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Microstructure and mechanical properties in TIG welding of CLAM steel

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ABSTRACT

Tungsten insert gas (TIG) welding on China low activation martensitic (CLAM) steel under identical conditions was performed. Microhardness test, tensile test, Charpy impact test and microstructure measurements were carried out on TIG welded joints after post weld heat-treatment. Hardening at WM and softening in HAZ is detected in the TIG weld joint. Microhardness in WM decreased when the temperature of PWHT increased. The ultimate tensile stress of weld metal is higher than that of HAZ and BM. Absorbed energy increased with PWHT temperature rising, until PWHT was done at 760 °C/30 min, the specimen ductile fractured in local area. The microstructure of the weld metal for every specimen was found to be tempered martensite with a little of delta ferrite. $M_{23}C_6$ particles are the predominant type of carbides. Oxide precipitate phases appeared in WM, which are the primary crack initiation sites and it is critically important minimize their formation.

1. Introduction

The reduced-activation ferritic/martensitic (RAFM) steels are candidate materials for the first wall and blanket of fusion reactors due to their attractive properties before and after neutron irradiation [1–3]. China low activation martensitic steel (CLAM), one of RAFMs and under development, is chosen as the primary candidate structural material for blanket components in fusion DEMO reactors in China [2,3]. For an application of candidate materials to fusion reactors, engineering technologies related to component fabrication are becoming major issues. Welding procedures have been considered to be particularly important in the fabrication of complex components. Researches on joining methods such as EBW [4,5] (electron beam welding), HIP [6] (hot isostatic pressing) and TIG [7–9] (tungsten insert gas) welding for CLAM are carried out in order to explore suitable techniques for manufacturing of the first wall (FW), the cooling plates (CP) and the assembly of these components.

In this study, two plates of CLAM steel were butt-welded by TIG under identical conditions (a) using the original CLAM composition filler metal and (b) using the modified composition. Microhardness measurements and tensile test were carried out on TIG welded joints after post weld heat-treatment. With metallurgical and microstructural observations, microstructure in the TIG weld joints was analyzed. The objective of this study is to characterize and analyze the microstructure and mechanical properties of TIG welds of CLAM steel made under identical conditions. The results and discussion are given in the following sections.

2. Experimental

The 5.0 mm thick plates of CLAM steel were prepared. Its composition is: 8.91Cr, 1.44W, 0.35Mn, 0.20 V, 0.15Ta, and 0.12C in wt.%, and Fe for the balance. The plates were normalized at 980 °C for 30min (air cooling) and tempered at 760 °C for 90 min (air cooling). Plates with 60° V-groove were TIG welded under identical conditions (a) using the original CLAM composition filler metal and (b) using the modified composition, which composition is: 9.8Cr, 2.0W, 0.5Ta, 0.35Mn, 0.19 V, and 0.12C in wt.%, and Fe for the balance. Welding current is 64 A, welding voltage is 13 V, the protecting gas flows about 10 L/min, the back of weldment was also protected by argon, welding speed is about 2 mm/s. Post weld heat-treatment (PWHT) was performed in order to study its effect on the joint properties, which is listed in Table 1.

Micro-Vickers hardness measurements were performed by a hardness tester (HVS-1000) on TIG weld joints, the testing load was 0.98 N. Tensile strength test (TS) and Charpy impact tests (CIT) of the joints were also carried out. Charpy specimens were V-notch specimens measuring 5 mm × 10 mm × 55 mm with a 2 mm deep 45° angle V-notch and a 0.25 mm root radius. The microstructure of joints was observed through optical microscope (OM), scanning electron microscope (SEM) and transmission electron microscope (TEM). The testing pieces for metallurgical observation were taken at the cross-section of the joints. All of them were polished followed

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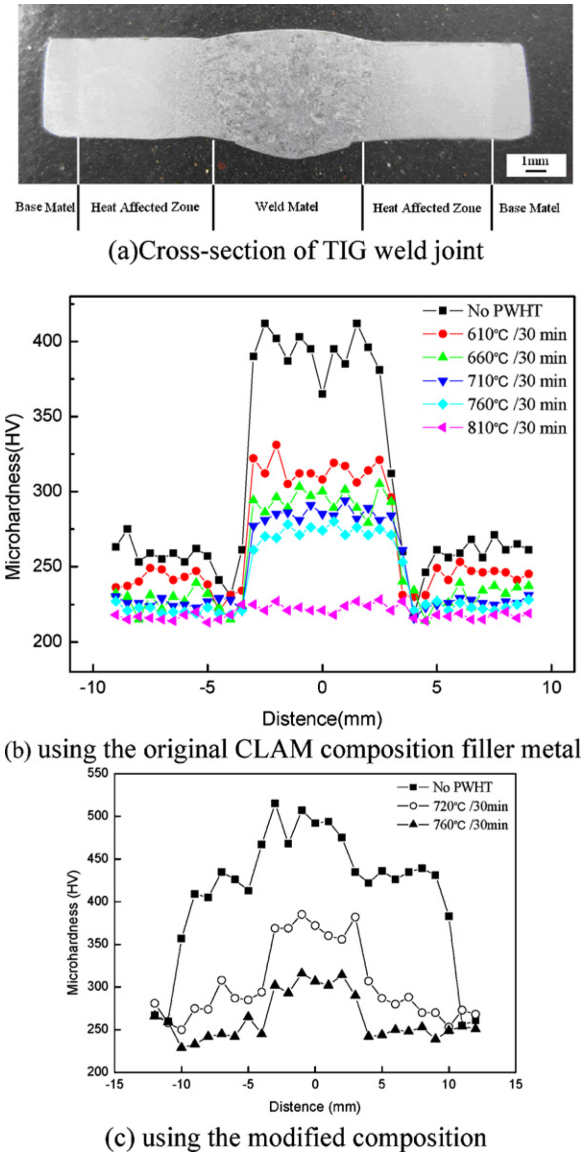

Fig. 1. Microhardness distributions on TIG weld joints (a) cross-section of TIG weld joint (b) using the original CLAM composition filler metal (c) using the modified composition.

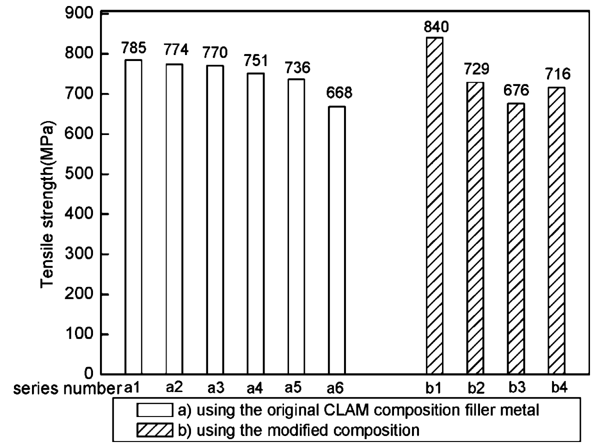

Fig. 2. Ultimate tensile strength of joints under identical conditions.

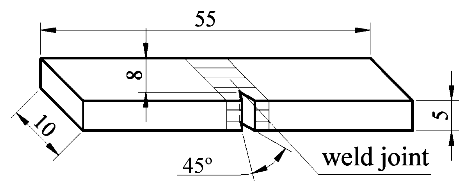

Fig. 3. Shape and dimensions of CIT specimen (a) a5 (b) b3.

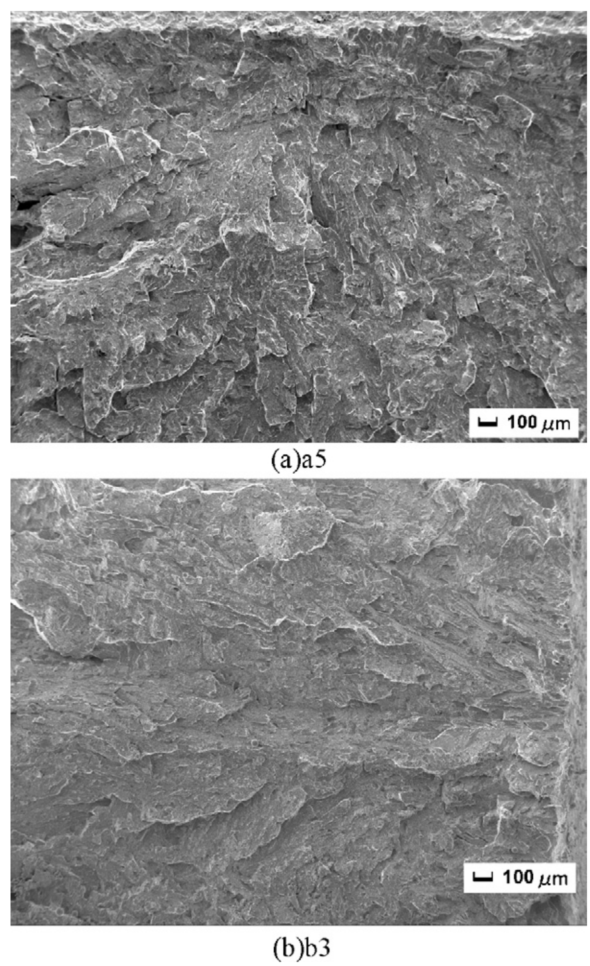

Fig. 4. SEM micrograph of fractured surface notched at the WM.

by chemical etching in a solution of 95 mL C_2H_5OH + 5 mL HCl + 1 g $C_6H_3O_7N_3$.

3. Results and discussion

3.1. Hardness test

Cross-section of TIG weld joint after PWHT is shown in Fig. 1(a), no obvious defects were found, weld metal (WM), heat affect zone (HAZ), base metal (BM) on weld joints can be identified clearly, and typical results of hardness tests on it are shown in Fig. 1(b and c).

Welding heat affects the weld joints both in hardening and softening [4,10]. Hardening at WM is detected in TIG weld joint whatever the filler metal is using the original CLAM composition or the modified composition. CLAM is quench-hardenable so that the cooling of WM, where the temperature is above Ac_3, easily makes a lath martensitic structure. Lath martensite has the high dislocation density and large lattice distortion and leads to the hardening behavior in WM zone. The hardness in WM decreased rapidly after PWHT. The hardness decreased about 50 Hv when the temperature