Element Transfer Study of Developed Agglomerated Fluxes during Submerged Arc Welding

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ABSTRACT

The aim of this work is to study the chemistry of element transfer in respect to developed agglomerated flux constituents during submerged arc welding. Fluxes have been designed by altering different minor constituents e.g. MnO, CaF_2, NiO, MgO and Fe-Cr. The ratio of major constituents i.e. CaO, SiO_2 and Al_2O_3 has been kept as a constant. Through this study it could be inferred that the chemical analysis of the element transfer during submerged arc welding can be correlated with the mechanical properties.

Keywords: Submerged arc welding; Element transfer study; Agglomerated fluxes

1.0 INTRODUCTION AND LITERATURE REVIEW

The submerged arc welding (SAW) is a versatile process. Therefore, it is used for wide range of applications including the critical applications e.g. joining of pressure vessels, thick plates, ship hulls etc. The flux plays a central role in welding and acts as a blanket for arc, eliminates flash, spatter and smoke. It also controls arc stability; governs bead shape and influences weld chemistry [1]. Submerged arc welding fluxes usually consist of combination of manganese oxide and silica or lime and silica with additions of various other oxides to produce complex oxide fluxes. Lately, fluxes having titania, magnesia, alumina, and fluorspar as the major constituents have also been produced. Lewis et al. [2] developed a new flux and filler wire for submerged arc welding HY-steel used in submarine hulls. The developed flux raises weld metal impact properties by reducing oxygen and inclusions, and changes in weld metal microstructure. Pokhodnya and Kostenko [3] studied the fusion of electrode metal and its interaction with the slag during submerged arc welding. Bennet & Stanley [4] used $CaO-SiO_2-CaF_2$, $CaO-SiO_2-Al_2O_3$, $CaO-SiO_2-TiO_2$ and miscellaneous commercial fluxes for the submerged arc welding of Q.T 35 steel. The study revealed that the flux composition affects the mechanical properties like impact strength and tensile strength very well in the presence of alloying elements or their oxides. Butler and Jackson [5] achieved good welding performance with the composition of 25% calcium oxide, 30% TiO_2 , 40% SiO_2 and 5% CaF_2 when used with a filler metal containing 1% manganese. Bennet [6] investigated the two aspects: moisture content and rough appearance of weld surface by using basic fluxes. P. Colvin [7] in his study stated that the use of basic fluxes in preference to acid fluxes which improved metallurgical quality without detracting from the physical and economic characteristics of the process. Palm [8] investigated that the dissolved oxygen is the deciding factor in determining impact properties of weld metal. Sorokin and Sidlin [9] examined the effect of transfer of alloying elements from the electrode into the deposited weld metal. Wittstock [10] gave some guidelines for the selection of electrode, flux and materials used for welding. Eagar [11] identified the source of weld metal oxygen contamination during submerged arc welding. North at al. [12] examined the influence of flux formulation on the oxygen content of submerged arc weld deposit. Koukabi [13] developed fused fluxes by using oxides and alloying elements. The effects of these constituents were studied with reference to good mechanical properties, cleanliness and microstructure in submerged arc weld deposits. Chai and Eagar [14] studied two commercial fluxes namely calcium silicate and manganese silicate during submerged arc welding for parametric study of manganese silicon, carbon and oxygen for their recovery. Davis and Bailey [15] described how submerged arc flux composition influences element transferred and analyzed in the light of what has been learned of slag/ metal reactions. Chai and Eagar [16] studied the stability of metal oxides with reference to oxygen level in the weld metal by producing binary CaF_2 -metal oxide fluxes. Snyder and Pense [17] observed that the effects of titanium on the mechanical properties and microstructure of submerged arc weld metal in HSLA Si-Al-killed low sulfur steels. Terashima and Tsuboi [18] described the development of submerged arc welding consumables for steel plate of tensile strength above 785 N/mm^2. Kohno et al. [19] developed new fluxes which can consistently micro alloy weld metal with Ti and B. The developed fluxes improved weld metal toughness for HSLA steels. Potapov [20] observed the results by calculating the reactions between slag and metal in automatic submerged arc welding. Indacochea and Olson [21] established the relationship of weld-metal microstructure and penetration to weld-metal oxygen content. Mitra and Eager [22] studied the transfer of Cr, Si, Mn, P, S, C, Ni and Mo between the slag and the weld pool for submerged arc weld for low alloy and stainless steels with calcium silicate and manganese silicate fluxes. Lau et al. [23] studied the sources of oxygen and nitrogen contamination during submerged arc welding of different CaO-Al_2O_3 based fluxes of varying basicity index (B.I.). Lau et al. [24] studied gas/ metal/ slag reaction in submerged arc welding using CaO-Al_2O_3 based fluxes. Burck et al. [25] observed the effect of welding flux additions on 4340 steel weld metal composition. Mitra and Eagar [26-28] studied a critical review of thermodynamic theories of slag-metal reactions. In part II, an entirely new theory was presented to explain the changes in weld chemistry, and a kinetic model was formulated to predict weld metal composition. The part III, verified the theory through several different experiments. Gupta and Arora [29] examined the weld bead geometry and heat affected zone which are generally dependent on the welding parameters and may also be influenced by the chemical composition of flux. Pandey et al. [30] observed the effect of submerged arc welding parameters and fluxes on element transfer behavior and weld metal chemistry. Paniagua et al. [31] studied on chemical and structural characterization of fluxes for submerged arc welding. Paniagua [32] observed the effect of flux composition for the microstructure and tensile property of SAW in AISI 1025 steel. Kanjilal et al. [33] developed model by rotatable design technique to study the combined effects of flux and welding parameters on chemical composition and mechanical properties of submerged arc weld metal. Kanjilal et al. [34] studied the prediction of element transfer across the molten pool in submerged arc welding by developing quadratic models in terms of flux ingredients with the application of statistical experiments for mixture design. Bang et al. [35] studied the effects of wire/flux combination on the chemical composition, tensile strength, and impact toughness of the weld metal.

The element transfer study which is an important study to see the element transfer behaviour of developed agglomerated fluxes into the weld metal during submerged arc welding process was proposed to be studied in the present work.

2.0 EXPERIMENTAL WORK

The flux based systems CaO-Al_2O_3 –SiO_2 have been selected for study as these are the most widely used fluxes at the commercial level. The ranges of these constituents are designed on the basis of binary and ternary phase diagrams for different oxide and fluoride systems. The details of basic constituents, alloying constituents and their ranges are listed in **Table 1**. After ascertaining their ranges, fluxes are prepared by agglomeration method. Experiments are planned on the basis of response surface methodology (RSM) technique. The Design- Expert trial version 8.0.6 software is used for central composite second order rotatable design with five variables as flux constituents; MnO, CaF_2, NiO, MgO and Fe-Cr are added for the development of agglomerated fluxes during submerged arc welding. The 2^5 factorial points (16 at half replication), plus 10 star points and plus 6 centre points give total 32 combinations of fluxes [36] given in **Table 2**. The physical properties—bulk density, grain size, and flowability of these developed fluxes are measured with the different setups. The

Table 1 : Flux constituents and their ranges

Basic constituents & alloying constituents	CaO	SiO_2	Al_2O_2	MnO	CaF_2	MgO	NiO	Fe-Cr
Amount (wt %)	20	35	10	5-10	10-20	5-15	0-10	0-10

Table 2 : The design Matrix of agglomerated fluxes constituents

Flux Code	Run	MnO (wt%)	CaF_2 (wt%)	MgO (wt%)	NiO (wt%)	Fe-Cr (wt%)
AGF1101	19	6.25	12.5	7.5	2.5	7.5
AGF1102	6	8.75	12.5	7.5	2.5	2.5
AGF1103	9	6.25	17.5	7.5	2.5	2.5
AGF1104	11	8.75	17.5	7.5	2.5	7.5
AGF1105	18	6.25	12.5	12.5	2.5	2.5
AGF1106	28	8.75	12.5	12.5	2.5	7.5
AGF1107	32	6.25	17.5	12.5	2.5	7.5
AGF1108	15	8.75	17.5	12.5	2.5	2.5
AGF1109	17	6.25	12.5	7.5	7.5	2.5
AGF1110	1	8.75	12.5	7.5	7.5	7.5
AGF1111	3	6.25	17.5	7.5	7.5	7.5
AGF1112	7	8.75	17.5	7.5	7.5	2.5
AGF1113	27	6.25	12.5	12.5	7.5	7.5
AGF1114	23	8.75	12.5	12.5	7.5	2.5
AGF1115	24	6.25	17.5	12.5	7.5	2.5
AGF1116	4	8.75	17.5	12.5	7.5	7.5
AGF1117	10	5	15	10	5	5
AGF1118	30	10	15	10	5	5
AGF1119	14	7.5	10	10	5	5
AGF1120	12	7.5	20	10	5	5
AGF1121	2	7.5	15	5	5	5
AGF1122	21	7.5	15	15	5	5
AGF1123	25	7.5	15	10	0	5
AGF1124	20	7.5	15	10	10	5
AGF1125	8	7.5	15	10	5	0
AGF1126	5	7.5	15	10	5	10
AGF1127	29	7.5	15	10	5	5
AGF1128	22	7.5	15	10	5	5
AGF1129	13	7.5	15	10	5	5
AGF1130	31	7.5	15	10	5	5
AGF1131	26	7.5	15	10	5	5
AGF1132	16	7.5	15	10	5	5

Table 3 : Physical Properties of developed agglomerated fluxes

S.No.	Physical properties	Observations
1.	Bulk density	The bulk densities of developed agglomerated fluxes range between 0.64 to 0.9 g/cc. In this section the bulk densities and weld bead penetration are correlated with the flux consumption.
2.	Grain size	The grain size of these fluxes ranges from 0.355 to 1.18 mm in size, which is a very good range for achieving good quality of welded surface.
3.	Flowability	Flow properties of one developed agglomerated flux is excellent, three haves satisfactory and rest twenty eight have good flow properties.

ranges of results of these properties are given in **Table 3**. These physical properties ascertained to the uniform weld bead, better arc initiation and good penetration by using these developed agglomerated fluxes.

To study the element transfer behaviour of these developed fluxes a pad of five weld beads, one above the others are laid on low carbon steel plates of 150X100X20 mm size by using developed agglomerated fluxes. All the weld beads are laid by submerged arc welding machine installed in NSIT, Delhi shown in **Fig.1** with a flux depth, and electrode stick-out is 25 mm. Welding conditions are set approximately 500 A and 36V DC electrode positive at 280 mm/min travel speed, with a wire diameter of 3.15 mm, giving a heat input of about 3.87 kJ/mm. The weld beads are shown in **Fig.2**. The chemical composition of submerged arc welding electrode and base plate are given in **Table 4.**

To measure the actual concentration of various elements in weld metal, the weld bead is drilled at four different locations 1, 2, 3 and 4 mentioned in **Fig. 3**, at the depth of 1mm to minimize the effect of dilution. The drilled chips are mixed thoroughly, and are used as samples for chemical analysis. The sample of 1 gm is dissolved into 100 ml of conc. HC1. 10 ml of this solution is diluted to 100 ml by adding double distilled water in it. This solution is tested by the atomic absorption spectrophotometer against the standard solutions and calculates the wt % of C, Si, Mn, P, S, Cr and Ni elements present in the weld metal. The same procedure is used for thirty two weld beads. The percentage of elements present in each sample by using each and every developed agglomerated flux during submerged arc welding process is given in **Table 5**.

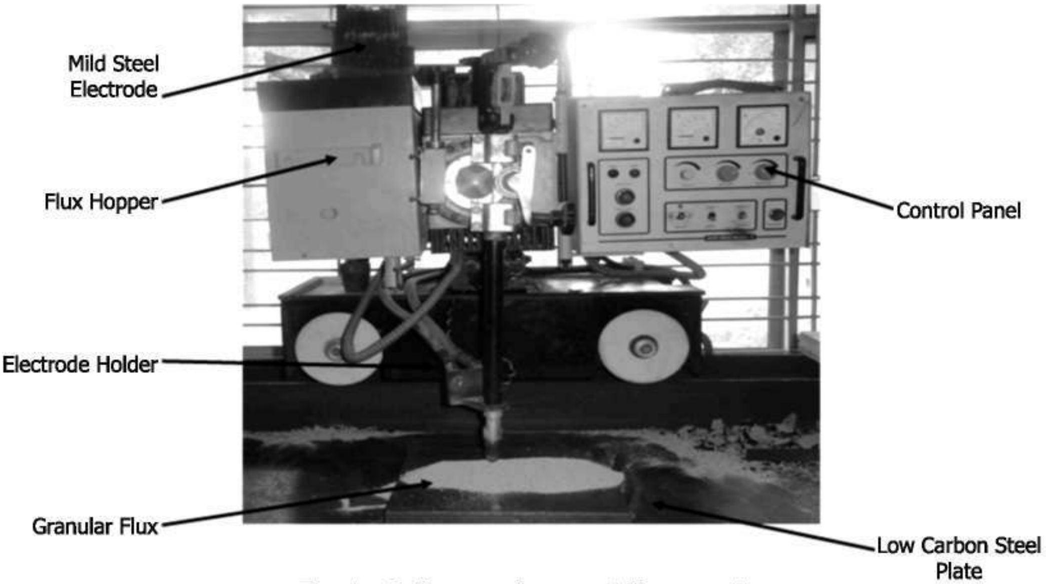

Fig. 1 : Submerged arc welding machine

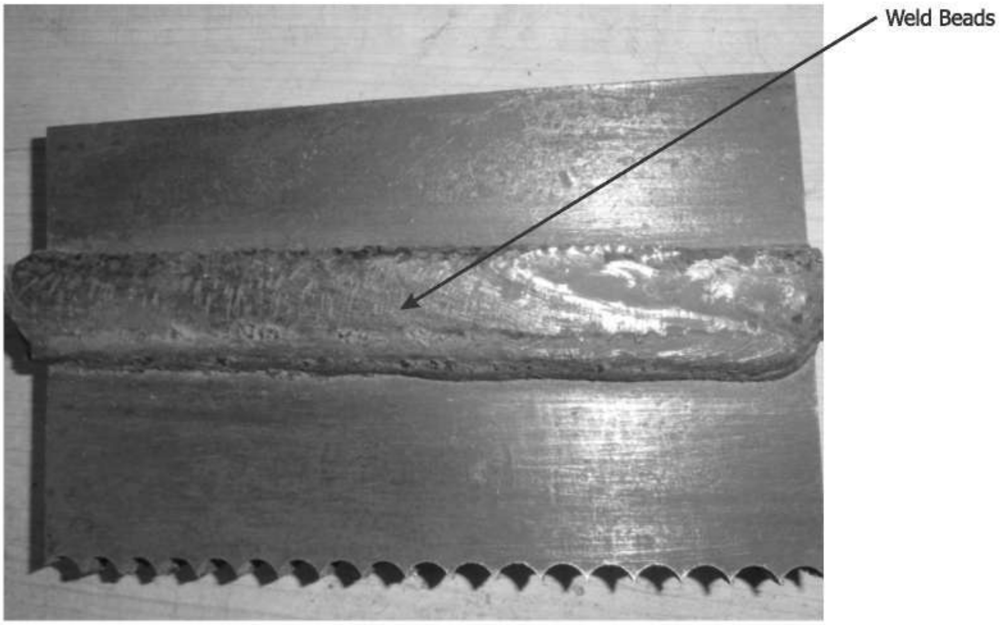

Fig. 2 : Weld beads on low carbon steel plate

Table 4 : Chemical composition of welding electrode and base plate

Composition of electrode and base plate	C (wt%)	Mn (wt%)	Si (wt%)	Ni (wt%)	Cr (wt%)
Electrode (Auto Rod 12.08L 3.15mm) EL-8 (ESAB)	0.08	0.5	0.05	-	-
Low carbon steel plate	0.13	0.5	0.2	0.01	0.02

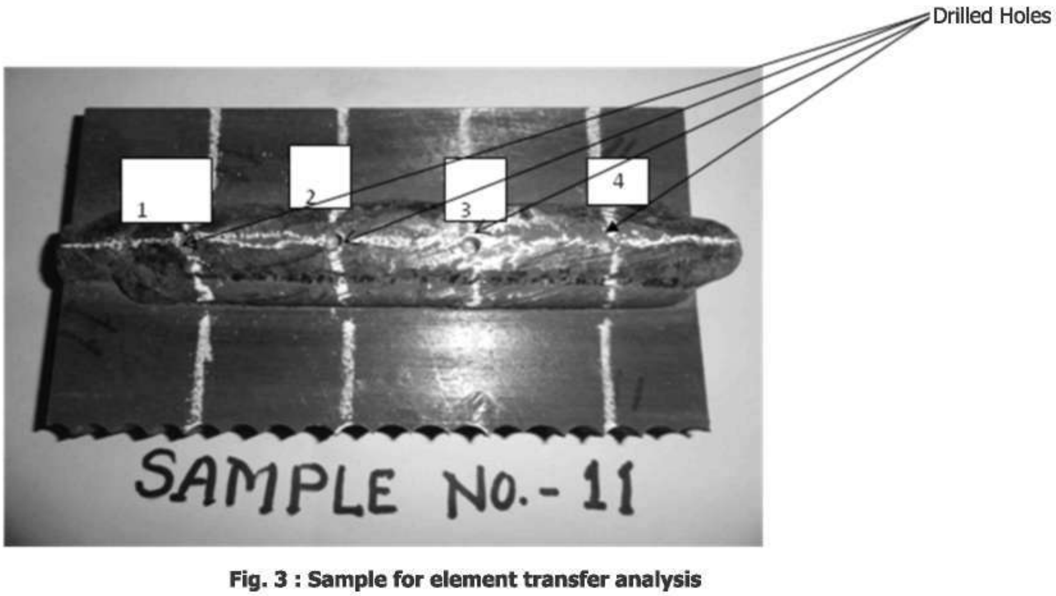

Fig. 3 : Sample for element transfer analysis

Table 5 : Element (wt%) in weld metal

S.No.	Flux Code	C (%)	Si (%)	Mn (%)	P (%)	S (%)	Cr (%)	Ni (%)	$C_{equivalent}$
1	AGF1101	0.10	0.33	0.87	0.026	0.00886	0.57	0.36	0.3818
2	AGF1102	0.11	0.33	0.78	0.022	0.01108	0.65	0.54	0.3973
3	AGF1103	0.07	0.33	0.37	0.028	0.01079	0.71	0.28	0.2944
4	AGF1104	0.07	0.33	0.64	0.024	0.02145	0.74	0.60	0.3534
5	AGF1105	0.08	0.23	0.31	0.026	0.01564	0.79	0.42	0.3098
6	AGF1106	0.10	0.23	0.54	0.026	0.01516	0.85	0.39	0.3793
7	AGF1107	0.09	0.23	0.54	0.026	0.01267	0.89	0.41	0.3778
8	AGF1108	0.07	0.23	0.35	0.032	0.00810	0.95	0.36	0.3369
9	AGF1109	0.08	0.15	0.30	0.022	0.01395	0.58	0.84	0.2733
10	AGF1110	0.11	0.18	0.69	0.024	0.00725	0.63	0.79	0.3783
11	AGF1111	0.10	0.18	0.51	0.024	0.02643	0.71	0.65	0.3508
12	AGF1112	0.11	0.15	0.31	0.026	0.01790	0.74	0.83	0.3367
13	AGF1113	0.11	0.15	0.57	0.027	0.01113	0.79	0.95	0.3930
14	AGF1114	0.11	0.15	0.36	0.026	0.00970	0.83	0.88	0.3643
15	AGF1115	0.11	0.15	0.34	0.026	0.02387	0.89	0.78	0.3704
16	AGF1116	0.10	0.15	0.57	0.030	0.00806	0.95	0.90	0.4138
17	AGF1117	0.11	0.15	0.43	0.024	0.01628	0.65	0.59	0.3327
18	AGF1118	0.11	0.15	0.47	0.027	0.01204	0.7	0.61	0.3498
19	AGF1119	0.12	0.10	0.46	0.022	0.01252	0.74	0.46	0.3603
20	AGF1120	0.10	0.11	0.47	0.022	0.02494	0.79	0.47	0.3527
21	AGF1121	0.08	0.14	0.52	0.023	0.02624	0.83	0.52	0.3515
22	AGF1122	0.07	0.19	0.41	0.022	0.02120	0.84	0.41	0.3245
23	AGF1123	0.10	0.23	0.44	0.023	0.01542	0.95	0.44	0.3839
24	AGF1124	0.07	0.19	0.52	0.032	0.01062	0.71	0.52	0.3196
25	AGF1125	0.07	0.14	0.31	0.029	0.01434	0.74	0.31	0.2833
26	AGF1126	0.10	0.28	0.73	0.024	0.02938	0.79	0.73	0.4096
27	AGF1127	0.08	0.14	0.57	0.023	0.02281	0.83	0.67	0.3636
28	AGF1128	0.07	0.14	0.56	0.020	0.02281	0.82	0.65	0.3494
29	AGF1129	0.08	0.12	0.57	0.023	0.02270	0.93	0.63	0.3818
30	AGF1130	0.07	0.13	0.55	0.022	0.02280	0.83	0.62	0.3486
31	AGF1131	0.08	0.12	0.54	0.023	0.02275	0.81	0.67	0.3538
32	AGF1132	0.08	0.13	0.53	0.023	0.02387	0.87	0.61	0.3630

3.0 RESULTS AND DISCUSSION

(i) Carbon (C) transfer

The carbon content of all weld-beads ranges from 0.07 to 0.12%. The carbon pick-up has occurred from $CaCO_3$, which yields CO_2 on dissociation. The CO_2 being unstable at high temperature dissociates into CO and O. Oxygen reacts with the element having high affinity for it, whereas CO, which was present in the vicinity of the weld bead at relatively high temperature, dissociates into CO and CO_2. This C is picked up by weld metal because of diffusion. The variations in mechanical properties of weld metal during submerged arc welding using developed agglomerated fluxes follow usual trends with the percentage of carbon pick up.

(ii) Manganese (Mn) transfer

In this study, Mn content of all weld-beads ranges from 0.30 to 0.87%. The Mn contents in the weld metal are always helpful additive in iron alloys. The presence of Mn works as desulphurization agent because of its greater affinity with the sulphur than iron.

(iii) Silicon (Si) transfer

In this study, Si content of all weld-beads ranges from 0.10 to 0.33%. This study shows that the Si content present in weld metal is always lower than that of the value of original flux. This is due to the transfer of Si from weld metal into slag. It is evident that Si is more prone to the oxidation losses than Cr and Ni.

(iv) Chromium (Cr) transfer

In this study, Cr content of all weld-beads ranges from 0.57 to 0.95%. The presence of Cr always strengthens weld metal and reduces the corrosion activity because it has been subjected to the oxidation losses, and it is less prone to oxidation than Mn and Si.

(v) Nickel (Ni) transfer

In this study, Ni content of all weld-beads ranges from 0.28 to 1.48%. The presence of Ni in weld metal shows good hardness because it often improves fracture toughness.

(vi) Sulphur (S) transfer

In this study S content of all weld-beads ranges from 0.00725 to 0.02938%. The content of sulphur S in steels is the big source of hot cracking, and to minimize the effect of Mn is added. Mn has more affinity than S, so, 1 to 2% Mn is added in steel to nullify the effect of S, so the chance of hot cracking is reduced.

(vii) Phosphorus (P) transfer

In this study, P content of all weld-beads ranges from 0.02 to 0.032%. The presence of P gives strength and also improves corrosion strength in weld metal.

3.1. Effect of element transfer on mechanical properties

Table 5 shows the wt% of different elements present in the welded joint by using developed agglomerated flux (AGF 1101-AGF 1132). The carbon equivalent to every welded joint is evaluated by the following equation.

$$C_{equivalent} = C + Mn/6 + Si/24 + Ni/40 + Cr/5 \qquad .... (1)$$

The calculated carbon equivalent to each welded joint ranges 0.273 to 0.413, which can be correlated with the mechanical properties viz. tensile strength and toughness of welded joint [32].

C, Mn, Si, Ni, and Cr, are the metallic contents, expressed as a

Table 6 : Mechanical properties of weld metal using developed agglomerated fluxes and base metal

Weld Joints using developed agglomerated fluxes	$C_{equivalent}$ range (wt %)		Tensile strength range (MPa)		Yield strength range (MPa)		Impact strength range at room temperature (Joule)		Elongation range at 17.9 mm gauge length (%)	
	Lowest	Highest	Lowest	Highest	Lowest	Highest	Lowest	Highest	Lowest	Highest
	0.273	0.414	520	580	254	290	60	99	26.5	29.5
Base metal (Low carbon steel)	0.2272		561				28		25.8	

percentage. It was reported [37] that an equivalent carbon higher than 0.45 had a high susceptibility to cold cracking after welding and more chance to form martensite which is very hard and brittle. The carbon equivalent to all the welded joints by using developed agglomerated fluxes are lower than the value of high susceptibility of cold cracking which indicates that these developed agglomerated fluxes are less prone to cold cracking at the welded joints. The details of mechanical properties of weld joints using developed agglomerated fluxes and base metal is given in **Table 6.** The range shows mechanical properties of the weld metal using new developed agglomerated fluxes which is superior to the base metal, so, these fluxes may be commercially used in the future.

4.0 CONCLUSIONS

a) The physical properties of developed agglomerated fluxes as good as commercial fluxes.

b) The carbon equivalents to all weld metals by using developed agglomerated fluxes during submerged arc welding process are with the range of high cold cracking susceptibility which prevents the formation of martensite.

c) The range percentage of elements in the weld metal by using developed agglomerated fluxes during submerged arc welding process is under the limit of percentage elements value prescribed by American welding society (AWS).

d) Mechanical properties of the weld metal using newly developed agglomerated fluxes are superior to the base metal.

e) The results of elements transfer study shows that these developed fluxes are as good as the commercial fluxes.

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