STUDY OF THE MECHANICAL AND METALLURGICAL PROPERTIES OF DISSIMILAR WELDS

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ABSTRACT

In this research dissimilar welds were made of low carbon steel (A516) and austenitic stainless steel (316L) by shielded metal arc welding (SMAW) and with different electrodes (E7018) , (E6013) , (E309L) and (E308L). The sheet thickness (6 mm), welding current (120 A), voltage (78V), polarity (DCRP) and electrode diameter (3.25 mm) were remained constant. Many tests were carried out, mechanical tests included tensile test, bending and microhardness also made , and metallurgical inspections included microstructure, delta- ferrite phase and x- ray diffraction analysis. It was found from tensile and bending tests results that the electrode (E309L) was the most convenient for dissimilar welds of base metal (C.St. A516) and (St. St. 316L). Hardness tests showed that the highest hardness value appears in (HAZ) and there are two peaks of maximum hardness, each peak value in each (HAZ) for both dissimilar metals, the peak values are not equal and the higher value appears in the zone, where the electrode differ from the base metal, i. e. when the electrode is used (E6013) the higher value appeared in the (HAZ) which is near the stainless steel (316L), and when the electrode (E309L) is used, the higher value appeared in (HAZ) near the low carbon steel (A516) .The tests demonstrated that the delta (δ) ferrite phase was about 3-10% near stainless steel and for all used electrodes.

KEY WORDS
SMAW , Dissimilar welds , Microstructure , Mechanical Properties

الخلاصة

تناول البحث انتاج وصلات لملحومات غير متشابهة من الفولاذ منخفض الكاربون (A516) مع الفولاذ مقاوم الصدأ الاوستنايتي (316L) بطريقة لحام القوس الكهربائي المعدني المغلف بالصهيرة (SMAW) باختيار اقطاب لحام مختلفة هي (E308 L, E309L, E6013, E7018) مع ثبات سمك الصفيحة (6 mm) وتيار اللحام (120 Amp) والفولتية (78 volt) والقطبية (DCRP) وقطر قطب اللحام (3.25mm) .تم اجراء فحوصات ميتالورجية مختلفة شملت البنية المجهرية وفحص طور دلتا فبرايت والفحص بحيود الاشعة السينية وكذلك اجريت الاختبارات الميكانيكية ومنها اختبار الشد والحني والصلادة الدقيقة . أظهرت نتائج أختبارات الشد والحني ان القطب (E309L) هو الاكثر ملائمة في لحام الوصلات للملحومات غير

المتشابهة من حيث المعدن الاساس (فولاذ منخفض الكاربون (A516) مع فولاذ مقاوم للصـــدأ (316L)) . اظهرت نتائج الصلادة ان أعلى صلادة هي في المنطقة المتأثرة بالحرارة (HAZ) وقد وصلت الصلادة الى قيم أعلى من منطقة اللحام (W.M) وهذا يعني ظهور قمتين للصلادة العظمى (قمة في كل منطقـــة HAZ) لكلا المعدنين غير المتشابهين وهاتين القمتين غير متساويتين وتكون الصلادة أعلى في الجانب الذي يكون فيه القطب مختلفا عن نوعية المعدن الاساس أي انه عند اللحام بقطب (E6013) اظهــرت القمـــة العليـــا فـــي (HAZ) القريب من الفولاذ مقاوم للصدأ (316 L) ، أما عند اللحام بقطب (E309 L) ظهرت القمة العليـــا في منطقة (HAZ) القريب من الفولاذ منخفض الكاربون في حالة الملحومات غير المتشابهة . أوضحت نتائج الفحص لطور الدلتا فيرايت ان قيمة هذا الطور تتراوح من (3-10) % من جانب الفـــولاذ مقـــاوم الصـــدأ ولجميع الاقطاب المستعملة .

INTRODUCTION

The processes available for joining dissimilar metals are :
Fusion welding include shielded metal arc welding (SMAW), gas metal arc welding (GMAW), gas tungsten arc welding (GTAW) ,and submerged arc welding (SAW).
Electron beam , Laser welding ,and Pulsed arc welding.
Friction, Explosion welding ,Diffusion bonding along with brazing and soldering.

It is possible to weld stainless steel by the majority of the known welding methods, and in spite of the existing of automatic and semi- automatic welding machines, the welding of stainless steel still carried out by manual metal arc welding (MMA) [Boyer and Gall, 1988 - Handbook A.W., 1974]. The same for welding of low carbon steel, it is widely used and easy to weld, all known welding methods can be used depending on work piece thickness and the purpose of welding [ASM, 1983 – Sindo Kou, 2003] . Dissimilar –metal welds (DMWs) can usually be made by any of these methods. DMWs encountered in power and chemical process industries are most often fusion welds made by the more common welding processes. A very common DMW application is joining ferritic (e.g.,2,25%Cr-1% Mo) tubes to austenitic boiler tubes such as 304 H or a similar austenitic stainless steel [Barnhouse, 2004 - Richard, 2003].

The selection of proper welding electrode is very significant for welding of different metals, and of the most important factors in welding processes is to minimize the intermetallic compound which is undesirable, so the electrode have to be compatible with the properties of both welded metals and to be able for precipitation during dilution. Dilution is the degree to which the base metals contributes to the resultant deposit , i. e. the chemical composition of base metal changes as a result of interference or contribution and metallurgical adaptability of the weld metal with two base metals [Barnhouse, 2004 - Richard, 2003] .

The aim of this work is to evaluate the mechanical and metallurgical properties of dissimilar welds of stainless steel (316L) and low carbon steel(A516) welded by SMAW process with different welding electrodes.

EXPERIMENTAL PROCEDURES

Used Materials

The used materials in this research are the low carbon steel (A516) and austenitic stainless steel (AISI 316L), the importance of these metals is very clear, the stainless steel is widely used in chemical, pharmaceutical, food industries, nuclear plants and power generation industries, that low carbon steel is also widely used in engineering industries [Sourmail, 2005-AISI Handbook, 2002] .The chemical composition analysis was performed by using spectrometer type (ARL) in Nasser State Company and the results are shown in Table (1).

Table (1) chemical composition of low carbon steel (A516) and stainless steel (316 L)

Element wt %	Low carbon (A 516)		Stainless steel (316 L)	
	Standard value	Actual value	Standard value	Actual value
C	0.21	0.186	0.03	0.03
Mn	0.6-0.9	0.97	0.5-0.8	0.624
Si	0.13-0.45	0.24	1.00	0.50
Cr	-	0.058	16.0-18.0	16.6
Ni	-	0.023	10-14	8.94
Cu	-	>0.37	-	0.18
Mo	-	<0.005	2-3	3.79
S	0.04	-	0.03<	0.009
Ti	-	0.008	-	0.021
P	0.035	-	0.045	-
Co	-	<0.005	-	0.14
V	-	0.006	-	-
W	-	0.007	-	-
Al	-	0.035	-	-
Nb	-	<0.004	-	0.016
Fe	Rem	Rem	Rem	Rem

Samples Preparation

(1) 6 mm thick plates of low carbon steel (A516) and stainless steel (316L) were prepared and cut with dimensions of (150 × 300) mm, then cleaned by sand blasting to remove lubricant and scales and surface contamination.

(2) The samples then machined on milling machine to prepare joint edges and to produce a taper of 30º on the long side (300 mm), and arranged to make single -V joint, as shown in Figure (1). lt is essential that making pieces to be joined should be carefully aligned for good quality welding.

Welding Process

The dissimilar specimens of low carbon steel (A516) and austenitic stainless steel (316L) were welded by shielded metal arc welding (SMAW) and welding electrodes of (3.25)mm diameter, the voltage (78)volt, welding current of (120) Amp and polarity (DCSP) were remained constant. The electrodes are (E7018 , E6013) of low carbon steel and (E309L , E308L) of stainless steel. So there are four new produced welds on Turkish machine (Nuris RCT 650C) and two passes in weld for each electrode. The Tables (2) and (3) are shown the chemical composition of the stainless steel and low carbon steel electrodes respectively .The welding was performed manually with the welder maintaining control over the arc length and directing the arc into the weld joint .

Table (2) Chemical composition of stainless steel electrodes.

Electrode Type Wt %	C	Cr	Ni	Mo	Mn	Si	P	S	N	Cu	Fe
E308L	0.04	18-21	9-11	0.75	0.5-2.5	0.9	0.04	0.03	0.75	0.75	Rem
E309L	0.04	22-25	12-14	0.75	0.5-2.5	0.9	0.04	0.03	0.75	0.75	Rem

Table (3) Chemical composition of low steel electrodes.

Electrode Type Wt %	C	Mn	P	S	Mo	Si	Ni	Cr	Fe
E6013	0.08	0.39	0.02	0.015	-	0.24	-	-	Rem
E7018	0.045	1.1	0.015	0.14	0.053	0.4	0.0355	0.018	Rem

X- ray Radiography Inspection

All the welded specimens are tested by X- ray radiography to detect the welding defects and to determine success of welding penetration using German apparatus type (Rich Seiferland Co Ahrensberg) in the State Company For Heavy Industries .

Tensile Test

The specimens are prepared and machined for tensile test according to the standard specifications (ASTM – E 8) [ASTM, 1988] as shown in Figure (2) and the tests are carried out using tensile test machine Fritschi Gmb – fpro and mebto onrik (PX – SRG 5000) of capacity 600 KN .

Bending Test

According to the standard specifications ASTM - E190 [ASTM, 1988], The specimens are machined by milling machine for bending test as shown in Figure (3) and the tests are done using the same machine using in tensile test.

Microhardness Test

The hardness was measured by Vickers hardness measurements along the cross – section of welded specimens in three zones weld metal zone (W. M) heat affected zone (HAZ) and the base metal (B. M). The hardness test is done by using apparatus of type (Letz Wetz Germany) and load of (500 gm) for (30 sec). The hardness is measured for both sides of dissimilar welds and at a distance of (1 mm) between one reading and other.

Microstructure Test

The specimens were prepared for microstructure testing according to the following procedures:-

(1) Wet grinding with water and using silicon carbide papers of grades, 220, 320, 400, 600, 800, 1000 and 1200.

(2) Polishing the specimens using polishing cloth and alumina ($A1_2O_3$) solution its grains are of size (5) microns.

(3) Etching process was done by using (Nital) solution , 2% HNO_3 acid and (98% alcohol) for low carbon steel, and for stainless steel the used solution consist of HNO_3 acid (3 ml) , HCl acid (9 ml) , acetic acid (2ml) and glycerin (1ml) . The specimens were immersed in solution for (40-45) sec, then watched by water and alcohol and finally dried.

δ-Ferrite phase Inspection

The valued of delta (**δ**) Ferrite phase (Ferrite No.) was measured in the weld metal (W.M) by using portable ferrite content meter (1.053) equipped with a probe of (1.5 mm) diameter ball. The value of **δ**-Ferrite phase is defined as the attraction force between magnetic probe and the tested area.

Results and Discussion

Microstructure Results

In fusion welding the weld metal is a mixture of the two metals being joined and filler metal. In shielded metal arc welding (SMAW) process welds made with consumable electrodes, the weld mixed or stirred by the arc action and the composition is quite uniform from one area to another. The central mass designated by (W.M)has been melted. It has characteristic dendrite structure of casting. When the dendrites form, the weld metal solidifies and cools from the outside toward and the crystal grow toward the center and segregation of constituent occurs with an alloy [Martti Vilpas, 1999] .

The Figures (4,5,6 and 7) represent the microstructure of dissimilar welds of stainless steel (316L) and low carbon (A516) welded by SMAW process with different electrodes show that the weld metal (W.M) at the interface between the two metals has different microstructure because of elements dilution which is leading to form three basic zones [Barnhouse, 2004 - Richard, 2003] :-

(1) Martensite (the area near low carbon steel).

(2) Austenite + Martensite + Ferrite (the area near the interface of stainless steel (316L)) .

(3) Austenite + Ferrite (weld metal in stainless steel) .

Results of Tensile Test

The Table (4) shows the results of tensile test of the base metal (As received) of stainless steel (316L) and low carbon steel (A516).

The Figure (8) shows the results of tensile test specimens of dissimilar welds of stainless steel (316L) and low carbon steel (A516) welded by (SMAW) process with using different electrodes (E308L, E309L, E7018 and E6013).The highest tensile strength was obtained by using the electrode (E7018) then (E308L), then (E6013) and finally (E309L) respectively and generally they are good results .

Table(4) Tensile test results of the base metal

Base Metal	Tensile Strength (MPa)	Yield Strength (MPa)	El% in (50.8mm)
St.St.316L	558	290	50
C.St.A516	345	193.2	28

Results of Bending Test

Table (5) shows the results of bending test for dissimilar welds of low carbon steel and stainless steel (316 L) at welding conditions (current 120 A , voltage 78 V.

Table (5) The results of bending test

Visual Inspection	Bending Angle (deg.)	Bending Force (k N)	Electrode Type
Accepted	42	22	E 309 L
Failure	125	19	E 308 L
Failure	75	21	E 7018
Failure	40	20.5	E 6013

The electrode (E 309 L) shows good results without cracks [Martti, 1999 - Barton, 1976] but the electrode (E 308 L) failed when the bending force reached (19KN) and the cracks appeared at the angle 125, which means it cannot be used in bending condition .

Richard E. Avery [2003] confirmed these results of mechanical properties of dissimilar metal welding .the properties of the three metals must be considered the two metals being joined and the filler metal used to join them. The weld metal should be equal to or stronger than the weaker material being joined although the American Society of Mechanical Engineers (ASME) code allows a weld stronger of 95% in some cases. Ductility comparable to the metals being joined is desirable but not always possible.

Results of Microhardness Test

It is observed that the dissimilar welds behave in different way than the similar welds . The hardness of dissimilar welds in the weld region is higher than the base metals from both sides (carbon steel (A516) and stainless steel (316L)).

Figure (9) shows that the hardness remains constant in the base metal then it increases in HAZ to reach its maximum value then it deceases till the middle of weld zone which remains constant but higher than the hardness of base metal, and form two maximum value (maximum hardness) in HAZ region .

The results showed also that using of carbon steel electrodes (E6013) causes that the maximum hardness value in HAZ near stainless steel side is higher than that of low carbon steel side. But using of stainless steel electrodes (E308L and E309L) make the maximum hardness value near low carbon steel side, and this is due to formation of martensite phase near low carbon steel side and presence of chromium carbide ($Cr_{23}C_6$) near stainless steel side as indicated by x-ray diffraction results.

Results of δ-Ferrite phase Inspection .

The value of δ-ferrite phase in the weld metal (W.M) and HAZ was measured for dissimilar welds by magnetic tests equipment.

Figure (10) shows the δ-ferrite phase distribution for dissimilar welds of low carbon steel (A516) and stainless steel (316L) welded by SMAW with using different electrodes E309L, E308L, E7018 and E6013. The Figure (10) shows that this value vary between 3-10% in the weld zone which acceptable and necessary to reduce the probability of forming microcracks in the weld zone [Brooks, 1984- Kujanpaa, 1984] , because δ-ferrite phase in this percentage lead to dissolve harmful elements like sulfur , phosphorous and selenium which contribute to form microcracks in the weld zone , so when these elements remain in the solid solution prevent the segregation of impurities and forming of phases with low melting temperature which play an important role in crack forming when the microstructure of stainless steel in the weld zone is completely austenite [Hebble et al, 1985 –ASME, 1989].

Many researchers [Vitek and David, 2003]were improved models for predication of microsegregation and ferrite content in austenitic stainless steel welds and their effects on mechanical properties and corrosion resistance of welds .

CONCLUSIONS

(1) The four electrodes (E308L, E308L , E7018 and E6013) showed good weldability for dissimilar welds of two base metals (low carbon steel and stainless steel) welded by shielded metal arc welding (SMAW) .

(2) Tensile test results show that the fracture of dissimilar welds happen in low carbon steel region (low tensile strength) .

(3) Bending test shows that the best electrode for dissimilar welds is stainless steel electrode (E309L) when using (SMAW) process .

(4) In the dissimilar welds there are two maximum peak (maximum hardness) values of hardness in HAZ .

(5) The value of δ-ferrite phase (Ferrite No.) reached to 3-10% in stainless steel side of dissimilar welds .

REFERENCES

American Society for Metal, Metals Handbook , Vol.6, 9th Edition ,Copyright , 1983.

American Iron and Steel Institute , Welding of Stainless Steel and Other Joining Method , Handbook Series , No.9 , 2002 .

ASTM , Annual Book , Laboratory Corrosion Testing of Metals , 1988.

ASME, Boiler and Pressure Vessel Code, The American Society of Mechanical Engineers, 1989 .

Boyer H.E. and Gall T.L., "Metal Handbook" , Desk Edition , ASM, 1988.

Barnhouse E.J. and Lippold J.C., Microstructure / Property Relationships in Dissimilar Weld Between Duplex Stainless Steel and Carbon Steel , Welding Journal , Vo1.83 , No.1, 2004. PP.205 S - 214S.

Barton N.R. and Lindberg R.A., Welding and Other Joining Processes , By Allyn and Bacon , Inc. 1976 .

Brooks J.A. and Williams J.C., "Fundamentals Study of the Beneficial Effects of δ- Ferrite in Reducing weld Cracking", Welding Journal, Vol. 63, No. 6 ,1984 , p.715.

Hebble T.L., Canonico D.A., Edmonds D.P. and Nan Stand R.K., "Analysis of Delta – Ferrite Data Form Production Welds on Stainless Steel Pipe", Welding Journal, Vol. 64, No. 9, 1985, pp.260S- 265S.

Kujanpaa V. P.,"Weld Discontinuities in Austenitic Stainless Steel Sheet – Effect of Impurities and Solidification Mode", Welding Journal, Vol. 63, No. 12, 1984, pp.369S- 375S.

Martti Vilpas, Predication of Microsegregation and Pitting Corrosion Resistance of Austenitic Stainless Steel Welds by Modeling , VTT Publication , 1999.

Richard E. Avery, "Pay Attention to Dissimilar-Metal Weld" Avery Consulting Associates , Inc.2003, pp.1-6 .

Sindo Kou , "Welding Metallurgy " , 2nd Edition , Wiley Interscience , John Wiley and Sons , Publication , 2003 .

Sourmail T. and Bhadeshia H.K.D.H, ,"Stainless Steel" , University Cambridge , 2005.

The Procedure Handbook of Arc Welding , 12th Edition, The Lincoln Electric Company of Canada , LTD , 1974.

Vitek J. M. and David S. A., "Improved Models for Predicating Ferrite Content in Stainless Steel

Welds", USA, 2003 (internet) .

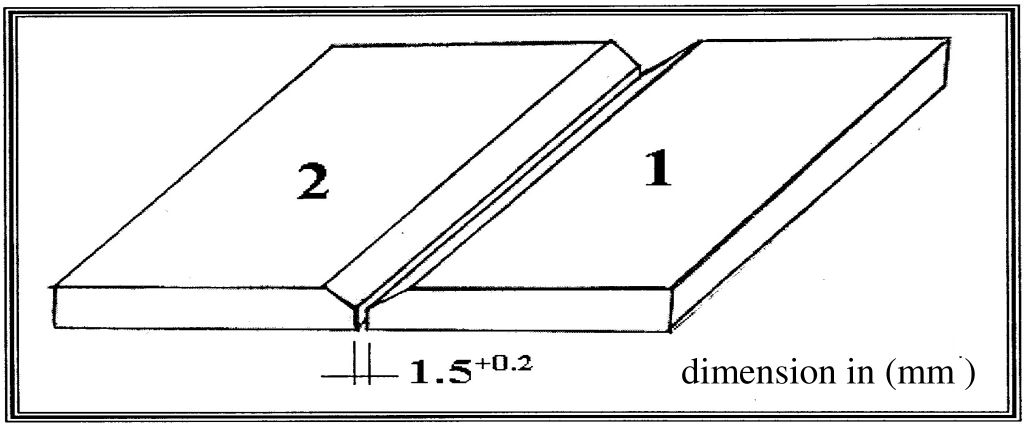

Fig (1) Typical joint design and position of pieces to be welded

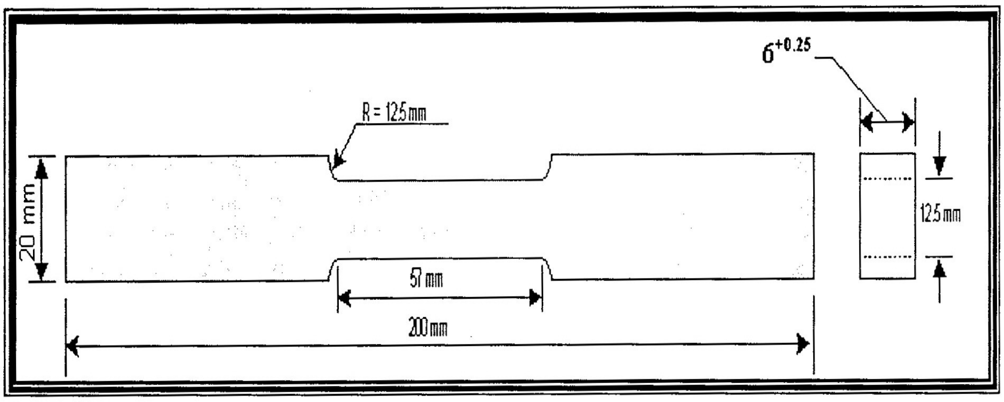

Fig (2) Tensile test specimen according to ASTM Standard (All dimensions in (mm))

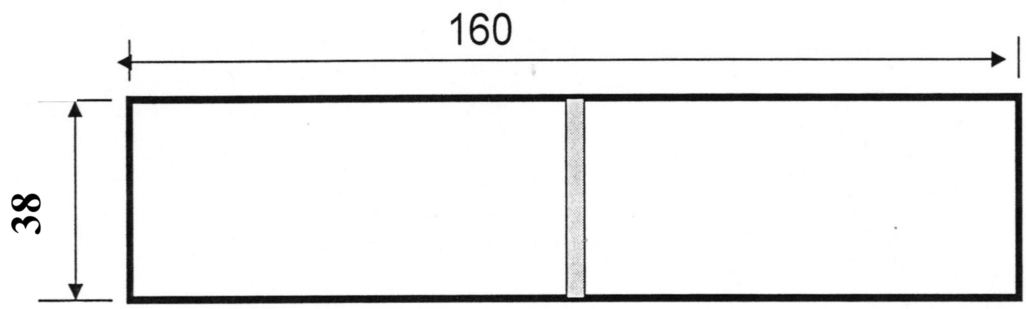

Fig (3) Bending test specimen according to ASTM Standard
(All dimensions in (mm))

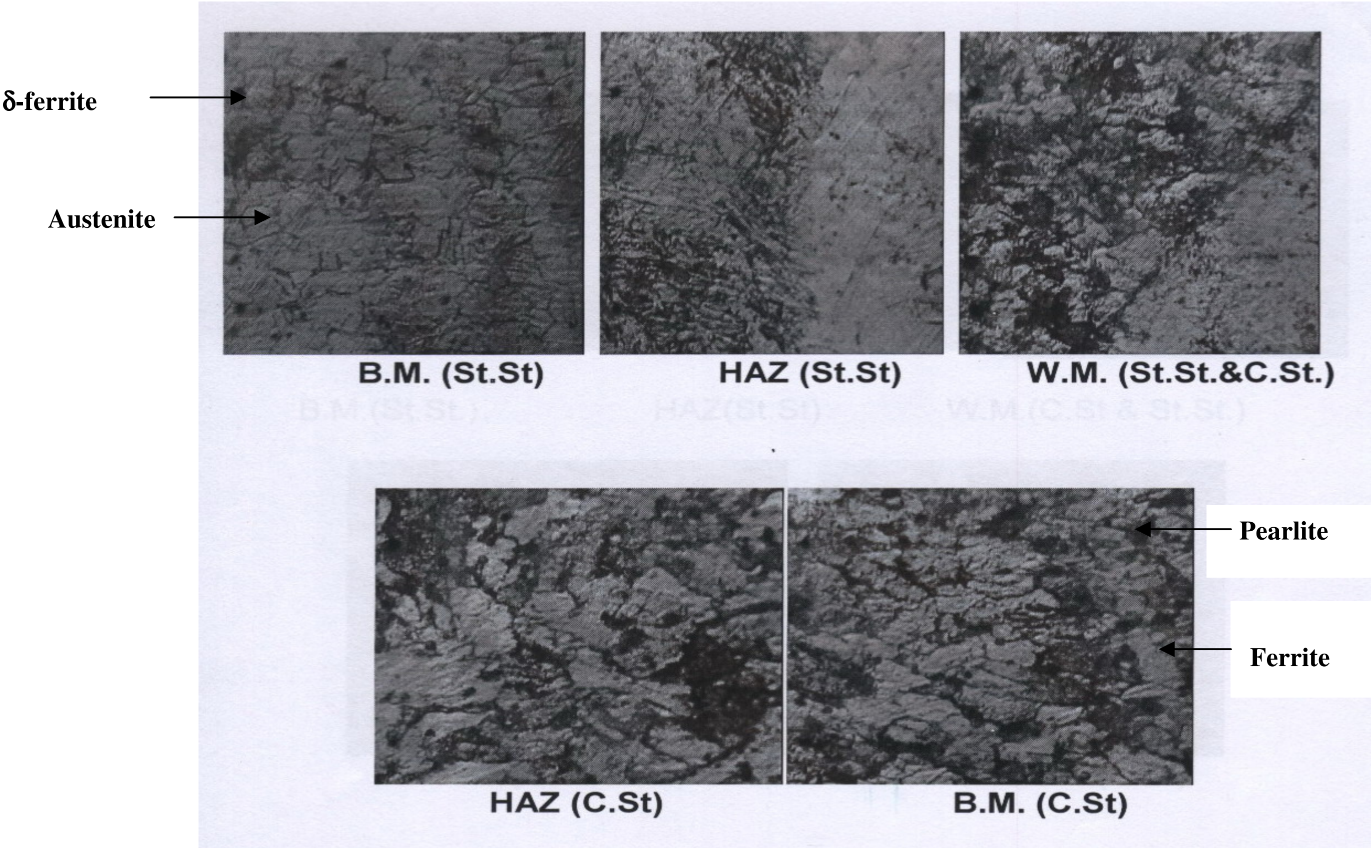

Fig (4) Microstructure of dissimilar welds of (C. St and St St) welded by SMAW using electrode (E 7018). 250x

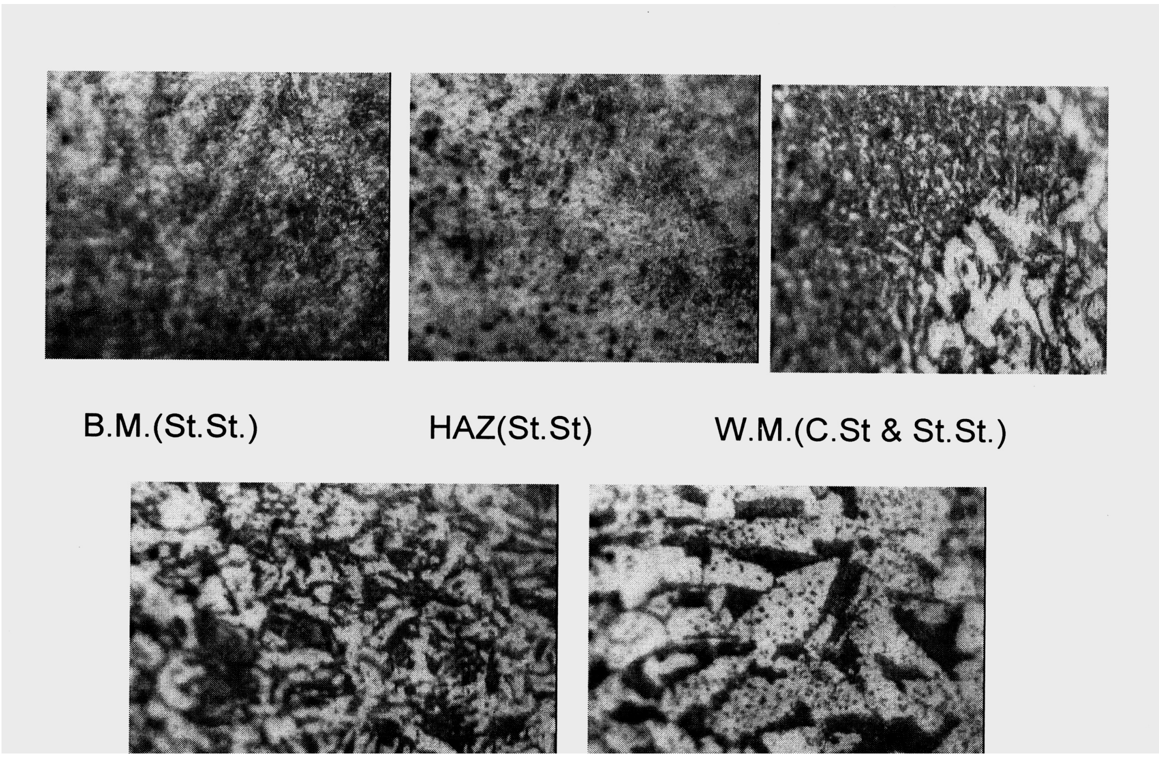

Fig (5) Microstructure of dissimilar welds of (C. St and St St) welded by SMAW using electrode (E 6013). 250x

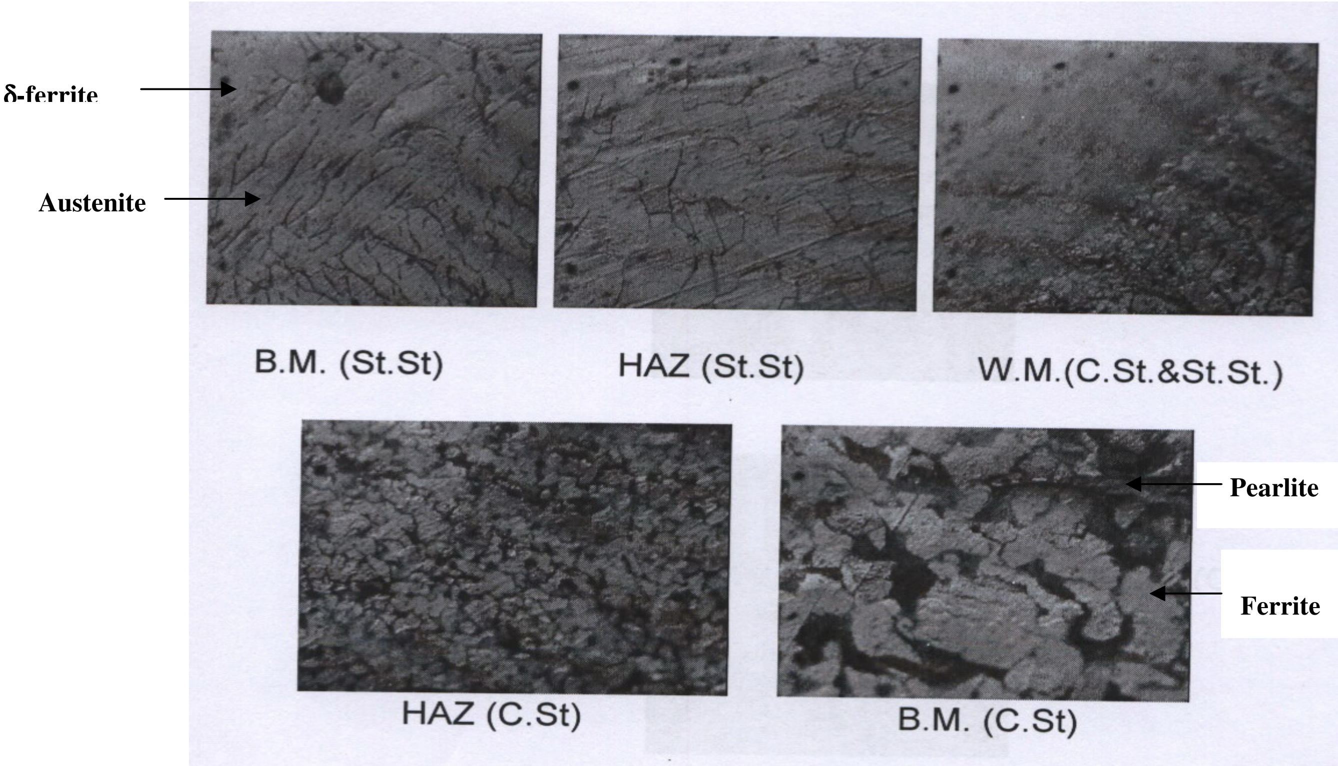

Fig (6) Microstructure of dissimilar welds of (C. St and St St) welded by SMAW using electrode (E309 L). 250x

W.M (C.St.&St.St) | HAZ(C.St) | B.M.(C.St)

Fig (7) Microstructure of dissimilar welds of (C.St and St St) welded by SMAW using electrode(E 308 L). 250x

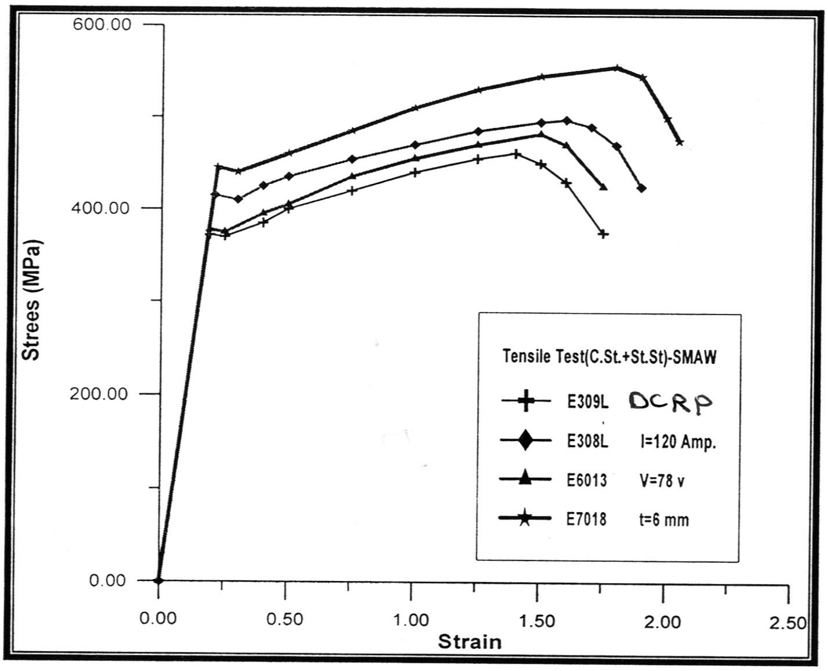

Fig (8) Stress – strain curves of dissimilar welds of stainless steel (316 L) and low carbon steel (A 516) welded by (SMAW) using different welding electrodes .

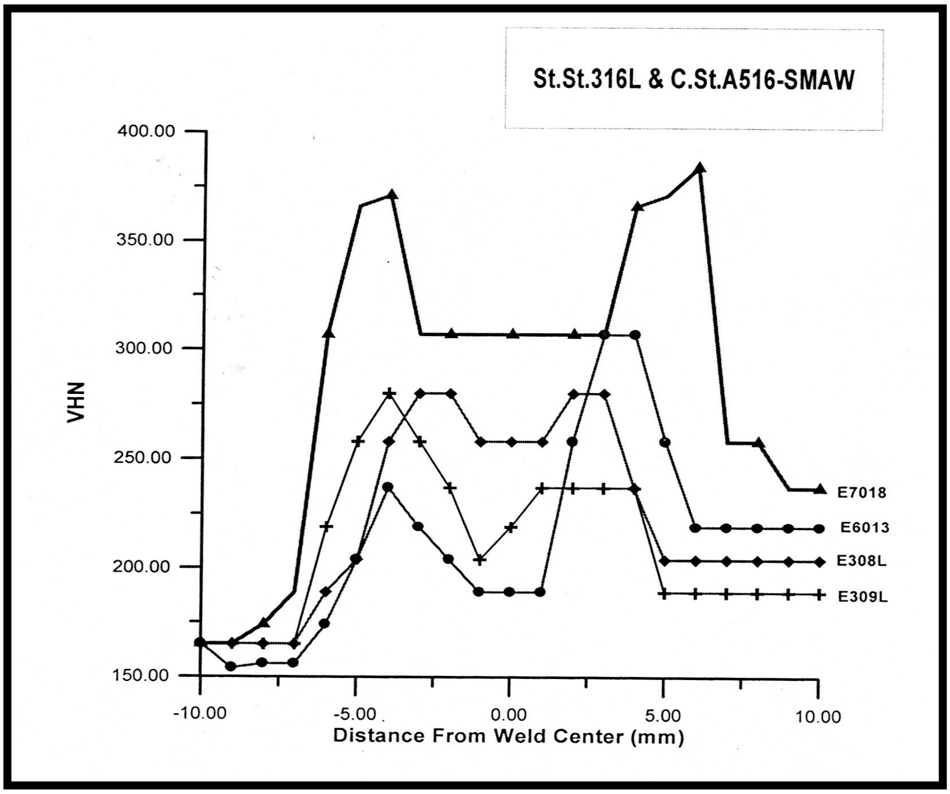

Fig (9) Relationship between microhardness and distance from weld center of dissimilar welds of stainless steel (316 L) and low carbon steel (A 516) welded by SMAW using different welding electrodes

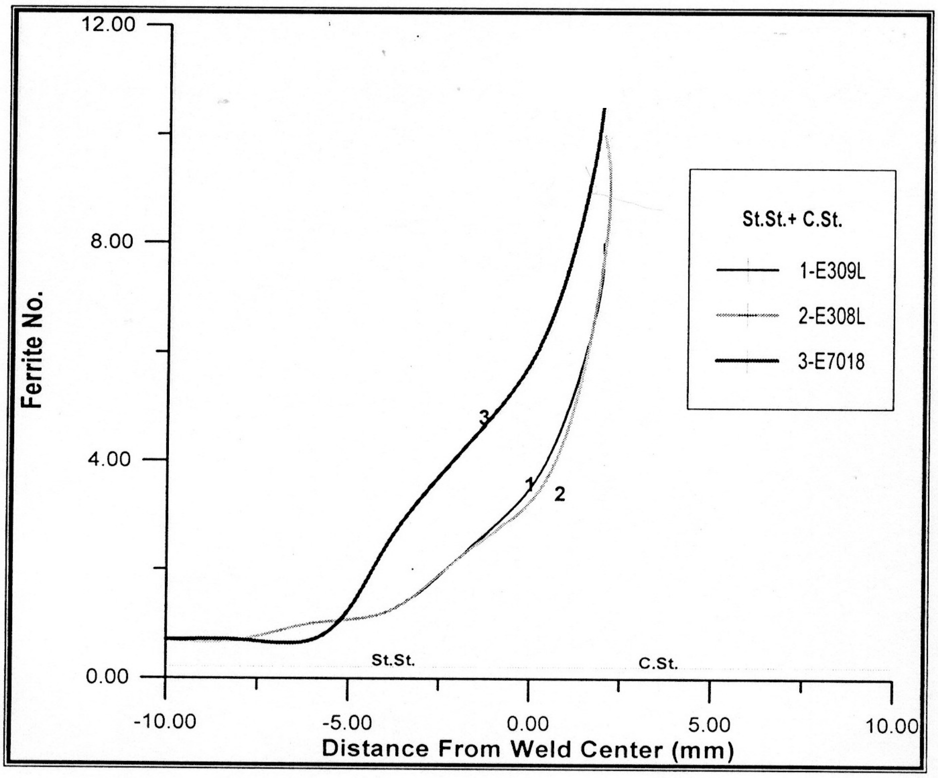

Fig (10) Shows distribution of δ- ferrite phase of dissimilar welds (St. St (316L) and C. St. (A516)) welded by SMAW using different welding electrodes