Effect of Single and Double Pass Arc Welding on HAZ of High Carbon Steel Weldments

Alaa Abdul Hasan Atiyah
Materials Eng. Dept. , University of Technology-Baghdad
Shaker J. Edrees
Materials Eng. College , University of Babylon
Farhad M. Kushnaw
Materials Eng. Dept. , University of Technology-Baghdad
dralishakerj@yahoo.com

Abstract

Measurements of heat affected zone width for multi high carbon steel joint in case of single and double pass arc welded have been studied. These measurements are carried out in accompanying of hardness and microstructural observations. Knowing that, high carbon steel has a poor weld ability and most of welding processes are carried out for repairing components. It is found that a preheating was a very important parameter in identifying the width of heat-affected zone. Preheating the joint at 450°C was found to gives less width heat affected zone (i.e.5.93mm) in the case of single pass welding practices. While, in the case of double pass welding, the heat affected zone becomes wider because the excessive heating during welding cycle. The double pass welding has coarsening the structure of first pass. Microscopic observations indicated that the structure of HAZ of high carbon steel was mainly lath martensite (ML) under the condition of lower weld heat input.

Key Words: Welding, Heat Affected zone width, High carbon steel.

الخلاصة

تم في هذا البحث قياس عرض المنطقة المتأثرة بالحرارة في حالة وصلات اللحام للفولاذ العالي الكاربون والذي تم لحامه بواسطة القوس الكهربائي بواقع تمريره واحدة وتمريرتان. إجريت هذه القياسات وفقا الى مراقبة البنية المجهرية والى قياسات قيم الصلادة لهذه الوصلات. علما إن الفولاذ عالي الكاربون هو واطي ألّلحامية وان معظم عمليات لحامه تتركز في عمليات التصليح للأجزاء. وقد وجد في هذا البحث إن عملية التسخين المسبق تعتبر عاملا مهما في تحديد عرض المنطقة المتأثرة باللحام. وقد كان تسخين الوصلة إلى درجة حرارة (450°) درجة مئوية يعطي اقل عرض للمنطقة المتأثرة بالحرارة حوالي ((5.93mm في حالة وصلة التمريرة الواحدة. بينما في حالة التمريرتان فأن المنطقة المتأثرة بالحرارة أصبحت اعرض(6.8mm) عند نفس ظروف ودرجة حرارة التسخين المسبق وذلك بسبب تعرضها للتسخين المضاعف أثناء التمريرة الثانية. وان الوصلات الملحومة بتمريرتان ذات بنية مجهرية اخشن من حالة الوصلات الملحومة بتمريره مفردة. كما أظهرت فحوصات المجهر الضوئي أن طور المارتنسايت يتكون في المنطقة المتأثرة بالحرارة تحت ظروف طاقة اللحام المنخفضة.

الكلمات المفتاحية : اللحام، عرض المنطقة المتأثرة باللحام، الفولاذ عالي الكاربون .

1. Theoretical Background

High carbon steels containing 0.55 to 1.00% C and 0.30 to 0.90% Mn have more restricted applications than the medium-carbon steels because of higher production cost and poor formability (or ductility) and weld ability. High carbon steels find applications in the spring industry (as light and thicker flat springs, laminated springs, and heavier coiled springs), farm implement industry (as beams, plowshares, scraper blades, disks, mower knives, and harrow teeth). They are usually purchased in the annealed condition; the manufactured parts are then heat – treated to achieve the desired properties (Sinha, 2003) .

The increasing or decreasing of carbon content affects the weld ability of steel because that, the region of the heat-affected zone (HAZ) of welds then develops unacceptable or acceptable hardness levels immediately after welding. The weld metal solidification behavior controls the size and shape of grains, the extent of segregation, the distribution of inclusions, the extent of defects such as hot cracking and porosity, and the properties of weld metal. In the last three decades, several excellent reviews have been published emphasizing various aspects of weld solidification and weld microstructure (Gunaraj & Murugan , 2002). Gunaraj & Murugan (Gunaraj & Murugan,2002) have demonstrated prediction of heat affected zone characteristics mathematically in recent years, for submerged welding of some structural steel. Heat affected zone characteristics also studied by Altaie &Ateia [Altaie & Ateia , 2007] in the welding of low carbon steel by brazing.

Figure (1) is a schematic diagram that describes an autogenously welding process, exhibiting three distinct zones of a fusion weld. They are the fusion zone (FZ), also called the weld metal; the un-melted heat-affected zone (HAZ) near the FZ; and the unaffected base metal (BM). The characteristics of the FZ depend, largely on the solidification behavior of the weld pool. However, according to close metallographic evaluation, the FZ can be further divided into three subzones: the composite zone (CZ), the unmixed zone (UZ), and a partially melted zone (PMZ), present between the FZ and the HAZ (Biloni & Boettinger, 1996).

Carbon content is important to the overall strength and hardness of the weld metal. The location of carbon atoms, whether they remain in solution or if they are precipitated, determines whether the steel is martensitic or ferritic. The level of carbon is critical for optimizing microstructure and mechanical properties. Greater additions of carbon lower the martensite transformation temperature. Increasing the amount of martensite with higher carbon in the HAZ raises the risk of hydrogen cracking and decreases toughness. At too low carbon contents, ferrite may form so carbon is made up for by increasing the alloying content (Savage, 1967).

The carbon content is also directly related to the risk of solidification cracking. At high carbon levels, greater amounts of Mn and lower levels of S are required in order to avoid this type of cracking. The carbon and sulphur content is generally kept low in welding consumables and solidification cracking is not a major problem. Preheating processes have a crucial effect on the subsequent welding results. Knowing that, the purpose of preheat was to reduce the risks of hydrogen cracking, reducing of heat affected zone hardness and decreasing of shrinkage stresses during cooling and also improving of the residual stresses distribution (Lancaster,1992).

In the course of this work, an attempt has been made to measure the HAZ width and to understand the changes in hardness numbers and micro structural behavior of heat-affected zone resulted from welding of high carbon steel with single and double passes arc welding. Knowing that, this type of steel was usually welded for repairing only. The weld metals examined have similar compositions.

2. Experimental Procedure

High carbon steel rectangular specimens where taken from a cold rolled plate. Specimens are of constant thickness (8 mm) as shown in figures (2 & 3). The average chemical composition of these specimens is mention as shown in table (1). The chemical composition has done by using a portable metal analyzer type (METAL SCAN 1650).

2.1 Pre-Heat Temperature Practices

Preheat practices in this work were not locally applied, it extends to all the weld location and there are no reasons to measure on the opposite face to the one joint being welded. Now, in order to accomplish the targets above, a set of temperatures (no preheat, 400 & 450°C) were selected as a preheat temperature. The heat input energy also varied by controlling the current supply to the welding machine. Knowing that, all heating practices were done by using of a well calibrated an electrical resistance furnace.

2.2 Welding Procedure

Shielded Metal Arc Welding (SMAW) type E1018 has used to produce all the Weldments metals analyzed in this work. SMAW is also called Manual Metal Arc (MMA) welding since a welder manually guiding a stick electrode normally carries out welding. The characteristics of welding process were mentioned in table (2). All welding practices were done inside the welding workshop at the University of Technology.

A rectangular joint type was selected for the design of weldments in this work. Selection of such weldments design is based on the following requirements (Jeffcott & Pohlman, 2004):

1. A large amount of heat could be supplied to melt the joint that resulted to noticeable changes in the adjacent non-molten heat affected zone.
2. Better heat distribution throughout the section that augmented by the good thermal conductivity of steel.

Using steel brushes and sand blasting in order to remove all the oxides layers and the surface dirt's cleaned all the steel joints. All welding processes were conducted under careful procedures and following variables as shown in table (3), where a single and double passes are performed on a weld joint preheated for three temperatures. In this work, it was calculated using the equation (Keehan, 2004):

$E = (U \times I \times 60) / (v \times 1000)$ …………………………………. (1)

Where E = energy input (kJ / mm)

U = voltage (V)

I = current (A)

v = speed (mm / min.)

2.3. Mechanical Properties Test

2.3.1. Hardness Test: Hardness tests were conducted to measure of the weld metal's resistance to localized plastic deformation. Hardness testing was conducted according to Vickers method using a 10 kg load with a Buehler hardness tester on joint cross-sections polished to 1 µm with diamond paste. Samples were hardness tested starting in the last bead and then proceeding vertically down the weld metal cross section in 1 mm steps. All hardness measurements were carried out in agreement with standard EN 11 25 17.

2.4 Microscopic Observations: Light Optical Microscopy is one of the most commonly used techniques for microstructure characterization in the development of weld metals. Steel weld metals are opaque to visible light and as a result, only the surface of the weld metal sample is subject to investigation with this technique. Investigations in this work were carried out using a light optical microscope. Samples of weld metal for these investigations were taken from the joint cross-section perpendicular to the welding direction. In this way, the cross-section of the weld beads and their geometry were taken into account when carrying out microstructural investigations.

The weld metal samples were then ground and polished to a mirror like surface. This was achieved by using successively finer abrasive paper and then polishing through 9-micron diamond paste on Struers polishing plates. For LOM. The microstructure was revealed using 1% Nital (HNO_3 in C_2H_5OH) etchant. HAZ width values were measured macroscopically by using a clip gauge device. These measurements were done carefully in accompanied with the evolutes microstructure.

3. Results & Discussions

The casting process is never perfect, especially when dealing with large components. Instead of scrapping defective castings, they can often be repaired by welding. Naturally, the very high carbon concentration of typical steel causes difficulties by introducing brittle martensite in the heat-affected zone of the weld. Therefore, it is very necessary to preheat to a specific temperature followed by slow cooling after welding. The materials used as fillers during welding usually contain large nickel concentrations so that the resulting austenitic weld metal is not sensitive to the pick-up of other elements to some extent. The deposits are soft and can be machined to provide the necessary shape and finish.

Increasing the number of passes during the welding of high carbon steel components introduce more problems where the heating cycle becomes more different from single pass welding case. Knowing that, double or multi pass welding is very usual in the welding of such material. The excessive heat input that introduce in double pass welding introducing a dramatic change in the microstructure evolution and certainly the dimensions of HAZ will be changed accordingly.

The widths of HAZ in each case (i.e. single and double pass) are clearly different. Each one is affected directly by the heat input energy and the value of preheating temperature. The following results clearly show the crucial effect of each parameter above on the width of the HAZ width. However, the values of width are so different in each case. A double pass condition gives wide values of HAZ width than the single pass conditions.

3.1 HAZ Microstructure (Single Pass Conditions)

Due to rapid solidification of melt zone in arc-welded carbon steels (base metal acts as a heat sink), it is likely to develop a martensitic structure. Heat affected zone may also undergo matrix change from pearlite to more brittle phases such as bainite and martensite. The following description of results and discussion of each case remembered in table (3):

1. As Received Samples Microstructure

The initial microstructure of the as received high carbon steel was shown in figure (4). It consisted of white ferrite network surrounding the grey high carbon pearlitic areas.

2. Microstructure of Joint

Figure (5), shows the microstructure observations of the joint in the case of single pass conditions according to the schematic representation shown in figure (1). These microstructure observations were taken along the transverse section of the welding joint in single pass welding conditions. Knowing that, all the joints were cooled after welding process inside the lab by still air.

Now, due to the welding process with an arc, the joint was subjected to a thermal cycle including heating and cooling. The heating part was started directly at the moment of welding immanent (i.e. when the electrode touching the joint). As it was expected, a lot of heating energy was transferred from the welding electrode to the joint. This is in turn rising the joint temperature to a fusion state especially at the center of welding which is called a fusion zone.

Adjacent to the fusion zone, the area that is called a heat-affected zone does not subject to a lot of heat energy for melting but it was sufficient to alter the microstructure of this area to an austenitic phase. The effect of heating was continued away from the center of fusion zone (i.e. base metal) which is still without any phase transformation due to the low heat energy arrived at this area.

Cooling part of the thermal cycle was started after the completion of the welding process. During this part of heating cycle, the base metal working as a heat sink for the high temperature at the center of welding pool. At this work and due to the relatively small dimensions of the joint, the joint was expected to subject to a slow cooling by still air and base metal. The slow cooling of this joint and due to the high carbon percentage in the joint material, there was an easiest to get a martensitic structure at the above center of the fusion zone. The center of fusion zone microstructure as shown in the figure (5), are clearly composed of a mixture of flux material and a martinsite microstructure.

Adjacent to the area of fusion zone, the heat affected zone also subjected to a phase transformation due to the cooling to room temperature. The microstructure of this area as shown in figure (5) consisting mainly from a coarse pearlitic structure with high carbon contents. The phase transformation of austenitic phase at this zone to a coarse pearlitic microstructure is so expected under the conditions of slow cooling of welding joint. After this area there is no phase transformation have occurred due to the decreasing of heating cycle at this area.

Regarding to the development in the HAZ width, single pass imparts a noticeable HAZ width according to the dramatic changes in microstructure at or adjacent to the welding pool. Figure (7) shows the effect of increasing heat input on the HAZ width at different preheat. It is clear that, as the heat input increased, HAZ width is developed. However, the preheat temperature has a remarkable effect on the HAZ width. No preheat conditions gives a large HAZ width and more response to the heat input by an arc electrode. Now as the preheat temperature was increased the value of HAZ width were decreased extensively.

3.2 HAZ Microstructure (Double Pass Conditions)

Figure (6), shows the microstructure observations of the joint in the case of double pass conditions according to the labels of schematic representations shown in figure (1). Under these conditions, thermal cycle becomes very complicated and the base metal also working as a heat sinks.

At the center of welding pool, a mixed microstructure of welding electrode flux with a coarse pearlitic structure. Next to the fusion zone, the microstructure obtained was a coarse pearlitic microstructure due to the very slow cooling at this area. The heat affected zone in this case (i.e. double pass welding conditions is larger than that obtained in the case of single pass welding conditions.

As shown in the figure (8), HAZ width was increased as the as the heat input was increased. In addition, preheating affect the HAZ width and it is clear that as well as preheat temperatures were increased, HAZ widths were decreased extensively. HAZ width values as can be seen were larger than that obtained in the case of single pass welding.

3.4 Hardness Results Discussion

Figure (9), shows the hardness numbers along the welding joint section starting from the center of joint to the 4 cm distance away. This figure shows interesting values for each type of welding conditions (i.e. single and double pass conditions). Single pass welding joint has a higher hardness values than the hardness numbers of the second welding conditions (i.e. double pass conditions). The reason behind such hardness properties was the high hardness of resulted microstructure constituents in the case of single pass conditions such as martinsite at the upper area of the single pass joint fusion zone.

In contrast, the double pass welding joint shows a lower hardness values than the values in the case of single pass welding conditions. The lower values of hardness are so expected because of the softening of hard constituents by heating cycle of second pass welding.

The sudden increasing in hardness numbers in the case of single pass welding (i.e. from 225 to 310 VHN) was expected at the transition line between the fusion zone and the heat-affected zone. This line separates the area where a clear semi transformation to a martensitic structure (fusion zone) and the area where a pearlitic structure was formed (heat-affected zone).

4.1 Conclusions

According to the above results and conditions, the following points can be concluded:

1. Single pass welding conditions of high carbon steel shows an interesting microstructure evolution especially at the center of fusion zone (mixture of martinsite and welding electrode flux) due to the cooling by still air and the parent material.
2. Double pass welding conditions of high carbon steel doesn't show a very hard constituent at the center of fusion zone due to the softening process that resulted from the second pass welding.
3. A coarse pearlitic microstructure could be seen in the heat-affected zone of each welding conditions with coarse grain size in the case of double pass welding because of low cooling rate.
4. HAZ width largely affected by the number of welding passes, single pass gives lower HAZ width in comparison with the double pass welding.
5. Both cases (single and double pass) welding, the HAZ width are affected by the values of heat input and the preheat practices.
6. Single pass welding joint has a higher hardness values than the hardness numbers of the second welding conditions (i.e. double pass conditions).
7. The sudden increasing in hardness numbers in the case of single pass welding (i.e. from 225 to 310 VHN) was expected at the transition line between the fusion zone and the heat-affected zone.

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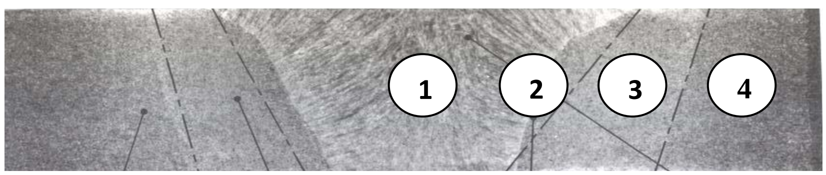

Figure (1): A schematic representations of the welding joint.

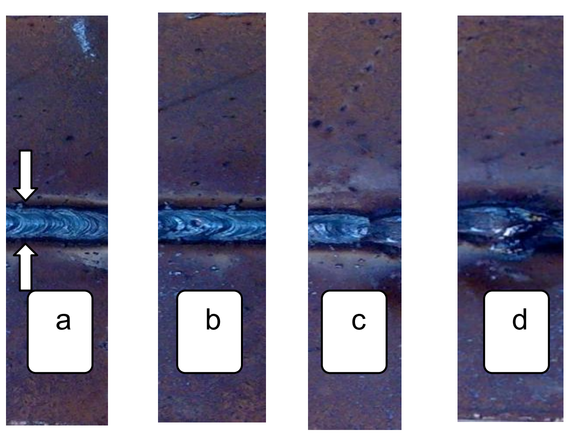

Figure (2): (a, b, c & d) shows samples of the welding joint at single pass without preheating.

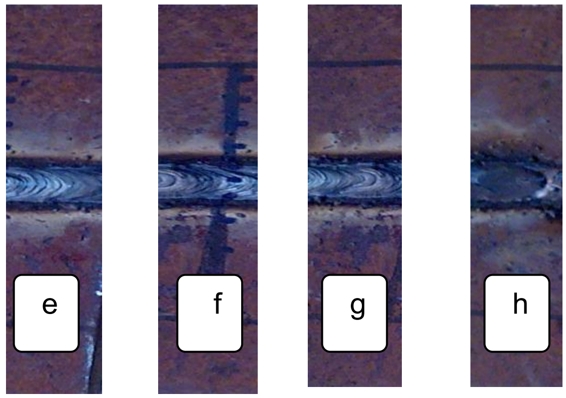

Figure (3): (e, f, g, & h) shows samples of the welding joint at double pass without preheating conditions

Table (1): Average chemical composition of used material

Element	C	Si	Mn	Al	Co	Cr	Cu	Ni	Fe
Wt%	0.945	0.851	0.164	0.02	0.0691	0.03	0.064	0.273	Balance

Table (2): Characteristics of welding process used in this work

Current (A)	variable
Voltage (V)	30
Travel Speed (mm/min.)	14
Arc Efficiency (%)	85
Plate Thickness (mm)	8
Ambient Temperature (°C)	25
Preheat & Interpass Temperature (°C)	variable

Table (3): Single &double pass welding procedure

Joint no. (single pass practices)	Heat input (KJ/Cm)	Preheating temperature °C	Joint no. (double pass practices)	Heat input (KJ/Cm)	Interpass temperature °C
A	6.4	no	E	6.4	no
		400			400
		450			450
B	9.1	no	F	9.1	no
		400			400
		450			450
C	10.1	no	G	10.1	no
		400			400
		450			450
D	12.1	no	H	12.1	no
		400			400
		450			450

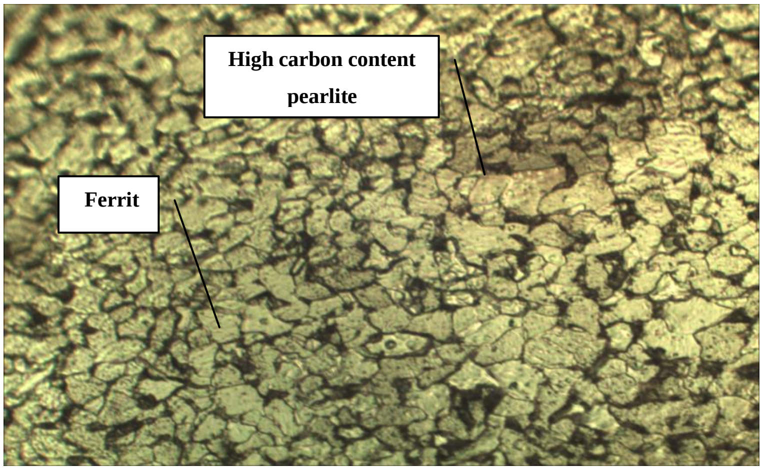

Figure (4): As received steel microstructure, (400X).

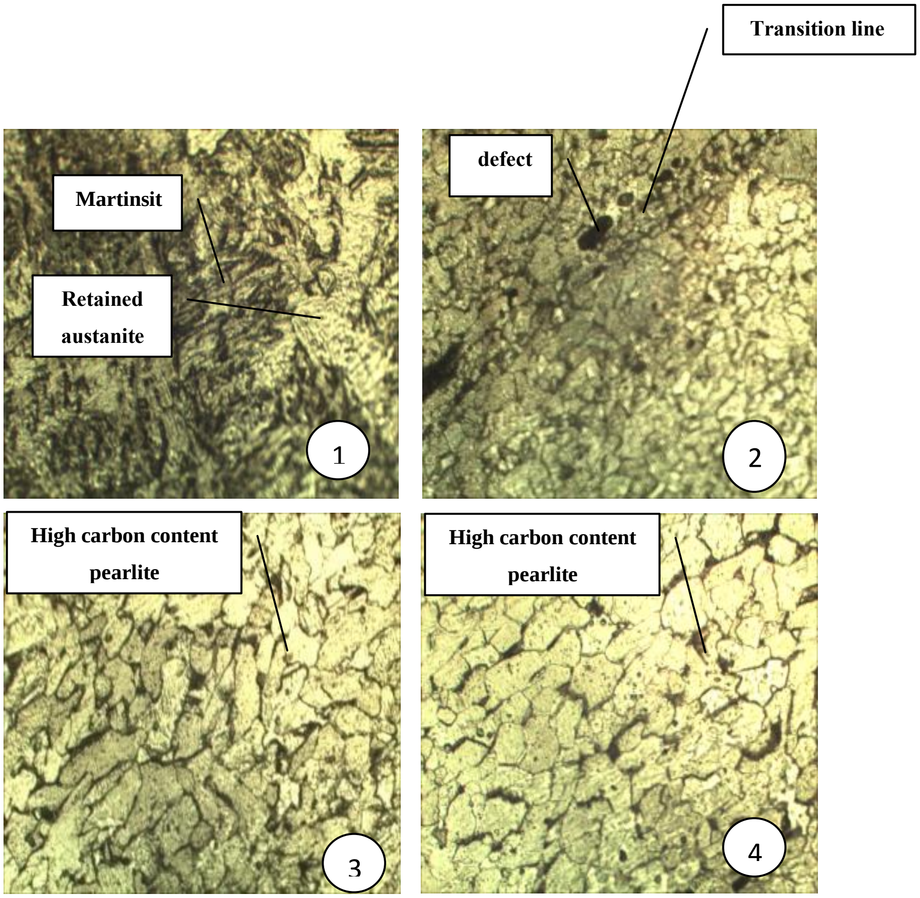

Figure (5): shows the microstructure observations at the selected areas in figure (1) (400X

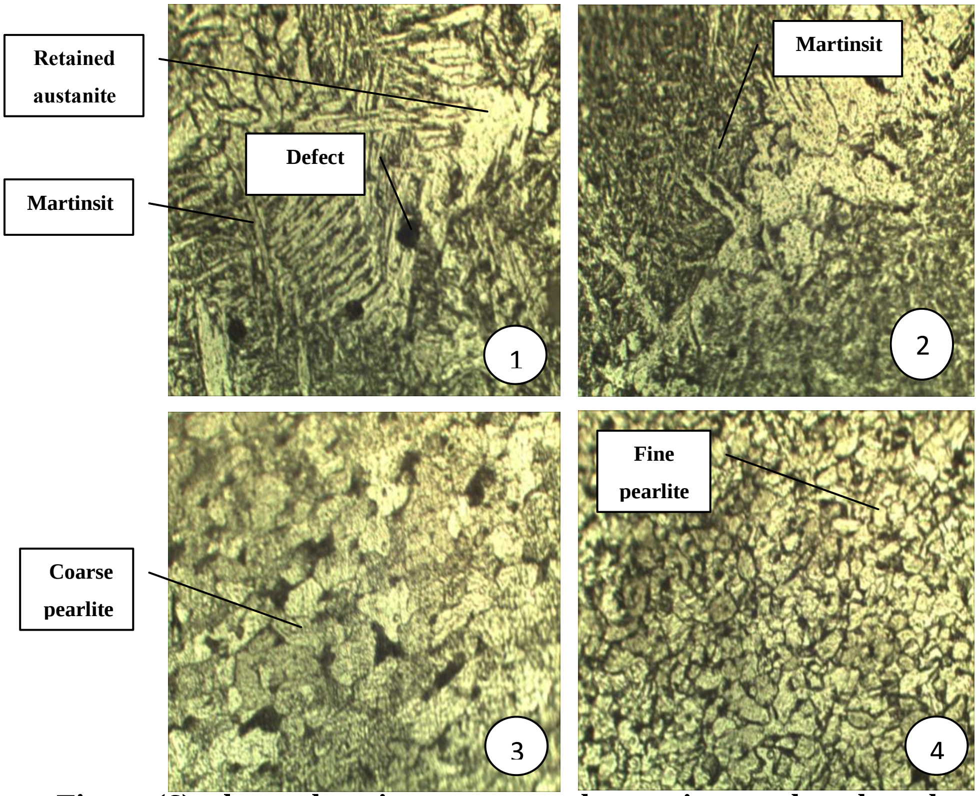

Figure (6): shows the microstructure observations at the selected areas in figure (1)

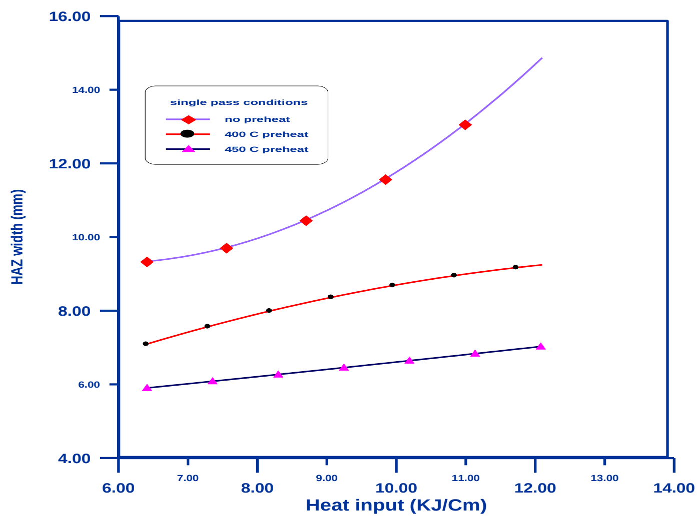

Figure (7): Effect of heat input on the width of HAZ at different pre-heat temperatures in the case of single pass welding

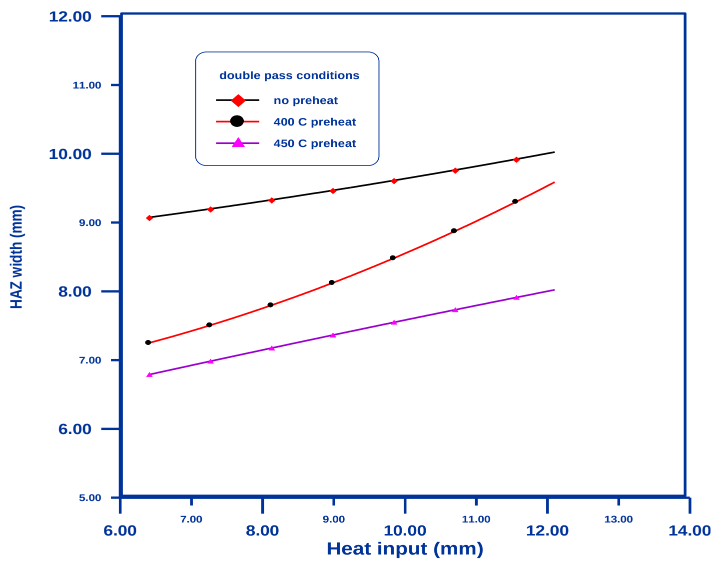

Figure (8): Effect of heat input on the width of HAZ at different pre-heat temperatures in the case of double pass welding

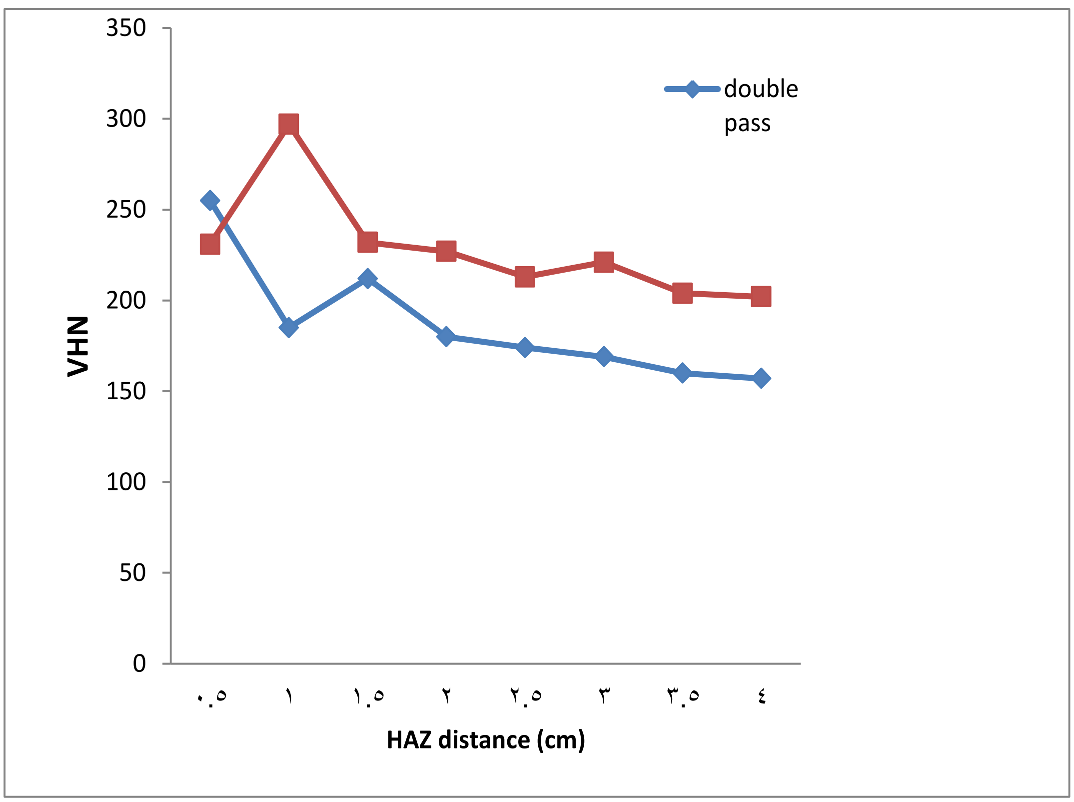

Figure (9): values of hardness numbers along the single and double pass welding staring from the center of joints of A & E joint respectively (at 450° C) preheating temperature