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CHARACTERIZATION FOR GTAW AISI 316 TO AISI 316 & SA 516 GRADE 70 STEELS WITH WELDED & PRE-WELDED ANNEALING CONDITIONS

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ABSTRACT

GTAW (Gas Tungsten Arc Welding) process is one of the most significant processes of joining two or more pieces of the same or dissimilar materials to achieve complete coalescence using an inconsumable tungsten electrode. The present investigation is an attempt to study the variations in mechanical properties by both changing the base materials with respect to AISI 316 steel i.e. using SA516GR70 as well as annealing AISI 316 and SA 516GR70 plates initially and then welding to AISI 316. TIG welded AISI 316 with AISI 316 steel gives most moderate results to be used in required applications with least number of service limitations. Since UTS for TIG welded AISI 316-SA 516 is higher than AISI 316-AISI 316 but it has a lower value of impact strength than AISI 316-AISI 316 welds. AISI 316-SA516GR70 weldment has a number of limitations when applicable in service conditions. An attempt to increase the properties by initially annealing can be of worth when the welding parameters could be considered (e.g. welding current, groove design, filler etc), hence mechanical characterization infers that AISI316-AISI316(annealed) can be thought of importance when the prevailing conditions are moderate enough and the weldment is quite feasible to bear such service conditions where as AISI316-SA516(annealed) proves to be of less importance from service point of view due to formation of complex grain structure near the fusion boundary and heat affected zone on the 516 annealed side of the weldment.

Keywords: Welding, GTAW, AISI 316, SA516 grade 70 pre weld annealing.

INTRODUCTION

Welding is a process of joining two or more pieces of the same or dissimilar materials to achieve a uniform assembly and it is swiftly replacing other joining processes like riveting and bolting. At times it may be used and alternative to casting. Presently welding is used extensively for fabrication of different components including critical structures like boilers and pressure vessels, ships, off-shore structures, bridges, storage tanks, pipelines, missile and rocket parts, nuclear reactors, fertilizer and chemical plans, earth moving equipment , automobile bodies. Welding is also used in heavy plate fabrication industries as well as pipe and tube fabrication. Welded joints for pressure vessels are pressure tight than riveted ones Sacks and Bohnart (2005). Gas Tungsten Arc welding process uses an arc between a non consumable tungsten electrode the weld pool. This process is used with shielding gas (usually an inert gas), without the application of pressure, to prevent the oxidation of both the base metal and tungsten electrode. Gas Tungsten Arc welding process has become an indispensable tool for many industries because of the high-quality welds produced and relatively low equipment costs. This welding technique is significantly preferred due to its excellent mechanical properties and high efficiency of weld joints. Stainless steel AISI 316 and carbon steel SA 516GR70 form the basis of a number of applications in process industry most important being pressure vessels design these days ASM (1998). The mechanical properties of the weld joints can be varied by the application of suitable pre-weld heat treatment specifically annealing and then weld the materials with the same welding parameters.

EXPERIMENTAL WORKING

Material selection and characterization:

Stainless steel grade AISI 316 and carbon steel SA 516 GRADE 70 was the material selected for experimentation. AISI 316 is the most preferred boiler grade steel for pressure vessel industry these days ASME (1989). This grade is highly corrosion resistant and bears elevated operating service temperature. SA516 is also one of the most popular Pressure Vessel grades of steel in the industry. Usually carbon steel SA 516 Grade 70 is recommended as the standard specification else than the 316 grade for pressure vessel plates. These steel specifications cover carbon steel plates intended primarily for service, where improved notch toughness is an important factor Crucci (1999). The square plates of AISI 316 and SA 516 grade 70 comprised of composition as determined by the emission spectrometer given in the table 1:

Table 1: Composition of AISI 316 & SA 516 Grade 70

Element Present	AISI 316	SA 516 Grade 70
Fe	67.2%	96.78%
C	0.0377%	0.276%
Cr	16.18%	-----
Ni	10.97%	-----
Mn	1.61%	0.85%
Mo	2.14%	-----
Si	0.589%	0.15%
P	0.037%	0.024%
S	0.001%	0.03%
Al	0.008%	-----
Co	0.242%	-----
Cu	0.288%	0.02%
Nb	0.21%	0.015%
Ti	0.004%	0.001%
V	0.101%	-----
W	0.03%	-----
Sn	0.008%	0.006%
Ca	0.0026%	-----
Ta	0.002%	-----
B	0.001%	-----

Cutting of Plates and Joint Preparation

Plates were subjected to cutting using the EDM CNC wire cut machine and the design of the joint is shown in fig 1 & 2.

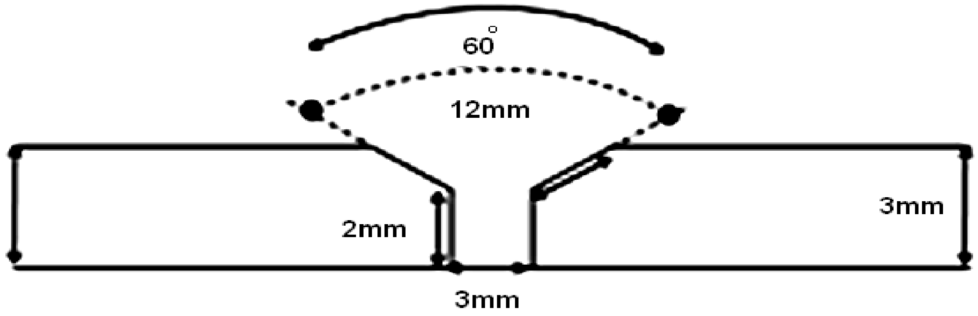


Fig 1: Weld Joint Design

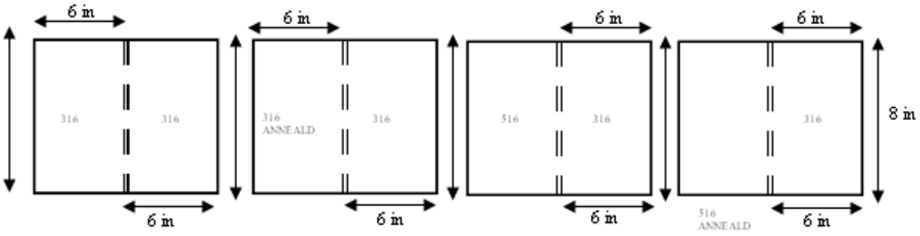


Fig 2: Plates* of selected Grades of steel.

**Note: Bold lines show weldments.*

Solution treatment (Annealing) of 316 & SA 516 Grade 70

AISI 316 and SA516 plates were cut into sections which were further used for heat treatment. These plate cut sections were heated to 1040 °C for annealing (solution treatment). These cut sections were placed in a muffle furnace when temperature reaches to 850 °C. Heating rate was 2–2.5 °C/min, while heating time was about 20 min at 1040 °C. After heating these sectioned specimens were left in furnace to cool for about 24 hours. A heavy black scale was found on these sectioned specimens (both AISI 316 and SA516) after solution treatment, which is in fair agreement with ASM (1999a,b). Solution treatment of AISI 316 dissolves all the chromium carbides formed during cutting or any other reasons. Similarly solution treatment of SA516 removes all residual stresses due to cutting, cold working or from any other sources so susceptibility of inter granular corrosion is minimized.

Gas Tungsten Arc Welding

Welding including fours steps, one was the welding bare base metals i.e. AISI 316 welded with AISI 316, second was annealed AISI 316 with AISI 316, third was bare AISI 316 welded with SA516, and fourth was AISI 316 welded with annealed SA516 as shown earlier in fig 1.

Welding of the base metals AISI 316 to AISI 316 and AISI 316 to SA 516 (as welded)

Stainless steel 316 and 516 plates were cut and then welded using GTAW process. For welding of stainless steel 309L were chosen. The filler wire used was ER 309L, diameter of 2mm AWS (2002). Filler wire used having composition as given in table 2.

Table 2: Composition of Filler Wire ER309L

Element	Fe	C	Cr	Ni	Mn	Si	Mo
Percent	63.38	0.02	18.8	12.5	1.7	0.8	2.8

Seven wires were consumed in welding. Total weight of the filler metal used was 166g. ER 309L wire was used because of low carbon content so as to give a good weld and less carbide formation after welding. Manual welding technique was used. Tungsten electrode (2.4 mm WT 20% Thoriated) AWS (2010) was used for welding. It was DCEN (direct current electrode negative) or DCSP (direct current straight polarity). Welding was performed on 100~109 Amp current. Each welding has four total passes, on each side. First pass was the root pass and second one was for the capping. When weld cooled down, it was grinded slightly from the other side to remove some excessive penetration and cleaning the root. Now the same root pass and capping pass were performed on this grinded side. Capping was about 4mm high. Total time for this welding was 10 min and 19 sec. This welding was designated as welding 1. Welding procedure is given in table 3.

Table 3: Weld Procedure Specification used for GTAW

Welding	**GTAW (TIG)**
Position	Flat (1G)
Current	100~109 Amps
Electrode	Tungsten (WT 20)
Electrode angle	45Degree
Polarity	DCEN
Shielding gas	Argon (99.99%)
Filler wire	ER 309L
Filler wire angle	15 deg

Welding of the AISI 316 to AISI 316 Annealed and AISI 316 to SA 516 Annealed

Stainless steel 316 annealed earlier and 516 annealed earlier plates were cut and then welded with AISI 316 base metal plates using GTAW process AWS (2002) with the same welding procedure specifications as given earlier in table 3. The filler wire used was ER 309L.

One rod was 1 meter long and had diameter of 2 mm as given in table 2. Almost nine wires were consumed in welding. Total weight of the filler metal used was 198g. ER 309L wire was used because of low carbon content so as to give a good weld joint and less carbide formation after welding. Manual welding technique was used. Tungsten electrode (2.4 mm WT 20% Thoriated) was used for welding. It was DCEN (direct current electrode negative) or DCSP (direct current straight polarity). Welding was performed on 100~109. Each welding has four total passes, on each side. First pass was the root pass and second one was for the capping. When weld became cool, it was grinded slightly from the other side to remove some excessive penetration and cleaning the root. Now the same root pass and capping pass were performed on this grinded side. Capping was about 4mm high. Total time for this welding was 12min and 19 sec. This welding was designated as welding 2.

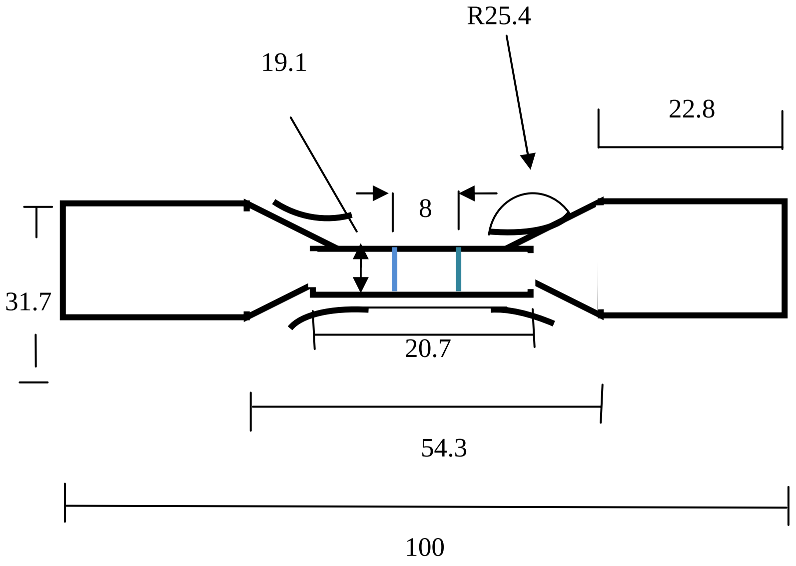


Fig.3 Specimen for Tensile Testing of Welded Plates according to ASME Section 9 Code QW.462.1 (a) Specifications in mm. Thickness 8 mm.

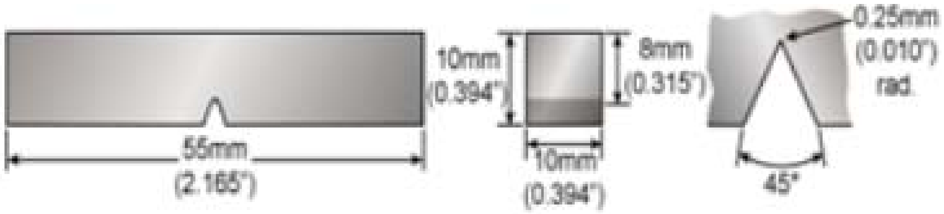


Fig. 4: Specimen for Impact Testing

Sample Preparation for Mechanical Testing and Nomenclature

Five different types of samples were prepared. One for tensile testing as shown in fig 3 while the other four were used for microscopy, hardness, impact as shown in fig 4 and bend testing. The dimensions of specimen required for tensile testing of welded sheets were according to ASME standards ASME (1989).

Specimens for microscopy and hardness testing were taken in different dimensions, from base metal plate as well as welded plates each. Specimens from welded plates were in different sizes but obviously all of them had weldments, heat affected zone and base metal.

Tensile Testing

Tensile tests were performed to report yield strength, percentage elongation, and ultimate tensile strength (UTS) of the as welded and heat treated welded specimens, base metal and welded specimens ANSI (2002). Testing was performed on universal tensile testing machine. Machine had maximum load capacity of 1000KN. Load application was electro hydraulic. Strain rate was 15mm per min. A Universal Testing Machine otherwise known as a materials testing machine/test frame was used to test the tensile and compressive properties of materials. Results are shown in tables 4 & table 5:

Table 4: Ultimate Tensile Strength of Samples

SAMPLES	UTS(MPa)
AISI 316 welded AISI 316	581.34
AISI 316 welded annealed AISI 316	459.45
AISI 316 welded SA 516 GRADE 70	609.69
AISI 316 welded annealed SA 516 GRADE 70	360.62

Table 5: %age Elongation for Samples

SAMPLES	%age Elongation
AISI 316 welded AISI 316	36.31
AISI 316 welded annealed AISI 316	29.21
AISI 316 welded SA 516 GRADE 70	38.01
AISI 316 welded annealed SA 516 GRADE 70	9.707

Impact Fracture Testing

About 55mm long and 10 mm thickness specimens were taken, grinded. Notch of 2mm deep was made at the center of the specimen ASTM (2005a) as shown in fig 4. These specimens were then placed in the Charpy impact testing machine, which consists of striking a suitable specimen with controlled blow and measuring the energy absorbed in bending or breaking the specimen. Like a pendulum one hammer strikes the notched specimen which is grasped by both sided support on the bed of testing machine, with the pointer set at zero. As pendulum hits the specimen with great force a knife edge mounted on the pendulum strikes and fractures the specimen at the notch which acts as point of stress concentration for this high velocity impact blow which fractures or bends the specimen. Results are shown in table 6:

Table 6: Impact Strength of Samples

SAMPLES	Impact Strength (m/Kg)
AISI 316 welded AISI 316	58.390
AISI 316 welded annealed AISI 316	45.714
AISI 316 welded SA 516 GRADE 70	50.089
AISI 316 welded annealed SA 516 GRADE 70	31.724

Hardness Testing

Hardness tests were performed on base metal and welded samples. Tests were performed on micro Indentec Rockwell hardness Tester ASTM (2005b). Load application time was 30 sec. For welded samples tests were performed on weldment, and at 2 mm, 4 mm, 6 mm distance from weld to check hardness variation along the weldment, HAZ and base metal etc. During testing major load of 60 kg while a minor load of 10 kg was used. Results are shown in table 7:

Table 7: Hardness Profile of Samples

SAMPLES	At Weld (HRA)	At 2mm (HRA)	At 6mm (HRA)	
AISI 316 welded AISI 316	58	55.5	51.5	
AISI 316 welded annealed AISI 316	58.5	52.5	51.5	
AISI 316 welded SA 516 Grade 70	59	67	51.5	54
AISI 316 welded annealed SA 516 Grade 70	59.5	57	51.5	49.5

Bend Testing

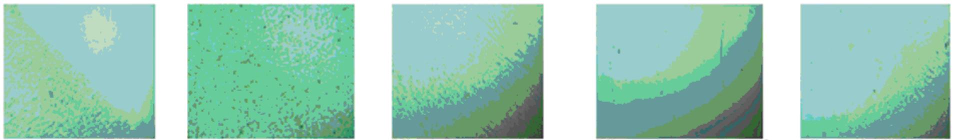
This test method covers a guided bend test for the determination of ductility of the welds ASTM (2005c). The specimen is bent on a U-shape die by means of a centrally applied force to the weldment in a flat specimen supported at two positions equidistant from the line of force. Specimens were bended in the test jig by placing both the root of the weld as well as the face of the weld in front of the plunger connected with a UTM. Stress is applied until the specimens confirm to U-shape and until a 3.2 mm diameter wire cannot be inserted between the specimen and any point on the curvature of the plunger. Results are given in table 8:

Table 8: Bend Test Results of Samples

SAMPLES	**Impact Strength (m/Kg)**
AISI 316 welded AISI 316	Satisfactory
AISI 316 welded annealed AISI 316	Satisfactory
AISI 316 welded SA 516 GRADE 70	Satisfactory
AISI 316 welded annealed SA 516 GRADE 70	Satisfactory

Microscopy

Base metal and welded samples were prepared for microscopy ASM (1999c). Samples were grinded subsequently on grit no. 120, 220, 400, 600, 1000, 1500, and 2000. Then these samples were polished on velvet cloth of polishing cloth disk. A problem occurred during the etching of the sample AISI 316 welded with SA516 and AISI 316 welded with SA516 annealed, because of the fact that these weldments have dissimilar base metals on their respective sides, so this problem was over come by using oxalic acid on stainless steel as well as weld zone and Nital on the carbon steel side. Different micrographs are shown in figure 5.



Micrograph of fusion boundary at 200X

Micrograph of base metal SA516 at 200X

Micrograph of weld zone at 200X

Micrograph of base metal AISI316 at 200X

Micrograph of HAZ at 200X

Micrograph of fusion boundary at 400X

Micrograph of SA516 at 400X

Micrograph of weld zone at 400X

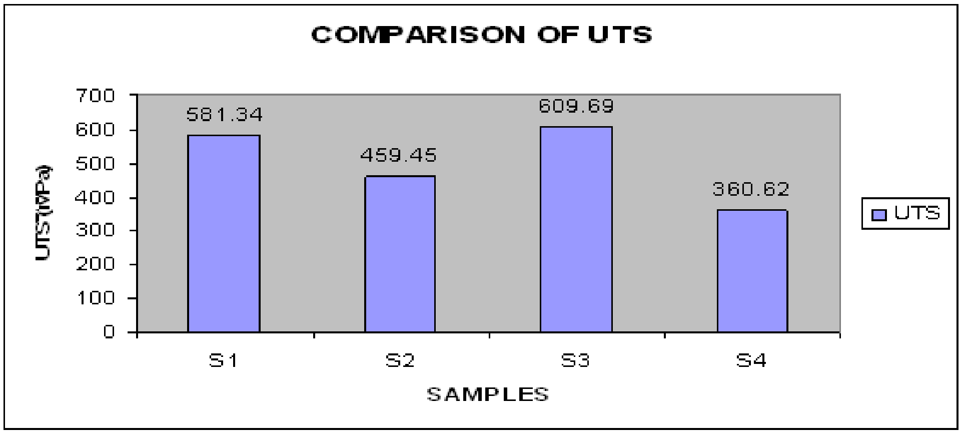
Micrograph of base metal AISI 316 at 4000X

Micrograph of HAZ at 4000X

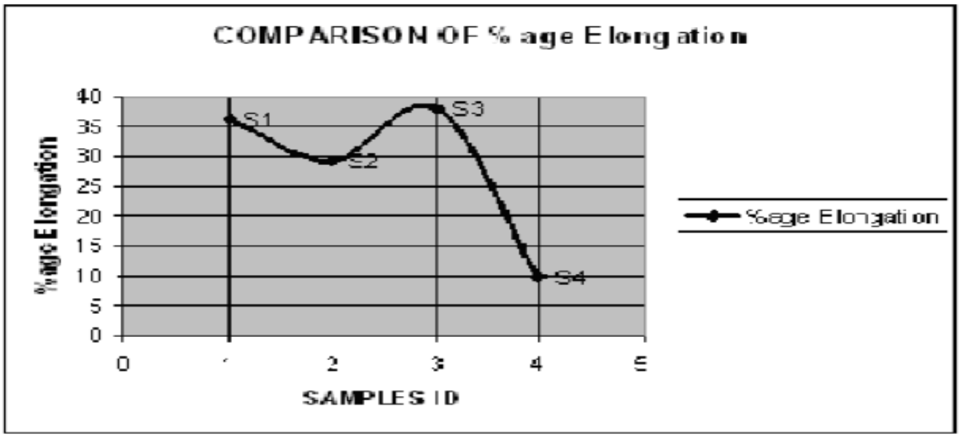
Fig. 5: Micrographs of the Specimens

RESULTS AND DISCUSSION

Results of the Mechanical properties determine i.e. Ultimate tensile strength, %age Elongation, Impact strength, bend tests, Hardness test on Rockwell (HRA) are tabulated in tables 4, 5, 6,7 & 8 respectively. Its clear from the graph 1 that AISI 316 to SA 516 as welded had highest UTS value of 609.69 MPa and highest Y.S value of 386.01 MPa.



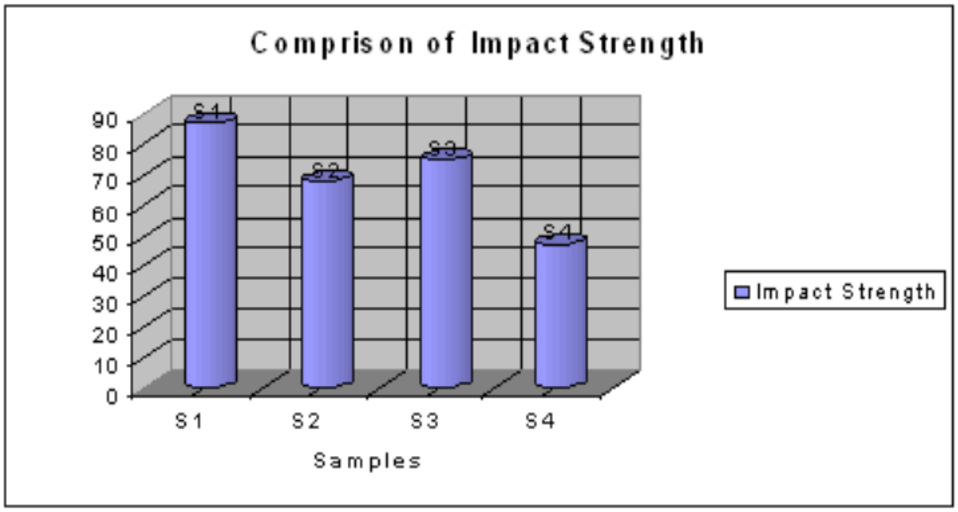
Graph 1: Graph for UTS of Samples.



Graph 2: Graph for the percentage elongation.

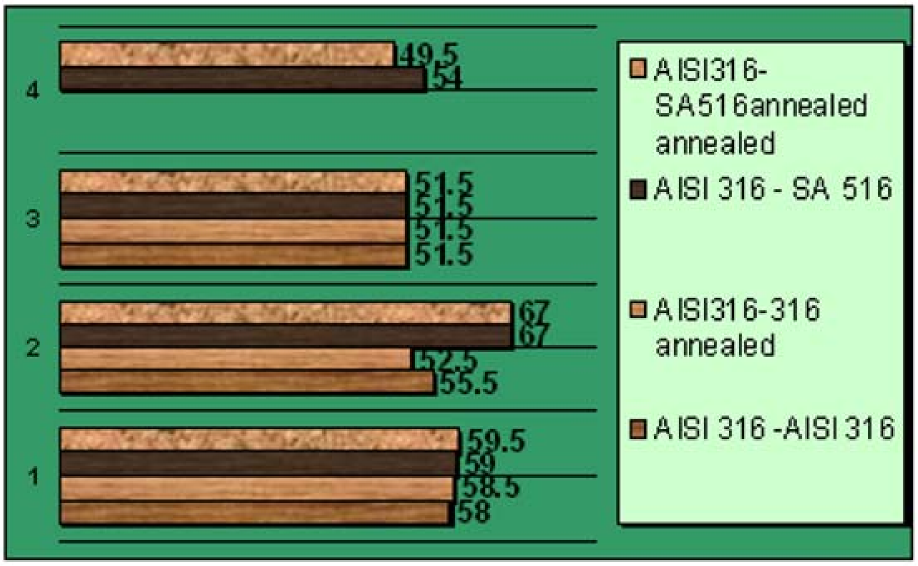
Max. percent elongtion from graph 2 of 38.01% was found. So AISI 316 welded SA 516 turns out to be highest with respect to tensile strength and yeild strength. But it may have some service limitations. Sample AISI316 welded SA 516 annealed could be used when limited service conditions are the prime concern because it has 360.62 MPa UTS value and 225.77 MPa Y.S and the %age elongation was 9.707 value which is the lowest among all the comparative tested samples as given in table 4 & table 5.

Sample AISI 316 welded AISI 316 had 581.34 MPa UTS and 334.09 MPa Y.S value and %age elongation 36.31 which is most moderate among all the samples with least number of service limitations. Sample AISI316 welded AISI316 had 58.39 m/kg . Its clear from the graph 3 that it had highest impact strength value which is feasible for high impact containing cicumstances which shows the application of this weldment in such conditions where higher fracture resistant charcteristic material are required.



Graph 3: Graph of Impact Strength Values

AISI 316 welded AISI 316 annealed has an impact strength of 52.41 m/kg which is less than the preceding, resultantly having less fracture resistance. In usual moderate impact circumstances this material can be preffered but it may have some service limitations. 316 welded 516 has an impact strength of 50.08 m/kg which minimise its use in severe impact situation. Yet it has a higher value of UTS but its lower value of impact strength make it unsuitable to be used in such environment where high impact strength is required. The results of bend tests show in table 7 that all the weldments were ductile enough to bear the bend stresses and hence the weldments in all the cases i.e. 316 welded 316, 316 welded annealed 316, 316 welded 516, and 316 welded 516 have the satisfactory ease of fabrication. The hardness profile is given in table 8 and graph 4.



Graph 4: Graph of hardness Values

The metallographic details as shown in fig 2, depicts the formation of coarse grains as well as fine grains for all the samples. For samples AISI316-AISI 316 welds and AISI316 welded 516, very fine grains are formed in the weld as well as in heat affected zone which contributes to higher UTS values and very high values of impact strength Kou (2002). This formation of fine grains near the fusion boundary keeps the weldment ductile enough to bear compression stresses and hence its bend results for both root and face are satisfactory. For samples 316 welded with 316 annealed and 316 welded 516 annealed, very complex grain structures are formed in the weld in addition to heat affected zones on the annealed side 316 plate which contributes to lower UTS values and lower values of impact strength. When these samples were welded, remelting of the surface and corresponding rapid cooling took place, which resulted in the formation of brittle cementite structures, hence a cementite and complex martensitic, bainitic flux formed due to self quenching of the pre annealed structure corresponds to the lower strength values. A very complex kind of structures can be seen at the edges of the fusion boundary encapsulating the heat affected zone comprising of mere carbides. The formation of complex grain structure near the fusion boundary on the 316 annealed side keeps the weldment ductile enough to bear bend stresses and hence its bend results for both root and face are satisfactory which has already seen in earlier results for other specimens, but this weldment is not efficient enough to bear high tensile stresses, thus these specimens just break within the heat affected zone and at the fusion boundary giving lower UTS values. Percentage elongation for this weldment is very low due to the formation of complex structure at the fusion boundary in case of AISI316 annealed side, seems to undergo brittle fracture as different slip planes can be oriented arbitrarily but the other side retains the high tensile stresses for the whole weldment.

CONCLUSION

GTAW welded AISI 316 with AISI 316 stainless steel gives most moderate results to be used in required applications with a least number of limitations. If the environmental conditions does not cause stress corrosion cracking or inter granular corrosion failures, than as welded material is preferred. Since UTS for GTAW welded ASIS 316 with SA 516 is higher than AISI 316 to AISI 316 but it has a lower value of impact strength than AISI 316 to AISI316 welds, yet AISI 316 welded SA 516 GRADE 70 has a number of limitations when applicable in service conditions, as the welding of these material can introduce residual stresses in the weldment hence limiting the service parameters. An attempt to increase the mechanical properties by initially annealing can be significant when the welding parameters i.e. groove design, filler angle etc. could be considered. Therefore on mechanical basis the results of 316 to 316(annealed) can be considered for service applications when the prevailing conditions are moderate enough and the weldment is quite feasible to bear such mechanical service conditions where as 316 welded 516(annealed) seems to be of less importance from service point of view.

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