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Effect of Normalizing Process on Mechanical Properties of Submerged-arc Weldment

Dr.Abbas Sheyaa Alwan*

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Abstract

Submerged arc welding is carried out and efficient metal- joining process widely used in great importance in many industrial applications, structures of ships, storage tanks and agriculture equipments**.** Low alloy steel used under welding conditions which are, (560 Amp) welding current, (42cm/min) welding speed, (3.25mm) wire diameter, direct current straight polarity (DCSP) with the joint geometry of single -V- butt joint and weld one pass are used for plate of thickness 16mm. After welding, the components have be submitted to a normalization heat treatment in order to recover the original mechanical properties of the welds. In this work two different filer metals both in the as welded condition and after normalizing heat treatment have been studied. Optical microscopy was used to observe the weld microstructure. Tensile and Charpy V toughness testing and microhardness measurements were used to evaluate the mechanical properties of joint. Results show that normalizing reduces the original columnar structure in the as welded condition to an equiaxial structure. It was observed a high decrease in the tensile properties specially the yield strength after normalizing. In respect of toughness, the normalizing heat treatment was observed to increase the Charpy V energy.

Keywords: Submerged-arc welding, low alloy steel, normalizing heat treatment.

تحسين الخواص الميكانيكية لملحومات القوس الكهربائي القاطع باستخدام المعاملة الحرارية بالمعادلة

الخلاصه

تعتبر عملية لحام القوس المغمورعملية فعالة في ربط المعادن والتي تستخدم بصورة واسعة في معظم تطبيقات الصناعات الفخمة كبناء السفن, الخزانات والمعدات الزراعية. أستخدم في هذا العمل فولاذ سبائكي منخفض الكربون تحت ظروف لحام هي: (تيار- 500 أمبير), (سرعة لحام- 42 سم/دقيقة), (قطر سلك اللحام- 3,25 ملم) وبتيار وقطبية مباشرة, مع شكل لهندسية وصلة اللحام -V- التناكبي لتمريرة لحام واحدة ولصفائح بسمك 16 ملم. بعد عملية اللحام , الملحومات يجب ان تعرض على المعاملة الحرارية بالمعادلة وذلك لأستعادة الخواص الميكانيكية الاصلية. في هذا العمل تم دراسة معدنين مختلفين من الحشو المعدني في حالتي الملحومة قبل وبعد المعاملة الحرارية بالمعادلة. استعمل المجهر الضوئي للكشف عن بنية الملحومات. كما أجريت أختبارات الشد, المتانة بمقياس شاربي وقياس الصلادة الدقيقة في تقييم الخواص الميكانيكية لوصلة اللحام. توضح النتائج بأن العاملة الحرارية بالمعادلة تقلل من بنية التراكيب الطولية الاصلية للملحومة وتحولها الى بنية متسلوية المحاور. وقد لوحظ نقصان في خواص الشد خاصة مقاومة الخضوع بعد اجراء المعاملة الحرارية بالمعادلة مع زيادة خاصية المتانة(طاقة شاربي).

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* **College of Agriculture, University of Baghdad / Baghdad**

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University of Technology-Iraq, Baghdad, Iraq/2412-0758

Introduction

The high quality of submerged-arc welds, the high deposition rates, the deep penetration, the adaptability of the process to full mechanization, and the comfort characteristic (no glare, spark, spatter and smoke) make it a preferred process in steel fabrication. It is used in ship and large building, pipe manufacture, railroad, car building and fabrication structure beams.

Weld metal carbon content is usually kept below 0.10%, and low alloy structural steels have 0.12%C-0.23%C. The low alloy steel weld metal microstructure is a complex mixture of two or more constituents, such as proeutectoide ferrite, polygonal ferrite, aligned and non-aligned side plate ferrite, ferrite-carbide aggregate and acicular ferrite **Elmer et al (2002).** When alloying elements are added to the weld metal, upper and lower bainite, martensite and the A-M (austenite with martensite) microconstituent may be formed (**Grong 1992**). Tensile properties of the weld metal are relatively high when compared to those of a base metal of similar chemical composition. When working with thick plates, welding generates a high level of residual stresses, and it is usual to perform a stress relieve heat treatment after welding. This is always done at temperatures between 600°C-700°C, well below AC_1, and therefore it does not change significantly the microstructure and mechanical properties of both base and weld metals. In some few cases, when the steel is hot or cold worked, it is necessary to perform a normalizing heat treatment in order to recover its original mechanical properties (**Evans et al 1991**). As normalizing involves heating above AC_3 in order to promote the base metal grain refinement, this will change the original characteristics of an as welded structure. The effect of the normalizing heat treatment on the weld metal microstructure has not been yet well studied on the literature (**Murugan et al 2001**). The present work has as objective the evaluation of the microstructure and mechanical properties of low alloy steel weld metals after normalizing heat treatment.

Experimental Procedure

Two weld joints were made with submerged-arc welding, and the adopted welding procedure was according to AWS A.5.17-69 [**5**]. Consumables of as-deposited weld metal obtained by applied single-pass, it was used a neutral flux and two different wires. **Table 1,** show the welding parameters used in this study. The Chemical Composition (wt- %) of base metal was shown in **Table 2**, and two different Filler metal (F62-EL12) and (F71-EM12K) was shown in **Table 3**.

The normalizing heat treatment was made by heating the welding joints at a rate of 250°C/h from ambient temperature up to 920°C and remained at this temperature for 2h. Afterwards, they were removed from the furnace and air cooled up to the ambient temperature. Quantitative metallography was carried out only on the weld cross section in the as welded condition. Samples were etched with nital 2%, and image acquisition was performed at 30°C different fields in the columnar zone (last weld bead) [**6**]. For the normalized condition the average ferrite grain size was measured by the linear method. The ASTM number was calculated according to the Voort equation [**7**]. Mechanical testing was performed for both as welded and normalized condition. Tension test, Charpy V impact testing at three different temperatures (35°C), and Vickers microhardness with 100g (HV 0.1) at 2mm below the weld joint surface.

Flux - A highly basic, commercially available agglomerated flux with basicity 3.1 was used to carry out the welding. To drive away the moisture absorbed during storage, the flux was heated in a drying furnace at 350°C for 2 h just before use. The approximate composition of the flux constituents is shown in **Table 4**.

Results and Discussion

1- Effect of Chemical Composition of filler metal

From **Table 3,** it was seen the chemical composition (weight percent) of the filler metal has effect on microstructure of the weld. The effect of 1.06%Cr addition can be observed comparing F71-EM12K with F62-EL12 filler metal. Although acicular ferrit can be observed the effect of Cr increasing the aligned side plate ferrite content and reducing the polygonal ferrite contents. This is also attributed to the higher Mn content of F62-EL12 filler metal, because Mn is considered to be more effective than Cr to reduce the austenite-ferrite temperature transformation. In fact, optical metallography does not have enough resolution to correctly identify microconstituents on the (filler metal) weld metal, which become clear only with the aid of SEM analysis. This result is in good agreement with the result of **Trindad Filho et al [8].**

2- Microstructure of weld metal

Table 5, shows the results of the performed grain size measurement on filler metals in the as welded and normalized condition. The grain size (measured in μm) by linear intercept method, using (Scope Photo programming, type-NTI-USA, 2008) and the corresponding to ASTM number. The addition of 0.50%Mo (F62-EL12 filler metal) promoted the increase of acicular ferrite, polygonal ferrite and Widmanstatten ferrite, as shown in **Fig. 1.** While the others ferrite morphology types were significantly reduced, showing the effect of Mo on promoting a microstructure refinement This result is in good agreement with the result of **Edna Keehan [9]**. A microscopy of (F71-EM12K), these weld metal constituents the Development of a weld microstructure after Cr addition is consisting Cr-Carbide and acicular ferrite, is shows in (**Fig.2**), and X-Ray results shown in **(Fig.3**).

3- Microstructure of Normalized Weld

The normalizing heat treatment changed the original as welded microstructures (**Fig. 1**) to an equiaxed ferrite microstructure (white) with ferrite-carbide aggregates (dark). **Figure 4** shows optical microstructure results from using F62-EL12 and F71-EM12K filler metal after the normalizing heat treatment. The complete austenitization of the welded metal imposed by the normalizing heat treatment, associated with its significantly lower thermal cycles when compared with unheated weld. With the welding thermal cycles, generates a fine equiaxed ferrite when compared to the as welded microstructure which is rich in acicular ferrite. It can be observed that the grain size of equiaxed ferrite in as weld and after heat treatment. This result is in good agreement with the result of **Yang. Z. and T.Debroy** [**10**].

Mechanical Properties

1- Microhardness

Table 6, shows the microhardness values for the weldments before and after normalized. For the as welded condition, hardness was 190 HV 0.1 for the F62-EL12 weld metal and 194 HV 0.1 for the F71-EM12K filler metals. After normalizing, F62-EL12 filler metal was experienced a significant drop in hardness (180 HV 0.1), while for the F71-EM12K, weld metals hardness was increase to (208 HV 0.1). This is attributed to the solid solution strengthening due to the addition of alloying elements (Mo and Cr) this lead to formation of carbide and to the formation of M-A-B (Martensite-Austenite and Bainiet) constituent in the low alloyed weld metals.

2-Tensile Properties

Table. 6 shows the mechanical properties for the two weld joints in the as welded and normalized conditions. For the as welded condition, yield and tensile strength increase for filler metals F62-EL12 and F71-EM12K. These results are consistent with the degree of alloying addition in the weld metals which can be measured by the carbon composition shown in (**Table 3**). In addition, low alloyed weld metals have a higher content of fine acicular ferrite, which has a high dislocation density and high angle grain boundary. Elongation and reduction of area, as expected, showed opposite behavior, i. e., have been reduced while carbon composition was increased [**10**]. For the normalized condition (**Table. 6)** shows a remarkable drop in yield strength when compared to the as welded condition; although the tensile strength also was decreased for all weld metals. This is attributed to the austenitization and low cooling rates characteristic of the normalizing heat treatment, producing a matrix of coarse equiaxial ferrite. It is known that the as welded metal and acicular ferrite have a high dislocation density which combined with the small grain size of the acicular ferrite which produces a considerable high yield and tensile strength. Elongation and reduction of area, as expected, showed opposite behavior, i. e., have been increased while yield and tensile strength was reduced. This result is in good agreement with the result of **IIW [11].**

3- Charpy V Toughness

Table 6, shows the charpy –V- toughness for as welded and after normalizing heat treatment of filler metal F62-EL12 and F71-EM12K. It is known in the literature the beneficial effect of acicular ferrite on toughness, although in the present work, the weld metal showed the lowest content of acicular ferrite grain size all weld metals studied (**Table 5**) and the greater values of impact toughness. The lower toughness of the low alloy weld metals which is attributed to the presence of A-M microconstituent on the as welded microstructure. The low toughness values are attributed to the presence of

M-A-B (Martensite-Austenite and Bainiet) constituent observed for the two low alloyed weld metals which, similar to the A-M constituent observed in the as welded condition, is considered to be harmful to toughness; this result is in good agreement with the result of **Yang. Z. and T.Debroy** [**12**].

The results obtained in the present work allow choosing welding conditions for both the as welded and after normalizing condition. For the normalized condition, F62-EL12 weld metal is considered to obtain the better compromise between toughness at 35°C and tensile strength. Despite it, attention should be given to the low yield strength obtained for all weld metals, because for many engineering purposes yield strength is the required property used in the design of equipments.

Conclusions

From this work, it is possible to draw the following conclusions when evaluating the effect of normalizing heat treatment on welded metal properties:

- The original as welded metal is a fine columnar ferrite with ferrite-carbide aggregates is changed to afine equiaxed ferrite grained microstructure.
- Yield and tensile strength properties are considerably reduced.
- Low alloyed filler metal (F62-EL12) and (F71-EM12K) developed M-A-B (Martensite-Austenite and Bainiet) constituent, which impaired toughness at low temperature.
- F62-EL12 filler metal presented the better compromise between tensile strength and toughness

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Table 1. Welding parameters and data[**5**].

Parameter	**Data**
Welding current	560 A
Voltage	28 V
Welding speed	42 cm/min
Interpass temperature	150 °C
Welding time	75 s
Wire diameter	3.25 mm
Groove opening	16 mm
Backing	Steel

Table 2. Chemical Composition (wt-%) of base metal

Elements	C	Si	Mn	Ni	Cr	Mo	S	P	Cu
Base Metal	0.08	0.23	0.4	1.8	0.44	0.29	0.01	0.01	0.38

Table 3. Chemical Composition (wt-%) of Filler metal

Elements	C	Si	Mn	Ni	Cr	Mo	S	P	Cu
F62-EL12	0.04	0.23	1.55	2.6	0.07	0.50	0.020	0.022	0.11
F71-EM12K	0.04	0.23	1.11	2.6	1.06	0.52	0.015	0.022	0.1

Table 4 - Chemical Composition of Flux

Constituents	MgO	CaF_2	SiO_2	Al_2O_3	TiO_2	MnO	CaO
Wt-%	36	26	13	12	0.5	0.5	12

Table 5. Results of the (filler metal) ferrite grain size after the normalizing heat treatment and in the as welded condition.

Filler Metals	Grain size (as welded) μm	Grain size (normalized) μm
F62-EL12	18.12	13.72
F71-EM12K	17.23	12.94

Table 6. Mechanical properties of the weldments before and after normalizing

	σ					

	σ_y [MPa]	**σ_u** [MPa]	**El** [%]	**RA** [%]	**Microhardness** (HV 0.1)	**Impact energy** (J)
As welded						
F62-EL12	450	505	25	60	190	90
F71-EM12K	500	650	24	55	194	70
Normalized						
F62-EL12	240	460	34	65	198	120
F71-EM12K	246	500	30	60	208	100

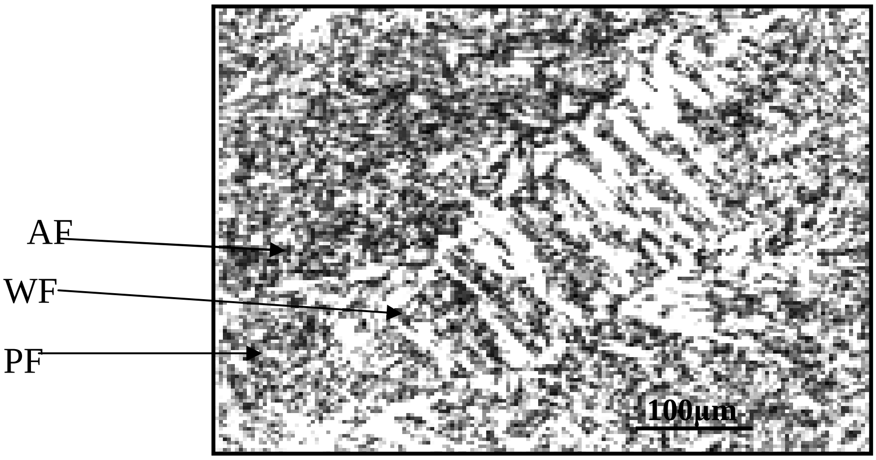

Figure 1. Optical microscopy of the weldment when F62-EL12 filler metal was used.

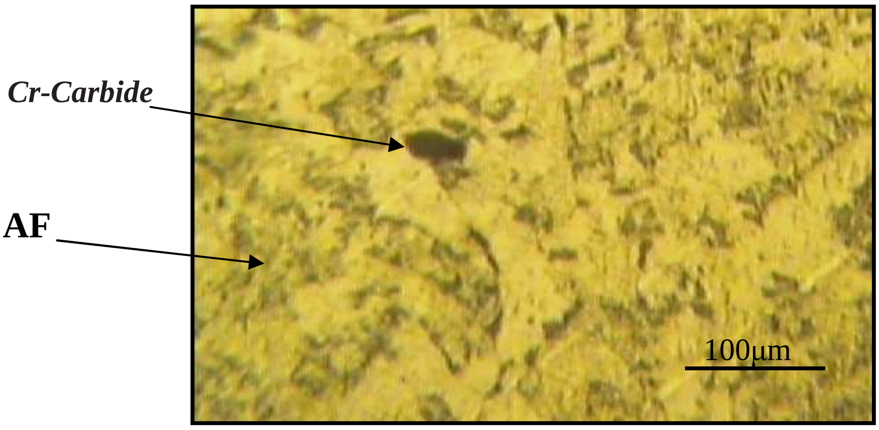

Figure2. Optical microscopy of the weldment when F71-EM12K filler metal was used.

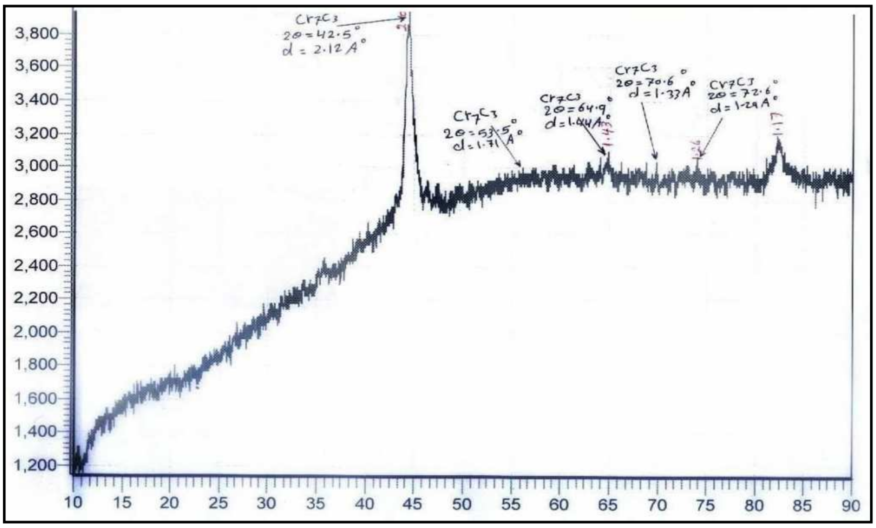

Figure3. Result of (X-Ray) for F71-EM12K (filler metal) was used.

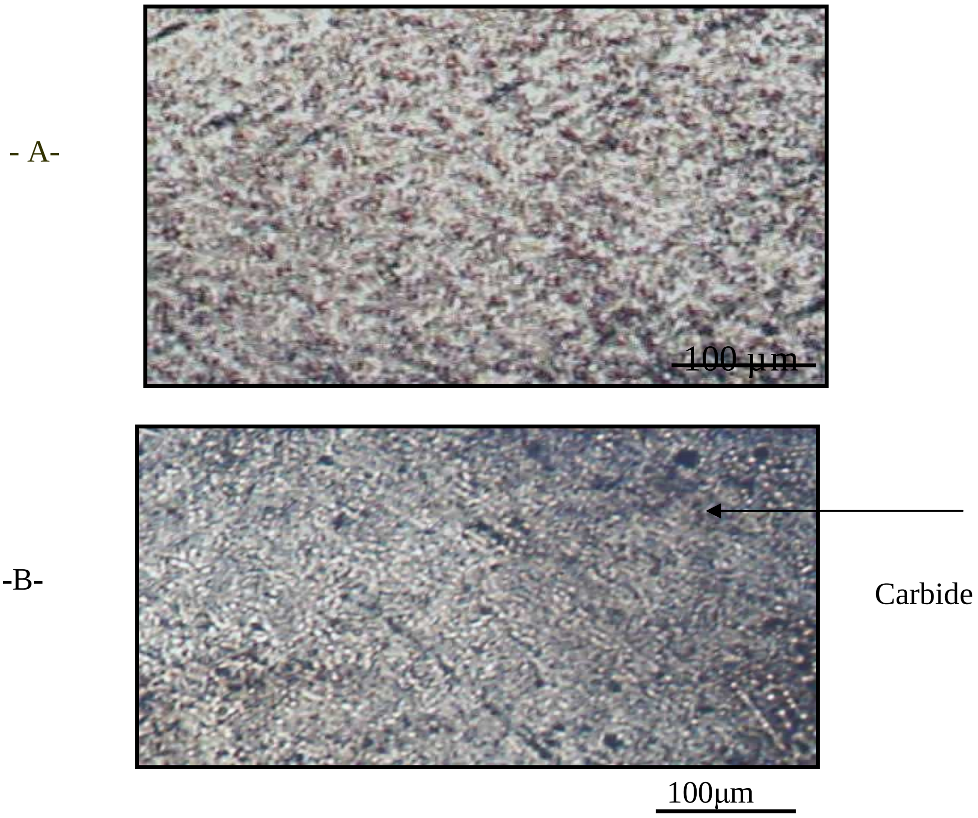

Figure 4. Show the effect of normalizing process on the microstructure (a) F62-EL12 (filler metal) and (b) F71-EM12K (filler metal).