STUDY THE MICROSTRUCTURE OF WELDING JOINT OF DISSIMILAR METALS

Abdul wahab H. Khuder **Esam J. Ebraheam**

Department of Welding Engineering/ Technical College Baghdad

SUMMARY:

The aim of this work is to study the microstructure of welding joint of dissimilar metals, stainless steel to low carbon steel that is thickness (4mm) for both by using the metal active gas (MAG) spot welding process. The welding wire (E80S-G) is used and have (1.2mm) diameter depend of (AWS), and Co_2 gas is used as shielded gas with flow rate (7L/min) for all times used in this work.

In this work, we select many samples from the welding joints from welding region and heat effective zone, these samples will change in there welding from the welding time, current and the wire feed. A different region that represents regions of joint interface between the two metals, and heat effected zone we noted that. The ratio of pearlite in low carbon steel more than in base metal and the ratio of ferrite is less than in parent metals. Furthermore, the microstructure of stainless steel has no change as compact with low carbon steel because most of heat concentrated in the low carbon steel.

Key words: Microstructure of Weldment, Weldment of Dissimilar Metals.

1. INTRODUCTION:

Carbon steel and low alloy steel bare electrodes and welding rods are available for uses with the gas metal arc welding process. The electrodes are classified on the basic of chemical composition and mechanical properties of the undiluted weld metal.

Shielding gas commonly use for gas metal arc welding (GMAW) of carbon selection depending on the electrodes composition and the type of the metal transfer. Generally carbon dioxide shielding is suitable for low carbon and wild steel [1].

The weld ability is defined as a capable of the metal and alloy to weld with others and employ once welding methods to purpose of production good life and free from defects. Weld ability of stainless steel not take only mechanical properties but take chemical properties which important in corrosion resistance because reaction which can be among chromium, carbon and (oxygen) in high temperature during welding generally most maybe weld stainless steel by weld method which known. The important factor affection the weld is the carbon equivalent (C.E):-

$$C.E = C + Mn / 6 + (Cr + Mo + V) / 5 + (Ni + Cu) /15 \qquad \ldots\ldots (1)$$

And alloying elements have advantage of the weld ability like:-

1. Increase the strength ability.
2. Improve resistance and mechanical properties at elevated temperature.
3. Increase corrosion resistance.
4. Increase fraction resistance [1, 2].

2. GAS METAL ARC WELDING (GMAW):

Is once of welding process that uses an arc between a continuous filler metal electrode and weld metal, as shown in figure (1) the MIG/MAG equipment .

The process is used with shielding from an externally supplied gas and without the application of a pressure it was developed in the late 1940, for welding aluminum and has became very popular this is process also called metal in arc gas (MIG) welding .There are many variation depending on the type of shielding gas the type of the metal transfer the type of the metal welded , and so in it has been given many names for example (MIG Welding , Co_2 welding , Fin wire welding ,Spray arc welding , Pals arc welding ,Dip transfer welding , Short circuit arc welding , and various trade names) [3].

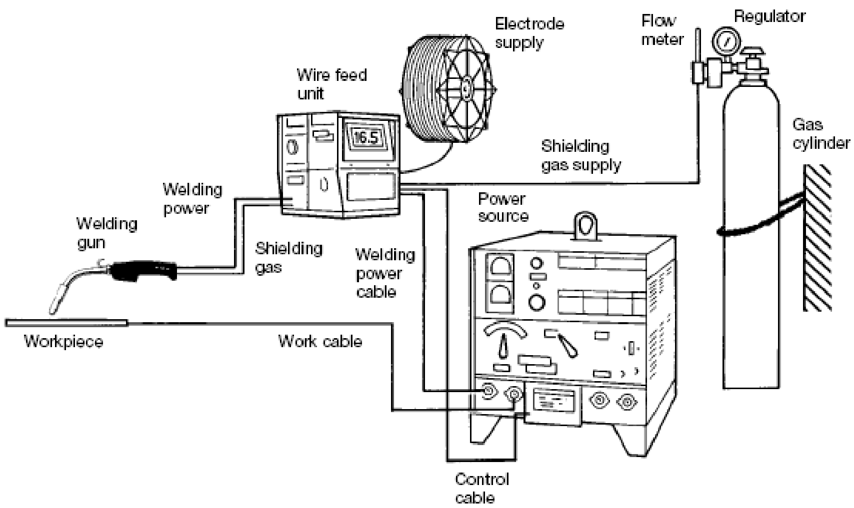

Figure (1) showing the MIG/MAG equipment [2].

When gas metal arc welding was first developed, it was considered to be fundamentally a high- current density, small diameter, bare metal electrodes process using an inert gas for arc shielding its primary application was for welding aluminum as a result, the term metal inert gas (MIG) was used and is still the most common reference for the process. Subsequent development include operation at low current densities and pulse direct current application to a broader range of materials, and the use of reactive gases (particularly CO_2) or gas mixtures. This latter development has lead to formal acceptance of the term gas metal arc welding (GMAW) for the process because both inert and reactive gases are used. Gas metal arc welding is operated in semi automatic machine and automatic modes; it is utilized particularly in high production welding operation. All commercially important such as carbon steel, stainless steel, aluminum and copper can be welded with this process in all positions by choosing the appropriate shielding gas, electrodes and welding conditions [3].

3. GAS METAL ARC SPOT WELDING:

The essential differences between conventional GMAW and gas metal arc spot welding are:-

1. No movement of the gun during spot welding.
2. The weld time is actively short period of no more than a few second.

The process is used to spot weld two overlapped sheet and into the other , and to tack weld other types of joint together the process can be used in the same manner as resistance spot welding. Build steel, stainless steel, and aluminum are commonly spot weld with the process.The weld is made by placing the welding gun on the joint so the spot weld will be made of the proper locution , the gun is held motionless when the trigger is depressed shielding gas flow is initiated. After a pre-flow interval, the electrode feed is energized and the arc starts .at the completion of a preset weld time. The welding current and electrodes feed are stopped. Finally gas flow stops automatically. Because of the inherent differences in the weld shape of convention welds and spot welds, the effects of the variables involved should be reviewed so that better understanding of the process will be obtained [3,4].

4. WELDING VARIABLES EFFECT:

4.1 Welding Current:

The welding current is a direct function of the electrode feed rate and has a major influence on weld metal penetration. Penetration increases approximately as the square of the current with CO_2 spot welding. Increasing the penetration will generally produce a larger diameter weld at the interface between steel and consequently greater weld shear strength virtually all gas metal arc spot welding is carried out with direct current reverse polarity, although straight polarity can be used under special conditions [6].

4.2 Welding Time:

The duration of welding current has an important effect on penetration and weld size at the interface. Penetration increases with weld time at a decreasing rate to a limiting value which depends on the current .Voltage and electrode also, the weld reinforcement height increases with weld time. Control of the weld time is best provided with an electronic timer. even with the most consistent timers, however the actual weld time can vary considerably because an arc is not always initiated the instant the advancing electrode touches the work surface sometimes the electrode causing the wire to melt and from a momentary arc, which is often of short duration stubbing of the wire electrode can occur several times before an arc is finally established. Unfortunately during this period little or no heating of the base metal is realized. In consistent weld time can be overcome by use of a control that does not time the weld period until the arc voltage reaches a preset value [6].

4.3 Arc Voltage:

The arc voltage is indirectly a measure of the arc length and consequently has a major bearing on the shape of the arc spot. If the welding amperage is maintained constant, an increase in arc voltage will cause the weld diameter at the interface to increase and the reinforcement height and penetration metal peat nation to decrease slight if the arc voltage is too high, heavy spatter is likely to occur. Also, insufficient arc voltage may result in the formation of a depression in center of reinforcement and inadequate fusion at the edge of weld [6].

4.4 Electrode Size:

The electrode size is selected on basis of the pant thickness being welded.
A sin conventional gas metal arc welding, there is an overlap of the properties electrode wire feeder must also be considered for electrode size selection [6].

4.5 Shielding Gas:

The shielding gases for arc spot welding are selected by using the same criteria as those employed for continuous welding. arc characteristic , filler metal transfer, weld penetration, weld shape , material joined , and cost arc all important factors to be considered in shielding gas selection the shielding gas performs the same function as in continues gas metal arc welding , but a flow rate of (25 – 50)% of that normally using is sat is factory [6,7].

4.6 Joint Design:

Gas metal arc spot welding is applicable to all the materials welded with process. Many weld joint types are used, with slight modification of the shielding gas nozzle design, including lap fillet (inside corner or edge of lap joint), corner (outside corner) and plug welds for best results. The top member should be no thicker than the bottom member is lap joint; if the top member must be thicker then the bottom one, plug welding should be used in plug welding care must be taken to insure complete penetration into the base plate and also into the side walls of the top member [7].

4.7 Welding Position:

Vertical and overhead arc spot welds can be made successfully on sheets up to (1.3mm) thick, to weld out position. The short circuiting made of metal transfer must generally be used. Spot welding of heaver gage material is usually restricted to the flat position because of the influence of gravity on the molten weld pool [7].

4.8 Weld Quality:

All of the above welding variables have an influence to varying degrees on the quality of weld. They should be controlled as much as possible, but in addition, good practice suggests that the resultant weld quality should be monitored directly. Unfortunately the shape and the size of weld reinforcement is not a reliable indication of weld size one inspection technique involves examining the back side of the join for slight melt ,through or bump indicating adequate penetration however when the back side is in accessible or the gage combination is not favorable , periodic destructive testing of welded coupons is the only dependable way to assess weld quality this may be done with tension - shear test to determine the spot weld strength or be metallographic examination to determine the weld size and soundness [7].

4.9 Dissimilar Metals:

Most combinations of dissimilar metals can be joined by solid state welding brazing, or soldering where alloying between the metals is normally insignificant, in these cases only the differences in the physical and mechanical properties of the base metals and their influence on the service ability of the joint should be considered. When dissimilar metals are joined by a fusion welding process alloying between the base metal and a filler metal ,when used becomes a major consideration the resulting weld metal can be have significantly different from one or base metals during subsequent processing or in service.

A combination of metals with significantly different chemical, mechanical and physical properties can easily problems during and after welding the combination can be two different base metals or three different metals one of which is a filler metal .The resulting weld metal composition will differ from that of any of the components, and can vary with the joint design welding process , filler metal, and the welding procedure .Consequently these factors and also any thermal treatment of the weldment must be established and properly evaluated prior to production the major pool of dissimilar metal welding should be produce a weldment that meets the intended service requirements[8].

5. METALLOGRAPHIC:

Metallographic or microscopy consists of the structural characteristics of a metal or an alloy. The microscope is by for the most important tool of the metallurgist from both the scientific and technical stand points; it is possible to determine grain size and the size shape and distribution of various phases and inclusion which have a great effect on the mechanical properties of the metal. The microstructure will reveal the mechanical and thermal treatment of the metal, and it may possible to predict has expected behavior under a given set of conditions. Experience has indicated that success in microscope study depends largely upon the care taken in the preparation of the specimens [5].

5.1 Sampling:

The choice of a sample for microscope study may be vary important. If a failure is chosen as close as possible to the area of failure is compared with one taken from the normal section [5].

5.2 Rough Grinding:

Whenever possible the specimen should be of a size that is convenient to handle a soft sample may be made flat by slowly moving it up and back across the surface of a flat smooth file. The soft or hard specimen may be rough ground on a belt sander. With the specimen kept cool by frequent dropping in water during the grinding operation. In all grinding and polishing operation the specimen should be moved perpendicular of the finer abrasive the rough grinding is continued until the surface is flat and nicks, burrs, etc, and all scratches due to the hacksaw or cutoff wheel are no longer visible [5].

5.3 Mounting:

Specimens that are small or awkwardly shaped should be facilitate intermediate and final polishing wires, small, rods, sheet metal specimens, than sections etc, must be appropriately mounted in a suitable material or rigidly clamped in a mechanical mount .Synthetic plastic materials applied in special mounting press will yield mounts of uniform convenient size (usually 2.5mm, 3mm, 3.6mm, in diameter) for handing subsequent polishing operation. These mounts when properly made are very resistant to attack by the etching reagents ordinarily used. The most common thermosetting resin for mounting is Bakelite. Bakelite madding powders are available in a variety of colors, which simplified the identification of mounted specimens, the specimen and the correct amount of Bakelite powder or a Bakelite perform are placed in the cylinder of the mounting press. The temperature is gradually raised to (150°C) and a molding pressure of about (4.000psi) is applied simultaneously. Since, Bakelite is set and cured when this temperature is reached the specimen mount may be ejected from the molding die while it is still hot.

Lucite is the most common thermoplastic resin for mounting. Lucite is completely transparent when properly molded. This transparency is useful when it is necessary to observe the exact section that is being polished or when it is desirable for any other reason to see the entire specimen in the mount. The thermoplastic resins do not under go curing at the molding temperature rather they set on cooling. The specimen and a proper a mount of Lucite powder are placed in the mounting press are subjected to the same temperature and pressure as for Bakelite (150°C) and (4.000psi) after this temperature has been reached, the heating coil is removed. And cooling fins are placed around the cylinder to cool the amount to below (75°C) in about (7min.) while the molding pressure is maintained. Then the mount may be ejected from the mold. Ejecting the mount while still hot or allowing it to cool slowly in the molding cylinder to ordinary temperature before ejection will cause the mount to be opaque. Small specimen may be conveniently mounted for metallographic preparation in a laboratory made clamping device. Thin sheet specimens when mounted in such clamping device are usually alternated with metal "filler" sheets which have approximately the same hardness as the specimen. The use of filler sheets will preserve surface irregularities of the specimen and will prevent to some extent the edges of the specimen from becoming rounded during polishing [6].

5.4 Polishing:

After mounting, the specimen is polished on a series of emery papers containing successively finer abrasive. The surface after intermediate polishing operations using emery paper is usually done dry; however in certain cases such as the preparation of soft materials, silicon carbide abrasive may be used. As compared to emery paper, silicon carbide has a greater removal rate and, as it is resin-bonded, can be used with a lubricant. Using a lubricant prevents overheating the sample, minimizes smearing of soft metals, and also provides a rinsing action to flush away surface removal products so the paper will not become clogged. The time consumed and the success of fine polishing depend largely upon the care that was exercised during the previous polishing steps .The final approximation to a flat scratching - free surface is obtained by the use of a wet rotating wheel covered with a special cloth that is charged with carefully sized abrasive particles a wide rage of abrasives is available for final polishing, there appears to be a preference for the gamma from of aluminum oxide for ferrous and copper based materials, and cerium oxide for aluminum magnesium, and their alloys. Other final polishing abrasives often used are diamond paste, chromium oxide, and magnesium oxide. The choice of a proper polishing cloth depending upon the particular metallographic study. Many cloths are available of varying nap or pile, from those having no pile, such as broad cloth, billiard cloth and canvas duck, and finally to a deep pile, such as velvet [7].

5.5 Etching:

The purpose of etching is to make visible the many structural characteristics of the metal or alloy. The process must be such that the various parts of the microstructure may be clearly differentiated. This is accomplished by use of an appropriate reagent which subjects the polished surface to chemical action the selection of the appropriate etching reagent is determined by the metal or alloy and the specific structure desired for viewing [7, 8].

6. EXPERIMENTAL WORK:

6.1 Materials Descriptions and Specimens Preparations:

The material used are a sheet of stainless steel that is thickness (4mm), and the low carbon steel of thickness (4mm). Table (1) & (2) are showing the chemical compositions and some mechanical properties of materials used.

Table (1) Chemical compositions of the alloy used.

Specimen Materials	Composition wt %								
	C	Mn	Si	P	S	Cr	Ni	Mo	Bal.
Stainless Steel	0.02	0.95	0.9	0.01	0.01	18	11.5	2.6	66.01
Low Carbon Steel	0.05	0.7	0.9	0.03	0.025	-	-	-	98.29

Table (2) Mechanical properties of the alloy used.

	Specimen Materials	
Mechanical Properties	Low Carbon Steel	Stainless Steel
Tensile Strength (N/mm2)	460	610
Yield Strength (N/mm2)	415	430
Elongation%	27	40
Hardness (HRB)	60	75

6.2 Welding Wire:

The type of welding wire used is (E80SG) have (1.2mm) diameter depend of (AWS), table (3) showing the chemical compositions and properties of this type of wire.

Table (3) Chemical compositions of the welding wire used.

Elements	C	Si	Mn	Mo	P	S	Cr	Ni	N	Cu	Co
Weight %	0.08	0.99	1.65	2.6	0.012	0.013	18.5	12	0.05	0.1	0.05

Yield strength = 560 MPa.
Tensile strength = (530 – 650) MPa.
Impact strength = 47J.
Elongation = 26%.

6.3 Shielded Gas:

The type of the shielded gas used in welding is Co_2 with flow rate (7L/min) for all times.

6.4 Procedure Operation for Welding Process:

1) Clean surface from gasses and oxide.
2) Preparation torch and suitable angle (90°).
3) The orifice of the torch should be suitable with the gas flow.
4) Fixed parts good from and limit suitable over lap distance.
5) Use direct current reverse polarity during welding.
6) Prepare the flow rate in the (7L/min).

6.5 Preparation the Specimens to Microstructure Examination:

To study the microstructure of the joint welding, we select specimens from the welding joints from welding region and adjacent. The specimen has some changing in found mental of process, like the current and welding time and feed wire, table (4) shown the specimens and there characteristics and the steps of preparation are:-

1. Cutting:

Cutting specimens from welding joints by using manual cutter with cooling water to prevent the effect of heat.

2. Cleaning:

Cleaning the faces of specimens after cutting process by using Alcohol.

3. Mounting:

The mounting of specimens by cold mounting, by using resin and hardener with using die and small face from class we mixed the resin and hardener and full this mixture on the die with covering the specimens, and leave it is to solidification to some minutes about (15min).

4. Grinding:

The grinding of specimens by using many grinding papers (200, 400, 800, and 1200) µm with rotated the specimens with (90^{o}) after each stage, to remove the lines of grinding.

5. Polishing:

Polishing done by using cloth and Alumina (Al_2O_3) to polish the face, and washes by water and alcohol.

6. Etching:

Using etchant solution that its composition, [50ml HCl + 50ml Ethanol + 2.5gm $CuCl_2$].

Table (4) Shows the specimens and there characteristics.

Specimens No.	Current (amp)	Spot Diameter (mm)	Time (sec)	Wire Feed (cm/min)
1	200	7.7	1.5	127
2	200	7.25	3	127
3	220	9.2	1.5	204
4	240	11.15	3	204
5	240	9.85	1.5	204

This specimens welding with flow rate of gas is (7L/min).

7. RESULTS AND DISCUSSIONS:

The structure of welded joints does not homogenous and its form from many region that is weld metal and its structure like or as cast, and heat effected zone it has metal structure is heat treble and the last the region of base metal its part not affected by heat prom joint. The process to carbon steel by stainless steel on of the important protection process to carbon steel surface from corrosion the structure of weld metal insulator limit between two metals it was different in microstructure. Because dilution in region of insulator limit between metals that is consist of three base regions:-

1) Pure martensite (in region near from carbon steel).
2) Austenite + Martensite + Ferrite (in region near from the insulator limit from side the stainless steel).

3) Austensite + Ferrite (in region welding of stainless steel).

7.1 Base Metals:

7.1.1 Stainless Steel (316L):

Figure (2) represents the base metal of stainless steel without welding, which is ferrite and pearlite structure with lens power (X 125).

7.1.2 Low Carbon Steel:

Figure (3) represents the base metal of low carbon steel, which is ferrite and pearlite structure with lens power (X 125).

7.2 Specimens (1):

This specimen is welded by using the current welding (200Amp) and the time welding (1.5sec) and wire feed (127cm/min). A different region that represent regions of start of joint and interface between the two metals, and heat effected zone we noted that, for figure (4) shown start of joint for two metals region (steel and stainless steel) which is weak region of welding and non completes joint because it is the start of joining between two metals. Figure (5) that shown joint region of weld metal ,and we find the ratio of pearlite in low carbon steel more than the ratio in base metal of low carbon steel, and the ratio of ferrite is less than in parent metal. The (β and α) interface with each other in the weld metal.

The microstructure of stainless steel has no change as compact with low carbon steel because most of heat concentrated in the low carbon steel. Figure (6), represent the line of joint between two metals and show the regions (WM, HAZ of two metals), and we noted some of impurities. Figure (7); show the weakness of joint and space in start joint.

7.3 Specimens (2):

This specimen is welded by current (200 Amp) and the time welding (3 sec) and wire feed (127cm/min).Figure (8), show the joint with appearance for the region of steel, there is blank point that is may be impurities or oxide that we noted it with large amount in this specimen only be cause oxidation is occur because it is generated in steel only or its impurities generated during welding processes. Figure (9), shows the heat affected zone for stainless steel.

Figure (10) showing the interface between the two metals and noted clearly the two metals; also we noted impurities or oxide in both metals. Figure (11), which shows the region of heat affected zone for stainless steel that we noted the change in its structure especially near the (WM).Figure (12), shows the interface the heat effected zone with the (WM) for the two metals and we noted percentage of the precipitation of pearlite because the time welding is increasing.

7.4 Specimens (3):

This specimen is welded with current (220 Amp), and welding time (1.5sec), with wire feed (204cm/min).Figures (13) & (14), represents the regions of the interface and the (WM) for the two metals (steel & stainless steel) and noted that some percentage of ferrite in the (WM).

Figure (15), show the heat affected zone of stainless steel, and the region of heat affected zone is less affected by heating of welding. Figure (16); show the (WM) for the two metals with noted large amount of ferrite in the (WM) more than the pearlite.

7.5 Specimens (4):

This specimen is welded with current (240 Amp), and welding time (3sec), and wire feed (204 cm/min).Figure (17), shows the (WM) & heat effected zone for stainless steel and we noted that the (WM) is contain a high amount of pearlite because the use for high current (240 Amp) and high speed of wire feed (204 cm/min).Figure (18), shows the start of the joining between the stainless steel and the steel and we note that the space in the start of the joint spot with some amount of impurities. Figures (19) & (20), shows the different shapes for the welding joint and we noted some of impurities concentration between the two metals.

7.6 Specimens (5):

The specimen welded by current (240 Amp) ,and welding time (1.5 sec) and wire feed (204 cm/min).Figure (21), shows the (WM) region to stainless steel and steel, we note increasing amount of pearlite in steel. Figure (22), shown the interface and joint between the two metals and filler metal precipitate, because of the increasing in wire feed noted the filler metal in clearance and noted amount from pearlite precipitate on filler region.

Figures (23) & (24), these figures shown joint between two metals and with noted the two metals are interfaced and no heat affected zone found, because low time and amount of heat input is little and increasing wire feed. Figure (25), shows the interface between two metals and appearance amount from pearlite more than ferrite in (WM).

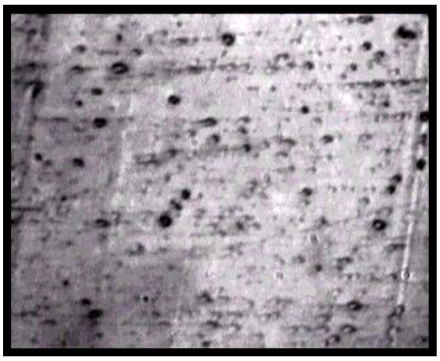

Figure (2) St. St. (Base metal) (X125)

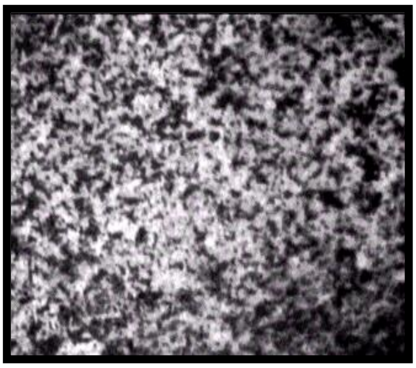

Figure (3) St. (Base metal) (X125)

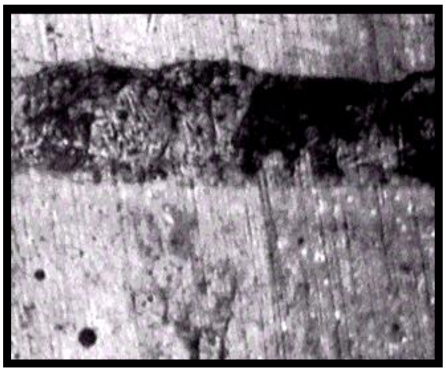

Figure (4) joint of the two metals (X125)

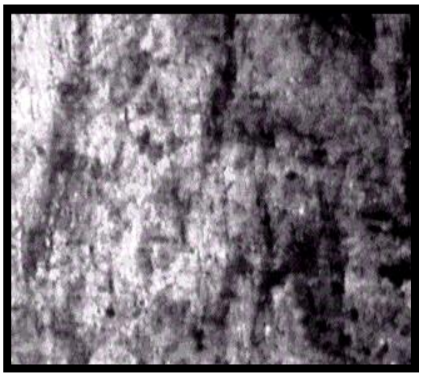

Figure (5) WM of the two metals (X125)

Figure (6) joint of St. to St. St. (X125)

Figure (7) the leak of joint between St. & St. St. (X125)

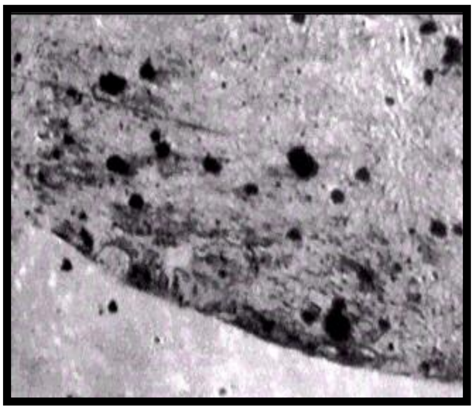

Figure (8) the area of joint of St. (X125)

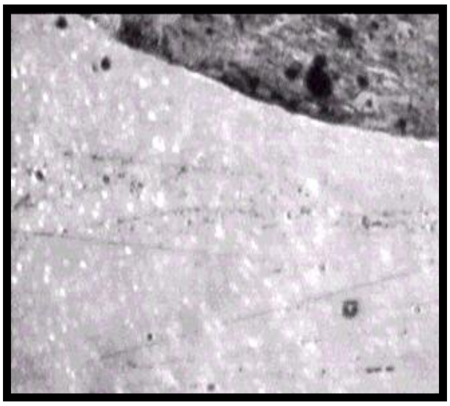

Figure (9) the HAZ of St. St. (X125)

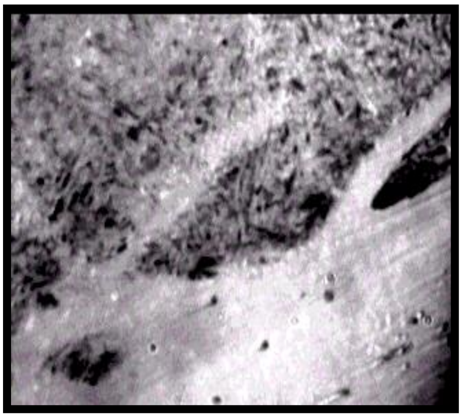

Figure (10) fusion between St. & St. St. (X125)

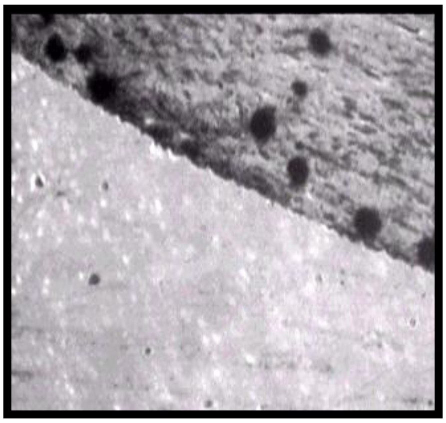

Figure (11) the region of HAZ of St. St. (X125)

Figure (12) the HAZ with the MW (X 125)

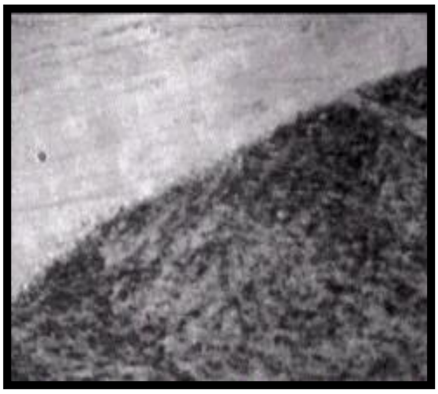

Figure (13) weld joint of St. to St. St. (X 125)

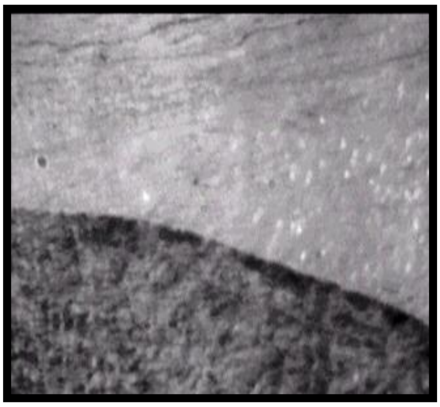

Figure (14) joint of two metals St. & St. St. (X125)

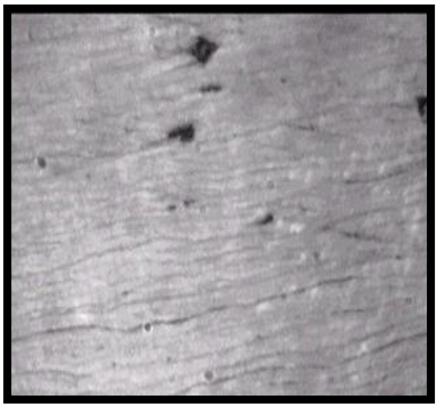

Figure (15) the HAZ of St. St. (X125)

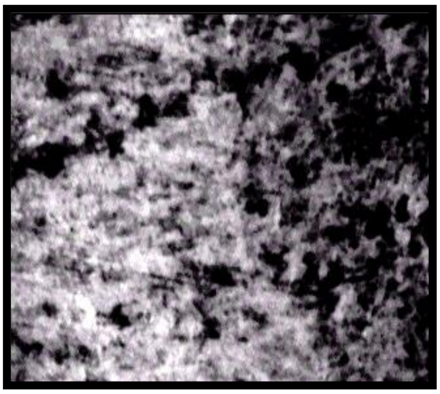

Figure (16) WM of St. & St. St. (X125)

Figure (17) MW and HAZ of St. St. (X125)

Figure (18) joining between the two metals (X125)

Figure (19) joint of St. to St. St. (X125)

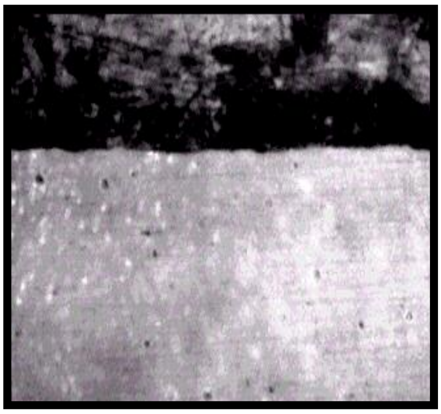

Figure (20) joint of St. to St. St. (X125)

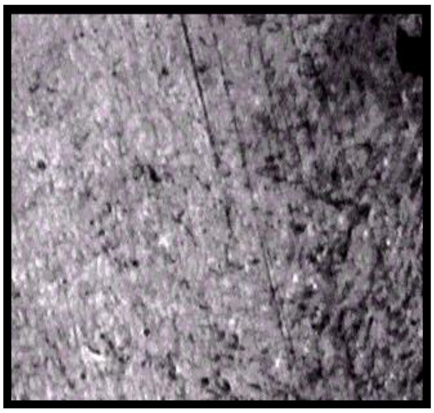

Figure (21) WM reign of St. & St. St. (X125)

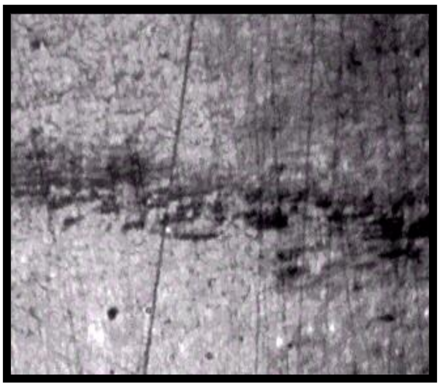

Figure (22) joint of St. & St. St. (X125)

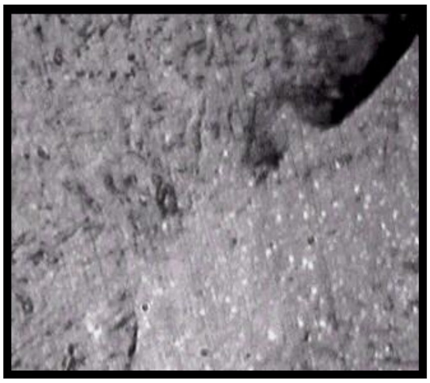

Figure (23) joint of St. to St. St. (X125)

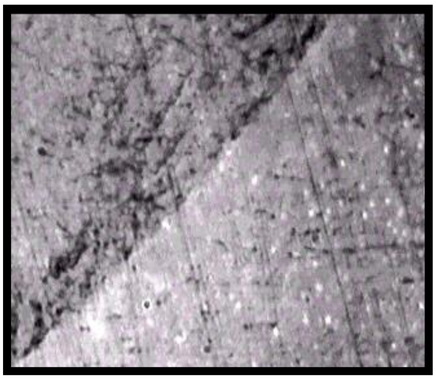

Figure (23) joint of St. to St. St. (X125)

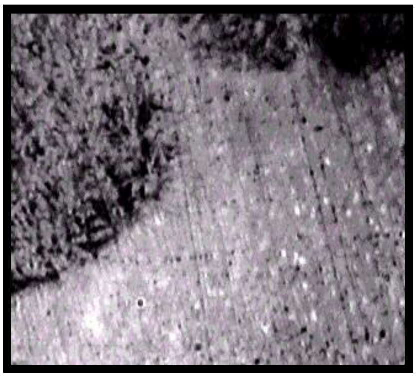

Figure (25) the two metals St. & St. St. (X125)

8. CONCLUSIONS:

1. The ratio of pearlite in low carbon steel more than in base metal and the ratio of ferrite is less than in parent metal.

2. The heat effected zone (HAZ) with the weld metal (WM) for the two metals and we noted percentage of the precipitation of pearlite because the time welding is increasing to three second.

3. The WM for the two metals with noted large amount of ferrite in the weld metal (WM) more than the pearlite.

4. The weld metal (WM) is containing a high amount of pearlite because the use for high current (240Amp) and high speed of wire feed (204cm/min).

5. The two metals are interfaced and no heat affected zone found, because low time and amount of heat input is little and increasing wire feed.

6. The increasing current lead to increase of pearlite in (WM).

7. The region of heat affected zone of stainless steel, which effected directly with increasing the current and noted precipitation large amount of the pearlite due to the increasing of the current.

8. The percentage of the pearlite increased more than the ferrite due to increase the heat input rate by increased the current, but we noted no increasing in pearlite, although increasing in current because low time and increasing in wire feed.

9. The microstructure of stainless steel has no change as compact with low carbon steel because most of heat concentrated in the low carbon steel.

9. REFERENCES:

[1] American Welding Society, “Metals and There Weld Ability”, Welding Hand Book, American Welding Society, 1984.

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

[3] American Welding Society, “Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding”, American Welding Society, Inc.1999.

[4] H.B. Cary, "Modern Welding Technology", 5th Edition, Prentice-Hall, 2002.

[5] Donald R. Askeland & Pradeep P. Phule, “The Science and Engineering of Materials", Thomson Brooks & Cole, 2004.

[6] S.W.Gibson, "Advanced Welding", Macmillan Press LTD, 1997.

[7] Materials "Specification for welding rods, electrodes, and filler metal" (ASME 1998).

[8] ASM "Mechanical Testing and Evaluation", ASM International Handbook Committee, Vol. 8, 2000.

[9] Stuart W. Gibson, "Advance Welding" Macmillan an press LTD, 1997.

[10] John C. Lippold & Damian J. Kotecki ,“Welding Metallurgy and Weldability of Stainless Steels”, John Wiley & Sons Inc., Hoboken, New Jersey, 2005.

[11] Sindo Kou "Welding Metallurgy", 2nd Edition, John Wiley & Sons Inc., 2003.

[12] Andrzej Sluzalec, "Theory of Thermo Mechanical Process in Welding" Technical University of Czestochowa, Poland, Netherlands, 2005.