Investigation on Mechanical Properties of Austenitic Stainless-Steel Pipes Welded by TIG Method

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Abstract

This paper investigates the mechanical properties of austenitic stainless steel (type 204) pipes welded by Tungsten Inert Gas (TIG) welding process. Testing of hardness (HRC), tensile strength and bending strength was performed for the steel pipes welded at two different welding temperatures (700 °C and 900 °C) with and without using the weld filler wire. The microstructure of the welding regions was examined by using an optical microscopy. The properties showed that the steel pipes welded by 900 °C with using the weld filler obtained the highest tensile strength and bending strength versus these welded by 700 °C without the use of the weld filler. This is attributed to the weld filler heated and melt at sufficient temperature (900 °C) and compensate losing in the Ni metal occurred in the base steel metal during the welding process.

Keywords: Mechanical properties; stainless steel; pipes; TIG welding

الخلاصه

هذا البحث يدرس الخواص الميكانيكية للأنابيب الفولاذية الاوستنايتي (نوع 204) الملحومة بطريقة اللحام بغاز التنغستن الخامل. اجريت فحوصات اختبار الصلادة روكويل C، قوة الشد وقوة الانحناء لأنابيب الصلب الملحومة بدرجتين مختلفتين من درجة حرارة اللحام 700 درجة مئوية و900 درجة مئوية مع وبدون استخدام حشوة اللحام. كذلك تم إجراء فحص البنية المجهرية لمناطق اللحام. أظهرت الخصائص أن اللحامات الفولاذية المكتملة عند 900 درجة مئوية مع استخدام حشوة اللحام أعلى مقاومة شد ومقاومة انحناء مقارنة بتلك الملحومة بدرجة 700 بدون حشوة اللحام ويعزى ذلك الى ان حشوة اللحام انصهرت بدرجة حرارة كافية وقد ملئت النقص الحاصل لمعدن النيكل في المادة الاساس اثناء فترة اللحام.

الكلمات المفتاحية: الخواص الميكانيكية، الفولاذ المقاوم للصدأ، الانابيب، اللحام بالغاز الخامل.

1. Introduction.

Stainless steels (S.S.) are Iron-Chromium-Nickel (Fe-Cr-Ni) based alloys with a low carbon content. The S.S. is a highly resistant to corrosion in many chemical environments. The existence of Cr in the steel gives its good corrosion-resistance that is named rustproof or stainless. If the Cr is less than the critical content of 10.5 %, the corrosion resistance of the stainless steel is lost upon heating since the carbon (C) cannot combine with the Cr to form chromium carbide (Cr_2O_3). The existence of Cr in the steel as well as nickel and molybdenum allows the formation of a passive adherent layer of Cr_2O_3 on the steel surface, which is transparent, impervious, and corrosion resistant in a variety of atmospheres such as the ambient environment (William Callister and Rethwisch ,2014).

Stainless steels are classified based on the dominant phase constituent of the microstructure into five grades; they are austenitic stainless steel, martensitic stainless steel, ferritic stainless steel, austenoferritic or duplex stainless steel and precipitation-hardened. Three parameters determining the best selection of these grades of stainless steels for a particular application. They are corrosion resistance property, the mechanical strength required for choosing structural applications, and the capability of the stainless steel to be fabricated, cold worked and welded. In brief, the austenitic stainless steel alloys consider as the best corrosion resistant for its high Cr and Ni contents and so they are produced in high quantities. These alloys are categorized according to the American Iron & Steel Institute (AISI) into three series: AISI 200 series i.e., Fe-Cr-Ni-Mn alloys, AISI 300 series i.e., Fe-Cr-Ni alloys; and Nitrogen-strengthened series i.e., Fe with N added to the AISI series. The AISI 200 austenitic steels are higher strength, lower cost and excellent low temperature properties compared to the AISI 300 austenitic steels, which allow the higher production rates of the AISI 200 steels. In general, the AISI 200 stainless steels and the used 204 alloy sort of are used for applications; their primary requirements are corrosion resistance and higher toughness such as sinks and saucepans, fasteners, shafts, and piping for processing food and processing chemicals and dairy products as well as servicing in seawater equipment (François ,2008).

Welding is normally used to fabricate the stainless steel, and care must be considered for selection of the steel series and selection of the welding process and parameters. For instance, during welding some alloys may be “sensitized” which makes them susceptible to corrosion. Some alloys during welding combine enhanced welding properties in addition to high strength. Among many welding processes used to weld the stainless steels such plasma welding, fusion welding, etc.; an arc tungsten inert gas (TIG) fusion welding or gas tungsten arc welding (GTAW) is commonly used to weld stainless steels and other non-ferrous metals or alloys. In the TIG method, the steel workpieces are joined by the non-consumable tungsten electrode and with/without the use of welding filler wire. The welding filler is heated to an adequate high temperature in order to melt and form a joint between the steel parts after solidification. The weld (fusion joint) area and tungsten electrode are shielded (protected) from atmospheric contamination or oxidation by an inert argon gas. Upon changing the current power supply of welding, extra energy is produced, which is passed through the arc for stronger and good quality welds.

The appropriate filler materials and welding parameters must be chosen to compensate for material loss during melting and avoid the generation of some welding defects such as dilutions, micro-cracks, secondary phase formation and segregation in the stainless steel weldments. Hence, several studies have been conducted to assess the mechanical properties and phase formation for the steel weldments via using different over-alloyed wire rods and different welding processing parameters. For example, (Ramkumar *et.al.,* 2012) investigated the weldability and mechanical properties of welding of Monel 400 and AISI 304 austenitic steel by using TIG welding method with the use of two different welding filler wires. It was revealed that using different filler materials considerably changed the mechanical properties and changing the behavior of weld zone and base metal for hot corrosion. Later, (Lee and Chang,2014) did a comparison study between the mechanical properties and the residual stresses for welded pipes from duplex stainless steel and austenitic stainless steel. It was concluded that austenitic stainless steel pipes produce much higher residual stresses with wider welding regions. Also, the behavior of welding of Monel 400 and AISI 904 Ferritic stainless steels by gas tungsten arc welding (GTAW) and four various filler metals (NiCrMo-4, NiCrMo-10, NiCrMo-14, and NiCu-7) was determined by (Ramkumar *et.al.,* 2016). It was observed that migrated grain boundaries are formed at the weld zone of Monel 400 structure and a partially melted zone (PMZ) also observed at the interface region with the use of ERNiCrMo-4 filler wire. Using a filler with high Ni-Mo content showed a higher hardness in the fusion (weld) zones versus the base metal, and this is ascribed to the presence of V and Ti in the filler, which precipitates in the weld zone. Nevertheless, to the best of our knowledge, there is no one considering the role of changing welding temperature on the mechanical properties of the AISI 204 stainless steel. Hence, this study investigates the effect of using two welding temperatures (700 °C and 900 °C) of TIG welding technique with and without using of filler wire on the mechanical properties of welded pipes of 204-grade stainless steel.

2. Experimental part

2.1. Materials used

The AISI 204 stainless steel pipes having a diameter of 50 mm and thickness of 1.5 mm (see **Fig 1)** were used in this study. The chemical composition of the used pipes is shown in **Table 1**.

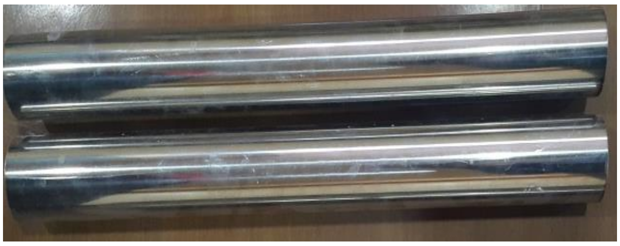


Fig. 1. Stainless steel pipes used in the study.

Table 1. Chemical composition of stainless steel pipes used in the study

% C	% Si	% Mn	% P	% S	% Cr	% Mo	% Ni	% Al	% Co
0.089	0.39	11.78	0.003	0.002	13.61	0.03	1.12	0.011	0.19
% Cu	% Nb	% Ti	% V	% W	% Pb	% Sn	% Zr	% B	% Fe
1.32	0.016	0.021	0.13	< 0.04	< 0.04	0.002	0.023	0.0005	71.3

2.2. Welding process

Tungsten inert gas (TIG) fusion welding technique shown in **Fig. 2** was used to complete the welding process of the stainless steel pipes. Argon gas was depended as a shielding gas. Welding filler named NiCrMo-16 (full chemical composition illustrated in **Table 2**) with a diameter of 1 mm (1/24 inch) was used as a wire metal to compensate the material loss during the welding process. Tungsten alloy having an ISO class of WL20 was used as TIG welding electrode. The electrode's head colored blue and its diameter and length of 1.5 mm and 120 mm, respectively.

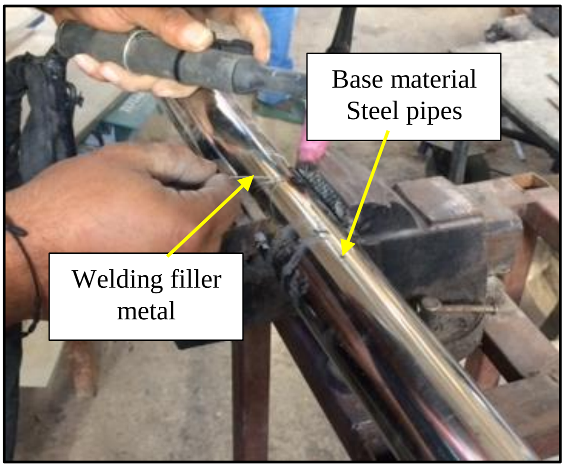


Fig. 2. Welding technique used in the study.

Two different welding temperatures of 700 °C and 900 °C were adapted with maintaining the current and power supply in order to investigate which temperature is sufficient to heat and melt the welding filler and base material. These temperatures were determined based on the phase diagram of the used 204-grade austenitic stainless steel.

Table 2. Chemical composition of welding filler wire used in the study

% C	% Si	% Mn	% P	% S	% Cr	% Mo	% Fe	% Al	% Co
0.015	0.04	0.55	0.004	0.005	15.55	16.15	5.5	0.02	2.2
% Cu	% Nb	% Ti	% V	% W	% Pb	% Sn	% Zr	% B	% Ni
0.45	0.02	0.03	0.17	3.65	0.05	0.02	0.03	0.004	Balance

2.3. Testing and method.

A number of mechanical tests viz hardness, tensile strength and bending strength tests as well as microstructure examination were performed in this study. The designated specimens required to complete these tests were cut from the welded steel pipes shown in **Fig. 3**.

Fig. 3. Samples of the welded pipes after cutting the testing specimens.

2.3.1. Hardness Test.

Hardness test of the base steel metal and three zones (weld zone, interface and heat affected zone, HAZ) of the welded pipes was performed according to Rockwell C (HRC) as shown in **Fig. 4**. To complete this test, a load of 150 kg and a diamond sphere-conical indenter were used.

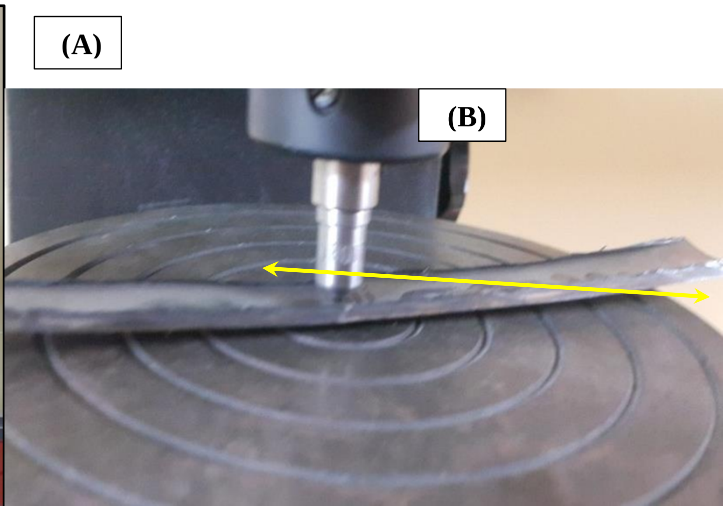


Fig. 4. Hardness test machine (A), and the testing sample under the diamond indenter (B).

2.3.2. Tensile Test.

The tensile strength test of the base metal and four different samples of the welded pipes as described in **Table 3** was carried out. The tensile testing samples were cut off through the welding area of the welded pipes. The welding area was maintained in the middle of the length of the prepared samples.

Table 3. Description of four welding parameters used in the study

Sample code	Description
700 W	The pipes welded by TIG welding method at 700 °C welding temperature without using of the welding filler metal.
700 F	The pipes welded at 700 °C with the use of welding filler metal.
900 W	The pipes welded at 900 °C without using of the filler metal.
900 F	The pipes welded at 900 °C with the use of filler metal.

2.3.3. Bending Test.

The bending strength test of the base metal and four different welded pipes (700 W, 700 F, 900 W, and 900 F) was performed. The prepared welded samples are shown in **Fig. 5**, and three-point load was applied.

Fig. 5. Four different samples of the welded pipes (interior view) for the 3-point bending test.

2.3.4. Microstructure Examination.

The microstructural changes of the steel pipes welded by TIG technique at two different welding temperature were examined by Olympus light microscopy (model BX51). The samples were cut into small pieces including the weld zone and the regions surrounded it. Thereafter, the specimens were fixed in a plastic (epoxy) mold and rapidly immersed in a pre-prepared appearance solution named Aqua regia prepared of 1 ml Nitric Acid (HNO_3) and 3 ml Hydraulic Acid (HCL).

3. Results and Discussion.

3.1. Hardness Test.

Rockwell C (HRC) hardness test was conducted for the weld (fusion) zone and the regions around it in both sides (left and right): fusion zone-interface zone-heat affected zone (HAZ) - base metal in order to determine the effect of using two different temperatures (700 °C & 900 °C) and determine the effect of using the weld wire on the hardness values. **Figure 6** shows the HRC values for the welded pipes that is clearly indicating that the pipes welded by 900 °C whether with the use of the weld wire or not had the lowest values of HRC. The HRC values were 13 and 18 for the 900 W and 900 F, respectively, and this is likely due to the relative higher temperature of 900 °C tends to precipitate more Ni and Cr metals on the boundaries and precipitate more carbide during welding (Ramkumar *et.al.*, 2016). To reduce the precipitation extent of carbide, attention must be taken in the selection of welding temperature between 425 and 815 °C, especially with stainless steel alloys. The intended temperature requires for welding a specific austenitic steel likely does not require preheat or post heat. In addition, shielding (covering) the welding zone by an inert gas (argon) as a protective atmosphere by TIG technique could also reduce the precipitation of carbide (Lakshminarayanan and Balasubramanian,2010; Elmer *et.al.*, 2017).

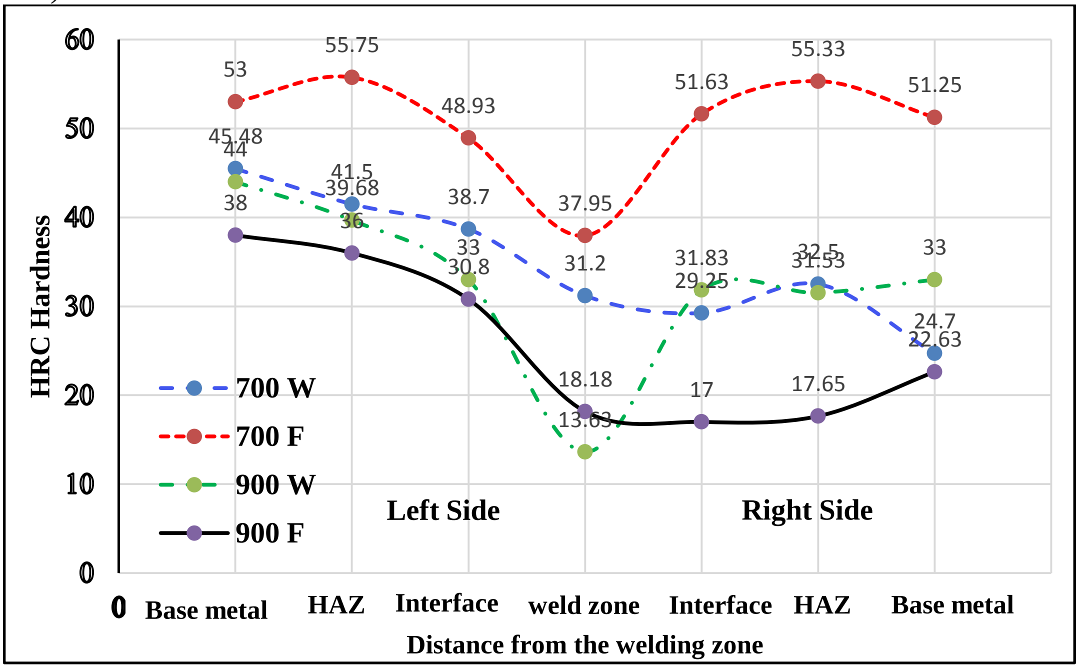


Fig. 6. Hardness (HRC) values for the welded steel pipes.

3.2. Tensile test.

Tensile strength is an important mechanical test that is necessary in most industrial applications, especially steel pipes used in the chemical, petrochemical and food industries. In this study, the tensile strength was conducted as an average of three tests for each of four groups (700 W, 700 F, 900 W, and 900 F) welded pipes. The tensile test specimens were cut from the welded pipes according to the standard specifications. The load-displacement curves for the base metal and the other welded steel pipes are plot in **Fig. 7**. It is observed that the base metal carried a maximum ultimate load is 30.1 KN before fracturing and the 900 F pipes next with a maximum load of 25.6 KN, while the 700 W steel pipes carried the lowest load of 15.9 KN. This gives a yield strength of 845 MPa and a tensile strength of 1003 MPa for the base metal; 735 MPa and 867 MPa for the 900 F steel pipes and 465 MPa and 533 MPa for the 700 W steel pipes as listed in **Table 4**. This is attributed to the weld wire used in the study heated and melt at adequate temperature which is 900 °C and thereby filled (compensate) losing of the alloying elements (Ni and Cr) occurred during the welding process. Hence, the 900 °C welding temperature with the use of weld wire can be considered as a typical temperature versus the 700 °C to complete the welding process of the steel pipes with a good tensile strength. **Figure 8** shows the tensile test samples before and after the breakage. Due to the excessive penetration that is sufficient to cause a spread of the molten region outside the protection of the inert gas, it is obvious to generate a wide welding pool (zone) in the pipes welded (see **Fig. 5**) with the use of welding wire.

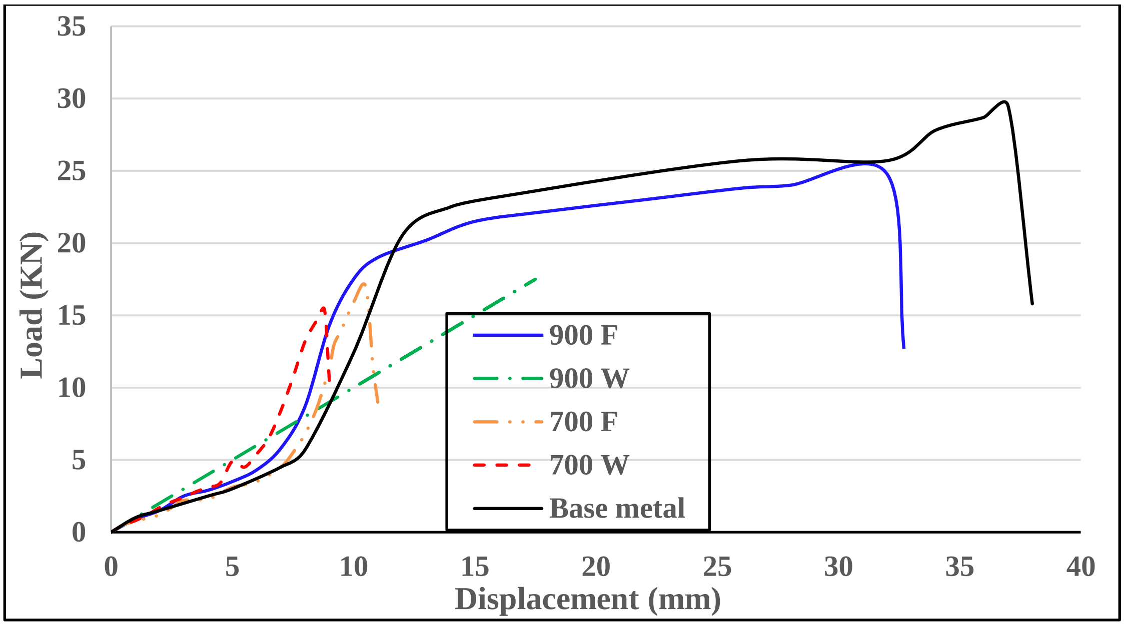


Fig. 7. The load-displacement curves for the base steel and four different steel pipes (700 W, 700 F, 900 W, and 900 F).

Table 4. Mechanical properties of the base steel and four steel welded pipes**.**

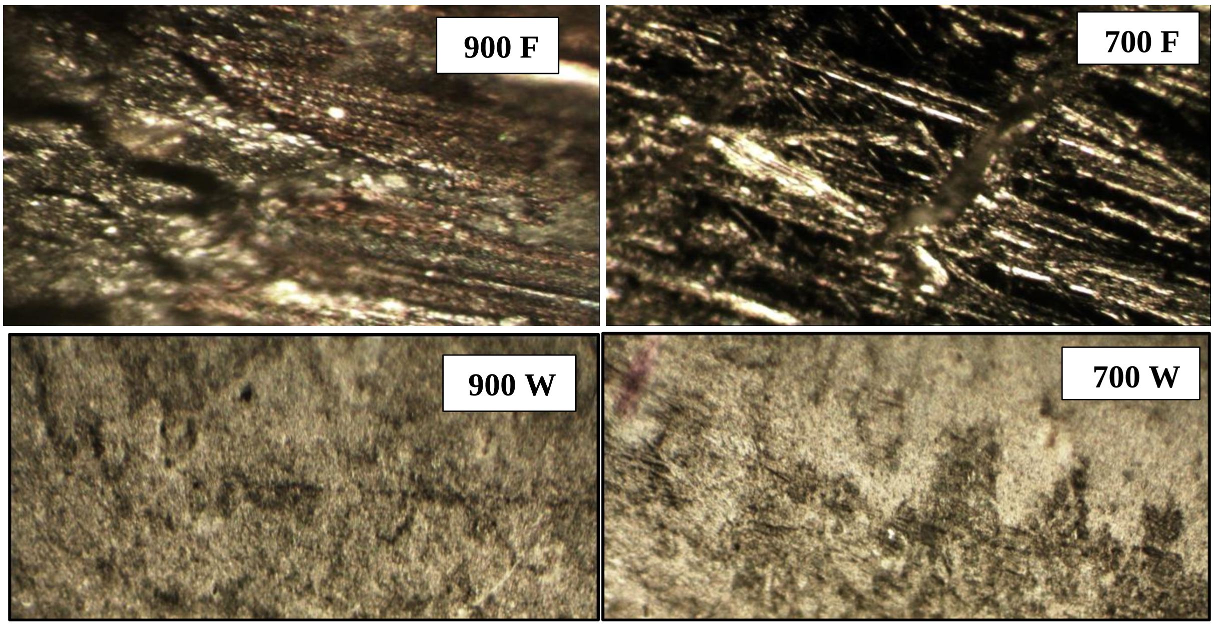
Sample code	Yield strength (MPa)	Tensile strength (MPa)	Young Modulus (GPa)	Bending strength (MPa)	Ductility (%)
Base metal	845	1003	2.59	500	38
700 W	465	533	5.3	267	9
700 F	480	566	5.8	817	10
900 W	470	550	5.83	750	10
900 F	735	867	2.58	633	32

Fig. 8. Tensile specimens before and after fracturing.

3.3. Bending strength test.

Bending (or flexural) strength is an important test for all materials in general and steel pipes in particular. This paper uses a three-point bending test to investigate the bending strength of the base steel pipes and the pipes welded by two different degrees (700 °C & 900 °C) with and without the weld wire. **Table 4** involves the bending strength values and **Fig. 9** shows the bending specimens after applying the load. In general, covering the welding area by an inert gas (like argon) may contribute in a very good ductility where this works to hold the welding zone in alignment to chill the due to limiting the heat area. At 900 °C or any elevated temperature around this, works to form fully austenite structure (as shown in **Fig. 10**) in Austenitic stainless steel. Upon cooling to ambient temperature, an undesirable one microstructural "martensite" maybe produced which is so brittle and susceptible to inter-granular embrittlement. Hence, it does not necessitate that using a high welding temperature would result in better welding characteristics, although it does in the term of tensile strength where it increases for the 900 F. However, the 900 F had the lowest bending strength due to intergranular embrittlement.

Fig. 9. Bending specimens through and after applying the load.



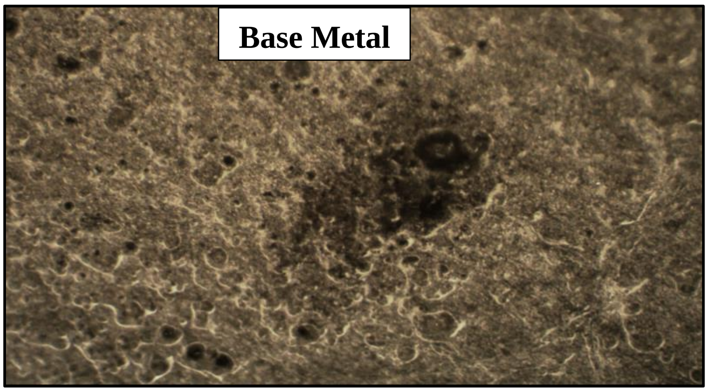


Fig. 10. Microstructural images of the base metal and the welded pipes (700 W, 700 F, 900 W, and 900 F)

4. Conclusions.

In this study, Austenitic stainless steel pipes of 50 mm diameter were welded at two different degrees of 700 °C and 900 °C with and without the use of the weld wire. It was observed that the pipes welded by 900 °C with the presence of weld wire (900 F) showed the highest tensile strength but the lowest hardness value. The pipes welded by 700 °C with the filler (700 F) had the highest bending strength due to the good ductility with the presence of the compensation of Ni and Cr elements. From the obtained results, it is recommended to use the 700°C welding temperature with welding filler gives desirable TIG welding characteristics.

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