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A comparison of mechanical properties between plasma arc welding (PAW) and three popular type of welding process (SMAW GMAW GTAW) on dissimilar materials

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Abstract The butt welds joints are extensively used in manufacturing of marine structures and shipbuilding in general Including hull structures, ship decks, ship piping, offshore structures and other heavy machinery. The objective of this study is to evaluate and to compare the mechanical properties on weld joint of dissimilar materials between austenitic stainless steel and low carbon steel using either between plasma arc welding (PAW) and three popular types of welding process (SMAW,GMAW,GTAW). In this study, first step, Welding first pass zero gap on dissimilar materials between austenitic stainless steel and low carbon steel was performed under optimum welding conditions. Next, Magnetic Particle testing (MT) method used to evaluate complete welding joint. The specimen are considered to be either complete joint penetration weld. Next, mechanical properties were assessed, including the static tensile strength and hardness distribution of a dissimilar material welded joint. The results were compared for different welding process PAW,SMAW,GMAW and GTAW welding processes. Finally, out of all the welding processes PAW welded first pass zero gap on dissimilar metal welded joint led to superior quality compared to three popular types of welding process.

1. Introduction

the most popular welding process around the world in manufacturing and construction are mentioned below with their requirements: **[1]**

Shielded Metal Arc Welding (SMAW) A manual process of stick welding is used by the welder in this style. The stick utilizes an electric current to form an arc between the stick and the metals. It's often used in the fabrication of steel structures, and to weld iron and steel **[1]**. (Fig. 1)

Gas Metal Arc Welding(GMAW) Also known as Metal Inert Gas (MIG), this method uses a shielding gas along the wire electrode, heating up the two metals that are to be joined. A constant voltage and direct-current power source is required for this style of welding. It's the most common industrial welding process **[1]**. (Fig. 1)

Gas Tungsten Arc Welding(GTAW) Gas Tungsten Arc Welding (aka Tungsten Inert Gas (TIG) welding) involves welding thick sections of stainless steel or non-ferrous metals together. It's an arc-welding process that uses a tungsten electrode to produce the weld. This process is complex and time-consuming **[1]**. (Fig. 1)

Submerged Arc Welding(SAW) This welding method uses a consumable electrode, as well as a blanket of fusible flux. The flux blanket protects the weld and arc zone from contamination **[1]**.

Flux-Cored Arc Welding(FCAW) This style is similar to MIG welding, however, it uses a flux-filled wire. Depending on the filler, it may or may not be used with shielding gas **[1]**.

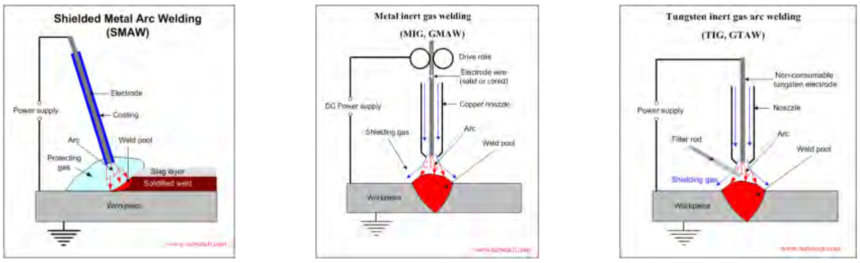


Fig. 2 Welding process (SMAW, GMAW, GTAW) **[2]**

In year 1953, **Plasma Arc Welding (PAW)** was invented and patented in 1953, by Robert M. Gage, at the Linde/Union Carbide laboratory in Buffalo NY. About 10 years of development and multiple subsequent patents occurred before the devices were brought to market in 1964. (Fig. 2) **[2]**

Therefore, this research has the idea to apply the welding process of plasma to compare with the popular welding process**.** Selected by comparision with three type of welding process (SMAW GMAW GTAW)

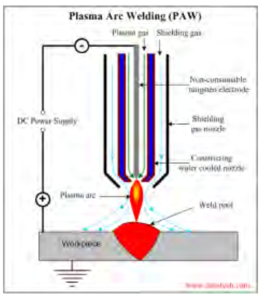


Fig. 2 Plasma Arc Welding (PAW) **[2]**

2. **Literature Review**

Plasma arc welding is a non-conventional form of welding which can be applied to almost any existing metals . the comparative review of plasma arc welding with respect to other existing forms of welding processes, based on existing literature content below. [3]

Michalec and Maronek (2012) conducted a comparative study of PAW and laser Beam Welding (LBW) of steel sheets after nitro-oxidation. Steel sheets treated by nitro-oxidation in comparison to material without surface treatment possess increased mechanical properties and enhanced corrosion resistance [4]. The study was conducted to find ways to reduce the high initial costs of LBW and to find an adequate counterpart from the arc welding sphere. The visual inspection of the joints welded by PAW revealed a significant presence of undercuts, whereas the macroscopic analysis confirmed the absence of porosity in the weld joint. But the tensile tests proved that PAW joints had great mechanical properties [4]. The LBW joints had more consistent micro-hardness trend along the measured length, whereas the PAW joints exhibited a continuous decrease of the micro-hardness towards the base material. The macroscopic analysis proved a three-times-wider HAZ in PAW joints. This was caused by the higher thermal density of the laser beam distributed into the narrower surface in comparison to plasma arc welding [4].

Bharathi et al (2014) explains that PAW has much better penetration capabilities than TIG welding does. Because of which, the process is often used for seam welding components as high as 12 mm in thickness [5]. TIG welding isn't capable of welding thicker plates due to the wider arc cone. When thin components need penetration a special process called micro-plasma can be used to bring the current down as low as 5amps. A major advantage of PAW over TIG welding is the increased life of the tungsten. One of the reasons for the longer life is that a pilot arc allows starts to be more constant and reliable and also due to the presence of the shielding gas [5]. PAW offers significant advantages over TIG in terms of joint preparation and thermal distortion as well [6].

Comparative study between plasma arc welding with two processes (LBW&TIG) mentioned above. Other welding processes have not been identified in previous research.

3. Materials Preparation

Austenitic stainless steel SUS304 of the dimensions 3mm thick and low carbon steel SS400 are chosen and their chemical compositions are given in Table 1.

Element	Weight percent (%)
C	0.0700
Si	0.0146
Mn	0.4813
P	0.019
S	0.0088
Cr	0.1244
Mo	0.0215
Ni	0.0909
V	0.0013
Al	0.0408
Cu	0.2807
Nb	0.0010
As	0.0059
Sn	0.0155
Pb	0.0025
Fe	Balance

Chemical composition of Low Carbon steel (SS400)

Element	Weight percent (%)
C	0.0448
Si	0.3847
Mn	1.0491
P	0.0274
S	0.0071
Cr	17.9180
Mo	0.0872
Ni	7.8608
V	0.1044
Al	0.0114
Cu	0.1708
Nb	0.0128
As	0.0047
Sn	0.0055
Pb	0.0085
Sb	0.0155
Bi	0.0187
Mg	0.0172
Fe	Balance

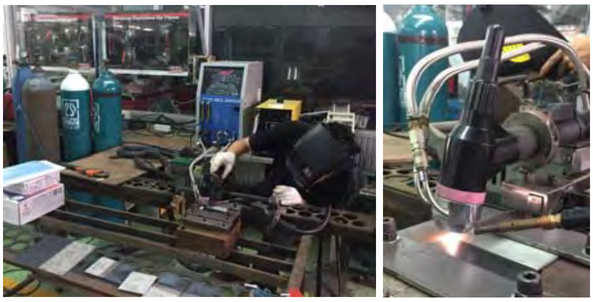
Chemical composition of Austenitic Stanless steel (SUS304)

Table 1 Chemical composition of Low carbon steel (SS400) and Austenitic stainless steel (SUS304)

4. Experimental Procedure

(A) Welding two plates of austenitic stainless steel and low carbon steel of the dimensions 120×120 (Fig 3) were taken for each welding process. And was used welding current 110 amperes in first pass zero gap for PAW welding process (Fig 4) and SMAW, GMAW, GTAW.

(Fig. 3) Welding two plates of SUS304 and SS400



(Fig. 4) PAW current 110 amperes
in First Pass Zero Gap

Welding Process :

Plasma Arc Welding arc process (PAW) with throated tungsten electrode of and argon 95% helium 5% shielding gas was employed to dissimilar materials weld joint steel plates in square-butt joint configuration. PAW parameters of current 110 A, travel speed 0.63 mm/s, first pass and zero gap were used.

Shielded metal arc welding process (SMAW) with electrode of AWS A5.4 E308L-15 of 1.0 mm diameter was used to dissimilar materials weld joint configuration[8]. SMAW welding parameters of current 110A, travel speed 0.63 mm/s, first pass and zero gap were used.

Gas metal arc welding process (GMAW) with electrode of AWS A5.9 ER 308L of 1.0 mm diameter and argon-carbon dioxide shielding gas was employed to dissimilar materials weld joint configuration[8].

GMAW welding parameters of current 110 A, travel speed 0.63 mm/s, first pass and zero gap were used.

Gas tungsten arc welding process (GTAW) with throated tungsten electrode of 1.6 mm diameter and argon shielding gas was employed to dissimilar materials weld joint configuration [8]. GTAW parameters of current 110 A, travel speed 0.63 mm/s, first pass and zero gap were used.

(B) Magnetic particle testing method **(MT)** used to evaluate complete welding joint of four welding process (Fig. 5) using a AC YOKE PARKER Y-6 : lifting capacity 4.5 kg., contrast medium type Magnaflux WCp-2 drying time 5 min, Testing Medium Magnetic Ink Magnaflux 7HF. Magnetic particle testing to check that the welded joint conforms to all speciments. Next, mechanical properties were assessed.

(Fig. 5) to evaluate complete welding joint by MT Test

(C) After the completion of welding the welded joint conforms to all speciments by MT Test. a no. of specimens were taken from the welded plates for the purpose of tensile testing and hardness testing.

Universal Tensile Testing Instron 8801 model (Fig. 6) was used to evaluate the tensile properties. In each condition, three specimens were tested and the average value was presented and used as tension test specimen. Based on ASTM E8M-04,is shown (Fig. 7)

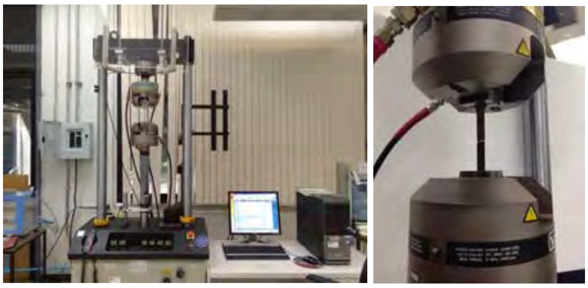


Fig. 6 Universal Tensile Testing Instron 8801

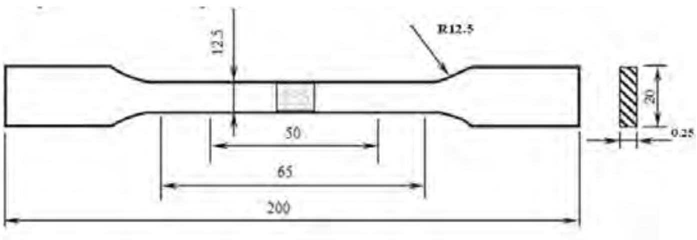


Fig. 7 Tension test specimen based on
ASTM E8M-04 [7]

(D) hardness test. Vicker's microhardness tester (Leica DMLM with HMT 10) (Fig. 8) was used for measuring the hardness distribution across the welded joint. Each specimen was impressed with loads of 200 g for 15 seconds, and Speed 20 g / seconds.

The specimen for hardness examination for 21 times was sectioned to the required size from the joint comprising weld metal, HAZ (heat-affected zone), and base metal regions.

Fig. 8 microhardness tester
(Leica DMLM with HMT 10)

5.Results

5.1 Tensile property

Tensile strength in MPa has been recorded for each set of experiment (SUS304,SS400,PAW, SMAW, GMAW, GTAW) as shown in Main effect plot in Stress-Strain relationship Fig.9 - Fig. 14

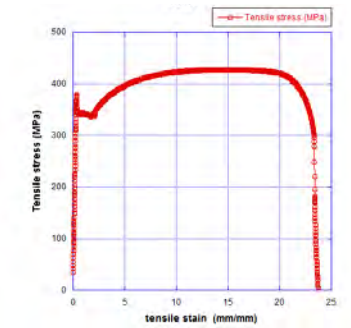


Fig. 9 Stress-Strain relationship for SS400

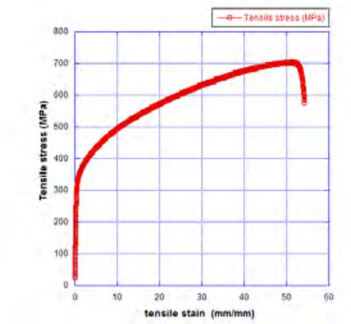


Fig. 10 Stress-Strain relationship for SUS304

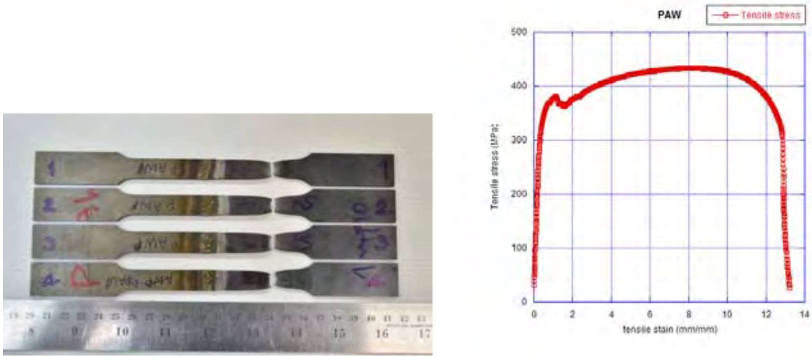


Fig. 11 Stress-Strain relationship for PAW

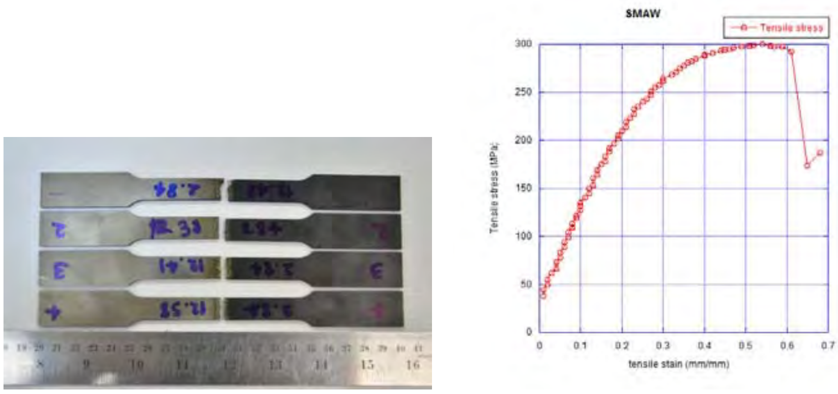


Fig. 12 Stress-Strain relationship for SMAW

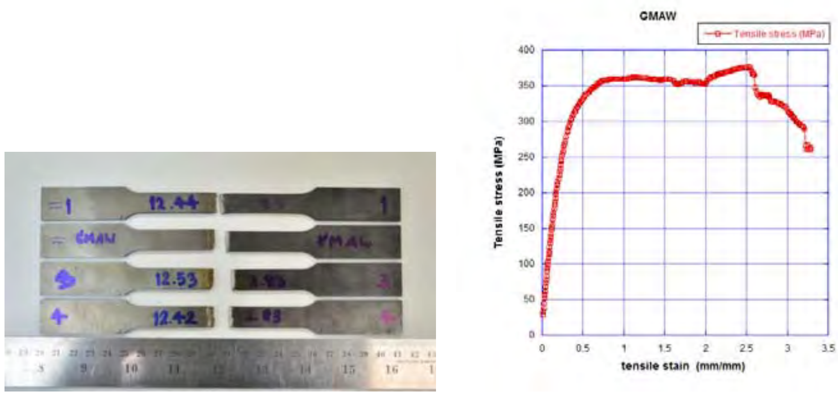


Fig. 13 Stress-Strain relationship for GMAW

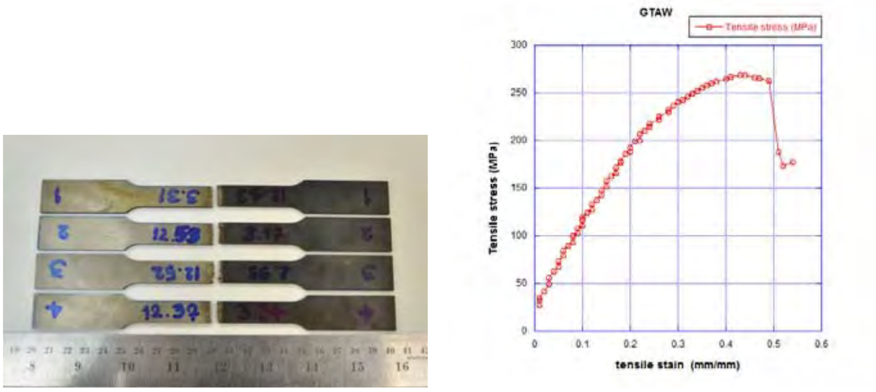


Fig. 14 Stress-Strain relationship for GTAW

Tensile strength in MPa was used to compare the effect of plasma arc welding process and three welding process to the tensile strength values. Difference tensile strength of four welding process in First Pass Zero Gap of the welded joint is shown in Fig.15 - Fig. 18

The Stress–Strain relationships of four welding process in first pass zero gap of the welded joint the welding process specimens are between Plasma Arc Welding (PAW) and Three Welding Process (SMAW GMAW GTAW)**.**Difference tensile strength of four welding process shown by the graph in Fig.15-Fig.17

Fig. 15 Comparison of Stress-Strain curves of PAW and SMAW

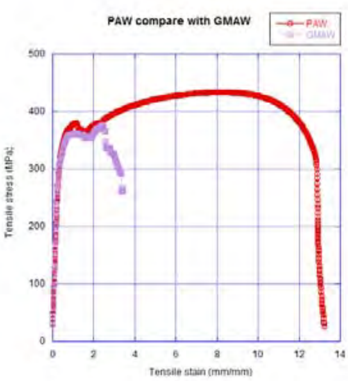


Fig. 16 Comparison of Stress-Strain curves of PAW and GMAW

Fig. 17 Comparison of Stress-Strain curves of PAW and GTAW

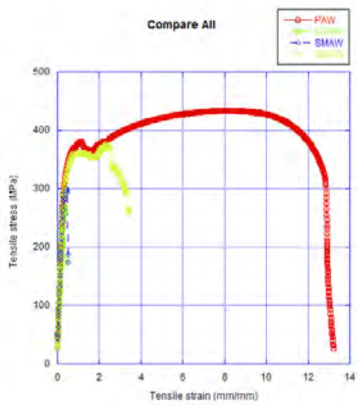


Fig. 18 Comparison of Stress-Strain curves of PAW, SMAW, GMAW and GTAW

5.2 Hardness

Hardness tests were performed on the etched specimens (Fig. 19). Hardness testing was carried out using a Leica DMLM with HMT 10 Hardness was measured at the center of the fusion zone and across the heata ffected zone (HAZ) into the base metal (Fig. 20) to estimate local mechanical properties.

Fig. 19 Hardness tests specimens

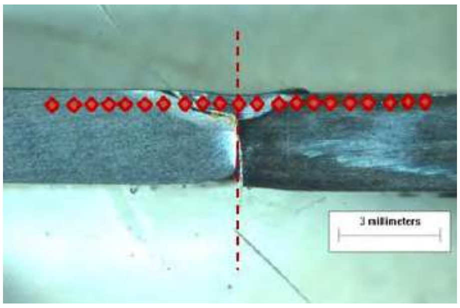


Fig. 20 measured at the center of the fusion zone and across the heata ffected zone (HAZ) into the base metal

The results are plotted in the graph below (Fig. 21 - Fig. 24) on the etched welding process and compared Plasma Arc Welding (PAW) and Three Welding Process (SMAW GMAW GTAW) (Fig. 25 - Fig. 27)

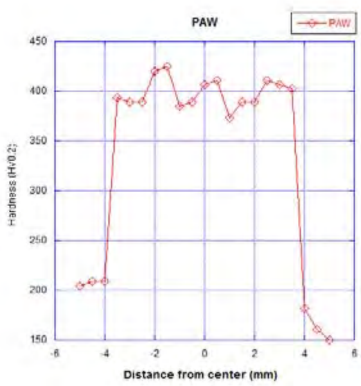


Fig. 21 Hardness measurement on surface across the weld metal of PAW

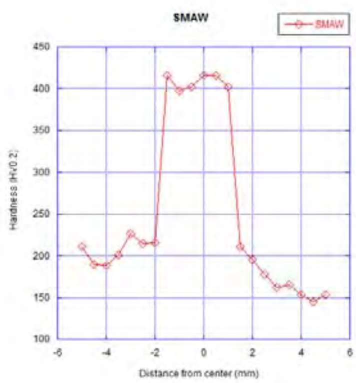


Fig. 22 Hardness measurement on surface across the weld metal of SMAW

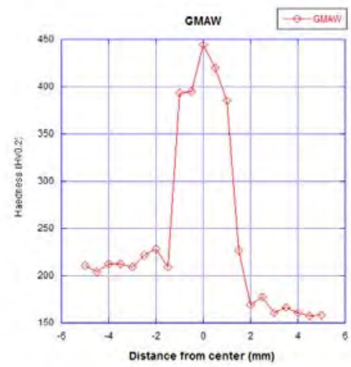


Fig. 23 Hardness measurement on surface across the weld metal of GMAW

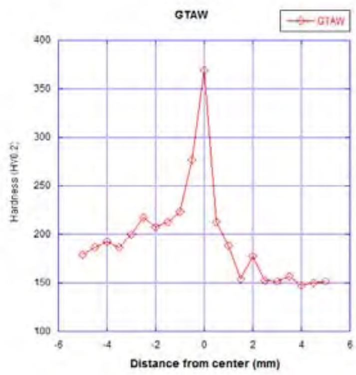


Fig. 24 Hardness measurement on surface across the weld metal of GTAW

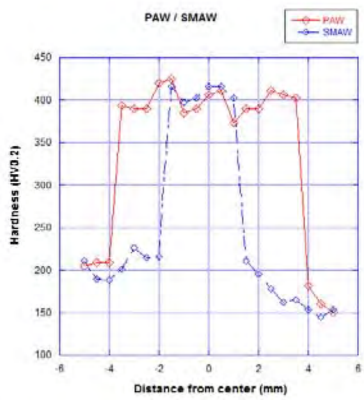


Fig. 25 Comparison of Hardness measurement on surface across the weld metal of PAW and SMAW

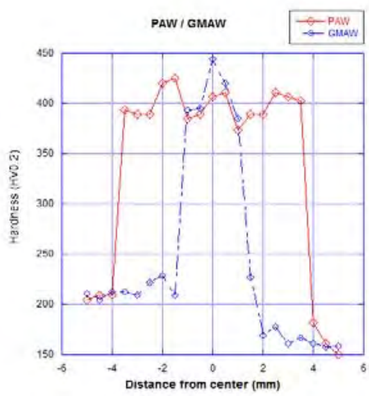


Fig. 26 Comparison of Hardness measurement on surface across the weld metal of PAW and GMAW

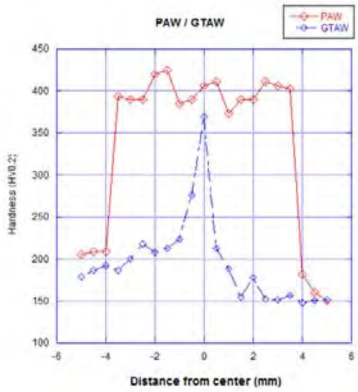


Fig. 27 Comparison of Hardness measurement on surface across the weld metal of PAW and GTAW

6. Conclusion

During the study, first pass weld with zero gap on Dissimilar Materials between austenitic stainless steel (SUS304) and low carbon steel (SS400) were joined using plasma arc welding (PAW) and three popular types of welding process(SMAW,GMAW,GTAW). The tensile strength and hardness of butt welded joints were investigated. The selection of different welding process used for welding play an important role in deciding the properties of the weld. From the study, following conclusions can be drawn.

1. Plasma arc welding is more suitable than three popular types of welding process (SMAW,GMAW, GTAW) for dissimilar metal welding of austenitic stainless steel and low carbon steel, PAW welding process provides better strength. It may be because of full penetration butt weld weld in dissimilar metal welds during PAW welding and three popular types of welding which comes out due to partial penetration butt weld.

2.The main flaw which occurs in welding dissimilar material by three popular types of welding process (SMAW,GMAW,GTAW) is the development of cracks during the tensile test, which needs more effort for achieving similar weld has by PAW welding.

3.The dissimilar metal joint of austenitic stainless steel and low carbon steel has the best ductility for only PAW.

4.The yield strength of dissimilar joint of austenitic stainless steel and low carbon steel is best for PAW welding process and the second is GMAW.

5.The dissimilar metal joint of austenitic stainless steel and low carbon steel has poor ultimate tensile stress for PAW due to full penetration **.**

6.The dissimilar metal joint of austenitic stainless steel and low carbon steel has poor ultimate tensile stress for three popular types of welding process (SMAW, GMAW,GTAW) due to partial penetration **.**

7. Hardness of GMAW joint (440 HV) at fusion zone FS is higher PAW SMAW and GTAW. The lower hardnesses at fusion zone of the SMAW joints (420 HV) and PAW joints (304 HV) the GTAW joints (410 HV) were recorded. Three Popular Types of Welding Process (SMAW,GMAW,GTAW) is the development of cracks during the tensile test, and higher than compared to the HAZ and BM regions. This is due to severe plastic deformation and continuous dynamic recrystallization occurred in the fusion zone and localized heating and fast cooling rate of the SMAW,GMAW,GTAW process.

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