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Technical Paper

Experimental investigation on microstructure and mechanical properties of activated TIG welded reduced activation ferritic/martensitic steel joints

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ABSTRACT

In the present study activated tungsten inert gas welding (A-TIG) process has been attempted for welding of 6 mm thick reduced activation ferritic/martensitic (RAFM) steel. Comparative studies on the effect of single (760 °C for 2 h) and double (760 °C for 2 h + 760 °C for 2 h) post-weld heat treatment (PWHT) cycles on microstructures, microhardness, tensile strength, impact strength and ductile to brittle transition temperatures (DBTT) of these welded joints have also been evaluated. It was inferred from the studies that ductility was improved for the weldments after undergoing double PWHT cycles. The toughness values increased after double PWHT cycles and were comparable to that of base metal values. DBTT values of −5 °C and −11 °C were obtained for the welded samples undergone single and double PWHT cycles respectively. This study also attested the detailed structure–property relationship of A-TIG weldments using optical microscopy, scanning electron microscopy, energy dispersive spectroscopy (EDS) techniques.

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1. Introduction

Reduced activation ferritic/martensitic (RAFM) steel is a specially developed steel to be used as the structural material in test blanket module (TBM) of international thermonuclear experimental reactor (ITER). Owing to its excellent weldability, low thermal expansion, excellent mechanical properties at high temperature and adequate corrosion resistance, the steel also has a promising future in equipment for fossil power and nuclear power plants [1–3]. RAFM steel is in a way modification of conventional P91 steels wherein elements molybdenum (Mo) and niobium (Nb) are replaced by tungsten (W) and tantalum (Ta) and proportion of elements like B, Cu, Mn, P, and S are lowered down to reduce the induced radioactivity [4]. The development of this steel allowed shallow land burial of fusion components after their service lives were over [5]. In view of this promising future of RAFM steel, countries participating in ITER program are working toward the development of an indigenous structural material with minor modification in the chemical composition of RAFM steel and its allied fabrication technologies.

Owing to the complicated structure and large dimensions of TBM, welding is by far the most suitable process for the fabrication. However, TBM and its sub-components shall be under irradiated environment during service, and the embrittlement phenomenon is likely to happen for weld joint as compared to base metal. Thus these components are supposed to have a minimum number of welds with the volume of weld metal and subsequent HAZ to be minimum [6]. This condition, rules out the possibility of using conventional welding processes (such as SMAW, GMAW, etc.) for fabrication and makes processes like electron beam welding (EBW), laser beam welding (LBW) and activated tungsten inert gas welding (A-TIG) as the candidate welding processes [7]. Out of these, A-TIG welding can be deemed to have a promising prospect as EBW and LBW processes lacks on-site welding and repair capability. The second challenge for researchers in the domain was to secure the right amount of alloying elements especially for the replaced elements W and Ta in order to achieve required properties. It was inferred from studies that, Ta reduces ductile to brittle transition temperature (DBTT) in RAFM steel, however, over addition of Ta reduces weldability. Similarly, W addition increases the creep rupture strength but increases DBTT even closer to room temperature. Thus an even balance of the alloying elements was necessary to achieve the required properties. Initial international efforts were

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Table 1
Chemical composition (Wt.%) of RAFM steel used in present study.

Elements	C	Si	Mn	P	S	Cr	Mo	Ni
	0.1	0.05	0.54	0.004	0.002	8.97	<0.002	0.008

Elements	Al	Co	V	W	Ta
	0.008	0.007	0.23	1.42	0.066

Table 2
Welding parameters.

Welding current	200 A
Crater current	200 A
Travel speed	100 mm/min
Electrode type	Tungsten (2% thoriated)
Electrode diameter	2.9 mm
Electrode angle	18–20° (Blunt ground at tip)
Arc gap	2–3 mm
Shielding gas	Argon (99.999% purity)
Gas flow rate	10–12 L/min
Welding position	1G (Flat)
Electrode extension	5–6 mm
Nozzle diameter	8 mm

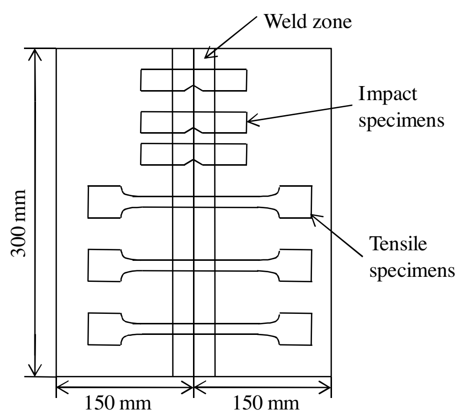

Fig. 1. Location for tensile and impact specimen extraction for testing from welded plates.

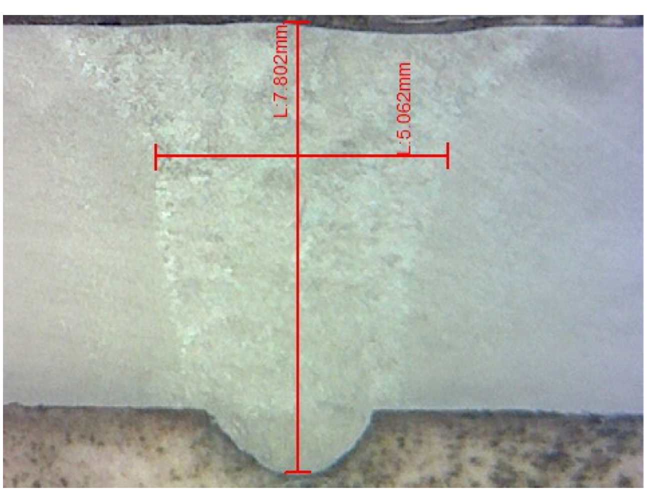

Fig. 2. Cross-sectional macrostructure image of A-TIG welded RAFM plate.

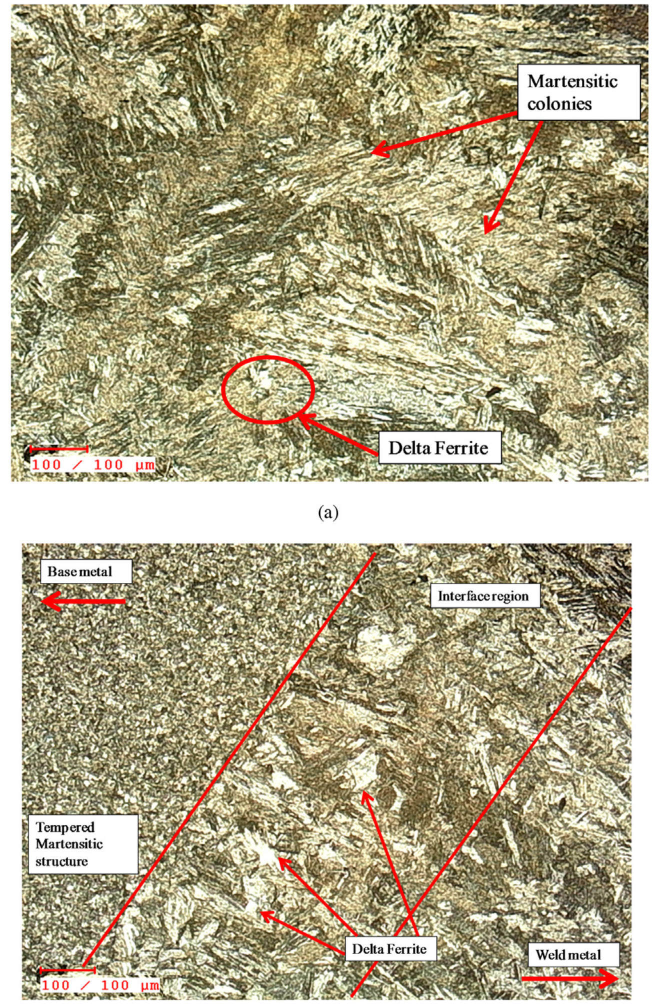

Fig. 3. Microstructures of as-welded RAFM joints (a) weld metal (b) HAZ and interface.

focused on varying proportion of W in the range of 1–2 wt.% and Ta in the range of 0.02–0.18 wt.% [8,9].

The initial composition of W in the RAFM steel was 1.0 wt.% and the studies on the development of suitable fabrication technologies pivoted to EBW [6,7,10], TIG [11,12] and A-TIG [13] welding processes have been reported. From these studies, it was inferred that delta ferrite in the weld metal had an influential effect on the mechanical properties of the RAFM steel [6]. The DBTT of RAFM steel with 1 wt.% of W was found to be around −80 °C [7]. Carbides and laves phases were reported in weld metal deposited by TIG welding process [11]. It was also found from the studies that employing A-TIG welding process on RAFM steel gave enhanced penetration during welding. However, mechanical properties of welded joint was found inferior compared to base material and it was suggested to employ repeated post-weld heat treatment (PWHT) cycles for improving these properties [13].

For India specific RAFM (IN-RAFM) steel, the proportion of W and Ta was fixed as 1.4 wt.% and 0.06 wt.% respectively [6]. Per best of author's knowledge, limited research work has been carried out on the development of welding procedures for RAFM steel with 1.4 wt.% of W. Given the condition set for fabrication of the TBM components (incorporating reduced volume of weld metal), A-TIG welding can be considered a candidate process for joining of RAFM steel wherein a suitable flux (chemical powder consisting of halides, sulphides, and oxides) paste is applied before the autogenous TIG welding [14,15]. It has been widely reported that the process has the capability to increase the penetration capability of autogenous TIG welding by up to 300% [16,17] and 6 mm

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