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A comparative study on microstructure and mechanical properties near interface for dissimilar materials during conventional V-groove and narrow gap welding

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ABSTRACT

Low alloy steel and 304 LN austenitic stainless steel pipes were welded together by gas tungsten arc and narrow gap welding. The aim of investigation was to identify particular welding technique, which may able to deliver better joint quality over the other considering mechanical properties of assemblies. Welding consumable was IN82 for both of them. Multilayered buttering was done over low alloy steel prior to welding for conventional GTAW. Microstructural characterisation was done and tensile strength was determined through in-situ deformation of miniature samples for welded joints. Low alloy steel consisted of heat affected zone close to interface. Near fusion boundary between low alloy steel and IN82, islands of martensite, complex alloy carbides, Types-I and II boundaries were formed. Width of heat affected zone and martensite layer was more for conventional welding in comparison to narrow gap welding. During in-situ tensile testing crack was initiated from stress concentration site and propagated through IN82. Joint strength and strain hardening co-efficient for narrow gap welded specimen was higher than conventional welded sample. This indicated better formability of narrow gap welded assembly with respect to gas tungsten arc welded specimen.

1. Introduction

Welding is one of the most effective manufacturing processes employed in wide range of industrial application for joining of materials. Conventional arc welding technique plays a key role due to its simplicity, mobility and versatility in joining materials with varying thickness, shape and physical properties. Base material properties are altered across weld line. A modified region close to the fusion boundary is developed and termed as heat affected zone (HAZ) [1–4]. Microstructure of weld joint becomes more complex if it involves dissimilar materials. One example is the joint between low alloy steel (LAS) and austenitic stainless steel (ASS). In nuclear power plants, austenitic stainless steels are used in corrosive environment at elevated temperature, whereas low alloy steels are preferred in reactor pressure vessels [3].

Gas Tungsten Arc Welding (GTAW) and Shielded Metal Arc Welding (SMAW) processes are employed to fabricate these joints using ASS or inconel filler materials. A steep compositional gradient between LAS and the weld metal is developed promoting diffusion of alloying elements at elevated temperatures [3,5–8]. Atomic migration of chemical species results in the formation of several intermetallic compounds and hard phases. These undesirable phase formation is responsible for reduction in joint efficiency [9,10]. To minimise such effects, buttering is done on the face of low alloy steel. Buttering layer minimises carbon diffusion across fusion boundary [11]. In restricting carbon diffusion and providing better compatibility with base material, IN82 filler material was found superior over austenitic stainless steel [12].

In spite of opting substantial preventive measures in selecting welding consumables and in process modification, there are several reports on premature failure of dissimilar materials welded joints (DMW) [2,13]. Most of the failures/dis-bondings occurred near fusion boundary between LAS and austenitic welding consumable (fusion boundary-1, FB-1) [2,14,15]. In this respect gross heterogeneity between weld metal and stainless steel was absent

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Table 1
Chemical composition of base metals and welding consumables.

Alloy	Concentration of alloying elements (wt pct)									
	C	Mn	P	S	Si	Ni	Cr	Mo	N	Nb	Fe
LAS	0.20	1.2	0.01	0.001	0.001	0.80	0.20	0.50	0.002	–	bal
304LN SS	0.03	2.0	0.05	0.03	1.0	8.0	18.0	–	0.1	–	bal
IN 82	0.10	3.2	0.03	0.01	0.4	bal	19.0	–	–	2.5	2.0

owing to adequate matching in between them considering crystal structure and physical properties. Therefore, the fusion boundary between them (FB-2) did not exhibit any degeneration [16]. Couple of attempts has been made in this area leading to considerable improvement in the life of these joints. Rathod et al. [5] attempted to improve the joint life by gradually reducing the compositional gradient at weld interface by depositing Ni–Fe layer as first layer of buttering. In another attempt, it was inferred that failure was due to formation of lenticular martensite and residual stress [13]. In a different endeavour, it was explained that martensite transformation in diffusion zone might be responsible for premature failure during service [17]. Tensile properties of DMW exhibited wide variation for standard and mini-sized specimens depending on welding consumables and process variables [18,19].

Effect of post weld heat treatment (PWHT) on stress corrosion cracking (SCC) of joint between ferritic and austenitic steel was also reported [20]. Results confirmed that PWHT aided carbon diffusion into weld metal producing localised de-carburised and carbon rich layers across interface. To eliminate the post weld heat treatment A-TIG welding process was attempted as it produced lesser heat input with respect to conventional GTAW [21]. In another study, the residual stress profile across weld line concluded that IN82 buttering layer reduced the residual stress in HAZ [22]. The effect of residual stress on fatigue crack growth rate for narrow gap welded stainless steel was studied by Jang et al. [23]. In that case austenitic layer became susceptible to stress corrosion cracking (SCC) after post weld heat treatment [23]. Work hardening behaviour of welded joints during mechanical deformation was also investigated [3,24]. In this respect, investigation on laser welded dual phase steel revealed that presence of martensite at interface and HAZ mainly controlled the nature of work hardening [24]. Though strain hardening occurred through number of stages, yet based on phase constituents for complex alloy like dual phase steel, couple of stages may be absent [24]. The tensile tested samples failed through HAZ exhibiting ductile dimple fracture. Seifert et al. [3] studied the local variation in mechanical properties at service temperature and reported an increase in strength at stainless steel, which was attributed to the effect of strain hardening.

Investigations have pointed out that the accumulated residual stress and the diffusion of alloying elements along with phase transformation were prime reasons for failure of DMWs from fusion boundary between LAS and austenitic alloy. Hot wire GTAW (HWGTAW) narrow gap welding could be a promising solution in reducing the residual stress. The reduced heat input in this welding process may improve mechanical properties of joint as the accumulated residual stress can be reduced [25].

As mentioned earlier, in pressurised water reactors of nuclear power plants the welded joint between low alloy steel and austenitic stainless is a critical component. There are continuous efforts in this field to improve the joint reliability and efficiency by adopting new joining techniques and various welding consumables. In spite of all these attempts, still welds of these particular materials combination failed prematurely in service exploitation. It was depicted in investigation that fusion boundary between LAS and austenitic alloy was prone to failure. Therefore, in present study the same base materials i.e. low alloy steel and 304LN stainless steel were considered. They were joined by narrow gap welding and conventional V-groove GTAW. IN 82 was used as welding consumable. Aim of the investigation thus included (i) explore microstructure across fusion boundaries (ii) evaluate the mechanical properties across FB-1 and (iii) co-relate structural characteristics with mechanical behaviour of assemblies to identify particular joining method which might be able to deliver better quality joint over the other in terms of strength and ease of fabrication.

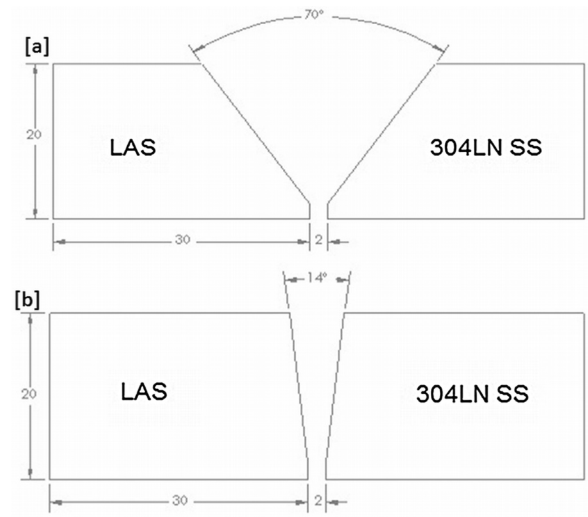

Fig. 1. Geometry of welded specimen (a) GTAW and (b) NGW (dimensions are in mm, not to scale).

2. Experimental procedure

Base materials were ASTM A508 Grade 3 Class 1 low alloy steel (LAS) and SA312 type 304LN austenitic stainless steel (304LN SS). Composition of base metals was presented in Table 1. Two different welded joints, one (hence forth IN82-W) by conventional V-groove Gas Tungsten Arc Welding (GTAW) and another (hence forth IN82-N) by hot wire narrow gap welding (NGW) were fabricated with IN82 filler alloy. Prior to welding, layer wise buttering was done on LAS side of the IN82-W specimen. During buttering, ~2.4 mm filler wire (ERNiCr-3) was used at a welding current of 140/120 to 170/150 A (peak/base) and voltage of 18–20 and 22–21 V. No such buttering process was carried out for IN82-N specimen. In case of In82-W, welding with 304LN SS was done using ~2.4 mm filler wire (ERNiCr-3), current of 140/120 (peak/base) and voltage of 18–20 V at a speed of 60 mm/min under 99.999% pure Ar atmosphere. For fabricating IN82-N same filler wire of ~0.8 mm diameter was used along with ~4.0 mm diameter tungsten electrode in automatic hot wire GTAW. High pulse current of 170–310 A was employed with LPC of 65–210 A during fabrication. Joints were produced at welding voltage of 8–9.6 V with speed of 65–95 mm/min under Ar atmosphere of same purity. The geometry of both joints is given in Fig. 1.

Sampling has been done from transverse section of weld and was prepared by metallographic technique. Polished samples were chemically etched in two stages, i.e. by Nital (3% HNO_3 in Alchhol) and Glycergia (1:3 ≈ HNO_3:HCl with few drops of glycerine). Sam-