to be used and the desired welding process.

2.2.1 SMAW

SMAW is the same as manual welding, in which consumable electrodes and the workpiece act as electrodes. Applying a flux material to the electrode causes it to release slag and protective gas for the molten weld pool during the welding process. Due to its inexpensive cost, this method is frequently used in hardfacing applications and may be used both indoors and outdoors. Nonetheless, SMAW is an effective method for adding layers of wear-resistant material to a substrate when welding with chromium-boron hard facing. But a quality and performance of the hard-faced layer are greatly affected by the welding parameters. Thus, factors, including welding current, arc voltage, and travel speed, control the heat input to the workpiece that defines the microstructure and hardness of the deposited layer. SMAW tends to produce higher heat input incurring longer cooling times which are accompanied by a coarser grain structure in the hard-faced material.



Fig. 1: SMAW Hardfaced Samples

2.2.2 FCAW

FCAW is the type of welding process in which the consumable electrode is in the form of a tubular wire, filled with materials of flux. During many welding applications, an external shielding gas is not required since the flux inside the wire core melts during welding and can serve as a shield against air contamination. Because of this, FCAW can be used outside where wind could easily carry the shielding gases away. Because of its high deposition rates and ability to produce relatively clean welds with minimal surface preparation needed, FCAW is highly valued for hard-facing applications that aim to increase the component's wear characteristics and surface layer durability. In hardfacing with chromium-boron alloy and the heat input can easily be controlled compared to those of SMAW. This enhanced control is advantageous to the process, as it enables depositing of finer micro structures in addition to homogenized coatings. The process generates less spatter and slag which minimize post-welding cleaning that can be paramount when large components have to be hardfaced in industrial settings where parts are exposed to abrasive or corrosive conditions.



Fig. 2: FCAW Hardfaced Samples

2.3 Welding Parameters

Table 2 provides a direct comparison of the key welding parameters for both SMAW and FCAW, when used for hardfacing applications. The parameters consist of welding current, voltage and travel speed, which influence the heat input, deposition rate, and microstructure of the hardfaced layer. By comparing these parameters, the table highlights the differences in heat control and productivity between the two processes, allowing for a better understanding of their suitability for various hardfacing requirements.

Table 2: SMAW and FCAW Welding Parameters

Welding Parameter	SMAW	FCAW
Welding Current (A)	200 - 300	200 - 300
Arc Voltage (V)	22 - 28	24 - 32
Travel Speed (mm/min)	150 - 300	100 - 250
Electrode Diameter (mm)	3.2	1.6
Preheat Temperature (°C)	100 - 200	150-300

In the present study the varying parameters as represented in Table 3 and Table 4 for SMAW and FCAW respectively were, carefully selected to investigate their effects on the microstructure and hardness of chromium-boron hardfacing layers deposited using both SMAW and FCAW. As the parameters are essential as directly influence the heat input into weld pool, cooling rates, and the resulting microstructural features such as grain size, phase formation, and hardness distribution. Below is a detailed description of the welding parameters and their ranges.

Table 3: Varying parameters in SMAW

Sample	Current (A)	Voltage (V)	Travel Speed (mm/min)
A1	250	20	160
A2	250	23	160
A3	250	26	160
A4	200	24	160
A5	250	24	160
A6	300	24	160
A7	250	24	140
A8	250	24	160
A9	250	24	180

Table 4: Varying parameters in FCAW

Sample	Current (A)	Voltage (V)	Travel Speed (mm/min)
B1	250	24	180
B2	250	28	180
B3	250	32	180
B4	200	28	180
B5	250	28	180
B6	300	28	180
B7	250	28	180
B8	250	28	200
B9	250	28	240

2.4 Sample Preparation

The preparation of samples for testing involved several meticulous steps to ensure accurate evaluation of the microstructure and hardness of the chromium-boron hardfacing layers. After the welding process was completed, samples of the hardfaced mild steel were cut using a water jet cutting machine. These sections were carefully taken from the center of weld to safeguard a representative sample of the hardfacing layer and the underlying heat-affected zone (HAZ).

The sectioned samples are then mounted in epoxy resin to provide a stable base for handling and testing. Following mounting, the samples using the finer grades of silicon carbide abrasive paper, starting from coarse grits and moving to finer ones. This ensured the removal of surface imperfections and scratches from cutting, leading to a smooth surface. After grinding, the samples are polished to achieve a mirror-like finish, which is necessary for clear observation of microstructural features under a microscope.

2.5 Microstructural Examination

The microstructural analysis of the chromium-boron hardfacing layers was conducted using a combination of optical microscopy and scanning electron microscopy (SEM) to evaluate the effect of different welding parameters on the microstructure and properties of the deposits. Initial observations are made using optical microscopy, where polished and etched samples were examined to assess the overall grain structure, phase distribution, and interface characteristics between the hardfacing layer and the mild steel substrate. Key aspects such as grain size and morphology, the presence of phases like chromium borides and carbides, and any significant microstructural features—such as porosity or cracks—were documented. This preliminary analysis provided insight into how the solidification behavior and cooling rates influenced the resulting microstructure.

For a more detailed investigation, SEM was employed to obtain high-resolution images of the microstructure, revealing the finer details of phase morphology and elemental composition. This analysis included the examination of the shape, size, and distribution of chromium borides and carbides. Energy Dispersive X-ray Spectroscopy (EDS) was integrated with SEM to confirm the elemental composition of specific phases, enhancing the understanding of alloy distribution. The data obtained from these techniques were then related to the measurements of hardness so as to establish interrelations between some microstructural features, such as grain size and phase distribution, and the properties of the hardfacing layers. This comprehensive analysis ultimately allowed for a better understanding of how welding parameters influence the microstructure, hardness, and wear resistance of chromium-boron hardfacing materials.



Fig 3: Microstructure Samples

2.6 Rockwell Hardness Test

The Rockwell hardness test is commonly used method for determining the hardness of materials, particularly metals and alloys. This test measures hardness based on the depth of penetration of an indenter under a specific load. The process begins with applying a minor load to create an initial indentation, followed by a major load that further penetrates the material. Once the major load is removed, the depth of the indentation is measured, and the Rockwell hardness number (HR) is calculated by comparing the penetration depths under the minor and major loads. The test follows standardized procedures, such as ASTM E18, to ensure accuracy and reproducibility. Rockwell hardness values are expressed in various scales, with the most common being Rockwell A (HRA), B (HRB), and C (HRC), each suitable for different types of materials based on the indenter and load used.



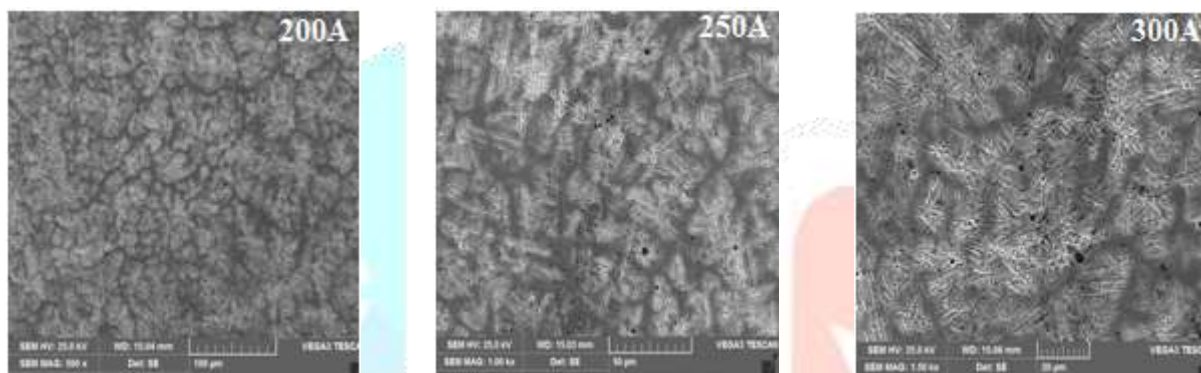
Fig 4: Hardness Test Samples

3. RESULTS AND DISCUSSIONS

3.1 Microstructure Analysis

3.1.1 SMAW Process

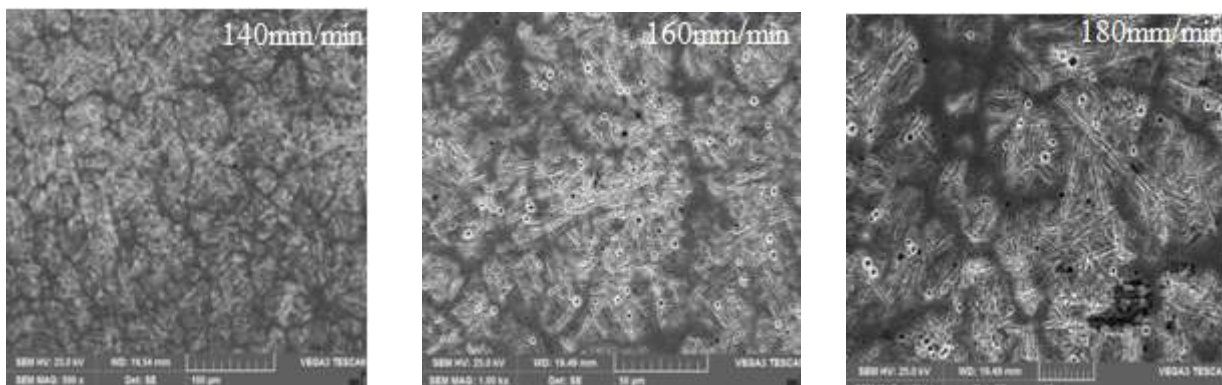
In the SMAW process, the microstructure of chromium-boron hardfacing on mild steel is heavily influenced by the varying welding parameters. Higher current leads to greater heat input, causing a slower cooling rate and formation of coarser carbides and borides. This can reduce hardness but improve toughness by enlarging the grain size in both the weld metal and the heat-affected zone. Lower current promotes rapid cooling, resulting in a finer microstructure with smaller carbides and borides, increasing the hardness but potentially making the deposit more brittle. Similarly, higher voltage spreads the heat over a larger area, leading to a coarser microstructure, while lower voltage focuses heat in a smaller zone, creating finer carbides and a harder deposit. Travel speed also affects the cooling rate; slower speeds provide more heat input, leading to coarser carbides and borides, while faster speeds reduce the heat input, resulting in a finer, harder, and more wear-resistant microstructure.



(a) Varying Current, constant Travel speed and Voltage



(b) Varying Voltage, constant Current and Travel speed

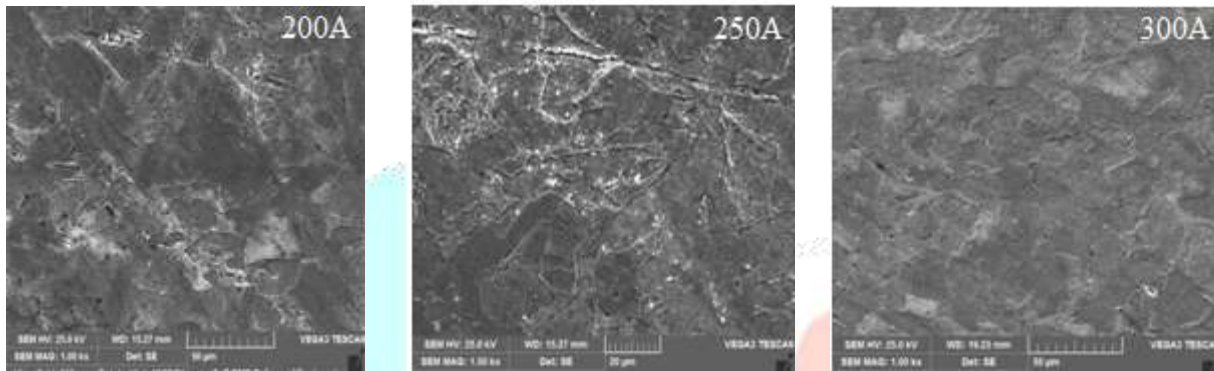


(c) Varying Travel Speed, constant Current and Voltage

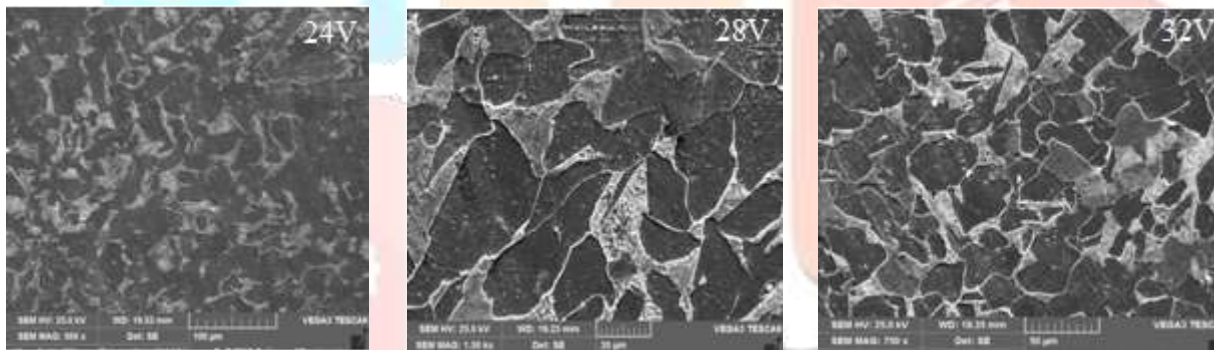
Fig. 5: SEM image of Varying (a) Current (b) Voltage and (c) Travel speed samples (A1-A9)

3.1.2 FCAW Process

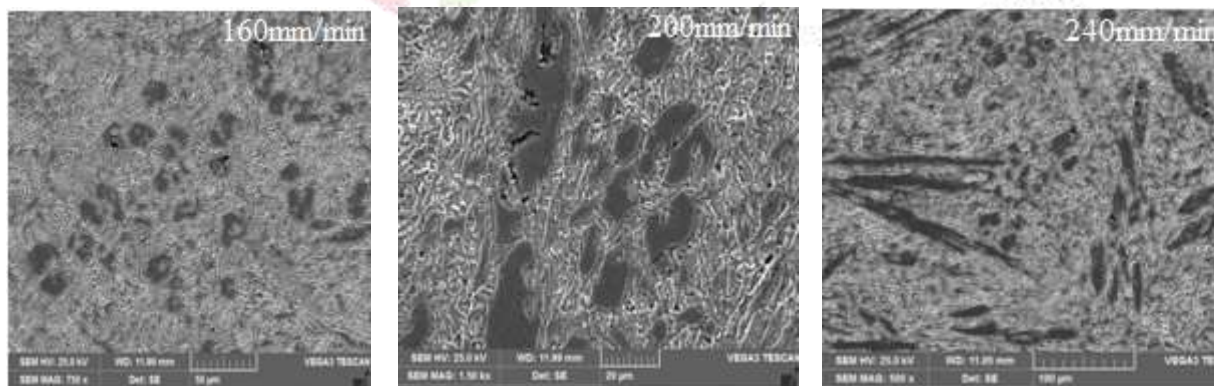
In the FCAW (Flux-Cored Arc Welding) process, the microstructure is influenced by similar parameters—current, voltage, and travel speed—but with greater control over the deposition due to the tubular electrode filled with flux. Higher current increases the heat input, leading to slower cooling and the formation of larger carbide and boride phases, similar to SMAW. However, FCAW tends to produce a more uniform and consistent weld bead, which can reduce porosity and improve toughness even at higher heat inputs. Lower current results in a finer microstructure with smaller chromium carbides and borides, enhancing hardness and wear resistance. Voltage also plays a role; higher voltage creates a longer arc and more heat, leading to a coarser microstructure, while lower voltage tightens the arc, refining the microstructure. Faster travel speed reduces heat input and promotes rapid solidification, yielding a finer microstructure with more dispersed carbides and borides, which improves hardness and wear resistance.



(a) Varying Current , constant Travel speed and Voltage



(b) Varying Voltage, constant Current and Travel speed



(c) Varying Travel Speed, constant Current and Voltage

Fig. 6: SEM image of Varying (a) Current (b) Voltage and (c) Travel speed samples (B1-B9)

3.2 Hardness test

The Rockwell hardness test is conducted on samples of chromium-boron hardfacing deposited using both SMAW and FCAW processes. The results showed that several welding factors, including current, voltage, and travel speed, significantly affected hardness.

Table 5: Taguchi L9 orthogonal array samples with HRC.

Hardfacing Welding Process	Sample Run No.	Hardness Number (HRC)
SMAW	A1	61
	A2	58
	A3	56
	A4	61
	A5	58
	A6	58
	A7	59
	A8	58
	A9	61
FCAW	B1	63
	B2	60
	B3	58
	B4	64
	B5	59
	B6	60
	B7	57
	B8	59
	B9	62

The results of the Rockwell hardness test, which were obtained by adjusting the voltage, current, and travel speed while welding chromium-boron hardfacing, highlight the complex connection between these variables and the weld's characteristics. A discernible rise in hardness occurs with an increase in current. This is explained by the increased heat input that comes with higher current levels, which makes it easier for the hardfacing material to melt and fuse. Consequently, this promotes the formation of desirable microstructural phases, such as chromium borides, that contribute to increased wear resistance and hardness. Similarly, variations in voltage also played a critical role in influencing the hardness of the hardfaced layers. High voltage levels can alter the bead shape and the size of the heat-affected zone, but they also tend to improve arc stability and increase heat input. Because too much voltage can result in broader beads and possible dilution with the substrate material, which could impair hardness, it is crucial to strike the ideal balance between voltage and current.

Another important element influencing hardness was found to be travel speed. More heat can typically be focused in a smaller region at slower transit speeds, which promotes fusion and produces a finer microstructure. Because of the refined grain structure, hardness can be greatly increased by this fine microstructure. On the other hand, a lower heat input from a quicker travel speed may result in coarser grains and less toughness. In order to maximize the cooling rate and guarantee that the required hardness is reached, it is imperative to acquire the proper travel speed.

To sum up, the Rockwell hardness data show that the hardness of chromium-boron hardfacing can vary significantly depending on the welding parameters of voltage, current, and travel speed. In order to customize the hardfacing process to produce the best mechanical qualities and guarantee that the welded components are appropriate for their intended uses, it is crucial to comprehend how these parameters interact. In addition to improving performance, this knowledge helps shape best practices in materials engineering and welding.

3.3 EDX Analysis

The study of chromium-boron hardfacing on mild steel using both SMAW and FCAW with variations in voltage, current, and travel speed, provided significant insights into the differences in elemental composition, dilution, and uniformity between the two processes. EDX analysis results were crucial in understanding how these welding parameters influenced the deposition quality, distribution of alloying elements, and microstructural integrity of the hardfaced layers.

The EDX mapping for the SMAW samples revealed a less uniform distribution of chromium and boron across the hardfaced surface. The lower travel speeds and higher heat inputs resulted in larger, coarser grains and uneven deposition of the hardfacing material. This non-uniformity can lead to localized weaknesses in the hardfacing, particularly in areas with lower chromium and boron concentrations, which would be more susceptible to wear and abrasion.

In contrast, the FCAW samples demonstrated a much more uniform distribution of chromium and boron throughout the hardfaced layer, even when varying the current, voltage, and travel speed. The improved deposition efficiency of FCAW, along with the flux-cored wire's ability to provide consistent alloying element retention, resulted in a more homogeneous microstructure. This uniform distribution of alloying elements, particularly the hard chromium carbides and borides, contributed to superior wear resistance and hardness across the entire hardfaced layer.

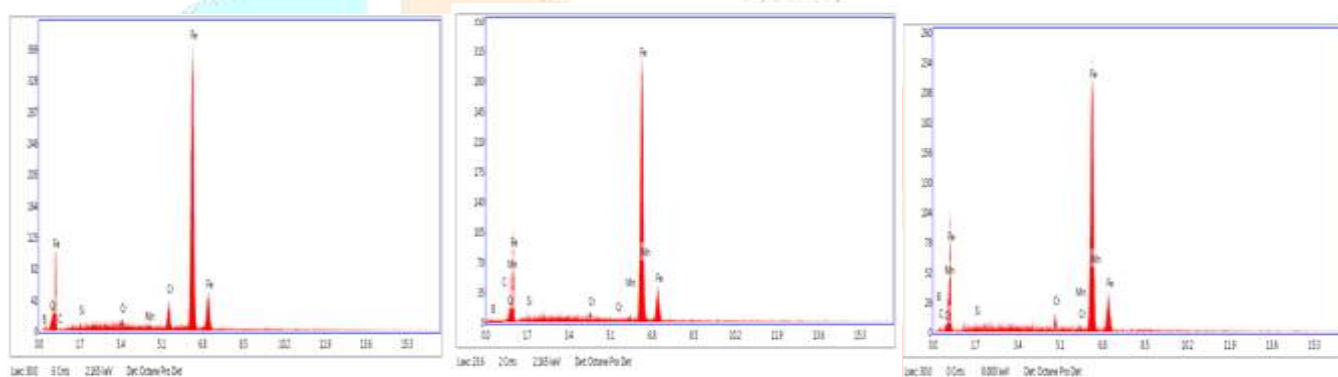


Fig 7: EDX spectrum of SMAW hardfacing samples

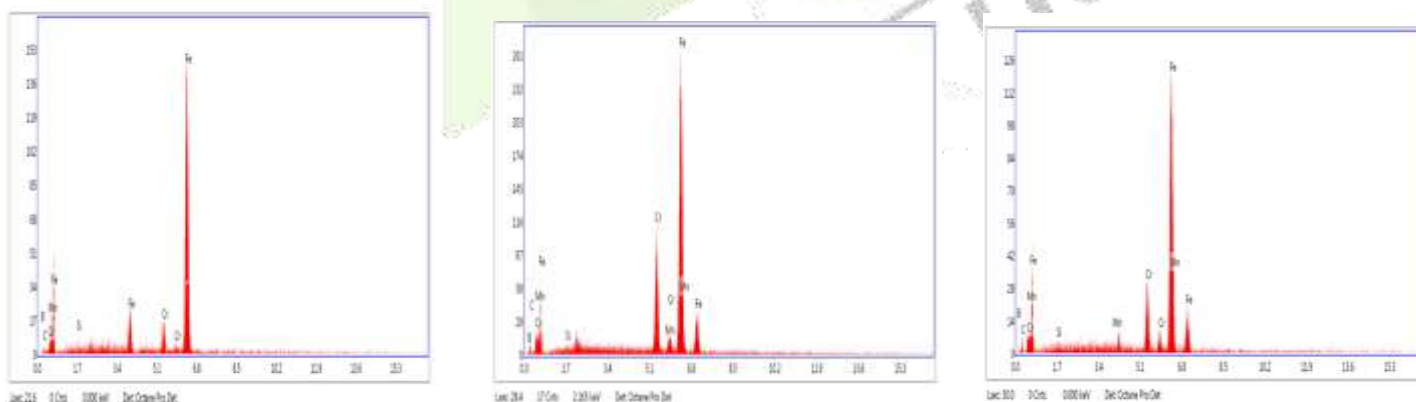


Fig 8: EDX spectrum of FCAW hardfacing samples

4. CONCLUSIONS

The research work carried out to investigate voltage, current, and travel speed: their impacts on microstructure and hardness of chromium-boron hardfacing SMAW and FCAW has offered beneficial prospects to enhance the operations of those methods.

1. **Influence of varying Current:** The results of chromium-boron hardfacing are greatly impacted by changes in the welding current. The hardness and wear resistance of the alloy are maintained at 200A due to the low penetration and dilution, although there may be a weaker binding to the substrate. A balanced result with moderate penetration, less dilution, and a finer microstructure is obtained at 250A, providing good hardness and strong bonding. Deeper penetration, however, improves bonding strength at 300A; yet, the hardness and wear resistance are diminished by greater dilution and coarser grain structure, which makes it less suitable for attaining ideal surface characteristics.
2. **Impact of Varying Voltage:** The results of chromium-boron hardfacing are greatly impacted by changes in the welding current. The hardness and wear resistance of the alloy are maintained at 200A due to the low penetration and dilution, although there may be a weaker binding to the substrate. A balanced result with moderate penetration, less dilution, and a finer microstructure is obtained at 250A, providing good hardness and strong bonding. Deeper penetration, however, improves hardness and wear resistance are diminished by greater dilution and coarser grain structure, which makes it less suitable for attaining ideal surface characteristics.
3. **Effect of Varying Travel Speed:** The results also showed that the hardfaced layers' microstructure changed as a result of the increased cooling rate caused by traveling speed. Grain size becomes finer and hardness increases as travel speed increases because the temperature takes longer to build up. Conversely, when travel speed falls, grain size becomes coarser and hardness reduces. Therefore, the most important component that needs to be managed to achieve the required microstructure and hardness is the traveling rate.
4. **Comparative study of SMAW and FCAW:** Because of its greater deposition rate and controlled heat input, FCAW had a higher hardness value than SMAW when it came to the deposition efficiency of the hardfacing layers with varying hardness values in the study. The advantages of FCAW in applications where superior wear and mechanical qualities are desired are illustrated by this contrast.
5. **Overall Optimization:** In order to optimize the mechanical properties of chromium-boron hardfacing, the study should emphasize the necessity of fine-tuning welding parameters. To be able to adjust the welding process according to the intended application, it makes sense to understand the relationships between the voltage, the current, and the speed. This information is especially helpful to industries that use hardfacing technologies to increase the longevity of products subjected to demanding wear conditions.

The investigation also shows that strict regulation of some welding characteristics affects the structure of chromium-boron hardfacing and its hardness. They suggest that these parameters can be tuned to augment various material characteristics so that the resulting microstructure delivers higher mechanical properties that contribute to better performance when subjected to taxing service conditions.

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