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ANALYSIS OF SENSITIZATION IN AUSTENITIC STAINLESS STEEL WELDED JOINT

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Abstract : Influence of sensitization on the microstructure and mechanical properties of gas tungsten arc welded 304L stainless steel (SS) joints was studied. 304L stainless steel was observed to be sensitized when heated to 450°C - 950°C and held for short soaking times of 0.5 – 2hrs. Three heat input combinations designated as low heat (2.2 kJ/mm), medium heat (3.32 kJ/mm) and high heat (3.8 kJ/mm) were selected from the operating window of the gas tungsten arc welding process (GTAW) and weld joints made using these combinations were subjected to normalization at 750°C, 850°C and 1000°C for 0.5h,1h and 2h respectively microstructural evaluations, impact strength testing, micro-hardness and tensile testing are performed to analyze the effect of sensitization on the microstructure and mechanical properties of these joints. The results of this investigation indicate that the tensile strength is maximum at weld joints normalized at 750°C but remarkably decreased as the temperature was increased while the yield strength did not notably changed with increasing of the temperature. The Charpy impact energy and micro-harness showed higher value at weld joints normalized at 750°C but remarkably decreased as the temperature was increased. The major reason of Charpy impact energy decreasing was compound of manganese-silicon-Sulphur formed in the weld pool during solidification. The microstructures of sensitized samples have been observed by optical microscope. Heat treated weldment and parent are more sensitized than untreated weldments and parents. Specifically, weldments treated at 850°C with a 2 h holding time and then cooled in a furnace are the most sensitized.

Keywords: Mechanical Properties, Microstructure,Micro hardness, Sensitization, Tensile Strength, Impact strength

I. INTRODUCTION

Austenitic stainless have excellent corrosion resistance and mechanical properties but when it is exposed in temperature between 450^0c and 950 ^{0}c than loss in corrosion resistance is due to the formation of the chromium-rich carbides, $M_{23}C_6$, in the grain boundaries. Adjacent to the carbides, there is a chromium-depleted zone in which chromium concentration is less than 12 wt. %[1].Austenitic stainless steels sensitized when it is heat treated (normalized) in between 450^0c to 900^0c and held for short soaking times of 0.5-2 hrs. Sensitization refers to the breakdown in corrosion resistance due to depletion of chromium by the formation, of chromium rich carbide particles in the grain boundaries where the steel encounters temperatures in the range of about 450°C to around 950°C, most notably in the HAZ of a weldTypically, the Cr carbide is Cr-enriched $M_{23}C_6$, in which M represents Cr and some small amount of Fe. Within the sensitization temperature range carbon atoms rapidly diffuse to grain boundaries, where they combine with Cr to form Cr carbide. Because of Cr carbide precipitation at the grain boundary, the areas adjacent to the grain boundary are depleted of Cr. These areas become anodic to the rest of the grain and hence are preferentially attacked in corrosive media, resulting in intergranular corrosion.

Sensitization leads to degradation of corrosion resistance as well as the mechanical properties [3,4].There are many studies [2,5–9]on the effect of heat input on the microstructural developments of ASSs, but the welding process and the conditions used are different in each case. Zumelzu et al. [5] studied the effect of microstructure on the mechanical behavior of welded 316L joints. They showed that the best mechanical properties can be obtained by shieldedmetal arc welding (SMAW) process using E316L-16 electrode under low thermal heat input conditions and with 5% ferrite in the welded region.

2. EXPERIMENTAL DETAILS.

2.1 BASE AND FILLER MATERIAL.

The base material used in the present investigation was AISI 304L austenitic stainless steel. Nine Plates of 6 mm thickness and dimensions of 250 mm (length) × 100 mm (width) was used for the GTAW welding process and the filler was 304L SS solid electrode of 3.15 mm diameter. Table 1 shows the chemical composition of the base and the filler material used.

2.2. WELDING PROCEDURE.

Before welding, the base material was thoroughly cleaned to remove contamination like rust, dust, oil, moisture etc. so as to avoid welding defects due to contamination of the base metal. During welding one end of the plate was firmly fixed, while the welding current and welding speed were varied to obtain different heat inputs. The welding current was varied from 130A to 210A and the voltage was kept approximately constant at 25V.

The welding process was carefully controlled so that weld beads possess good geometry and was free from surface porosity, blow holes and other defects. The details of the welding parameters used are given in Table 2. The samples for micro structural examination, hardness, impact strength and tensile strength measurements were taken from the thickness section (perpendicular to the direction of the flow of weld bead). Microstructures were observed using an optical microscope. Fig. 1shows the weld samples taken for the tests.

2.3. SENSITIZATION TREATMENT.

Performance of the samples welded at lowest heat input 2.2 kJ/mm (210 A) was found to be the best when tensile strength, impact strength, micro hardness, microstructure were compared among the welded samples (welded under different heat input conditions) and base metal. Therefore, 210 A current was selected for sensitization studies and one more test coupon of SS 304L, 250 mm long, 500 mm wide and 6 mm thick was prepared by using same parameters and procedure as mentioned above. Nine set of samples for mechanical and micro structural studies were extracted from the welded plate and sensitized by performing the normalized heat treatment by varying the temperature and soaking time. Temperatures used were 750^0C, 850^0C and 1000^0C. The different soaking times at these temperatures were 30 minutes, 60 minutes, and 120 minutes. Samples were sensitized at six different time and temperature combinations.

Heat treatment was done in muffle furnace All the 12 specimens (9 tensile specimens + 9 specimens for microstructure and microhardness+9 specimens for impact) extracted from a plate welded at 210 A were normalized by heated at above mention temperature and time followed by cooling in still air. For example : 3 specimens (1 tensile specimen + 1 microstructure and micro hardness +1 impact) were heated at 750^0 C for 30 minutes and then air cooled and 3 specimens (1 tensile specimen + 1 specimen for microstructure and micro hardness +1 impact) were heated at 750^0 C for 60 minutes and cooled in air and so on.

Table 1 Chemical composition of the base metal and the filler electrode (in wt. %) as determined by optical emission spectroscopy.

	C	Mn	Si	Cr	Ni	P	S	Mo
Base metal (304L)	0.02	1.00	0.50	18.00	9.0	-	-	-
Filler electrode (304L)	0.04	1.5	1.0	19.5	10	0.04	0.03	0.75

2.4. SPECIMEN SAMPLING.

The specimens for tensile testing, micro hardness testing and micro structural studies
Were taken from the weld pads as schematic
-ally illustrated in Fig. 1.

2.5. TENSILE, MICRO-HARDNESS AND IMPACTTEST.

Three specimens were machined out from the weld pads as mentioned in Fig. 1. Each tensile, hardness and impact specimen size was prepared in accordance with ASTM E08 standards [22] as illustrated schematically in Fig. 2. The specimens were tested on a servo hydraulically controlled digital tensile testing machine of 400 kN capacity.Micro hardness of different zones of the weldments was measured using Vickers's micro hardness testing machine with a load of 0.5 kg. Impact strength was measured using Charpy impact testing machine. Fig4. Photograph of the tensile, micro hardness and inpact tested specimens showing the location of fracture at different normalization condition.

2.6. METALLOGRAPHIC

In order to observe the micro structural changes that take place during welding, corresponding to each heat input combination; specimens were machined out from the weld pads as shown in Fig. 1. The samples were ground and polished with successively fine emery papers (1/0, 2/0, 3/0 and 4/0). After polishing with emery papers, all the samples were subsequently polished on velvet cloth using alumina slurry and finally using diamond paste (1 μm) using Hiffin chloride as lubricant. The mirror polished samples were then deep etched with Kalling's reagent (5 g CuCl2, 100 ml HCl and 100 ml C_2H_5OH) [20] to observe the microstructure.

Table 2 Welding parameters used for butt welded joints.

Welding Current (A)	Voltage (V)	Pass	Welding Speed mm/min	Heat input per unit length per pass (Kj/mm)	Total heat input per unit length of weld (Kj/mm)
130	25	1st	95	1.43	3.32
		2nd	72	1.89	
170	25	1st	105	1.7	3.8
		2nd	85	2.1	
210	25	1st	215	1.02	2.2
		2nd	187	1.18	

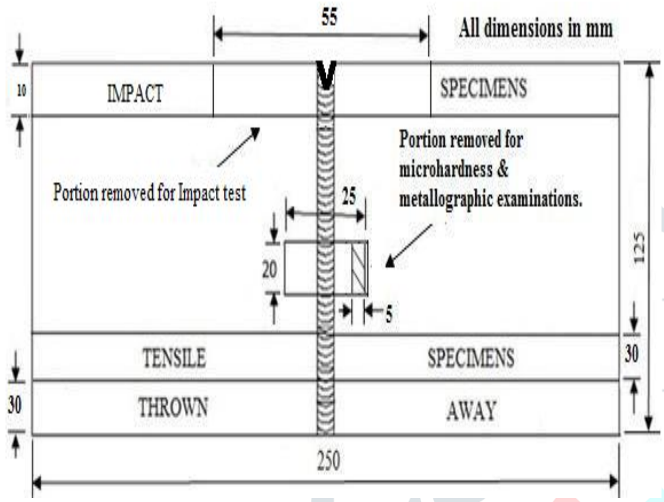


Figure 1: Illustration of weld samples for the tests.

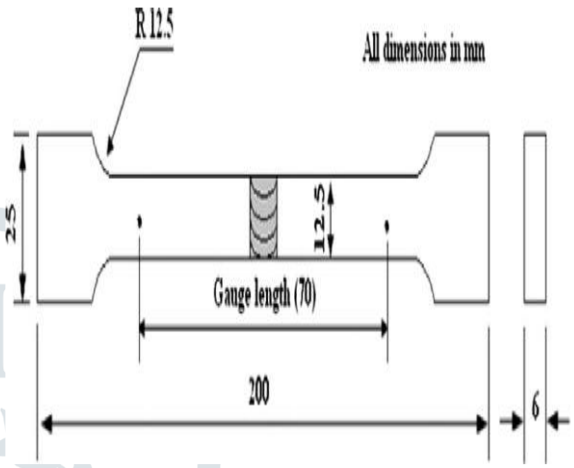


Figure 2: Specifications of the tensile Specimen used in the present work.

3. RESULTS AND DISCUSSION

3.1 METALLOGRAPHIC STUDIES OF SPECIMEN WELDED AT DIFFERENT WELDING CONDITIONS.

The microstructure of weld metal shows delta ferrite in the matrix of austenite and of parent metal shows equiaxed grains of austenite. Dark streaks visible are stringers of ferrite and these are minimum in sample welded at minimum heat input of 2.20 kJ/mm. Fig. 3. Photomicrographs of base metal and as welded specimens, welded under different heat conditions (A) 2.2kJ/mm, (B) 3.32kJ/mm, (C) 3.8 kJ/mm and (D) Base metal. (at 100x). All the welds have good joint strength, Specimen welded at 130A, 170A and 210A are fractured within the weld bead. Lack of fusion was also absorbed in weld made at 130A, when it was polished. Highest tensile strength is found at lowest heat input of 2.2 kJ/mm, it is about 94.28 % of the base metal. Hardness is maximum at lowest heat input 2.2 kJ/mm and minimum in sample welded at 130 A because arc formed by using this current was quite weak. Table 3shows the Macro and microstructural details of the weld joints

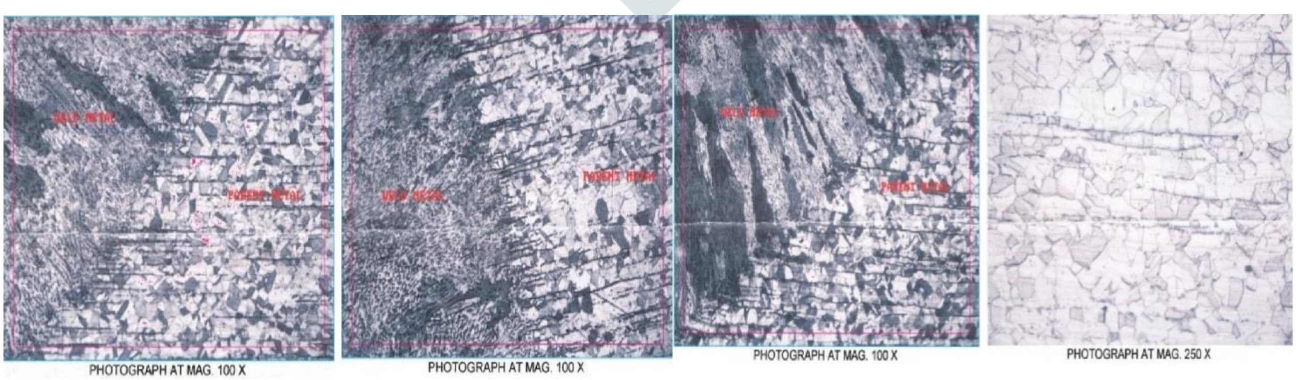


Fig. 3. Photomicrographsof base metal and as welded specimens, welded under different heat conditions (A) 2.2kJ/mm, (B) 3.32kJ/mm, (C) 3.8 kJ/mm and (D) Base metal.(At 100x).

Figure. 4. Optical micrograph showing the microstructure ofthe tensile, microhardness and impact tested specimens showing the location of fracture at different normalization temperature.

Table 3 Macro and microstructural details of the weld joints

Description	Tensile Strength Mpa	Yield Strength Mpa	Micro hardness HV	Impact strength KJ/mm^2
Base Metal	787.4	453.5	253	1.6
2.2 kJ/mm (210A)	747.7	288.431	250	1.56
3.8 kJ/mm (170A)	471.6	304.902	250	1.48
3.32 kJ/mm (130A)	630	296.471	240	1.4

3.2 Metallographic studies of specimen normalizing at 750^{o}C.

The photomicrographs of the normalized specimens are shown in Figs.5. Figs 5(a-c) show the photomicrographs of the normalized specimens from 750^{0}C each held at the soaking temperature for 30 mins, 1hr, and 2hrs respectively. Chromium depleted zones could be seen here but negligible in the sample soaked for 30mins but increased when shocking time increased.Table 4shows the Macro and microstructural details of the weld jointsnormalizing at 750^{0}C.Tensile, impact strength and micro hardness was found to be decreases with increasing soaking time and normalization temperature.

Figures 5. (a) Optical micrograph showing the microstructure ofsample heated to 750^{0}C held for 30mins, (b) Sample heated to 750 ^{0}C held for 1hr, (c) Sample heated to 750 ^{0}C held for 2h.

Table 4 Macro and microstructural details of the weld jointsnormalizing at 750^{0}C.

Description	Tensile Strength Mpa	Yield Strength Mpa	Micro hardness HV	Impact Strength KJ/mm^2
750^0 C for 30 min.	750.78	443.48	246	1.4
750^0 C for 1 hour.	736.76	477.023	235	1.28
750^0 C for 2 hour.	732.13	497.196	232	1.2

3.3 Metallographic studies of specimen normalizing at 850⁰C.

Figs 6(a-c) show the photomicrographs of the normalized specimens from 850^{0}C each held at the soaking temperature for 30 mins, 1hr and 2hrsrespectively. Chromium depleted zones could be seen here but increases when shocking timeincreased.Pattern followed by mechanical properties of samples sensitized at 850^{0}C resembles with the samples sensitized at 750^{0}C. Tensile strength, micro hardness and impact strength had decreased when temperature and normalizing time increased.Table 5shows the Macro and microstructural details of the weld joints normalizing at 850^{0}C.Tensile, impact strength and micro hardness was found to be decreases with increasing soaking time and normalization temperature.

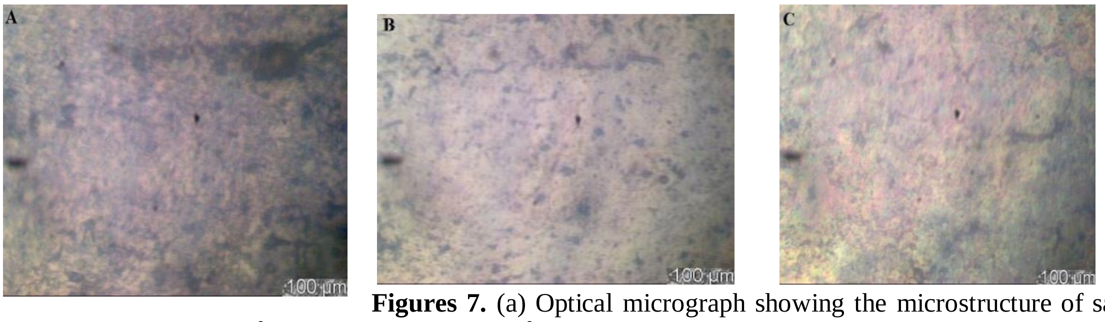
Figures 6. (a)Optical micrograph showing the microstructure ofSample heated to 850 ^{0}C held for 30mins, (b) Sample heated to 850 ^{0}C held for 1hr, (c) Sample heated to 850 ^{0}C held for 2hrs

Table 5 Macro and microstructural details of the weld jointsNormalizing at 850^{0}C.

Description	Tensile Strength Mpa	Yield Strength Mpa	Micro hardness HV	Impact strength KJ/mm^2
850^0 C for 30 min.	742.63	463.56	234	2.6
850$^{.0}$C for 1 hour.	736.711	452.63	260	2.5
850^{0}C for 2 hour.	722.04	462.15	242	1.9

3.3 Metallographic studies of specimen normalizing at 1000⁰C.

Fig. 7 shows the optical microstructures of specimens heat-treated at 1000^{0}C. Carbide precipitates could be seen here but negligible in sample soaked for 30 minutes and minimum in sample soaked for 120 minutes, with increasing temperature and exposer time Carbide precipitates are negligible that are due to desensitization which is clearly visible in fig. 7 (C).Table 6 shows theMacro and microstructural details of the weld joints normalizing at 1000^{0}C. At 1000^0 C, sensitization was observed at 30 minute soaking time and desensitization was observed at 1 and 2 hrs soaking time.Tensile and Impact strength of normalized 304Lstainless steel was also observed to increcreases with increasing soaking time and normalization temperature but hardness is decreases due to desensitization.



Figures 7. (a) Optical micrograph showing the microstructure of sample heated to 1000 ^{0}C held for 30mins, (b) 1000^{0}C held for 1hr, (c) 1000 ^{0}Cheld for 2hrs

Table 6 Macro and microstructural details of the weld jointsNormalizing at 1000^{0}C.

Description	Tensile Strength Mpa	Yield Strength Mpa	Micro hardness HV	Impact strength J/mm^2
1000C for 30 min.	616.88	431.25	235	1.84
1000C for 1 hour.	629.61	376.52	227	2
1000 C for 2 hour.	685.93	371.03	225	2.2

CONCLUSIONS

The following conclusions can be drawn from the presentwork:-SS 304L was observed to go into Sensitization when heated to 750^0 C and 850^0 C for 30, 60 and 120 minutes. All the three welds showed good joint strength but best results were achieved under condition of lowest heat input **(2.2 kJ/mm)** in terms of tensile strength and micro hardness obtained viz. **747.70 MPa** and **250 HV** respectively as compared to **787.40 MPa** and **253 HV** of the base metal.Tensile strength was found to be

Decreases with increasing soaking time and normalization temperature.The hardness of normalized 304L stainless steel was also observed to decreases with increasing soaking time and normalization temperature. Impact strength of normalized 304 Lstainless steel was also observed to decreases with increasing soaking time and normalization temperature. At 1000^0 C, sensitization was observed at 30 minute soaking time and desensitization was observed at 1 and 2 hrs soaking time.

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