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Develop a flux cored wire for submerged arc welding of Ni-Mo low alloy steel

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Abstract. Ni-Mo low alloy steel exhibits an admirable amalgamation of high strength and toughness at subzero temperature and show resistance to brittle fracture with good weldability. This steel has been established to fulfill the needs of specific applications, such as the construction of ships and submarines. To develop a companionable wire for welding of Ni-Mo low alloy steel, the amount of the alloying elements in a wire is increased to toughen of weld metal, the wire itself has high strength so that the wire is hardened at the wire drawing, making the wire production difficult. In order to avoid the problems related to the solid wires, various flux cored wires have been developed. In this work, the effect of flux basicity index and heat input on chemical composition, oxygen-nitrogen analysis, mechanical properties and microstructure of Ni-Mo low alloy steel welded by SAW welding using flux cored wires are presented along with the effect of flux cored wire and basicity index on deposition rate.

Keywords. Submerged arc welding; Ni-Mo low alloy steel; element transfer; flux basicity.

1. Introduction

Submerged arc welding (SAW) process, a coalescence of metal take place at the beneath of the flux layer. In this process, solid wire and tubular wire used as a filler material. Tubular wire is also known as composite wire consists of the metal sheath and a core of wire is filled with flux powder [1]. Flux cored wire produced complex weld composition which is difficult to produce by solid electrode [2].

Ni-Mo low alloy steel has excellent tensile properties and high impact toughness value at a lower temperature [3] and it is very difficult to produce weld metal of such composition with SAW process by solid wire. Conventionally, solid wires containing alloy components such as Ni, Mn, Mo and the like are mainly used as a wire for submerged arc welding to get a tough weld metal at subzero temperature. But when the amount of the alloy components in a wire is increased to toughen of weld metal, the wire itself has high strength, so that the wire is hardened at the wire drawing process due to added work hardening. If the wire is hardened, worn dies and broken wire appear more often, making the wire production difficult. Also, if a solid wire with high strength is used for welding, the wire is difficult to be straightened, so that decentering to the groove center is easily caused, and that favorable beads cannot be obtained. To resolve this problem, flux cored wire is developed, also for the same diameter flux cored wire has a high deposition rate compare to solid wire due to higher current density which increased productivity [4]. The weld metal composition depends on electrode, flux and weld dilution and also basicity index of the flux play important roles in element transfer from slag to weld metal and vice versa [5, 6]. Element transfer also influenced by welding parameters so the final composition of weld metal and its mechanical and metallurgical properties are determined by electrode, flux and base metal composition and welding parameters [7].

In this work, Ni-Mo low alloy steel was welded by submerged arc welding with different heat input using flux cored wires and fluxes of different basicity index. The effect of electrode/flux composition on chemical composition, oxygen-nitrogen analysis, mechanical properties and microstructural changes in the weld metal was investigated. Apart from the basicity of flux, the effect of heat input especially welding speed on weld metal chemistry and mechanical properties have also been studied here.

2. Materials and methods

The Indian navy has been using different grades of structural steel in various types of ships dependingon their country of origin [8]. The wide variety of steels used, many

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of which were imported caused problems due to large inventory, uncertain availability, and procurement of odd lots by the Indian navy. Therefore, Ni-Mo low alloy steel developed are high strength high toughness steels, meeting the stringent naval requirements [3]. To ensure full potential utilization of these steels, the weld consumables used, also require high sub-zero impact toughness in combination with high strength [9].

2.1 *Base material*

Ni-Mo low alloy steels are low carbon HSLA steels with very good low-temperature toughness. Table 1 lists the chemical composition and mechanical properties of Ni-Mo low alloy steel.

2.2 *Classification of fluxes*

The basicity index is a ratio of a basic and acid compound, shows the ability of oxygen transfer to the base metal during the welding. Acid fluxes have a basicity index of 0.5 to 0.9; neutral fluxes 0.9 to 1.1; basic fluxes 1.1 to 2.5 and highly basic fluxes 2.5 to 4.0.

In this experimental work basic and highly basic agglomerated fluxes are used. Chemical compositions of both fluxes are given in table 2. B1 is slightly active flux in terms of Manganese (Mn) and Silicon (Si) while B2 is passive flux.

2.3 *Classification of flux cored wire*

Band steel shaping method was used to produce two different types of flux cored wire designated as FC1 and FC2 with an 18% filling ratio. In this process cold rolling coil steel sheared into the band steel with 14 mm width, roll such band steel into "U" shaped channel and then fill up with flux powder, roll to feed into closed loop as "O" type tube blank, rolled it in further and drawn it to become end product welding wire Φ1.6 mm as shown in figure 1.

For classification of flux cored wire, chemical analysis of weld test assembly is shown in figure 2. Weld test assemblies prepared by different flux cored wire and fluxes with 26 voltage, 250 amp arc current and 300 mm/min welding speed and the inter pass temperature was maintained between two weld passes is 150°C.

Each weld pad of 125 mm length cut from middle and cleaned at the uppermost layer and examined by spectroscope with the results are summarized in table 3.

2.4 *Bead on plate weld*

Bead on weld performed on the plates of 300 × 75 × 12 mm, using basic and highly basic flux with different

Table 1. Chemical composition and mechanical properties of Ni-Mo low alloy steel.

Chemical composition (weight %)											Mechanical properties			
C	Mn	Si	P	S	Cr	Ni	V	Cu	Mo	Al	Y.S. (Mpa)	U.T.S. (Mpa)	% EL	Impact Toughness at -40 °C
0.08 to 0.10	0.30 to 0.60	0.17 to 0.37	0.0015 Max	0.01 Max	0.30 to 0.70	1.80 to 2.20	0.03 Max	0.40 to 0.70	0.25 to 0.35	0.03 Max	588-686	≥650	≥18	≥78 J

Table 2. Chemical composition of fluxes (weight %).

Symbol	SiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaF_2	TiO_2	ZrO_2	Other	B.I.
B1	19.81	30.16	2.15	6.6	12.6	13.3	3.04	0.04	12.27	1.4
B2	8.12	28.75	1.29	5.54	11.02	43.79	0.58	0.09	0.83	2.8

$$B.I. = \frac{\%CaO + \%MgO + \%BaO + \%CaF_2 + \%Na_2O + \%K_2O + 0.5(\%MnO + \%FeO)}{\%SiO_2 + 0.5\,(Al_2O_3 + TiO_2 + ZrO_2)}$$

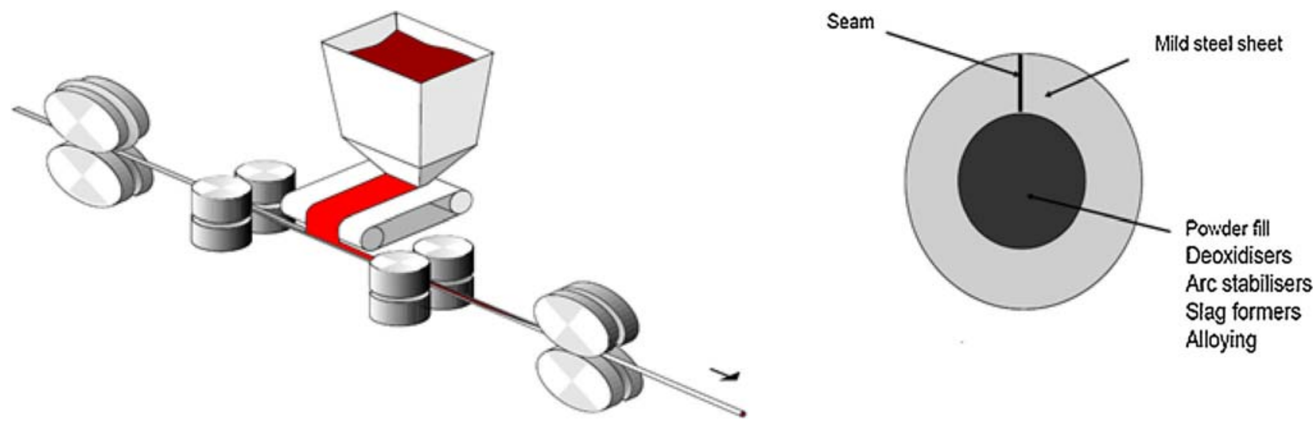

Figure 1. Schametic diagram of band steel shaping method for flux cored wire production.

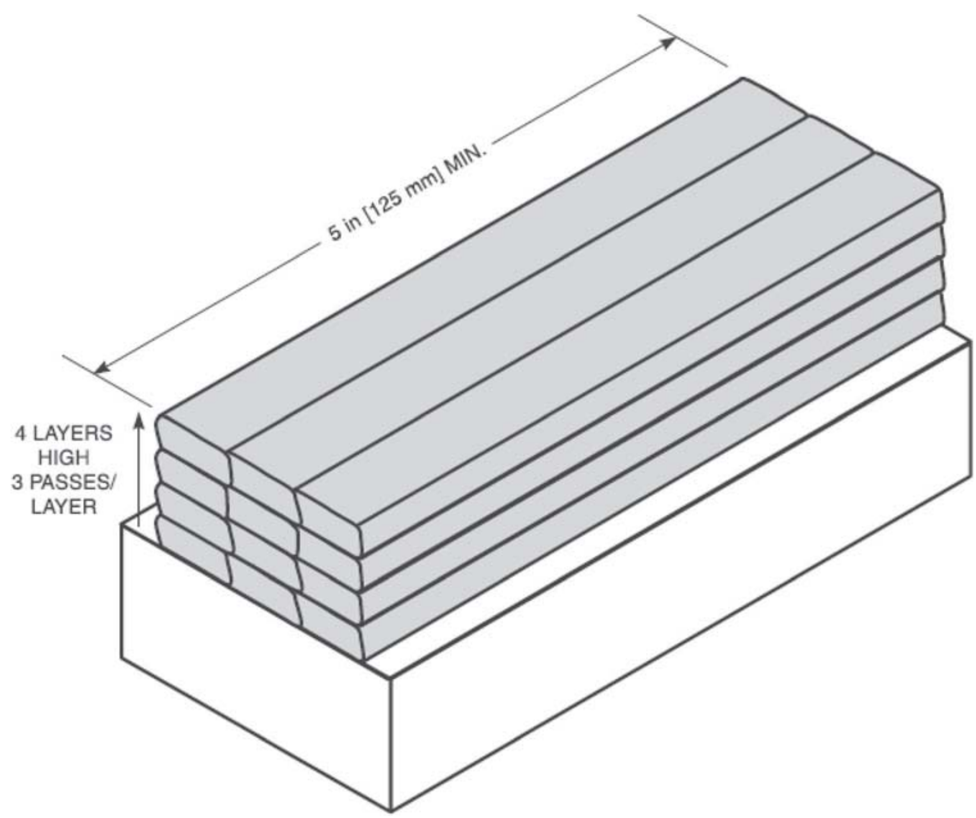

Figure 2. Weld pad for chemical analysis [10].

Table 3. Chemical composition of the flux cored wire and flux combination (wt %).

Sl. No.	Wire	Flux	C	Mn	Si	S	P	Cr	Ni	Mo	Al	Ti
1	FC1	B1	0.041	1.80	0.720	0.020	0.026	0.038	1.72	0.401	0.012	0.0055
2	FC1	B2	0.032	0.81	0.401	0.020	0.017	0.028	1.77	0.405	0.021	0.0027
3	FC2	B1	0.042	2.05	0.540	0.017	0.015	0.238	2.12	0.414	0.019	0.0047
4	FC2	B2	0.039	1.39	0.379	0.016	0.011	0.212	1.95	0.381	0.026	0.0044

Table 4. Welding parameters for bead on plate weld.

Bead on plate weld No.	Wire	Flux	Arc current (A)	Arc voltage (V)	Speed of welding (mm/min)	Heat input (KJ/mm)	Reinforcement (mm)	Bead width (mm)	Penetration (mm)	Deposition Rate (Kg/hr)
1	FC1	B1	280	26	800	0.546	2.31	8.1	2.12	4.673
2	FC1	B2	280	26	800	0.546	2.17	7.88	1.75	4.214
3	FC1	B1	400	34	800	1.02	3.1	10.42	4.2	7.652
4	FC1	B2	400	34	800	1.02	2.8	10.48	4.04	6.783
5	Solid	B1	280	26	800	0.546	1.93	8.19	2.04	3.745
6	Solid	B2	280	26	800	0.546	1.82	8.38	1.97	3.293
7	Solid	B1	400	34	800	1.02	2.6	11.09	4.32	6.298
8	Solid	B2	400	34	800	1.02	2.4	10.65	3.99	5.617

welding parameters by FC1 wire and solid wire and measured amount of weld metal deposited in unit time. Also, after welding, weld bead cuts from the middle portion of the plates and specimen are prepared by standard metallography procedure for macro analysis. The specimens are etched with 2% nital and analysis of the weld morphology in terms of f bead width, depth of penetration and reinforcement and the results are shown in table 4.

2.5 *Welding of all weld joint assembly*

The six all weld assembly were made with Φ 1.6 mm flux cored wires and different basicity of fluxes at various welding speeds using constant voltage direct current power source. Flux is heated in an oven at 300°C for 2 hours before use to remove moisture content from it. Experiments performed with DCEP polarity and interpass temperature were kept to a minimum of 150 °C. A combination of welding variables used for all weld test assembly is as given in table 5.

Mechanical testing is carried out to ensure the required levels of values have been achieved. The location of samples extracted for different tensile and impact testing from a test coupon is as shown in figure 3. Also, weld metal oxygen and nitrogen were analyzed using the inert gas fusion method on LECO machine. The chemical analysis for oxygen and nitrogen was an average of three. To check the level of hardness, Vickers hardness testing was carried out across the weld and fusion zone with 30 Kg of fixed load using a square base pyramid diamond. Results of all weld test assembly are shown in table 6.

3. Results and discussion

3.1 *Effect of flux cored wire on deposition rate*

To measure the deposition rate, bead on plate welding was done with flux cored and solid wire at various heat input with the use of different basicity index fluxes by the SAW process are shown in table 4. The deposition rate was increased to 20-30% more during welding with FC1 wire using the same basicity of flux at constant welding parameters as shown in figure 4. In addition to this, it also shows that higher the heat input, the deposition rate of filler material increases by considering the effect of the current.

The current density of flux cored wire is higher than solid wire results in higher melting of filler material and thereby a higher deposition rate compared to the solid wire at the same amperage.

3.2 *Effect of Flux basicity on deposition rate*

Lower basicity flux B1 gives 10 to 15 % more deposition rate than higher basicity of flux B2 during both flux cored and solid wire at the same welding parameters which are shown in figure 5. This is because flux B1 is slightly active flux in terms of manganese and silicon, so manganese and

Table 5. Combination of welding variables for all weld test assembly.

Experiment No.	Sample designation	Decoding of Sample designation				
		Wire (1st digit)	Welding parameters (2nd digit)			Flux (3rd & 4th digit)
			Current (A)	Voltage (V)	Speed (mm/min)	
1	11B1	FC1	280	29	700	B1
2	12B1	FC1	280	29	300	B1
3	11B2	FC1	280	29	700	B2
4	21B1	FC2	280	29	700	B1
5	22B1	FC2	280	29	300	B1
6	21B2	FC2	280	29	700	B2

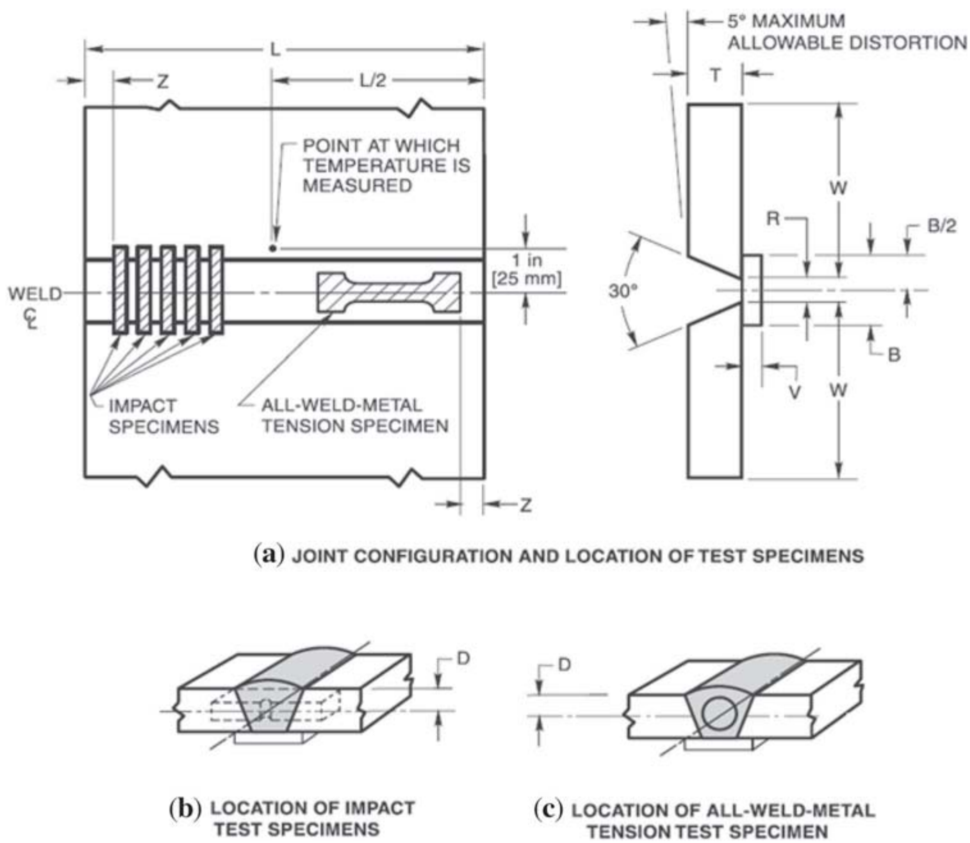

Figure 3. Location of samples extracted for different testing [1].

silicon are added form the flux during welding so it gives more deposition rate[11].

3.3 *Effect of basicity index on bead profile*

Weld bead profile is not only influenced by welding parameters but it is also influenced by basicity index of flux as shown in table 4. For a constant welding parameter, penetration is more with lower basicity of flux B1 due to high viscosity and arc concentration which enhanced penetration. Higher penetration achieved with increasing viscosity, surface tension, and stability of arc [12, 13]. Also, as flux basicity index increased the reinforcement of weld decreased. The effect of flux basicity on bead width is not much significant.

3.4 *Weld metal chemical analysis*

The results of chemical analysis of all weld assembly show that as flux basicity increases 11B1 to 11B2 or 21B1 to

Table 6. Chemical composition and mechanical properties of all weld test assembly.

	Chemical Composition											Mechanical Properties				
Sample	C wt%	Mn wt%	Si wt%	S wt%	P wt%	Cr wt%	Ni wt%	Mo wt%	Cu wt%	O ppm	N ppm	Y.S. Mpa	UTS Mpa	% EL	IT J	Hv VHN
11B1	0.060	1.51	0.53	0.022	0.018	0.038	1.78	0.382	0.06	835	56	687	729	22.9	41	235
12B1	0.042	1.51	0.51	0.021	0.021	0.046	1.7	0.386	0.064	930	67	601	686	22.1	39	221
11B2	0.033	0.98	0.39	0.023	0.016	0.031	1.91	0.439	0.051	670	54	563	625	22.7	47	190
21B1	0.054	1.93	0.53	0.015	0.012	0.23	2.12	0.395	0.263	773	69	776	803	18.2	46	287
22B1	0.041	1.91	0.52	0.015	0.014	0.223	2.13	0.388	0.273	868	63	647	748	20.1	40	265
21B2	0.035	1.41	0.38	0.015	0.010	0.222	2.15	0.399	0.261	628	57	671	716	19.2	51	233

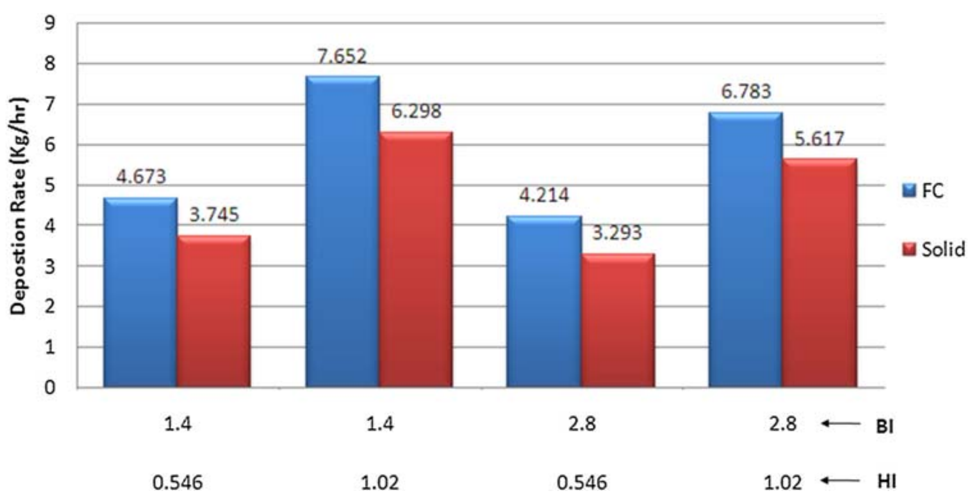

Figure 4. Comparison of flux cored wire and solid wire in terms of deposition rate.

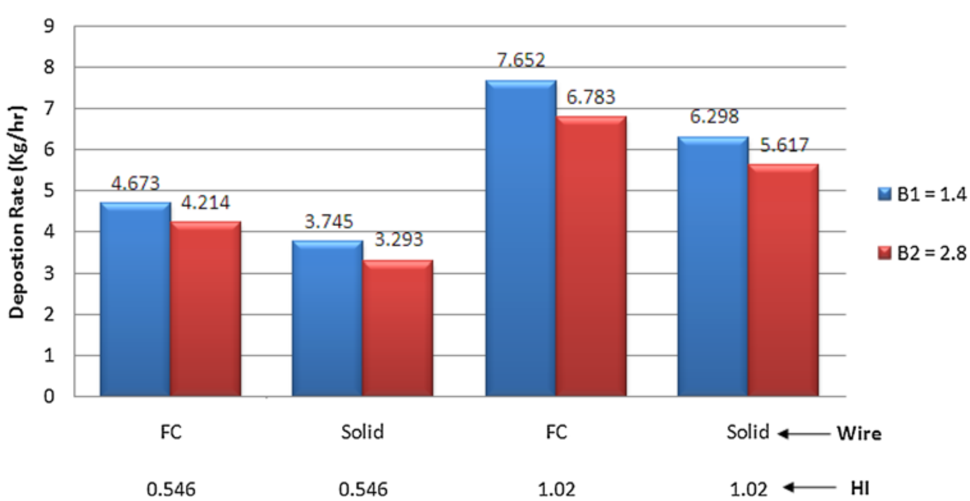

Figure 5. Comparison of Basicity of fluxes in terms of deposition rate.

21B2 (BI = 1.4 to BI = 2.4), the reduction in the percentage of C, Mn and Si in weld-metal is seen as shown in figure 6. With an increase in the basicity of flux, the weld-metal carbon, and manganese decrease, also oxygen content in the weld metal decreased and higher manganese activity in slag. Silicon transfer is influenced by the amount of Al_2O_3, TiO_2,

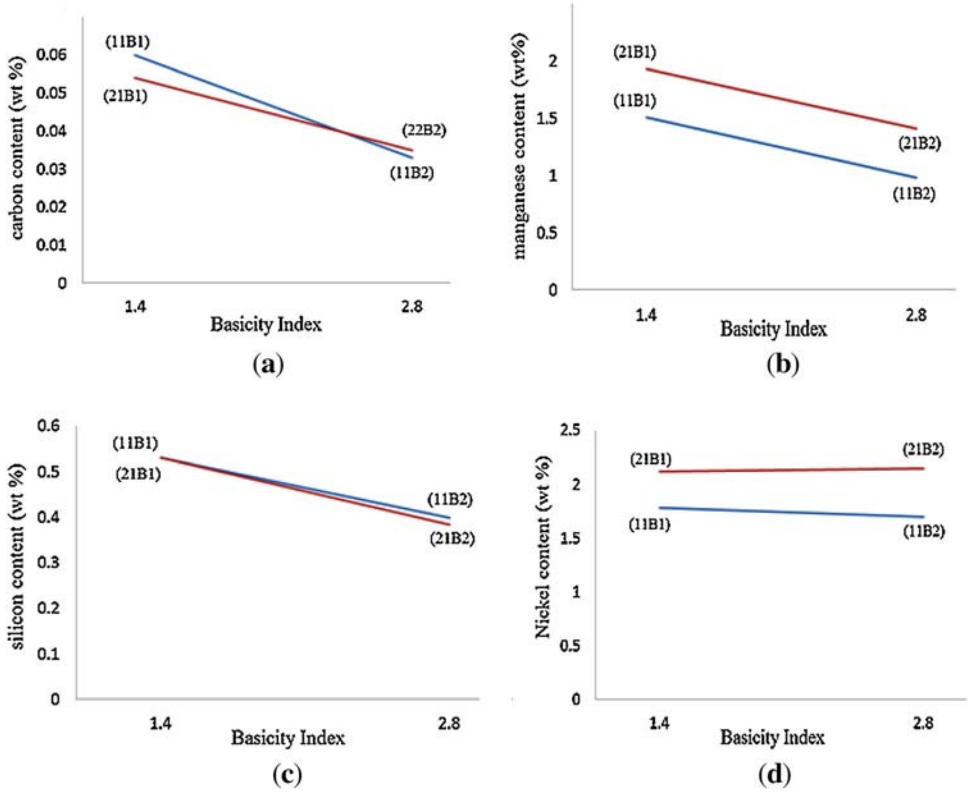

Figure 6. Effect of basicity index on chemical composition of weld metal. (a) carbon, (b) manganese, (c) silicon and (d) nickel.

and ZrO_2 in the flux [14]. Silicon content in weld metal composition is increased due to the higher amount of oxide.

With an increase in welding speed 12B1 to 11B1 or 22B1 to 21B1 (300 mm/min to 700 mm/min), carbon increases as shown in figure 7. As the welding speed increases, carbon loss due to oxidation reduced due to less time to react for carbon with oxygen [15]. Also, sulfur and phosphorous loss by oxidation are negligible because of the least attraction of these elements towards oxygen.

The Oxygen and nitrogen analysis results show, the changes in the weld nitrogen content ranged from54 to 67 ppm or 57 to 69 ppm. It shows that the variation of the welding speed and basicity index did not affect the nitrogen content. However, the weld metal oxygen was affected by the basicity index and welding speed. Increase in flux basicity index from 1.4 to 2.8 oxygen content in weld metal decreases from 835 ppm to 670 ppm (11B1 to 11B2) and 773 ppm to 628 ppm (21B1 to 21B2). At lower basicity of flux arc becomes acid and then oxygen content in weld metal increases as shown in figure 8(a).

The speed of welding increases from 300 mm/min to 700 mm/min and oxygen content in weld metal decreases from 930 ppm to 835 ppm(12B1 to 11B21) and 868 ppm to 773 ppm (22B1 to 21B1). As welding speeds increase, decreased heat input resulted in smaller weld bead and higher cooling rates with lower oxygen content shown in figure 8(b).

3.5 *Mechanical properties*

Table 6 lists all weld tensile test samples and physical properties and the results are discussed below.

3.5a *Tensile testing*: Flux basicity increases from 1.4 to 2.8 (11B1 to 11B2 or 21B1 to 21B2), there is a considerable reduction in yield strength and ultimate tensile strength value. This is due to an increase in flux basicity, reduction in carbon, manganese and silicon percentage in weld metal.

Similar way as the welding speed decreases from 700 mm/min to 300 mm/min (11B1 to 12B1 or 21B1 to 22B1), there is a considerable reduction in yield strength and ultimate tensile strength value. This is due to lower welding speed, percentage of carbon increase in weld metal which increased yield strength and ultimate tensile strength value.

3.5b *Impact testing*: To find out the toughness value of the welded joint Charpy V notch impact test was carried out at -50°C. Five specimens were made from each all weld assembly as per American Welding Society Standard A5.23-90. Among them, five-toughness value, highest and lowest impact values were rejected and the remaining three specimens' average impact toughness values are shown in table 6.

The impact test results show that as the flux basicity increases from 1.4 to 2.8 (11B1 to 11B2 or 21B1 to 21B2), there is an increase in impact value at -50 °C. Here we saw

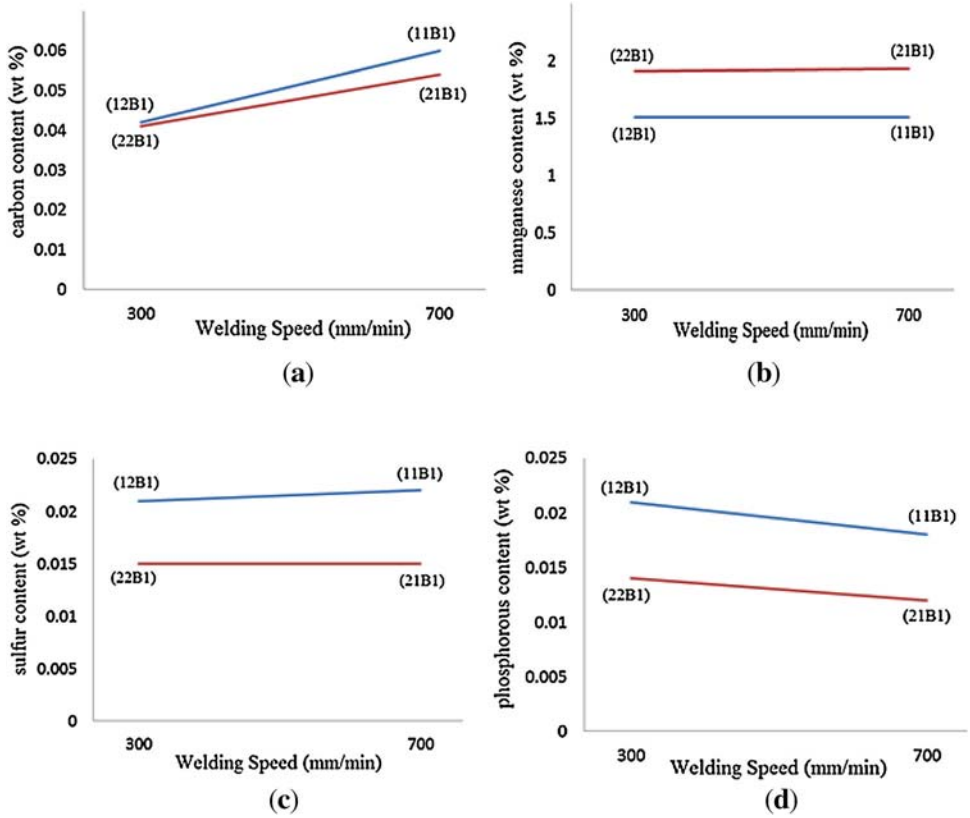

Figure 7. Effect of welding speed on the chemical composition of weld metal. (a) carbon, (b) manganese, (c) sulfur and (d) phosphorous.

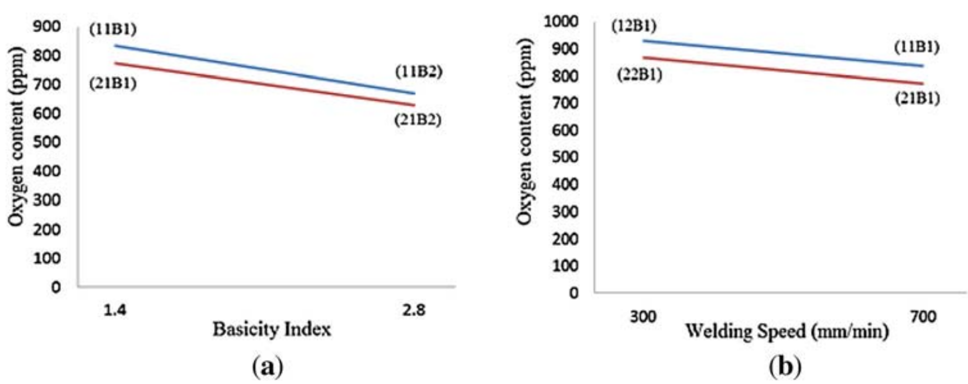

Figure 8. Effect on Oxygen content of weld metal by (a) basicity index and (b) welding speed.

increase in flux basicity, decrease in the oxygen content of the weld metal resulting in higher impact toughness value.

Similarly, as the welding speed increases from 300 mm/min to 700 mm/min (12B1 to 11B1 or 22B1 to 21B1), there is an increase in impact value at -50 °C, because increased in welding speeds resulted smaller weld bead and higher cooling rates and also decrease in weld metal oxygen content therefore increase in toughness value.

3.5c *Hardness testing*: As flux basicity increases from 1.4 to 2.8 (11B1 to 11B2 or 21B1 to 21B2) the results show reduction in hardness value of weld metal. Weldmetal carbon and manganese amount decreased with increasing the basicity of flux which reduced hardness value.

With an increase in welding speed 300 mm/min to 700 mm/min (12B1 to 11B1 or 22B1 to 21B1), there is an increase in hardness value of weld metal. Carbon content in

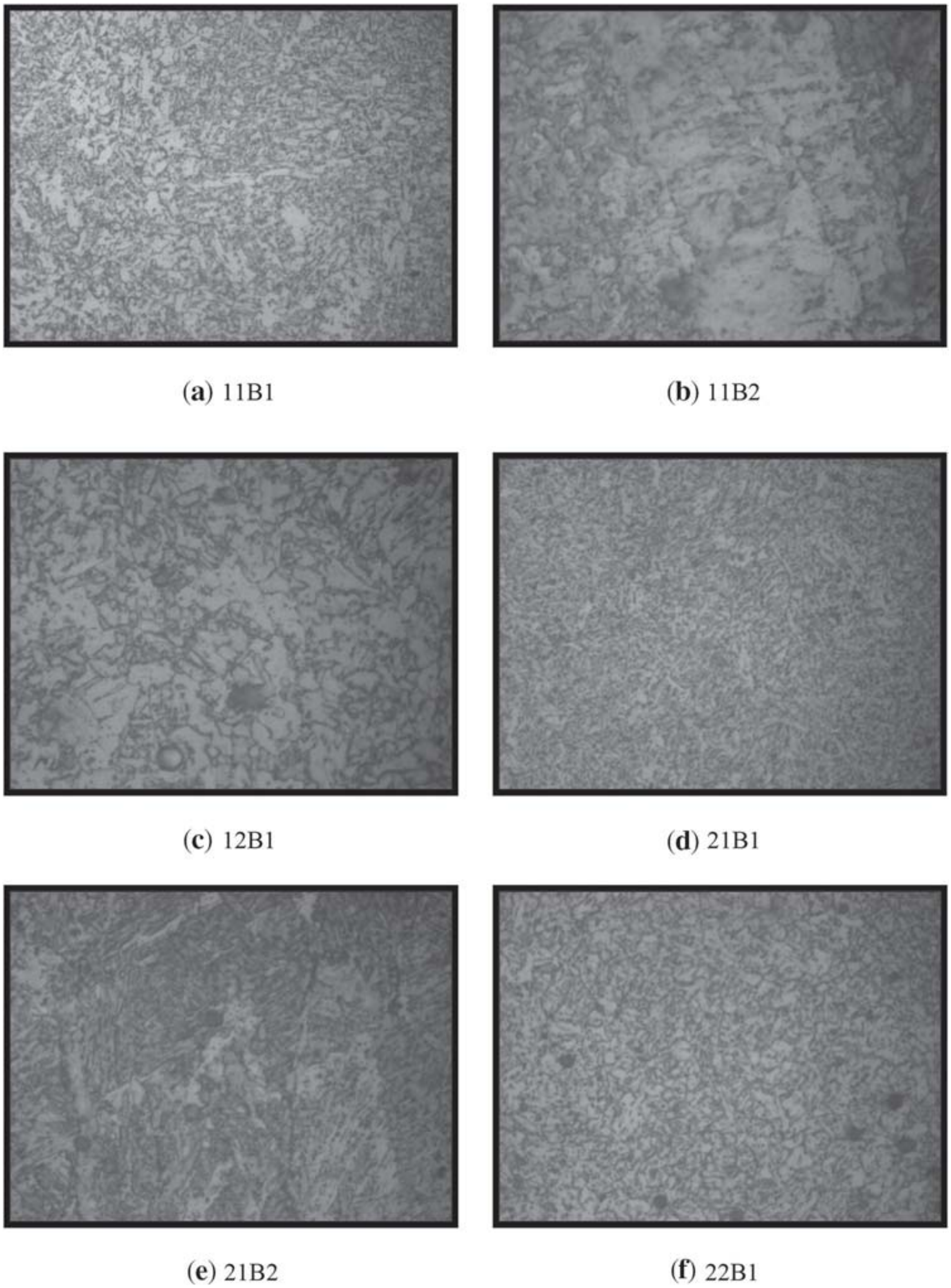

Figure 9. Microstructure of weld samples at 1000X.

weld metal increased during welding by higher weld speed which results in high hardness value [16].

3.6 *Microstructure examination*

Figure 9 shows typical optical micrographs of weld metals of all weld samples at 1000 X, respectively. The primary microstructures of as-deposited weld metal samples, consisting mainly of acicular ferrite (volume fraction is 0.8 to 0.9) with very little allotriomorphic and widmanstatten ferrite. Micrograph shows the different sizes of grains size produced using welding speeds of 300 and 700 mm/min. and welding speed increases from 300 mm/min and 700 mm/min (12B1 to 11B1 or 22B1 to 21B1), the weld microstructure becomes finer, so it increases toughness value [17].

4. Conclusions

From the present research work, the following conclusions are drawn.

(1) The deposition rate of flux cored increased up to 30 percent than solid wire of the same diameter during the same welding parameters.
(2) The deposition rate with lower basicity flux B1 exceeds that of higher basicity flux B2 up to 15% when welded with the same current and same wire.
(3) For the same welding parameters and wire, penetration is higher with a lower basicity of flux and reinforcement decrease with increasing the basicity of flux.
(4) As for flux basicity increases, reduction in the percentage of C, Mn, and Si in weld metal. With an increase in the basicity of flux, the weld metal C and Mn decrease, through the decreased amount of oxygen in the weld metal and higher Mn activity in slag. The silicon transfer is effected by the amount of Al_2O_3, TiO_2, and ZrO_2 in the flux.
(5) Welding speed influences weld metal carbon content through oxidation reaction. The increase in UTS value with increasing the welding speed due to an increase in carbon content.
(6) If the basicity of flux is less, the arc atmosphere becomes acid and then the amount of oxygen in the weld metal increases, resulting in low toughness.

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Nomenclature

Y.S.	yield strength
UTS	ultimate tensile strength
% EL	percentage elongation
IT	impact toughness value at -50^0 C
Hv	Vicker hardness number
B.I	basicity Index,
H.I.	heat input

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