American Journal of Materials Science 2019, 9(1): 15-21
DOI: 10.5923/j.materials.20190901.03

Effect of Welding Parameters on Mechanical Properties of Low Carbon Steel API 5L Shielded Metal Arc Welds

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Abstract The main objective of this research is to study the mechanical properties of welding results on API 5L low carbon steel through SMAW welding. The welding variable used consists of various types of welding electrodes and variations in the amount of current. The types of welding electrodes are E6010, E7016 and E7018 and the welding current given is 90A and 100A. Welding samples were cut and machined to standard configurations for tensile strength, impact, hardness tests and SEM for microstructure test. The results shows that there are significant effects of welding variables (type of electrodes and current given) the tensile strength, impact and hardness on the welding metal. The result shows that for all types of electrodes when the amount of current given increase then the mechanical properties such as tensile strength, impact and hardness decrease. The optimum tensile strength for welding metal is produced by the welding electrode E7016 at 90A with 617.155 MPa while the lowest value is 505.215 MPa for E6013 at 100A, the optimum of hardness is produced by E7018 at welding current of 90A with 194.40 VH while the lowest is 170.60 VH for E6013 at 100A and impact 1.915 J/mm^2 by E 7018 at 90A while the lowest 0.728 J/mm^2 for E6013 at 100A. Observation microstructure by SEM shows several phases namely Acicular Ferrite (AF), Grain Boundary Ferrite (GBF) and Bainite.

Keywords Electrodes, Welding current, Weld metal, Mechanical properties

1. Introduction

Welding is an important joining process because of high joint efficiency, simple set up, flexibility and low fabrication cost [1]. Welding is an efficient, dependable and economical process. Welded joints are finding applications in critical components where failures are catastrophe. Hence, inspection methods and adherence to acceptable standards are increasing. These acceptance standards represent the minimum weld quality which is based upon test of welded specimen containing some discontinuities. Welding involves a wide range of variables such as time, temperature, electrode, pulse frequency, power input and welding speed that influence the eventual properties of the weld metal [2-9]. Welding of steel is not always easy. There is the need to properly select welding parameters for a given task to provide a good weld quality.

Welding is a permanent process for connecting two or more pieces of metal together localized coalescence resulting from a desirable combination of temperature, pressure and metallurgical condition [10]. Therefore, the use of the control system in arc welding can eliminate much of the “guess work” often employed by welders to specify welding parameters for a given task [11]. Welding parameters significantly influence the mechanical properties of the welded materials.

The major types of welding parameters are current (effecting the heat input), voltage usage, polarity, welding filler type, welding filler size, are length, electrode angle, arc travel speed and welding technique [12].

The Shielded Metal Arc Welding (SMAW) is defined as a welding process, which melts and joins metals with an are between a welding filler (electrode rod) and the workpieces.

The effect of welding parameters (different type of electrode and current) on the mechanical properties such as tensile strength, impact toughness and hardness of low carbon steel arc welded joints with SMAW was studied in this research.

2. Experimental

In this research the types of welding electrode used were E6010, E7016 and E7018, which were manufactured by the Raajratna Electrodes Pvt, Ltd. The low carbon steel API 5L Grade X52 was chosen as the workpieces. The steel chemical composition is C (0,20%), Mn (1.35%), P (0,025% max), S (0.01% max) and Fe. The standard used refers to ASME (The American Society of Mechanical Engineers) Boiler and Pressure Vessel Code Section IX,

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Published online at http://journal.sapub.org/materials

which is one of the many standards used in the oil and gas industry [13].

The experiment was design with the types of welding electrode and current as variable factors. The types of welding electrode were E6010, E7016 and E7018, while for welding current were 90A and 100A. The observed effects were the mechanical properties of weld zone, which include tensile strength, impact toughness and hardness.

3. Result and Discussions

3.1. Tensile Properties

Tensile testing is carried out using a servopulser machine at a scale of 10 tons and room temperature. The test specimen consists of tensile testing to determine the quality of tensile strength of low alloy steel produced by SMAW welding with E6010, E7016 and E7018 electrode and current about 90A, 100A. The effects of the types of welding electrode and welding current, on the tensile strength of the weld metal was observed. Each condition was run under 5 replications with total run of 30 sets. The result was summarized in **Table 1** and **Figure 1**. The different electrode usage and variation of currents produce significantly different tensile strength values. The main variables in the SMAW process can be described as weld electrode, flux and welding parameters [14]. The welding parameters of SMAW are current, polarity, voltage, weld groove, travel speed, distance between electrodes, electrode extension, angle and diameter [15, 16].

Table 1. Test Results for Tensile Strength in the Weld Metal

Electrode	Welding Current (A)	Tensile Strength, MPa					
		1	2	3	4	5	Average
E6013	90	552.665	550.364	548.015	551.033	549.498	550.315
E6013	100	504.540	507.346	503.124	506.331	504.734	505.215
E7016	90	620.025	615.623	625.784	618.357	605.786	617.115
E7016	100	600.558	607.335	601.589	606.777	590.021	601.256
E7018	90	550.897	600.874	651.774	580.779	544.604	585.785
E7018	100	570.689	580.339	540.338	556.724	589.585	567.535

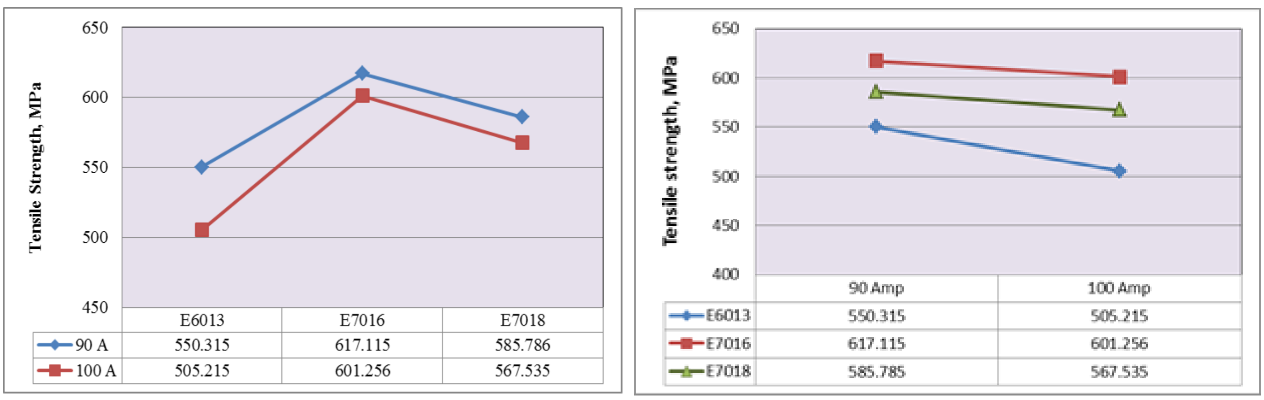

Figure 1. Tensile Strength of Weld Metal: a. Welding Electrode and b. Welding Current

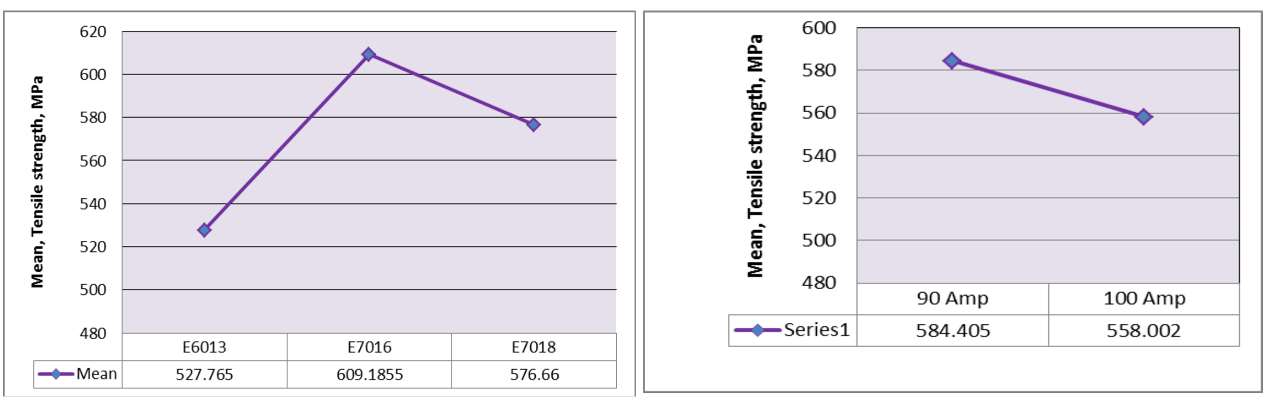

Figure 2. Average of Each Welding Variable: a. Welding Electrode and b. Welding Current

The Figure 2a shows that the welding electrode E6013 produces the lowest average tensile strength value which about 527.76 MPa. However, the welding electrode E7016 produces the highest average tensile strength value which about 609.18 MPa. This result is similar to research conducted by several other researchers [17-20]. **The Figure 2b** shows that as the current increased, the tensile strength in welding area will decreased. As the welding current increase from 90A to 100A, the average tensile strength value decrease from 584.40 MPa to 558.00 MPa. The result is similar will other reseachers [21-23]. The relationship is that as the welding current increase, the welding heat input also increase and decrease in tensile strength on the weld metal.The decrease in strength may be associated with the presence of void and other defects occurring as a result of increasing current. Excessive grain growth could also lead to the decrease in the tensile properties [24]. This result is also similar to the work of another author [25]

The difference in performance between different type of welding electrode can be explained theoretically by the material composition. The material composition for welding electrode E6013 is C(0.08%), Mn(0.5%) Cr(0.06%); Si(0.3); E7016 is C(0.1%), Mn(0.9%) and Cr(0.14%), Si(0.7) and welding electrode E7018 is C(0.9%), Mn(1.10%); Cr(0.1%) and Si(0.6%). The result shows that the welding electrode E6013 has the lower tensile strength because the composition of C, Mn and Cr is lower compared to E7016 and 7018 [20]. This research proved that an increase in Mn, C or Cr individually may increase of tensile strength values and hardness values of welded joint [23].

3.2. Hardness

The influence of the type welding electrode and welding current, on Vickers hardness in the wel metal can be seen in **Table 2** and **Figure 3**. The hardness value with E7018 is higher than the other electrodes.

The **Figure 4a** shows that E 6013 produces the lowest average Vickers Hardness value on the weld metal which is about 173.19 HV. However, E7018 produces the highest average hardness value which is about 192.82 HV. This result is similar to research conducted by several other researchers [17-20]. The **Figure 4b** also shows that as the current increased the hardness will decrease. As the welding current increase from 90A to 100A, the average Vickers hardness value decrease from 185.75 HV to 181.27 HV. The relationship is that as the welding current increase, the welding heat input also increases and reduces the hardness of the weld zone and HAZ (Heat Affected Zone).

Table 2. The Result of Vickers Hardness Test

Area	Electrode	Welding Current (A)	Vickers Hardness Test (VH)					
			1	2	3	4	5	Average
Weld Metal	E6013	90	179	175	176	177	175	176.40
	E6013	100	169	171	172	170	171	170.60
	E7016	90	188	185	187	187	187	186.80
	E7016	100	181	183	182	183	182	182.20
	E7018	90	196	196	195	195	190	**194.40**
	E7018	100	190	193	193	190	191	191.40
HAZ	E6013	90	196	196	196	196	196	196.00
	E6013	100	188	188	188	187	189	188.00
	E7016	90	232	231	230	231	231	231.00
	E7016	100	224	225	225	225	226	225.00
	E7018	90	245	245	243	245	243	**244.20**
	E7018	90	239	239	241	241	239	239.80

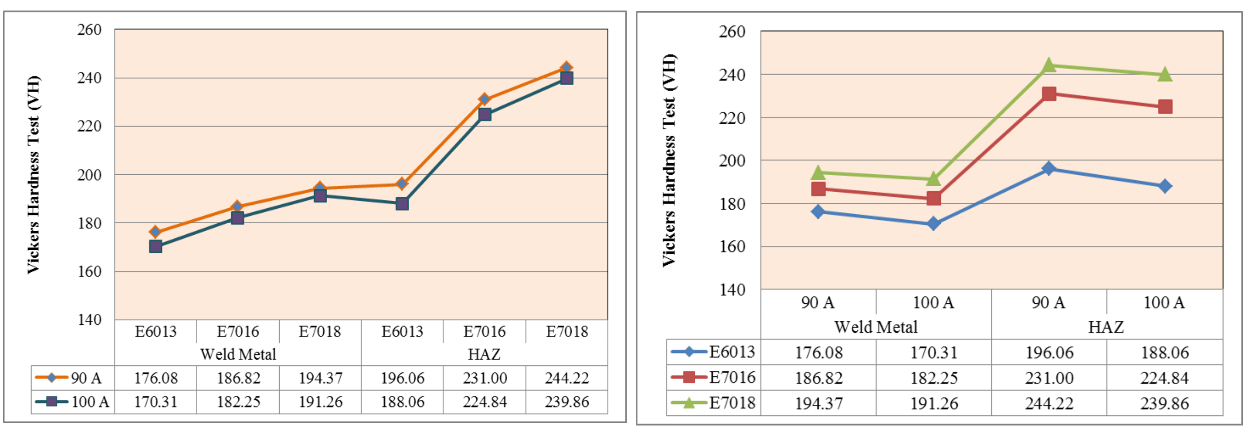

Figure 3. The Vickers Hardness Test: a. Welding electrode and b. Welding Current

The heat input affects the metallurgical behavior of weld melt during solidification and chance of formation the defects in different conditions of welding. As increasing the input energy, grain growth in weld microstructure increases and grain boundaries are reduced in background. Reduction in grains boundaries as locks for movement of dislocation, increases possibility and amount of dislocations movement as line defects in structure. It will cause reduction in strength and hardness of weld metal [20] as shown by the inferior performance for welding current 100 A. At the same time, the weld microstructure is mainly controlled by cooling rate. When the energy input is lower, the time for solidification was less and rapid cooling promotes smaller grains. However, the higher energy input, the time required for solidification increase and cooling rate slow down which yield coarse grains. Since the grain size becomes coarse when welding current increase, the mechanical properties such as hardness value, impact and tensile strength value reduce [24-25]. As the heat energy input was increased, the mechanical properties for tensile strength, impact and hardness decrease due to microstructure of coarse pearlite in ferrite matrix become coarse as the grain size increase [22].

3.3. Impact Toughness

Impact toughness is the ability of a weld to permanently deform while absorbing energy before fracturing. The effects of the types of electrodes and welding current, on impact toughness on the weld metal was summarized in **Table 3** and **Figure 5**. Each condition was run under 5 replications. The figure shows similar profile with those of the hardness properties.

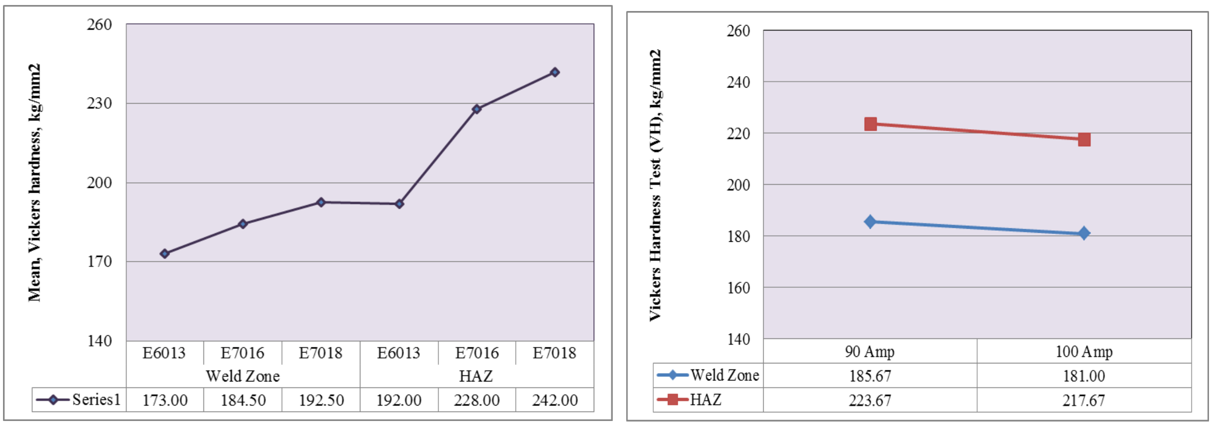

Figure 4. Average of each welding variable on weld metal hardness: a. Welding Electrode and b. Welding Current

Table 3. The result of Impact Toughness Test

Electrode	Welding Current (A)	Impact J/mm^2					
		1	2	3	4	5	Average
E6013	90	0.985	0.995	0.915	0.925	0.985	0.961
E6013	100	0.715	0.705	0.718	0.781	0.725	0.728
E7016	90	1.842	1.822	1.810	1.831	1.825	1.826
E7016	100	1.710	1.712	1.692	1.684	1.688	1.697
E7018	90	1.916	1.910	1.895	1.985	1.869	1.915
E7018	100	1.847	1.775	1.831	1.850	1.850	1.831

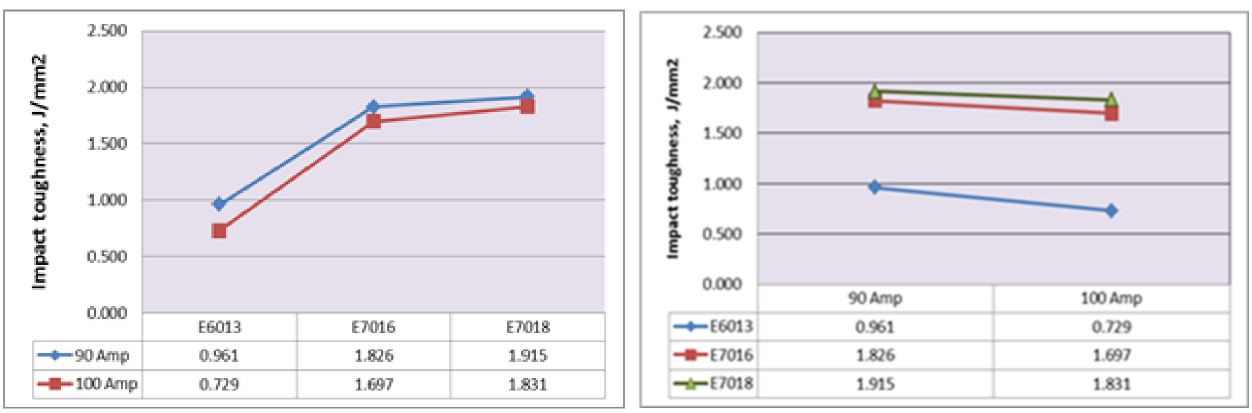

Figure 5. The Impact Toughness Test: a. Welding Electrodes and b. Welding Current

The **Figure 6a** shows that the electrode E 6013 produces the lowest average impact toughness value which is about 0.85 J/mm^2. However E7018 produces the highest average impact toughness value which is about 1.87 J/mm^2. The **Figure 6b** also shows that as the current increased, the impact toughness will decrease. As the welding current increase from 90A to 100A, the average impact toughness value decrease from 1.57 J/mm^2 to 1.42 J/mm^2. The relationship is that as the welding current increase, the welding heat input also increase and which can create room for defect formation, thus reduced mechanical decrease in toughness impact of **welding zone**. In the future work, the authors plan to report the effect of this welding variable on the microstructure of steel sample. The structure properties relationship will also be characterised.

3.4. Weld Metal Microstructure

Performance of weld metal depends on its microstructure which is influenced by chemical composition of weld metal and welding parameters. In order to gain welded joints of low alloy high strength steels with satisfactory mechanical properties and cracking resistance, it is necessary for weld metal to obtain high volume fraction of acicular ferrite. Fine acicular ferrite containing high density of dislocations is the expected microstructure in weld metal. High-angle boundaries among ferrite laths act as an obstacle to cleavage propagation, forcing cleavage crack to change the microscopic plane of propagation [26-27]. For this reason, more acicular ferrite in weld metal is of the utmost importance to reach a weld joint with optimal combination of strength and toughness.

The type of microstructure in welded metals usually consists of two or more phases, namely: grain boundary ferrite, ferrite widmanstatten, acicular ferrite, bainit and martensite. The acicular ferrite is intragranular in size with a small size and has a random direction orientation. Usually the type of acicular ferrite microstructure is formed around the temperature of 650°C and has the highest toughness compared to other microstructure [28].

Figure 7a shows the microstructure in weld metal with E 6013 electrode. There is a significant amount of fine bainit and some small amounts of acicular ferrite (AF). **Figure 7b** shows the microstructure in weld metal with E7018 electrode and there is a significant amount of fine acicular and some small amounts of grain boundary ferrite (GBF). Acicular ferrite is one of the microstructural constituents which is most commonly formed in the weld metal deposits of low alloy steel and directly affects mechanical properties, especially toughness and hardness [29-30].

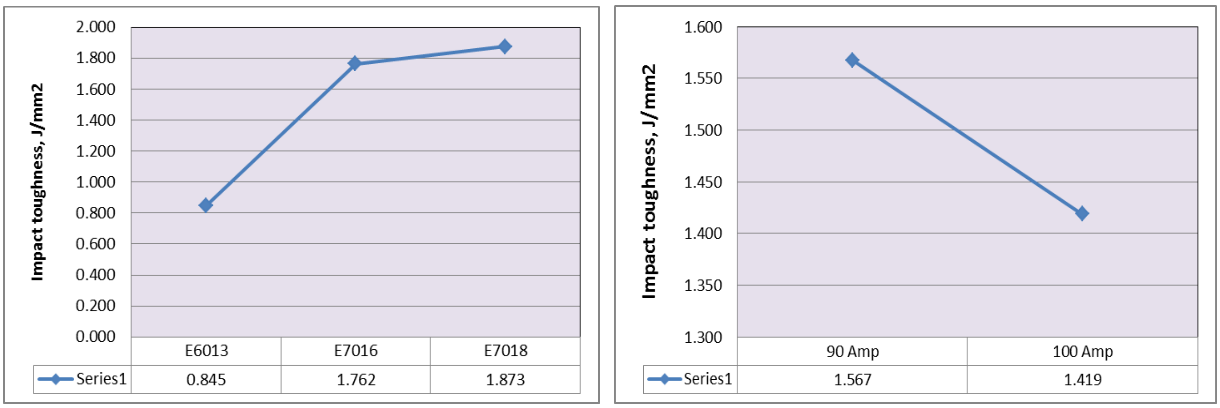

Figure 6. Average of each welding variable on weld metal Impact Toughness: a. Welding Electrodes and b. Welding Current

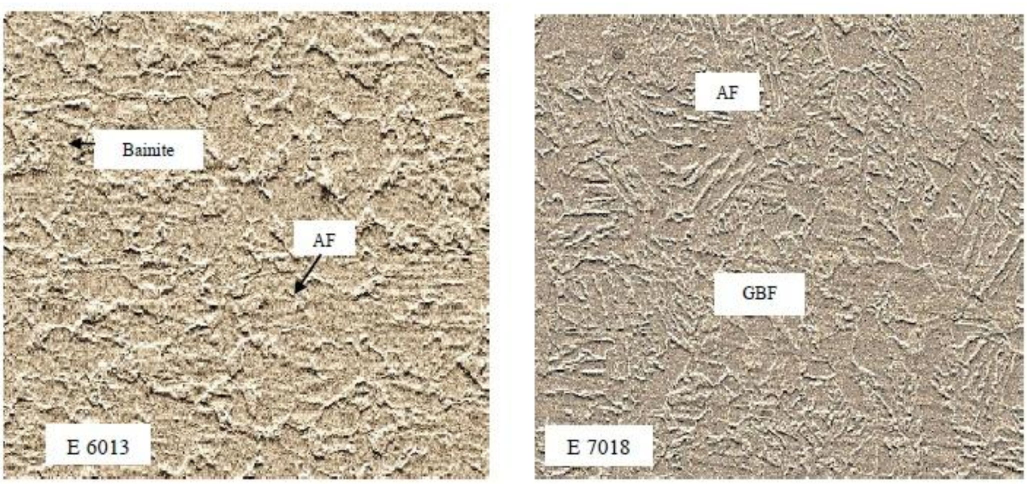

Figure 7. Microstructure Weld Metal: a. With E 6013 Electrode and b. E 7018 Electrode

4. Conclusions

This researh concluded that:

1. There are significant effects of welding parameters (electrode type and heat input / welding current) on the tensile strength, hardness and impact of the welded metal on API 5L low carbon steel through SMAW welding.
2. When the amount of heat input increase (shown by the current), the mechanical properties such as tensile strength, hardness and impact decrease. The optimum tensile strength for welding metal is produced by the welding electrode E7016 at 90A with 617.155 MPa while the lowest value is 505.215 MPa (decline of 22%) for E6013 at 100A, the optimum of hardness is produced by E7018 at welding current of 90A with 194.40 VH while the lowest is 170.60 VH (decline of 14%) for E6013 at 100A and impact toughness is 1.915 J/mm^2 by E7018 at 90A while the lowest 0.728 J/mm^2 (decline of 16%) for E6013 at 100A.
3. Observation microstructure by SEM shows several phases namely Acicular Ferrite (AF), Grain Boundary Ferrite (GBF) and Bainite.

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