Microstructural Behaviour of SS304 & SS310 Hardfaced Steels

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Abstract—*Erosion of metal parts is the serious problem in many engineering systems such as turbines and boiler. SS304 and SS310 steel is used to make nozzle of the boiler for feeding coal with certain advantages i.e. price, strength & formability. But the main limitation of stainless steel is erosion due to which the nozzle needs to be replaced frequently. Hardfacing is commonly applied method to improve the surface properties of components. In the present study SS304 and SS310 steel is hardfaced by three different hardfacing electrodes by manual metal arc welding process to compare the microstructure and microhardness of hardfacing alloys deposits. The deposited alloys have shown good bonding with the substrate steels. The Microstructure reveals the presence of chromium carbide and silicon carbide in the form of hexagonal type, needle type and cubodial type shapes. The addition of SiC in alloying elements improved the hardness of the substrate steels; however, higher microhardness has been achieved by deposition of chromium based electrode.*

Keywords: *Erosion, Hard facing, Microstructure.*

Introduction

Wear is probably the most significant cause of mechanical damage of equipment components coming in contact with abrasive/erosive bodies [1]. Erosion is a generalized wear mechanism whereby mass loss occurs through impact of discrete particles entrained in a fluid stream [2]. In industrial application and power generation, such as coal fired boilers, fluidized beds and gas turbines, high sulfur content and ash particles are produced during the combustion of heavy oils, synthetic fuels and pulverized coal. So these particles erode the material from the surface of equipment [3]. In thermal power plants pulverized coal travelling at high velocity through coal burner nozzle and nozzle tip typically produces significance component of erosion. During operation this erosion results in the loss of burner's geometry. Hardfacing alloys are widely used to protect machinery equipment exposed either to pure abrasion or to a combination of abrasion and impact. Erosion is to be reduced by either in the form of using new material or by improving the wear resistance of the existing material by addition of any wear resisting alloying elements [4]. The application of a hard, wear resistance surface of various metal and alloys on a metallic substrate by weld deposition is one of the versatile and expensive ways, especially when these components are large or expensive. The hardfacing can be deposited as a thick alloy coating ranging from 750µm to few mm [5]. Hardfacing by open arc welding process is less expensive and can be applied to the critical parts of the machine components prone to severe wear [1].

Aim of the present research work is to characterize SS304 and SS310 steel hardfaced by Manual metal arc welding process. SS304 and SS310 steel is used in steam boilers. The hardfaced samples were characterized with respect to microstructure, microhardness and phase formation using the combined techniques of optical microscopy and scanning electron microscopy/energy-dispersive analysis (SEM/EDAX).

Experimentation

Substrate Material

Two types of steels namely SS304 and SS310 were used in the present investigation. Each specimen measuring approximately 150mm×50mm×5mm were cut from the rolled sheet. The chemical composition of substrate steels according to weight % is given in Table 1.

Hardfacing Electrodes

Commercially available hardfacing tubular coated electrode (CPET 071) is used for deposing single layer on the flats and without any buffer electrode. CPET 071 (Alloy 1) is a tubular cored of chromium carbide type, reinforced with alloying additives. Two new composition of alloy powder were prepared by mixing the 15% and 30% of SiC powder into the commercially available alloy powder of CPET 071. Silicon carbide (SiC) is a traditional wear resistant material which is used for hardfacing on these steels. These new alloy powders (Alloy 2 and Alloy 3) were filled into the tubular electrodes along with potassium silicate as bonding agent. Before welding, the electrodes were dried at 80 °C for 3–4 days. The chemical composition of all alloys is determined with the help of the Spectrometer and presented in Table 2.

Table 1: Chemical Composition of base Materials

Material	C	Mn	Si	P	S	Cr	Al	Ni	Fe
SS304	.08	2	.75	.045	.030	20	.1	10.50	Balance
SS310	.25	2	1.5	.045	.030	26	.1	22	Balance

Table 2: Chemical Composition of Electrodes

Electrode	Cr	SiO_2	Co	Ni	Mn	S	P	Fe	SiC
1	27.73	7.97	0.12	0.21	0.18	5.16	0.48	58.45	________
2	27.73	7.97	0.12	0.21	0.18	5.16	0.48	58.45	15% of wt.
3	27.73	7.97	0.12	0.21	0.18	5.16	0.48	58.45	30% of wt.

Hardfacing Formulation

The open arc welding process was used to apply hardfacing on the substrate steels. The parameters of welding are; arc current of 130A and arc voltage of 24V. Hardfacing layer of about 4-5mm thickness was deposited on the substrate steels (SS304 & SS310).

Microstructure Analysis

The hardfaced samples were mirror polishing prior to studying its cross-sectional features. The characterization of the microstructure was done using optical microscopy and scanning electron microscopy (SEM).

SEM/EDS Analysis

Microstructure and element analysis was studied using SEM/EDS technique (Joel Scanning Microscope (JSM-840A) with EDAX attachment, Link ISIS). The equipment could directly indicate the alloying elements present at the point based on built in EDS software.

Microhardness Analysis

The microhardness of the hardfaced samples is measured by using microhardness tester Miniload 2 (Leitz, Germany). A 1000 g load is provided to the indenter for penetration and maintained for 10 s.

Results and Discussion

Microstructure

The cross-sectional analysis of microstructure has been done with optical microscopy after engraving with reagent. The cross-sectional microstructures of hardfaced specimens are shown in Fig. 1 to Fig. 6. Fig. 1 shows the cross-sectional microstructure of SS304 steel hardfaced by electrode 1. Microstructure shows the weak bonding between the hardfacing and substrate steels. Cracks are revealed at the interface. There is limited dilution at the interface, but heat effected zone can be seen near the substrate material. The large size chromium carbides may be identified in form of the hexagonal and spines. Long spines rich in chromium carbide are clearly visible in the microstructure of hardfacing. These chromium carbide spines may offer excellent wear resistance to the base steel. According to Choteborsky et al, [7] these carbides are an effective barriers against the abrasion wear.

Fig. 1: Optical Microstructure for the Cross-section of SS304 Steel Hardfaced by Electrode 1

Figure 2 shows optical microstructure along the cross-section for SS304 steel hardfaced by electrode 2. Microstructure shows the good bonding between the hardfacing and substrate material. It may be noted that the grain boundary regions are enriched in Cr and Si. Hence, the bright network interconnecting the grain boundary is due to presence of very fine silicon carbide and chromium carbide particles. Buchanan et al, [8] observed that these carbides can form relatively large micro-constituents, which provide enhanced abrasion resistance. Further microstructure shows the limited dilution at the interface. As reported by Lakshminarayanan *et al.*, [9] control of dilution is important in hardfacing, where low dilution is normally desirable. When the rate of dilution is low, the final deposit composition will be closer to that of the filler metal, and the wear and corrosion resistance of the hardfacing will be maintained. Figure 3 presents the optical microstructure for the cross-section of electrode 3 deposited on SS304 steel. It is evident from the microstructure that the bonding between the hardfacing and substrate is of a diffusion type. Diffusion takes place around the interfaces at very high temperature and particularly at the liquid stage, and thus, the bond formed between the substrate and hardfacing is relatively strong. Silicon carbide can be seen in the form of small grains and the chromium carbides can be seen in long spines and hexagonal shapes. Ramesh and Srinivas [10] observed that the dispersion of silicon carbide, a hardface in the soft iron matrix tends to reduce the wear rates of iron composites. Wear rate of iron–silicon carbide composites decreases with increase in silicon carbide content.

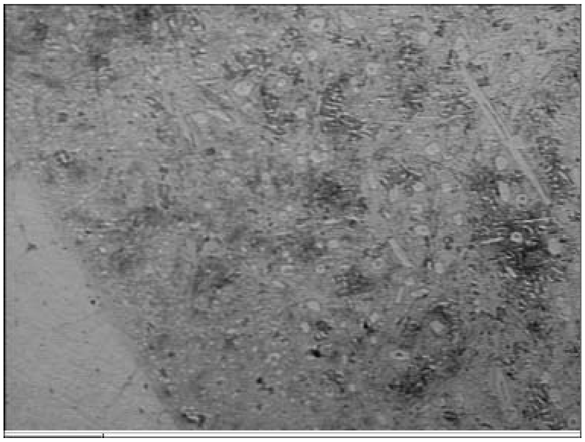


Fig. 2: Optical Microstructure for the Cross-section of Electrode 2 Deposited on SS304 Steel Substrate

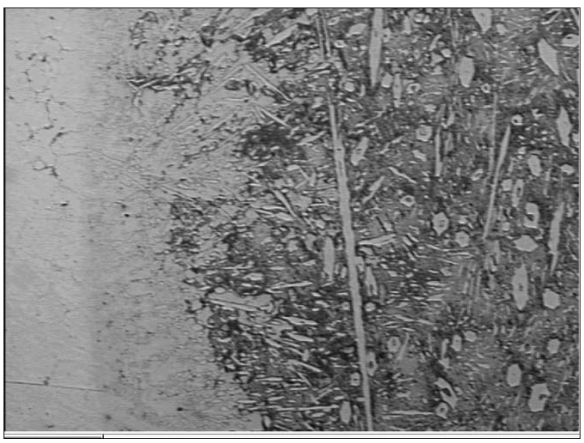


Fig. 3: Optical Microstructure for the Cross-section of Electrode 3 Deposited on SS304 Steel Substrate

Figure 4 shows the optical microstructure for the cross-section of electrode 1 deposited on SS310 steel substrate. It is cleared from the Fig. 1 that there are no defect like crack and porosity between the hardfacing and substrate steel. A limited dilution can be seen at the interface of hardfacing and substrate steel. The microstructure of hardfacing layer consists of uniformly distributed chromium carbide phases. In a study by Karamis et al, [11] Cr-rich carbides prepications were discovered in the hardfaced layers with Cr addition. Further it was reported that due to existent of intensive chromium-carbide in hardfaced substrate, erosion resistance of the hardfaced layer having high Cr is two times higher than those of the layer without Cr. Optical microstructure for the cross section of SS310 steel substrate on electrode 3 deposition is depicted in Fig. 5. Microstructure reveals good bonding between the hardfacing and substrate. It is evident from figure that the microstructure consists of a pearlitic phase in the matrix of ferrite and the grain boundary regions are enriched in Cr and Si. The nature of the bonding is diffusion and the interface regions are free from any porosities, defects and segregation. It shows very small iron and chromium carbides with SiC particles bonded in the sub-surface. As reported by Majumdar et al, [12] increase in SiC content in the iron matrix results in significant improvement in both hardness and wear resistance. However, partial dissolution of SiC from the interface could not be avoided in the present study. According to Sue et al, [13] dissolution improves the strength of matrix phase and increased its wear resistance but reduces the toughness of the hardfacing. Fig 6 shows the optical microstructure for the cross-section of electrode 3 deposited on SS310 steel substrate. Microstructure reveals very limited dilution and heat affected zone, and the bonding between hardfacing and substrate seems good. The microstructure consists of uniformly distributed hexagonal and needle-like chromium carbide phases.

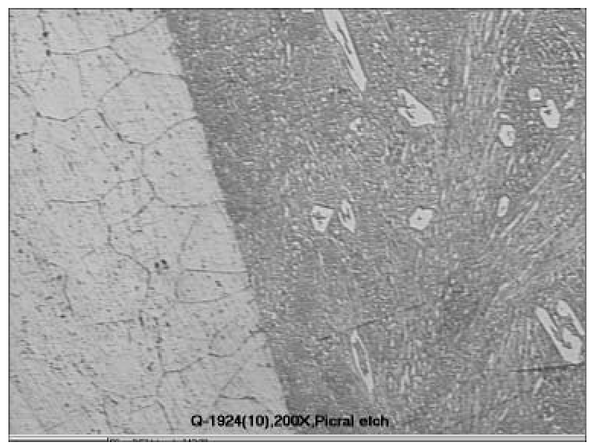


Fig. 4: Optical Microstructure for the Cross Section of Electrode 1 Deposited on SS310 Steel Substrate

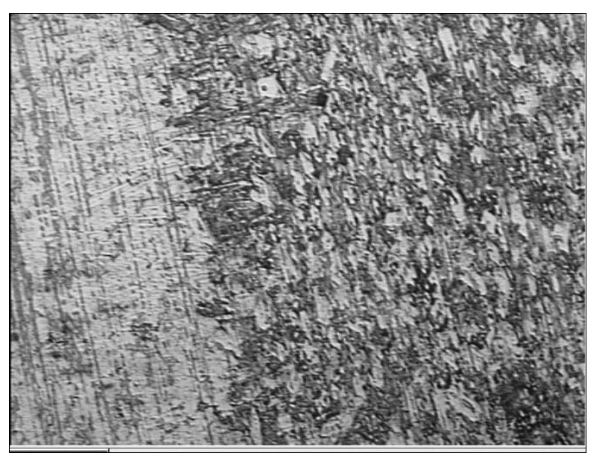


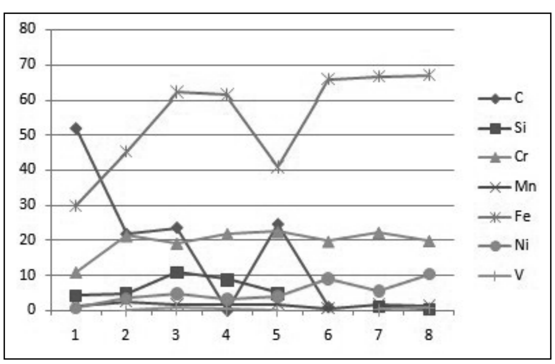
Fig. 5: Optical Microstructure for the Cross Section of Electrode 2 Deposited on SS310 Steel Substrate

Fig. 6: Optical Microstructure for the Cross Section of Electrode 3 Deposited on SS310 Steel Substrate

As reported by KenchiReddy and Jayadeva [14] as the hardness increases, the loss of wear decreases. Higher amount of chromium, carbon, silicon and finer structure resulted in higher hardness.

Cross Section SEM/ EDS Analysis

SEM/EDS micrograph and variation in alloying elements across the cross-section of SS304 steel substrate by deposition of electrode 1 has been presented in Fig. 7. EDS analysis at point1 and 2 shows the composition of substrate steel with the presence of Fe, Ni and Cr, along with tracing of others alloying elements. EDS analysis of points 4 to 8 presents the hardfacing zone with the presence of Fe and Cr, along with significant amount of Ni and Si, approaching the composition of deposited alloy. SEM micrograph display good bonding of the deposited alloy over the substrate steel. Microstructure reveals the formation of chromium carbides which has been observed in microstructure analysis also (Fig 1). In the hardfacing zone the carbon content has increased due to additional alloying of the hardfacing weld. Kezjar and Grum et al, [15] reported that the higher carbon content in these hardfacing welds thus results in a martensitic-ledeburitic structure showing higher hardness and wear resistance.



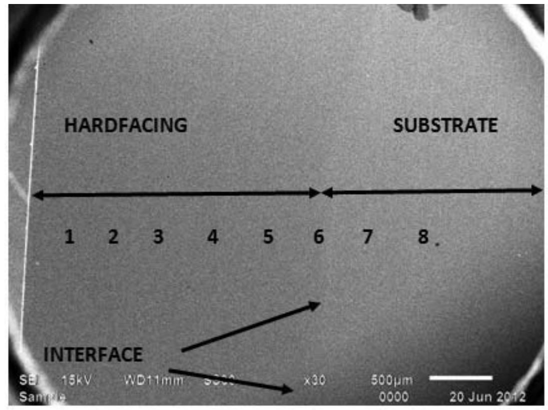


Fig. 7: SEM/ EDS Micrograph and Variation in Element Composition Across theCross Section of Electrode 1 Deposited on SS 304 Steel Substrate

Fig. 8 shows the SEM/EDS micrograph of SS304 steel substrate hardfaced by electrode 2. EDS analysis of point 8 and 9 shows the rich presence of Cr and Fe, which is substrate steel. It shows the fine distribution of Fe, Cr, Si, C and Ni in the hardfacing zone. According to Lee et al, [16] if Cr and C contents increase higher than eutectic point, hypereutectic structure is formed after formation of primary phase.

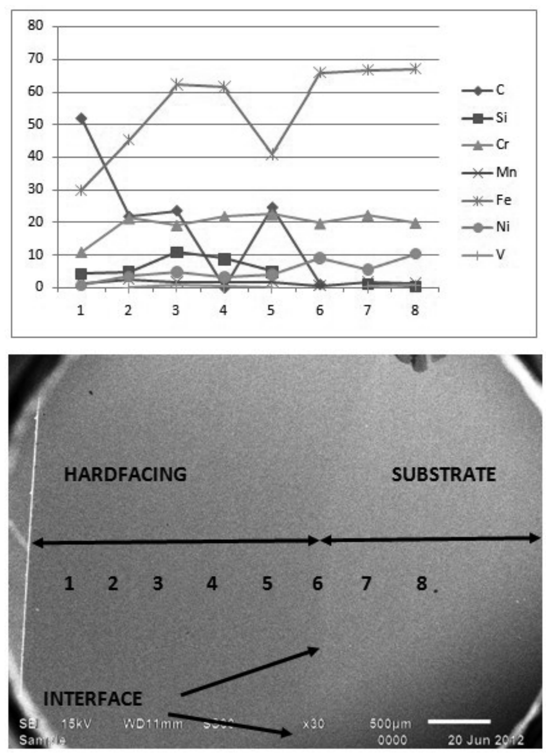


Fig. 8: SEM/ EDS Micrograph and Variation in Element Composition Across the Cross Section of Electrode 2 Deposited on SS304 Steel Substrate

Therefore, Cr and C appear to be an optimum composition for the improved wear resistance. Das *et al.*, [17] observed that the addition of silicon carbide particles make the alloy brittle and improve its hardness, strength and modulus. SEM/EDS micrograph and variation in alloying elements across the cross-section of electrode 3 deposited on SS304 steel substrate has been shown in Fig. 9. EDS analysis of point 7 and 8 shows the rich presence Cr and Fe with the absence of Si, indicating the substrate material. In the hardface zone the alloying elements like Fe, Cr, Si and Ni are equally distributed from point 1 to 6. EDS reveals the carbon content on the upper layer of hardfacing. Further microstructure reveals the high dilution at the interface of substrate and hardfacing as shown in Fig 3. As reported by Ma et al, [18] SiC is very effective as a reinforcing agent. SiC improves significantly the size distribution and homogeneity of phase of reinforced matrix composites.

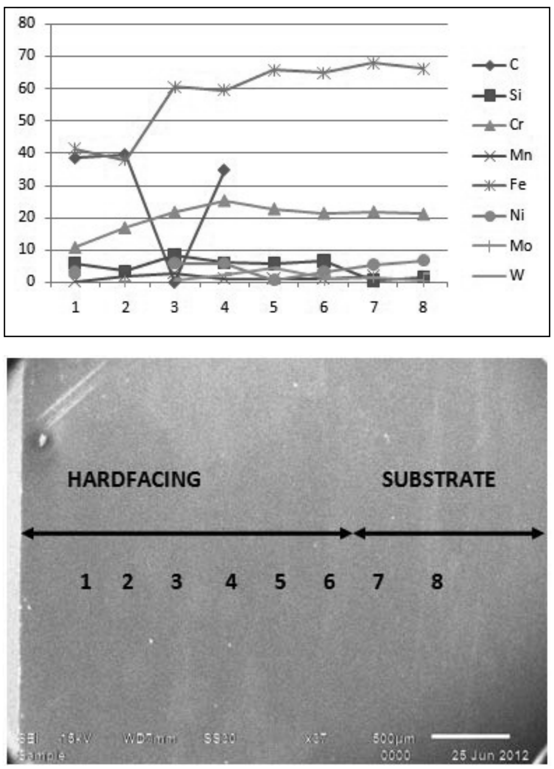


Fig. 9: SEM/ EDS Micrograph and Variation in Element Composition Across the Cross-section of Electrode 3 Deposited on SS304 Steel Substrate

Fig. 10 shows the SEM/EDS micrograph and variation in alloying elements across the cross-section of SS310 steel substrate hardfaced by electrode 1. SEM micrograph reveals good bonding between hardfacing and substrate steel. EDS analysis of point 7 and 8 shows the rich presence of Cr, C and Fe, and negligible amount of other elements, indicating the substrate material. EDS analysis of hardface reveals the large amount of Fe, Cr and C with very small amount of Ni. The existence of chromium along with carbon makes the formation of CrC in the matrix phase which has been observed in the microstructure in Fig 4. As reported by Buchanan et al, [19] 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.

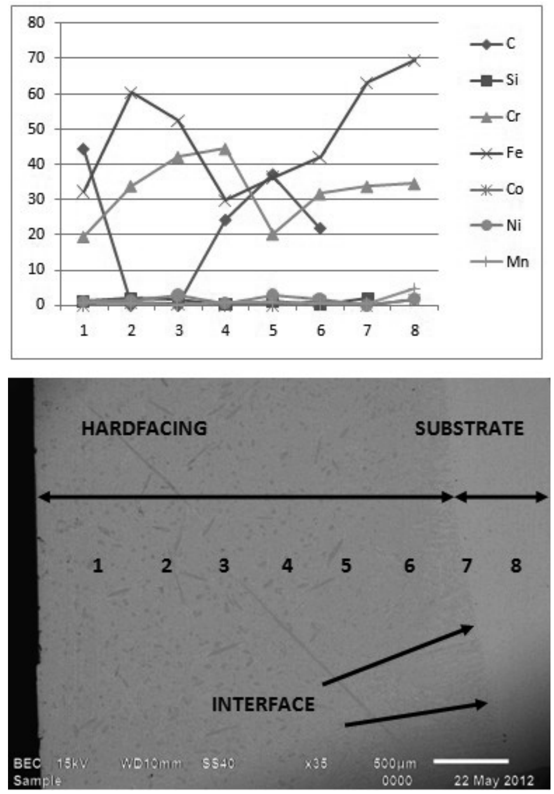


Fig. 10: SEM/ EDS Micrograph and Variation in Element Composition Across the Cross-section of Electrode 1 Deposited on SS310 Steel Substrate

Fig. 11 shows the SEM/EDS micrograph across the cross-section of SS310 steel substrate hardfaced by electrode 2. EDS analysis of point 1 shows the substrate steel with higher amount of Cr and Fe. The point 2 shows the interface of hardfacing and substrate, which reveals good bonding. EDS analysis reveals the presence of elements like Fe, Cr and Si distributed uniformly at the hardface zone. SEM/EDS micrograph and variation in alloying elements across the cross-section of electrode 3 deposited on SS310 steel substrate has been shown in Fig. 12. EDS analysis of point 7 and 8 reveals the higher value of Fe, Cr and Ni, indicating the substrate steel. There has been rich presence of Fe and Cr along with C and Si in the hardfacing zone. Further SEM reveals the good bonding between hardfacing and substrate, with limited dilution and heat affected zone. Due to carbon present the alloying elements Cr and Si suggests the formation of carbides. Aoh and Chen [20] observed that the wear resistance is determined by the size, shape, distribution and chemical composition of the carbides, as well as by the matrix microstructure.

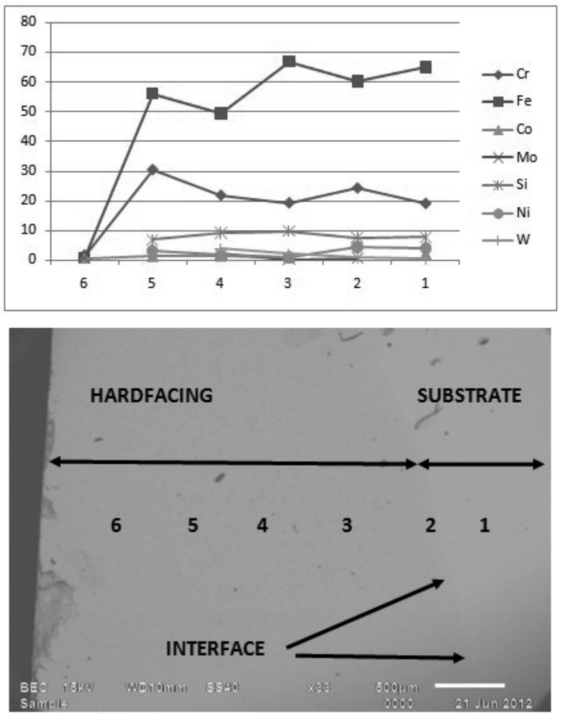


Fig. 11: SEM/ EDS Micrograph and Variation in Element Composition Across the Cross Section of Electrode 2 Deposited on SS310 Steel Substrate

Microhardness

Microhardness graph along the substrate weld metal interface for hardfaced steels SS304 and SS310 are given in Fig. 13 and Fig. 14 respectively. As shown in figures the microhardness of all tested specimens lies in the range of 400 to 700 HV. Microhardness of the substrates steels has been observed to be 200 HV. The hardfacing of electrode 1 seems to have higher hardness as compared to the hardfacing of electrode 2 and 3. Higher hardness of hardfacing by electrode 1 may be due to presence of high fraction of rich chromium carbides in the form of spines, cuboidal and needle type carbides as shown in Fig 1 and Fig. 4. As reported by Choo et al, [21] as the complex carbide fraction increase, hardness and wear resistance of matrix also improves. However, it is found that the fraction of rod-type carbides is not much related to hardness and wears resistance; whereas, that of cuboidal carbides is closely correlated with them. This finding indicates that the amount of cuboidal carbides is the most important microstructural factor in determining the hardness and wear resistance of the hardfaced layer. The alloying electrode 2 and 3 shows the low microhardness as compared to deposition of electrode 1. As reported by Dolatkhah *et al.*, [22] SiC particles have pinning effect and they also restraint grain boundary migration, so they impede grain growth. On the other hand SiC particles act as nucleation sites and they also redound to grain break-up. But the alloying electrodes 2 and 3 deposited on substrate steels have high hardness than the substrate steels from the interface to top of hardfacing. The element SiC improves the hardness and wear resistance of matrix. As reported by Ravikumar *et al.*, [23] SiC is one of the hardest materials known to man, only diamond and boron nitride are harder. The short bond length of 1.89 Å between 'Si' and 'C' atoms result is in high bond strength and excellent hardness.

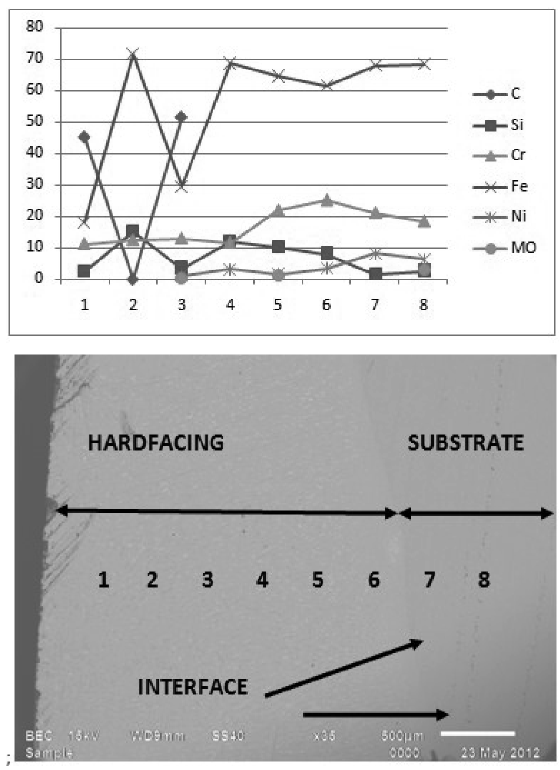


Fig. 12: SEM/ EDS Micrograph and Variation in Element Composition Across the Cross Section of Electrode 2 Deposited on SS310 Steel Substrate

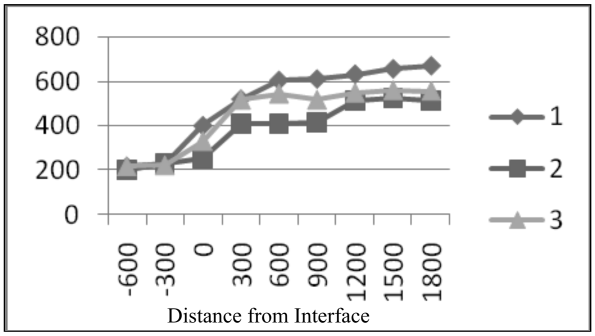


Fig. 13: Microhardnass of SS304 Steel Hardfaced with Electrode 1, 2 and 3

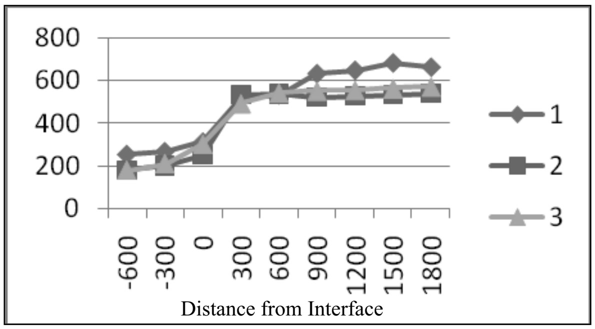


Fig. 14: Microhardnass of SS310 Steel Hardfaced with Electrode 1, 2 and 3

Conclusion

Electrodes 1, 2 and 3 of different alloying elements were deposited on SS304 and SS310 steel substrates by open arc welding process. Deposited hardfacing layer showed good bonding with the steel substrates.

- EDS analysis reveals the distribution of alloying elements like Cr, Fe, Si and C randomly into the matrix for deposited hardfacing.
- Microstructure shows the carbides of chromium and silicon in the form of hexagonal, needle and cobodial shapes.
- Microstructure of deposited hardfacing alloys has been found to be free from defects like cracks and porosity.
- The microhardness value was found to increase with the increase in chromium and silicon carbide content in the deposited hardfacing alloys.

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