ANALYSIS OF SENSITIZATION IN AUSTENITIC STAINLESS STEEL WELDED JOINT

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ABSTRACT

An experimental study was carried out to study the influence of sensitization on the microstructure and mechanical properties of gas tungsten arc welded (GTAW) 304L stainless steel (SS) joints. Austenitic stainless steel 304L was sensitized when normalized between 450°C-850°C and held for short soaking times of 1/2–2hrs. Flat plate of dimension 500x100x5mm is used for the experiment. Weld joints and base metal were normalized at 750°C, 850°C and 1000°C for 0.5h, 1h and 2h respectively. Tensile strength, Impact strength and Micro hardness of the sensitized sample has been investigated to find out the effect of sensitization on mechanical properties of stainless steel 304L. Tensile strength, Impact strength and Micro hardness of the sensitized sample has been evaluated by using tensile testing (UTM) machine, Charpy Impact testing machine and Viker's micro hardness testing machine. Microstructure evaluations of sensitized sample were analyzed by Optical microscopy. 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. 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 microstructures of sensitized samples indicate that heat treated weldments are more sensitized than untreated weldments specifically, weldments treated at 850°C with a 2 h holding time and then cooled in air are the most sensitized.

Keywords: *Microstructure, Micro hardness, Normalization, Sensitization, Tensile Strength.*

1. INTRODUCTION

Sensitization refers to the breakdown in corrosion resistance due to depletion of chromium by the formation, growth, and precipitation of chromium rich carbide particles in the grain boundaries where the steel encounters temperatures in the range of about 450 °C to around 850 °C, most notably in the HAZ of a weld. In addition to the loss in corrosion resistance due to chromium depletion, weld sensitization also causes a loss of fracture toughness due to the fracture path provided by the complex carbides within and along HAZ grain boundaries [1]. Typically, the Cr carbide is Cr-enriched M23C6, 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 inter-granular corrosion. It was also observed that deformation prior to welding or strain during cooling can enhance sensitization, this is perhaps due to the fact that dislocations can increase the carbide nucleation rate and the diffusion rate [2]. The sensitization below the sensitization temperature range is termed low temperature sensitization (LTS). The pre-existing tiny carbide particles were observed to grow in size when failed components were investigated; this was accompanied by severe chromium depletion from adjacent grain boundaries [3].

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2. EXPERIMENTAL TECHNIQUES

2.1 Material and Heat Treatment

The material used in this study was austenitic stainless steel AISI 304L. Nine Plates of 5 mm thickness and dimensions of 250 mm (length) × 125 mm (width) was used for the GTAW process and the filler wire was 304L SS electrode of 3.0 mm diameter. Table 1 shows the chemical composition of the base and the filler material used. Before start welding, the material was cleaned to remove rust, dust, oil, moisture etc. During welding the welding current and welding speed were varied to obtain different heat inputs and one end of the plate was fixed. The welding current which is used in this study was varied from 120A to 200A and the voltage was kept at approx. 30V. After compared the tensile strength, impact strength, micro hardness samples welded at lowest heat input was found to be the best among all the welded samples and base metal. Therefore, 210 A current was selected for welding for samples which is used for sensitization studies. One sample 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 were extracted from the welded plate and sensitized by heat treatment (normalization) by varying the temperature and soaking time.

Temperatures used for normalization are 750^0C, 850^0C and 1000^0C. The soaking times for normalization are 1/2hour, 1 hour, and 2 hours. 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) taken from a plate welded at 210A and normalized by heat treatment.

Table1. Chemical composition of the base metal and the filler electrode (in wt. %) used in these investigations.

	C	Mn	Si	Cr	Ni	P	S	Mo
Base metal (304L)	0.03	1.1	0.4	17	8	-	-	-
Filler electrode (304L)	0.02	1.2	0.9	18	9	0	0	0.7

2.2 Mechanical Testing

The specimens for tensile testing, micro hardness testing and micro structural studies were taken from the weld pads. Three specimens were machined out from the weld pads each tensile, hardness and impact specimen size was prepared in accordance with ASTM E08 standards. The specimens were tested on a servo hydraulically controlled digital tensile testing machine of 400 KN capacities. 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.

2.3 Microstructural Examination

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. 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 $CuCl_2$, 100 ml HCl and 100 ml C_2H_5OH) to observe the microstructure.

3. RESULTS AND DISCUSSION

3.1 Microstructural and Metallographic Analysis Of Specimen Normalizing At 750^{0}C

Figs 1(a-c) shows the photographs of the specimen's heat treated at 750^{0}C and held at the soaking time for 1/2 hr, 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 2 shows the Macro and microstructural details of the weld joints normalizing at 750^{0}C.Tensile, impact strength and micro hardness was found to be decreases with increasing soaking time and normalization temperature.

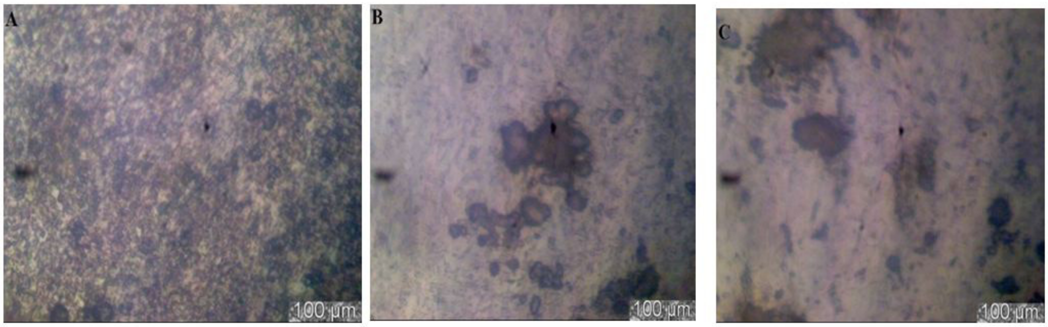

Fig 1. Optical photograph showing the microstructure of sample heated to 750^{0}C and held for (a) 30mins (b) 1hr (c) 2hrs.

Table 2. Mechanical testing result of the weld joints normalizing 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

3.2 Microstructural and Metallographic Analysis of Specimen Normalizing at 850^0 C.

Figs 2(a-c) shows the photographs of the specimen's heat treated at 850^{0}C and held at the soaking time for 1/2hr, 1hr and 2hrs respectively. Chromium depleted zones could be seen here but increases when shocking time increased. 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 3 shows the Macro and micro structural 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.

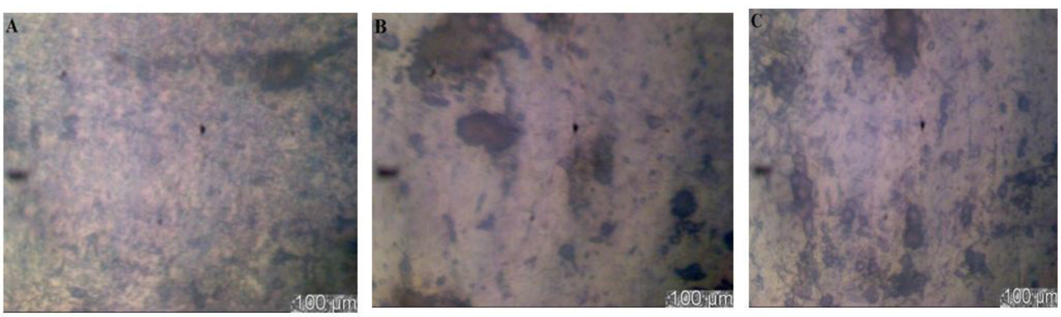

Fig 2. Optical photograph showing the microstructure of Sample heated to 850^{0}C and held for (a) 30mins (b) 1hr (c) 2hrs

Table 3. Mechanical testing result of the weld joints normalizing 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 Microstructural and Metallographic Analysis of Specimen Normalizing at 1000^{0}C.

Fig. 3 shows the photographs of specimens heat-treated at 1000^{0}C. Carbide precipitates could be seen here but negligible in sample soaked for 30 minutes and very less carbide precipitates 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. 3 (C).Table 4 shows the Macro and microstructural details of the weld joints normalizing at 1000^{0}C. At 10000 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 304L stainless steel was also observed to increases with increasing soaking time and normalization temperature but hardness is decreases due to desensitization.

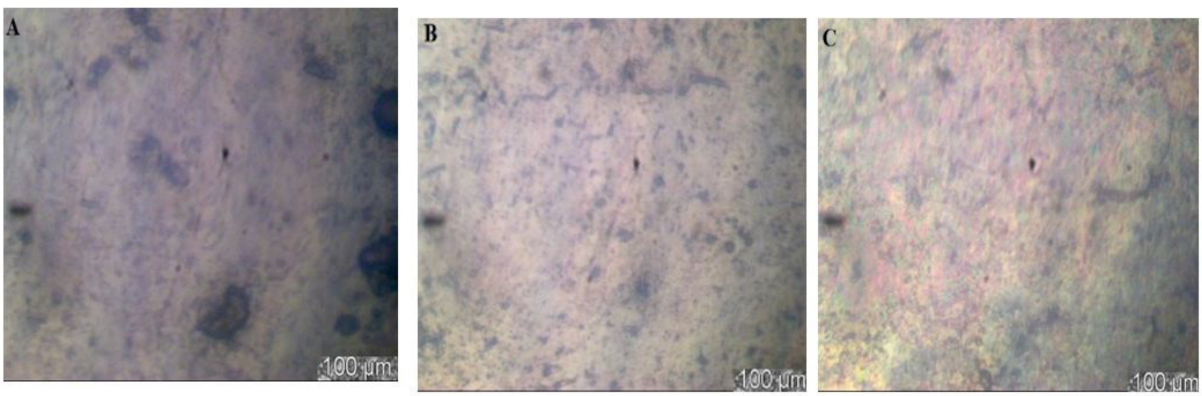

Fig 3. Optical photograph showing the microstructure of sample heated to 1000^0 C and held for (a) 30 mins. (b) 1hr (c) 2hrs.

Table 4. Macro and microstructural details of the weld joints normalizing at 1000^{0}C.

Description	Tensile Strength MPa	Yield Strength MPa	Micro-hardness HV	Impact strength J/mm^2
1000^{0}C for 30 min.	742.63	463.56	235	1.84
1000^{0}C for 1 hour.	736.711	452.63	227	2
1000^{0}C for 2 hour.	722.04	462.15	225	2.2

4. CONCLUSION

SS 304L was observed to go into Sensitization when heated to 750^0C and 850^0C 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 normalization time and temperature. With increasing normalization temperature and time hardness and impact strength of the sensitized samples also decreased. At 1000^0C, sensitization was observed at 30 minute soaking time and desensitization was observed at 1 and 2 hrs soaking time. When sensitization time and temperature increased carbide precipitation at grain boundary also increased and due to carbide precipitation ductility of material is reduced.

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