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Comparative Study of Mechanical Properties of TIG Welded Joints of Similar and Dissimilar Grades of Stainless Steel Material

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Abstract
This paper discuss and experimentally analyse the mechanical properties of TIG welded joints of similar and dissimilar grades of stainless steel and to find out the best joint. In this study. Different combinations from samples of AISI 304 and AISI 316 are welded under standard conditions by using Tungsten Inert Gas welding (TIG Welding) technique,.. The welded joints were tested for Tensile strength, Hardness & toughness and best combination is pointed out. The three combinations analysed were AISI 304-304, AISI 316-316 and AISI 304-316. It was found that the tensile strength and toughness of AISI 304-304 combination was highest and maximum hardness is observed in AISI 304-316 combination. The results indicate that there is not a single combination which excels in all tests.

1. Introduction

The Gas Tungsten Arc Welding (GTAW) process is also referred as TIG, or Heliarc. Helium gas had been used for the first time during this welding process, from where the term Heliarc has been produced. Until the 19^{th} century, forge welding was the only technique known for joining metal pieces [2]. In the late 1930s and 1940s, an aircraft industry had used this technique for welding of magnesium.

TIG welding is a metal joining process in which electricity is used to form an electric arc between the tip of a non-consumable tungsten electrode and the work piece [3]. The heat from the arc melts the metal pieces and with the help of filler material joint is formed. In order to provide the shield to an arc, inert gas has been used which passes from the GTAW torch, this shield also prevent the heat affected zone, molten metal and tungsten electrode from an atmospheric contamination. Generally, in the TIG welding, Argon and Helium gases are the preferred due to their inert gases as they do not react with metals that need to being joined. Along with this benefit, the shielding gases also used in order to cover the weld pool and thereby avoiding the contamination of weld portion.

TIG welding is different from most other welding processes because of its process of forming arc and adding filler material. While performing the TIG Welding one hand is used for holding the TIG torch that will produce an arc and the other hand is required to add the filler metal to the weld joint. Here tungsten is used because of its properties which makes an arc to maintain its temperature up to 11000^0F. Due to its high melting point and excellent electrical conductivity it is used for welding with a hotter arc then the actual melting point of the tungsten. Although it is cleaner and more versatile that results in a high quality welds and can be works on steel, aluminium, brass and many other metals but this is more expensive than a normal welding.

Also the Stainless Steel has been used here which is an alloy of an iron with a chromium (minimum 10.5%). This chromium forms a passive layer which is a thin layer of oxide on the surface of the steel which prevents the corrosion of the surface. There are also other elements present in it which makes it useful for variety of purposes. Some of the elements are carbon, silicon, manganese, nickel, molybdenum, sulphur, etc.

2. Experimental Procedure

The two grades of austenitic stainless steel i.e. AISI 304 and AISI 316 are used. The material was in the form of sheets of 1mm thickness. Both of these have same elements in them except for the presence of molybdenum which is only present in AISI 316 thus making it useful in the harsh chemical environment. The details of their respective composition are shown in following table 1 [8]

The process started with welding of two rectangular piece if AISI 304. The same process was repeated with AISI 316. At last two rectangular sheets of AISI 304 an AISI 316 are welded together. Prior to the welding, the specimen was cleaned properly with sand paper followed by cleaning with acetone. For welding a standard TIG welding apparatus was used. The specimen was kept on a horizontal surface and clamped properly before welding. The work piece was connected to positive terminal and electrode with negative terminal which gave us Direct current straight polarity setting. Under the protective environment of Argon gas with a flow rate of 15L/min, the welding was started. A dimension of the specimen for EDM cutting has been shown as such in the figure 1. The standard dimensions used were 120mm x 100mm x 1mm.

Table 1: Chemical compositions of specimens

	Elements	Fe	C	Mn	Si	Mo	Cr	Cu	Ni	
Composition	AISI 304	70.78	0.025	1.140	0.14	0.36	18.40	0.18	8.19	
(% by weight)	AISI 316	67.69	0.018	1.28	0.38	2.42	16.63	0.21	10.85	

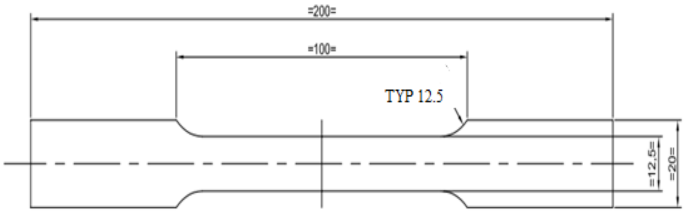

Fig.1. Dimension of Specimen

For each case a different filler rod was used which have same composition as parent material. The filler rods used in each case have different composition which is shown in the following table 2.

Table 2: Chemical composition of filler material (% weight)

	C	Si	S	P	Mn	Ni	Cr	Mo
ER316	0.019	0.470	0.003	0.024	1.570	12.20	18.5	2.30
	C	**Mo**	**Nb**	**-**	**Mn**	**Ni**	**Cr**	**-**
ER304	0.063	0.22	0.01	-	0.9	8.11	18.4	-

The voltage was kept constant while current was varied. The variation of current in each case along with other parameters used in welding is shown in table 2. After the welding, we took out the three pieces for testing from each of the combination with the help of an EDM machine.

After getting the required dimension, we need to test different mechanical properties such as tensile test, Hardness and Toughness on different machine set-up.

3. Experimental Test

3.1. Tensile test

It is basically the property of a material that tells the maximum amount of tensile stress that it can take before failure, such as permanent deformation [2]. It specifies the point when a material goes from elastic to plastic deformation. The tensile strength of the specimen was

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determined by UTM (Universal Testing Machine) as shown in fig. 4.14. For that a H50K-S UTM from Tinius Olsen of 50kN Capacity is used. The speed of the UTM was kept at 0.5mm/min. The tensile strength of the metal is proportional to its ductility, more is the tensile strength then more will be its ductility and vice versa [7]. It was observed form the test that the strength of welded joint increased proportionally with the welding current in all the cases. For different combinations of metals, we have used different set of the parameters in order to achieve optimum quality welding. It is imperative to note that while performing the test for the tensile strength of the specimens, the parting off took place away from heat affected zone in all the three cases. This shows that the joint obtained was more than 100% efficient. The universal testing machine has been shown in the following figure 2.

Fig. 2. Universal Testing Machine

3.2. Hardness

It is the property of a material that enables the material to resist indentation of localized displacement. It is the resistance to indentation, wear and abrasion. The strength coefficient and strain hardening exponent gives a measure of increase in hardness due to plastic deformation [8]. Hardness tests are used as a means of controlling the properties of materials. Once the hardness is calculated, by altering the composition of various compounds of material a certain desired properties can be obtained. Here we have uses the Brinell hardness machine. In the Brinell tests, the specimen is mounted on the anvil of the machine and a load of 750 kg is applied against a hardened steel ball which is in contact with the surface of the specimen being tested. The steel ball is 5 mm in diameter. The load is allowed to remain 5 second and is then released, and the depth of the depression made by the ball on the specimen is measured. The Resultant Brinell hardness number was obtained by the eq. (1):

$$\frac{P}{\frac{\pi D}{2}\left(D-\sqrt{D^2-d^2}\right)} \qquad (1)$$

Where P is applied load, D is diameter of steel ball and d is diameter of impression.

3.3. Toughness

It is the ability of a material to absorb energy. As the ductility of a metal decrease, the toughness of a material decreases with it [6]. The toughness of the specimen is obtained from the stress strain graph formed from the UTM. This is done by measuring the area under the curve of stress strain curve. The toughness is expressed as energy per unit volume.

4. Results and Discussion

4.1 Tensile strength

4.1.1 AISI 304-304

The results obtained from tensile test are shown in Table. From the Stress Vs Strain curve and Force-Displacement graph it was observed that the joint bore the force upto 4880 N before finally undergoing fracture. The fracture was observed from the heat affected zone on the parent metal. The maximum stress the joint experienced was of the order of 390 Mpa which is clearly seen in the stress Vs Strain curve. Furthermore, it was observed that the combination experienced a consolidated elongation of 40.8 %. The graph shows various results obtained.

Table 3: Results obtained in tensile test of AISI 304-304 combination

Width	Thickness mm	Initial Gauge length mm	Final gauge length mm	Area mm^2	Ultimate force N	Ultimate stress MPa	offset @ 0.2 % N	offset @0.2 % MPa	TE %
12.5	1.00	82.2	115	12.5	4880	390	1730	138	40.8

The stress vs strain curve and force displacement graphs in this case is given by figure 3 and figure 4.

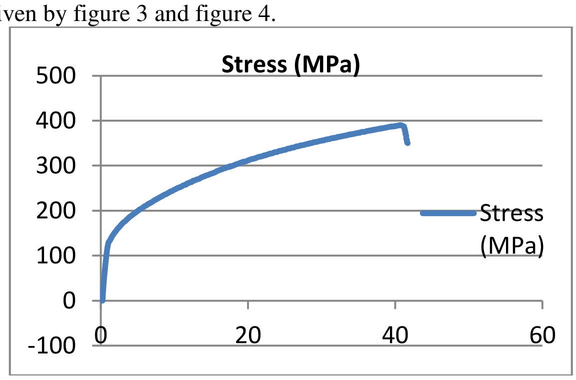

Fig. 3. Stress Vs Strain curve of 304-304 combination

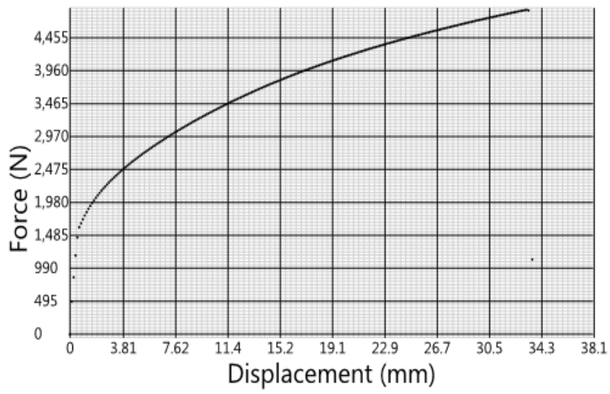

Fig. 4. Force Vs Displacement of 304-304 combination

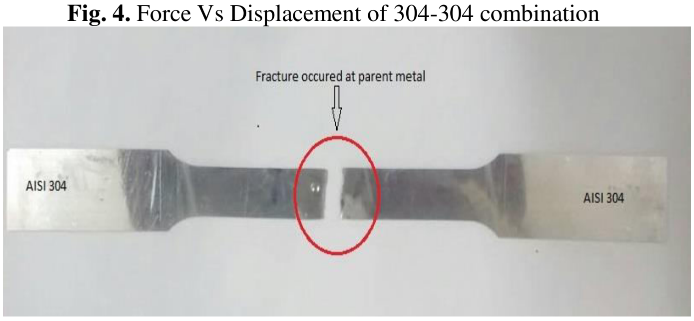

Fig.5. AISI 304-304 Specimen after Tensile Test

4.1.2 AISI 304-316

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From the stress Vs Strain curve and force-displacement graph it was observed that the joint bore the force upto 4480 N before finally undergoing fracture. The maximum stress the joint experienced was of the order of 357 MPa which is clearly seen in the stress Vs Strain curve. Furthermore, it was observed that the combination experienced a consolidated elongation of 28.8 %. The fracture was observed from the heat affected zone on the parent metal. The results obtained are shown in table 4.

Table 4: Results obtained in tensile test of AISI 316-316 combination

Width mm	Thickness mm	Initial Gauge length mm	Final gauge length mm	Area mm	Ultimate force N	Ultimate stress MPa	offset @ 0.2 % N	offset @0.2 % MPa	TE %
12.5	1.00	82.2	106	12.5	4480	357	2060	165	28.8

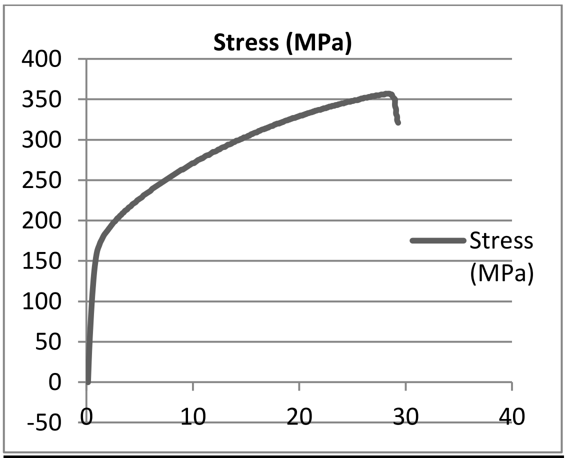

Fig.6. Stress Vs strain curve of 316-316 combination

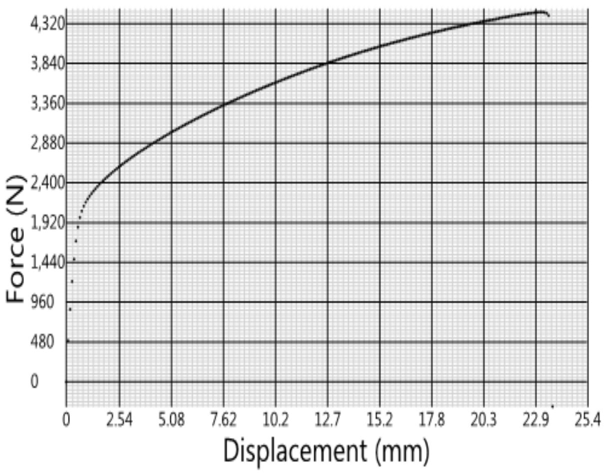

Fig.7. Force Vs displacement curve of 316-316 joint

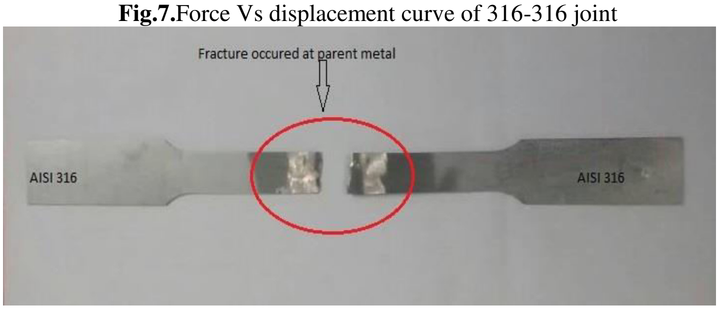

Fig.8. AISI 316-316 Specimen after Tensile Test

4.1.3.AISI 304-316

From the stress Vs Strain curve and force-displacement graph it was observed that the maximum stress the joint experienced was of the order of 300 MPa. The joint bore the force upto 3750 N before finally undergoing fracture which is clearly seen in the stress Vs Strain curve. Furthermore, it was observed that the combination experienced a consolidated elongation of 10.7 %. The joint in this case fractured from parent metal of AISI 316.

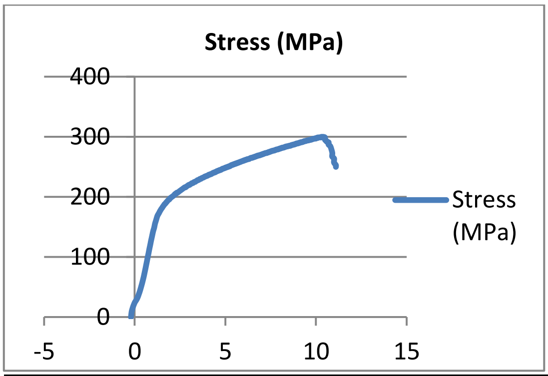

Fig.9. Stress Vs strain curve of 304-316 joint

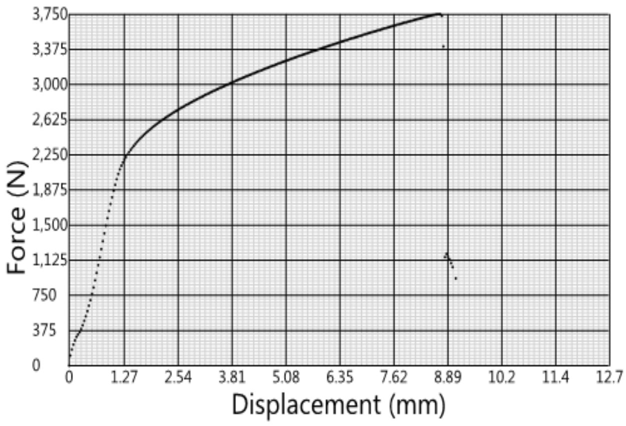

Fig.10. Force Vs displacement curve of 304-316 joint

Table 4: Results obtained in AISI 304-316 combination

Width Mm	Thickness Mm	Initial Gauge length Mm	Final gauge length Mm	Area mm	Ultimate force N	Ultimate stress MPa	offset @ 0.2 % N	offset @0.2 % MPa	TE %
12.5	1.00	82.2	91.3	12.5	3750	300	2280	182	10.7

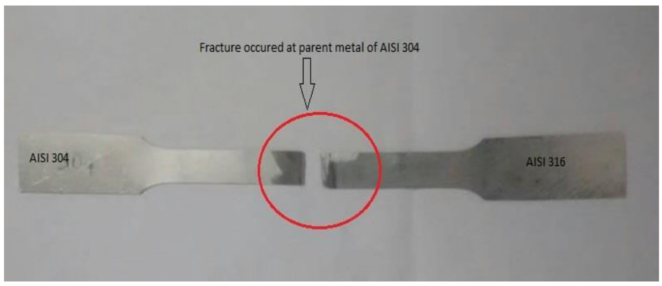

Fig.11. AISI 304-316 Specimen after tensile test

4.2 Hardness

The results obtained from hardness test performed on Brinell Hardness testing machine are as follow. The following figure shows the indentation obtained from the test.

4.2.1 For AISI 304- AISI 304 welded Specimen

Load applied: 750kg
Time for which load is applied: 5second
Diameter of ball: 5mm
Diameter of Impression produced: 2.4mm
Brinell Hardness Number (BHN)

$$= \frac{P}{\frac{\pi D}{2}(D-\sqrt{D^2-d^2})} = 154.85 \text{ BHN}$$

4.2.2 For AISI 316- AISI 316 welded Specimen

Load applied: 750kg
Time for which load is applied: 5second
Diameter of ball: 5mm
Diameter of Impression produced: 2.8mm
Brinell Hardness Number (BHN)

$$= \quad = \frac{750}{\frac{3.14*5}{2}(5-\sqrt{5^2-2.8^2})} = 112.40 \text{ BHN}$$

4.2.3 For AISI 304- AISI 316 welded specimen :

Load applied: 750kg
Time for which load is applied: 5second
Diameter of ball: 5mm
Diameter of Impression produced: 2 mm
Brinell Hardness Number (BHN)

$$= \frac{750}{\frac{3.14*5}{2}(5-\sqrt{5^2-2^2})} = 228.56 \text{ BHN}$$

4.3 Toughness

The toughness was measured from stress vs strain curve. By measuring the area under the curve, the toughness was obtained. The following table shows the toughness obtained in each case.

Table 6 : Results obtained from toughness

Combination	AISI 304-304	AISI 316-316	AISI 304-316
Toughness(Energy per unit volume)	12388.44	8376.50	10495.28

Table 7. Comparative Results

Combination/Properties	Tensile Strength (Mpa)	Toughness (Energy per unit volume)	Hardness (BHN)
AISI 304-304	390	12388.44	154.85
AISI 316-316	357	8376.5	112.4
AISI 304-316	300	10494.28	228.56

4. Conclusions

The major conclusions drawn from this study are as following:

- It is concluded from the experiment that for proper welding the parameters need to be changed according to the working conditions. Appropriate welding cannot be accomplished. By keeping the variables constant in every case,
- It has been observed that specimens should be clamped properly using the fixtures because during solidification of metals, their tendency of shrinking may results in bending of the specimen near the weld area. So in order to prevent such errors they need to be clamped.
- It has been found that the hardness of AISI 304-AISI 316 combination is more than that of AISI 304-AISI 304 and AISI 316-AISI 316 combination. Whereas the tensile strength of AISI 304-AISI 304 combination is found to be more than that of AISI 316-304 and AISI 316-316 combinations.
- It has been observed that there is not any single combination which has the highest magnitude of properties in every case. So in case whenever these kinds of materials are available, one need to make a balance between tensile strength & hardness according to their requirements.

This study can be useful in field of manufacturing and production. For example, now a day the automobile components are made as lighter as possible to minimize fuel consumption by using metals like stainless steel. So in case AISI 304 and AISI 316 are available, the manufacturer can take the help of data obtained from this study and according to his requirement, can choose the right combination for manufacturing.

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