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The Effects of Flux Type on Mechanical Properties of High Strength Steel (HSS) by Submerged Arc Welding

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Abstract

In this study the sample with the standard of ASTM (514E) which used especially in critical applications in defense, rolled plates with 18mm thickness were submerged arc welded by two different types of agglomerated fluxes, the first welding flux was selected as EN ISO 14174: S A AR1 with basicity index of (0.3)(A81-319) AR1and the second was selected as SA AB1 with basicity index of (1.6)(A81-319)ABCr2 by both using the same welding wire according to SFA/AWS A5.23:EB2R, EN ISO 24598-AS CrMo1 standard 4mm in diameter. The welding parameters selected for this study are as follows, 470A, 35V, and welding speed 45mm/s. the welding parameters were kept constant for different conditions. The sample joined by type (A81-319) AR1 of flux, the micrograph of the fusion zone was fully martensitic structure and there was an insignificant amount of bainite. But the sample joined with another type of flux which content of Cr tends to form acicular ferrite (AF) and fine carbides in the fusion zone. The microhardness measurements show that the overall hardness in the fusion zone increases due to martensite with some carbide. Regardless of the different types of fluxes, the hardness of the fusion zone (FZ) and heat-affected zone (HAZ) regions was found to be higher the base metal (BM); From the tensile test results, it showed that the fracture was accrued at the heat-affected zone as a result of its weakness; Finally, it was found from the study that the alloy welded with the type of flux (A81-319)ABCr2 had better mechanical properties than those corresponding to fluxes (A81-319)AR1 is expected to be higher than those corresponding to flux (319)AR1 due to microstructure behavior.

Keywords: **High Strength Steel (HSS) ASTM (514E), Submerged Arc Welding (SAW). AF Acicular ferrite, FZ(Fusion Zone), Hardness, Tension Test.**

1. Introduction

In recent years, the focus has become on the use of the hardened type of steel in the military industries, especially in the towers and combat vehicles. High-strength steels are the most known family of armor materials following more than a century of research and development (Ade F,1991) [1]. For the majority of armor applications of the material should be welded by using traditional welding methods. However, the main problems in welding steels of greater than 0.25% in weight carbon are concerned with the formation of very hard untempered martensite in the heat-affected zone, as well as the occurrence of cold cracking, associated with hydrogen migration from the weld pool to the heat-affected zone. The most fundamental reason of this is that steel is reached higher melting temperature (Nowacki J, and Lukojc A, 2005) [2]. Also known as high-strength steel, these materials are generally used as armored combat vehicles (Rajkumar et al 2014: Edwards et al 1996) [3,4]. Choosing correct welding method and parameters is crucial in-field performance of armored vehicles (Unfried et.al, 2009; Mercan et.al. 2015)[5,6]. The operation of steels depends on the properties coupled with their microstructures, that is, on the crystallographic arrangements, volume fractions, sizes, and morphologies of the many phases constituting a macroscopic fragment of steel with agreed concerto in a set processed order. Each type of internal composition of the products has been developed to be suitable and distinct in its scope of use by means of a specific treatment that controls the conditions of changes that occur in the internal structures and thus exploits them (Edwards .1990) [7]. Researchers say considered the capabilities of the several inclusions to develop intergranular ferrite. All studies prove that circular ferrite is responsible for improving the mechanical properties of bladder, stiffness, and lowering of ductility to brittle transition temperature (DBTT) as compared to steels with simple pearlite and ferrite. This is result of uniform microstructure and clean steel [8]. Acicular ferrite is chaotic and it tends to spread in all directions (Loder et.al. 2016) [9]. It has been found that the TiO_2 and Al_2O_3 inclusions form ferrite layers between the steel and oxide interfaces.

The study of Chai and Eagar (Sirin, et al 20016) [10] also indicates that weld metal chemistry is mainly dependent on flux composition, whereas parameters have insignificant effect. (Ramirez. 2008)[11] Indicated that additional effort may be prepared in the enhancement of welding consumables techniques to get welded metals with mechanical properties correspondent to the base metal in steel technology. However, to achieve this, better understanding of chemistry and microstructure property relationships in hollow structural section (HSS) weld metals is needed. In this paper, the SAW fluxes EN ISO 14174: SA AB and SA AR1 in different proportions of constituents and their effects on microstructural and mechanical properties have been analyzed.

2. Experimental Procedure

2.1. Material Specification a sheet of high-strength (514E) plate couples of 18mm in thickness are prepared for joining with submerged arc welding used with dimensions of length 150mm, width 100mm. The samples which cutting from a plate of combat vehicle armor. The elements composition of the alloy and mechanical properties is given in the Table 1. The fillers Wire specified composition values and chemical composition by Wt. Percent of fluxes used according to EN ISO 14174 (Technical Handbook for Esap Company1-800-ESAB-123) [12] in table 2a and b.

Table 1 The elements composition of the alloy and mechanical properties.

HSS	C	Si	Mn	P	S	Cr	Mo	B	Cu	V	Fe
B.M	0.1130	0.261	0.7	≤0.03	≤0.03	2.08	0.53	-0.001 0.005	.0413	0.035	Bal.

Mechanical Properties		
Ultimate tensile strength (MPa)	**Yield strength (MPa)**	**Elongation (%)**
760-895	≥690	≥18

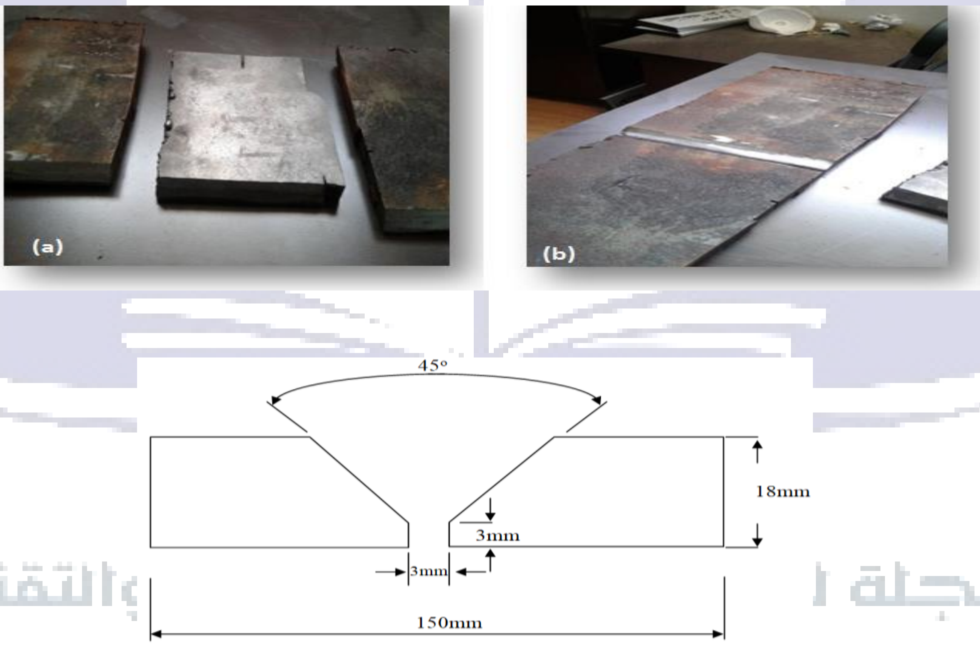
Table 2a Fillers Wire Specified Composition Values Wt. %.

C	Mn	Si	Cr	Mo
0.1	0.83	0.12	1.21	0.49

Table 2b Chemical Composition by Wt. % of Fluxes Used According to EN ISO 14174

Flux Composition	**SiO_2+ TiO_2**	**MnO+ Al_2O_3%**	**MgO+ CaO**	**CaF_2**	**Cr**	**Metal alloy**
EN760- SA AB 1 67 (AC H5) $ABCr_2$	20%	25%	30%	20%	2%	3%
ISO 14174: SA AR 1 87 AC	**Ca+ $CaFe_2$+ MgO**		**MnO+ Fe**	**SiO_2**	**Al_2O_3+ TiO_2+ ZrO_2**	
	11%		17%	19%	52%	

The specimens were turned in a milling machine and faced to prepare the joint configuration as shown in Fig. 1c, joint surfaces. Further, were finished with grinding paper and the surfaces to be welded were cleaned with acetone prior to welding; The welding joint was designed single ‘v’ groove and edge 3mm with angle 45° (150x100x18mm) the welding process was performed as two passes from the front side Fig. 1a& Fig.1b.



Figs .1.a Sample Base Metal (b) Joint Configuration with Dimensions, (c) Configuration Single V Butt Joint

2.2 Submerged Arc Welding (SAW)

The welding of grade of high-strength steels (HSS) was carried out. The process parameters selected for SAW welding processes are shown in Table3. By both using the same welding wire according to standard (SFA/AWS A5.23:EB2R, EN ISO 24598-A:S S CrMo1) 4mm in diameter. The welding process parameters were 470A, 35V, and welding speed45mm/s of the weld. Each sample will be welded separately with a different type of flux and with the same parameters as mentioned above. During the welding process, part of the welding flux does not melt while the other part does. These melted fluxes protect the arc and the melted weld metal from the atmospheric influences, attracts impurities and oxides, stabilizes the arc, and metallurgically work the melt. The welding head moves from right to left, During the welding process, the arc is invisible because it is covered with welding flux that is introduced to welding area from a flux hopper as shown in Fig. 2a and Fig. 2b. This thick layer of each types of flux completely covers for each sample, the molten metal and thus preventing spatter. After that the fused fluxes removed by brush as shown in Fig. 2c, & Fig. 2d.

Table 3 Parameters of Welding Joints.

Parameters Type	Parameters Name	Unit	Parameters used BM (HSL) (18mm thick)
Parameters are applied at the same conditions for both welding fluxes	Current(I)	Ampere	470
	Welding Speed (S)	cm/min	45
	Voltage (V)	Volt	35
Type of Fluxes	(A81-319)AR1& ABCr2		

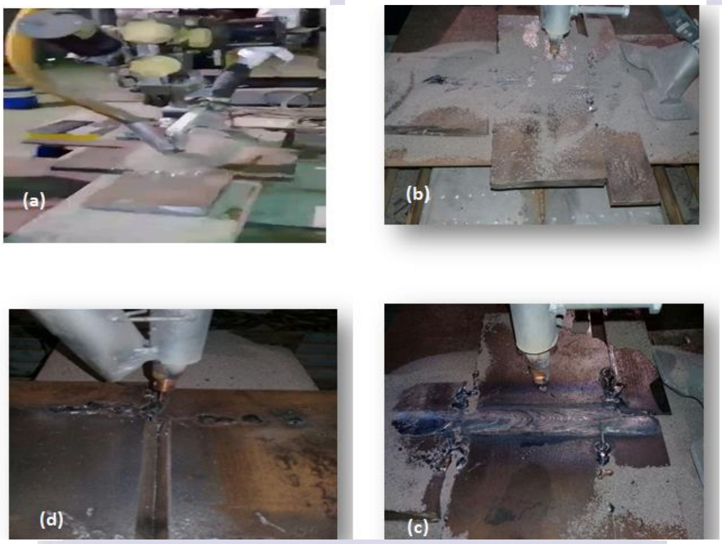
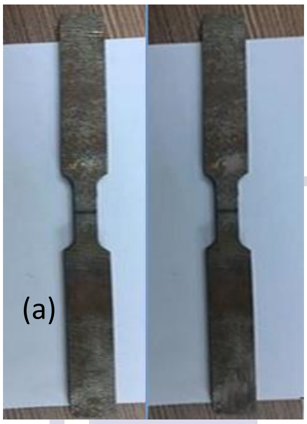


Fig. 2. Schematic Presentations of the Sequence Steps (SAW) of the Samples, (a&b) Specimens with Different Agglomerated Fluxes, (d&c) Welding Parameters, During Welding Process.

2.3 Evaluation of Welded Joint specimens were visually inspected and evaluated using naked eye, sectioned and cutting transverse to the welding direction by water jet machine in miseratha technique. In order to determine the structural changes in the welded samples, grinding and polishing were applied to them. Etchings of samples were performed by using 2% HNO_3+98% Ethyl alcohol solution for 20 second. Microstructure examinations were performed with a Nikon Eclips. The tensile test was carried out at Industrial Research Center by using an (SHIMADZU-1000KN) testing machine with 1000KN capacity.

2.4 Hardness as an additional destructive test method, Vickers microhardness measurement (HV0.3) was carried out under load of (300g) over cross section on vertical (the welding centerline) and horizontal lines 1mm distance between each indentation on metallographic specimens taken from three distinct places on welded samples for each welding fluxes including fusion zones and heat-affected zones separately. Hardness was also taken for eight points, including the first and second weld metal along the thickness. After submerged arc welding, tensile specimens with different agglomerated fluxes were prepared as shown in Fig. 3a, & Fig. 3b. The fusion zone was at the center of the specimen. For two specimens the tensile test prepared according to TS ISO 6892/1998 standards



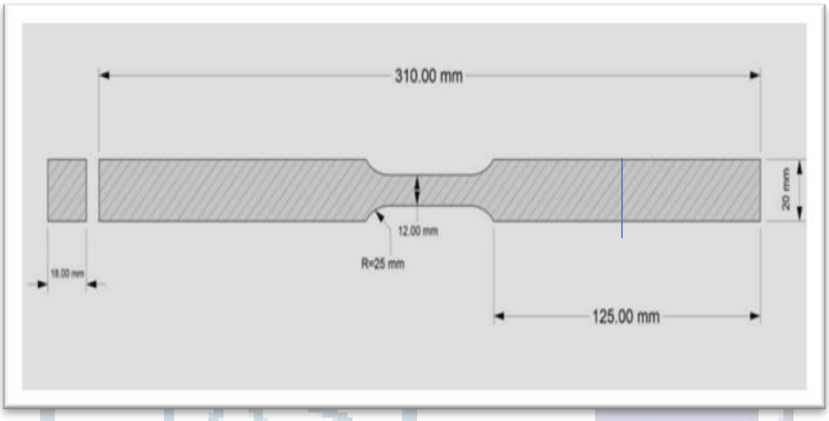


Fig. 3. a. Tensile Test Specimens with Different Agglomerated Fluxes, b. Standard of Tensile Test Samples.

3. Result and Discussion

3.1. Microstructural investigations micro-structural examinations are applied on fusion zones and heat-affected zones for each samples:

3.1.1. Micrographs of Base Metal **v**isual examination of (SAW) welds showed no welding defects such as porosity, undercut, outside cracks, incomplete penetration or lack of fusion. The microstructure of the base metal A514E is given in Fig. 4, the microstructure revealed consist of temperd martensite with a few spheroidal particles of alloy carbides and bainite (dark).

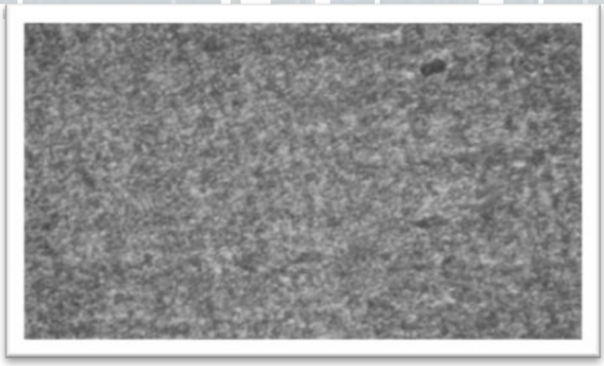


Fig. 4. Microstructure of Base Metal of High-Strength Steel 514E (40X).

3.1.2. Micrographs of fusion zone of the samples joined by different of agglomerated fluoride (A81-319) AR1 and ABCr2 are given in Fig. 5a, & Fig. 5b.

The micrograph of fusion zone was fully martensitic structure along with insignificant amount of bainite in the flux (A81-319) AR1. On the other hand, the microstructure of the welds corresponding to the flux (A81-319) ABCr2 is mainly composed of acicular ferrite with abundant dispersion of fine carbides on microstructure of fusion zone.

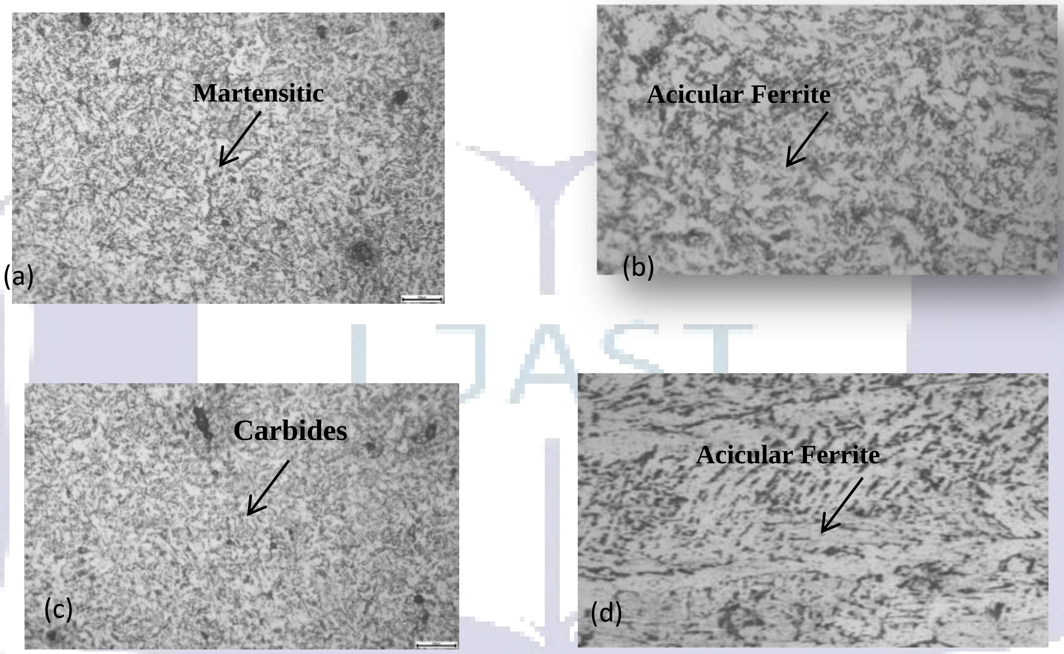


Fig. 5. Fusion zone Microstructures of Samples Joined by (a) (A81-319) AR1 (b) (A81-319) ABCr2 .

Also, the microstructure of fusion zone with the fluxABCr2 which content of Cr element it showed the retained micro phases retained between the acicular ferrite laths were predominately and the martensite austenite transformation (M/A) phase was finely dispersed and irregular in form as shown in Figure 5c, the Figure5d has much of the AF spread across the fusion zone . The GBF and equiaxed ferrite grains have been acted as the separators for AF at some locations. The acicular ferrite and large ferrite laths dominate the microstructure. influx (ABCr2) promote the formation of a circular ferrite, acting as point sites from which intergranular nucleation is developed.

3.1.3. Microstructures of Heat-affected Zones on welded samples, microstructures of heat-affected zones are given in Fig.6a, and Fig. 6b the HAZ was found to be martensite along with austenite (co-existence of ferrite and austenite this can be ascribed that the reduced heat input in HAZ accelerates the cooling and leads to transformation of martensite, therefore a few dispersed carbides were also noticed which could be to enrichment of carbon at the weld and weld interface during the solidification shown in Fig. 6a. However, in the HAZ was martensite-austenite between acicular ferrite laths and at grain boundaries was observed. This change in microstructure revealed is due to a slight decrease of acicular ferrite with energy input by minor constituent of Cr in flux. The structure promotes composed of martensite-austenite and decrease percentage of ferrite in weld metal. There was an increase in the proportion of carbides shown in Fig. 6b. There is an appreciable morphology difference in the formation of acicular ferrite with different agglomerated fluxes. Generally, FZ microstructure of conventional low-alloy steel and high strength steel consists of varying amounts of acicular ferrite (AF),polygonal ferrite, widmanstatten ferrite, pearlite and martensite-austenite (M-A)micro phases.

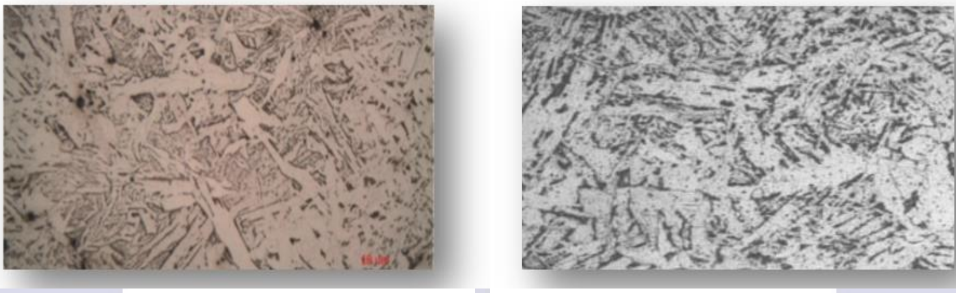


Fig. 6. HAZ Microstructures of Samples Metal Joined by (a) (A81-319) AR1 (b) (A81-319) ABCr2.

Work by (Muhmet Turker,. 2018) [13]. The same results were found which welded the high strength steel with submerged arc welding (SAW) and the microstructure revealed the same above described. Non-metallic inclusion plays a significant role in controlling the microstructure of WMs. It is clearly that all kinds of inclusions may pin austenite grain boundaries for reducing their grain size (Danijela,.2011) [14]. Weld metal chemistry is mainly dependent on flux composition, whereas welding parameters have insignificant effect.

3.2. Microhardness of (SAW) Weld results of micro-hardness measurements for FZ, HAZ and BM of submerged arc welding difference agglomerated fluoride (A81-319) AR1 and ABCr2.

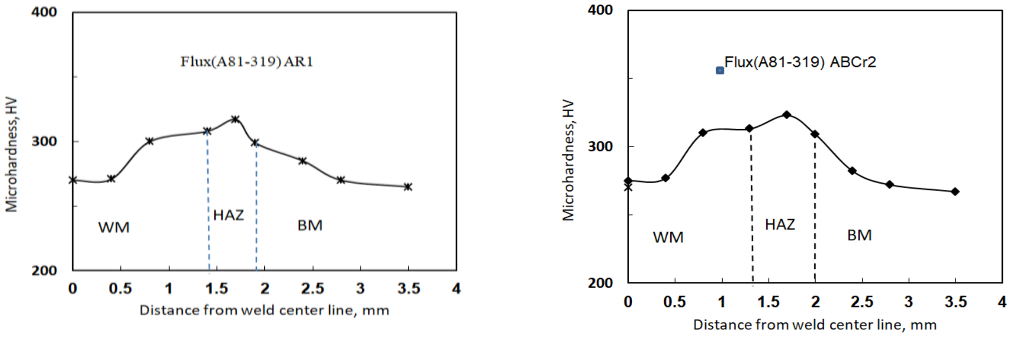


Fig. 7. Hardness Profiles of FZ, HAZ and BM of Agglomerated Fluoride (a)(A81-319) AR1 and (b) (A81-319) ABCr2.

As shown in Fig. 7. Exhibit similar profiles, the microhardness measured in the BM were 285HV; the hardness profiles reveal that there is no significant difference. The microhardness measured of FZ and HAZ was (271-317HV) influx (A81-319) AR1 and the effect of flux with constituent of minor Cr (A81-319) ABCr2 on microhardness measured was FZ and HAZ (277-323HV). The difference of hardness across the FZ zone HAZ, base metal could be due to changes in metallurgical phase constituents. Because hardness of high-strength steels (HSS), in general, is not remarkably affected by such variation. Higher hardness clearly envisaged the formation of martensitic phase and carbides in the fusion zone, the fluctuation of hardness at this zone can be attributed to the difference in the carbon content. It is evident from the hardness plot that the hardness at the fusion zone and HAZ was found to be greater when compared to other zones of the weldment

3.3. Tensile Test in the Investigating the tensile test specimens, the fracture occurred outside of the welded joint. Tacking account of submerged arc welding, a high heat input occurs according to the other welding processes. High heat input promotes grain growth and adverse effect on both strength and toughness. At the same time, it causes decreasing the material hardness. Since both hardness and tensile strength present the resistances against the plastic deformation of metals. Results of tensile test profiles of base metal, HAZ and fusion zone for different agglomerated fluoride (A81-319) AR1 and ABCr2 is shown in Figure 8a. The fracture occurred at HAZ in Figures 8b presented in Table 4.

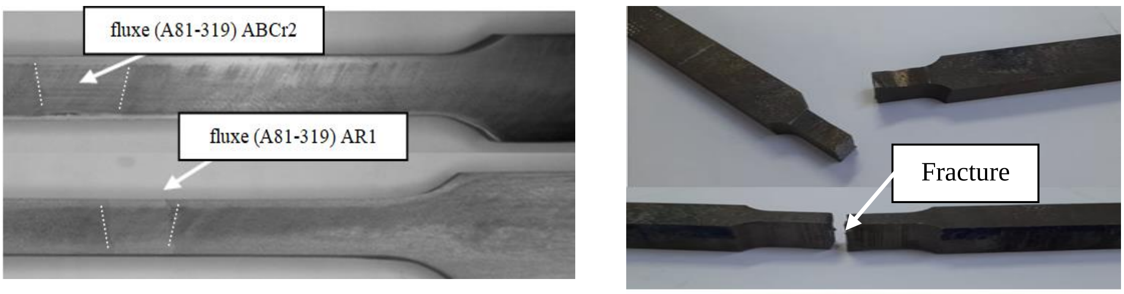


Fig. 8. Photographs of tensile test specimens of BM, HAZ and WM welded with Different Agglomerated Fluoride (A81-319) AR1 and ABCr2, before (a) and after (b) fracture.

Table 4 Tensile Test Results.

Test	(A81-319) AR1	(A81-319)ABCr2
Tensile Strength (N/mm)	669.149	685.54
Break Stress(N/mm)	484.829	497.19
Percentage Elongation (%)	17.8%	19.5%

It has been that ultimate tensile strength and yield strength of submerged arc welding produced with different fluxes. Elongation of welded joint produced using fluxes (A81-319) AR1 is less than the of (ABCr2). Also, It can be noticed that yield and tensile strengths for test sample (A81-319) AR1 and ABCr2 are comparable in value, however higher strength in the case of using (A81-319)ABCr2 due to Cr contained.

4. Conclusions

The results obtained from present study are as follows:

1. It has also It is difficult to clarification changes in the microstructure that occurred in the heat-affected zone (HAZ) and the fusion regions to a single welding process parameter.
2. It has additionally been reported that inclusions may restrain austenite grain boundaries for reducing their grain size. These inclusions may as well as also be responsible for determining the slight quantity of bainite was also observed in the center of the weld metal.
3. Microstructure is found to consist of a mixture of acicular ferrite, bainite and low carbon martensite. It was found that lowering the C content and optimizing the Mn, Ni, Mo and Cr contents of the deposited metal significantly improved the strength and toughness.
4. High basicity fluxes produce weld metal with excellent mechanical properties and resistance to cracking.
5. The average hardness of the fusion zone was 317HV, whereas the average hardness of the HAZ was 312 HV and 271HV for base metal. The difference of hardness across weld HAZ-base metal could be due to changes in metallurgical phase constituents.
6. Tensile test results of submerged arc welding, as well as that of -base metal, elongation of welded joint produced using fluxes (A81-319) AR1 &ABCr2 (17.8%) is the same of base metal A514 Grade E. the tensile properties and hardness for the different welds. As can be seen, the Cr contents increase. This behaviour agrees with the weld microstructures. Impact test energy at room temperature and the elongation and area

reduction values were higher in the welds corresponding to flux (A81-319) AR1. This behaviour can be attributed to the formation of pearlite and ferrite in the weld.

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