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Effect of welding processes on mechanical and microstructural characteristics of high strength low alloy naval grade steel joints

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Abstract

Naval grade high strength low alloy (HSLA) steels can be easily welded by all types of fusion welding processes. However, fusion welding of these steels leads to the problems such as cold cracking, residual stress, distortion and fatigue damage. These problems can be eliminated by solid state welding process such as friction stir welding (FSW). In this investigation, a comparative evaluation of mechanical (tensile, impact, hardness) properties and microstructural features of shielded metal arc (SMA), gas metal arc (GMA) and friction stir welded (FSW) naval grade HSLA steel joints was carried out. It was found that the use of FSW process eliminated the problems related to fusion welding processes and also resulted in the superior mechanical properties compared to GMA and SMA welded joints.

Keywords: High strength low alloy steel; Friction stir welding; Shielded metal arc welding; Gas metal arc welding; Tensile properties; Impact toughness

1. Introduction

High strength low alloy (HSLA) steels were primarily developed to replace low-carbon steels for the automotive industry in order to improve the strength-to-weight ratio and meet the need for higher-strength construction grade materials. When high strength steel is welded, non-uniform heating and cooling in weld metal and base metal generate harder heat affected zone (HAZ), cold crack susceptibility and residual stress in weldments. HSLA steels demonstrate unique properties, such as high strength, excellent ductility, and good weldability, and also exhibit outstanding low temperature impact toughness superior to that of high yield strength (HY) steels. HSLA steels have much improved weldability compared to HY steels [1]. Now-a-days, the micro-alloyed or HSLA steels become an indispensable class for different applications like construction of large ships, oil and gas transmission lines, offshore oil drilling platforms, pressure vessels, building construction, bridges, storage tanks.

DMR-249A is a low carbon micro-alloyed high strength low alloy (HSLA) steel, which is far superior grade compared to the numerous grades which have been in use for naval applications like construction of warships. Obviously, DMR249A demands weld metal with superior properties compatible with its own, i.e., a combination of high strength and high toughness. This is due to its composition that consists of 0.001−0.1wt% of alloying elements such as V or Ti [2]. An acicular ferrite in weld metals and wrought steels has predominant one owing to its combination of high strength and

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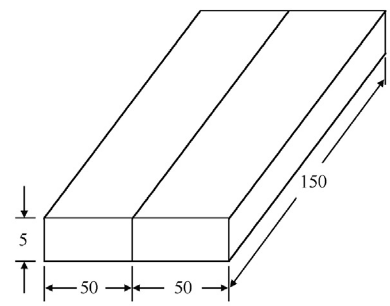
high toughness [2,4,5], thus this steel has designed to have a ferrite microstructure with small amount of pearlite less than 10% by volume [2,3].

In these grade steels, the heat affected zone (HAZ) is prone to failure due to the possibility of hydrogen induced cracking and only way to weld such steels is to use low hydrogen ferritic steel filler wire [6]. Charpy impact fracture of HSLA steel was improved by intercritical heat treatment which enhances the microstructure through the formation of ferrite microstructure with various morphologies, irregular martensite and 75% of microstructure with high angle grain boundaries [7]. The resistance to hydrogen-induced cracking and stress corrosion cracking was improved by coarse grain heat affected zone which consists of martensite-austenite constituents, thus showing the importance of reduction in carbon content of these steels [8].

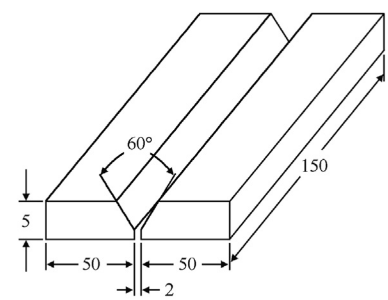
Friction stir welding (FSW) is a novel solid state joining technique that is presently attracting significant attention on welding of hard metals such as steel and titanium [9–11]. FSW has appeared as an easy, ecological and promising productive welding method that reduces material waste and avoids radiation and harmful gas emissions, usually associated with the fusion welding processes. Mechanical action in the form of frictional stirring on the base material has modified the microstructure from the coarse grains to very fine grains due to plastic deformation and fast cooling rate [12–14]. Welding of steels is affected by both the temperature and composition which extensively affects the microstructure evolution. Friction stir welding enables us to control these factors and produce superior joint strength [1]. Much of the tool degradation may be attributed to the high heat (temperature around 1200 °C) and the stresses generated during friction stir welding of the high strength materials. However, the development of the wear resistant tool materials has benefited the FSW process and paved way for the rapid implementation of this process in the fabrication of high strength steel structures [15,16]. The present investigation is to study the feasibility of friction stir welding of naval grade HSLA steel and compare the mechanical properties and metallurgical characteristics of FSW joints with the fusion welded (SMA and GMA welded) joints.

2. Experimental details

The rolled plates of naval grade HSLA steel with thickness of 5 mm were cut to the required dimensions (100 mm × 150 mm) by abrasive cutting to prepare the joint configurations, as shown in Fig. 1(a) and (b). The chemical composition of parent metal is presented in Table 1. The microstructure of parent metal (Fig. 2(a) and (b)) is composed of ferrite with small amount of pearlite. A non-consumable rotating tool made of tungsten base alloy was used to fabricate FSW joints. The tool was manufactured through powder metallurgy route having a shoulder diameter of 25 mm and a tapered pin, tapering from 12 mm at the shoulder to 8 mm at the pin tip. The electrode for SMAW and filler wire for GMAW processes were supplied by Honavar Electrodes Pvt. Ltd. The basic classification of Mn and Ni base E 8018-C1 with nominal composition of 0.06% C, 1.8% Mn and 2.5% Ni electrode was used to weld the naval grade steels. The welding conditions and parameters used to fabricate the defect free joints are presented in Tables 2 and 3.



(a) Joint configuration for FSW



(b) Joint configuration for SMA and GMAW

Fig. 1. Experimental details (unit:mm).

ASTM E8M-04 guidelines were followed for preparing the tensile test specimens. 100 kN electromechanical controlled universal testing machine (Make: FIE Bluestar, India; Model: UNITEK-94100) was used to evaluate the tensile properties. In each condition, three specimens were tested and the average value was presented. Charpy impact specimens were prepared to evaluate the impact toughness of the weld metal and hence the notch was placed (machined) in the weld metal (weld center). Since the plate thickness was small, the sub-size specimens were prepared. Impact testing was conducted on a pendulum-type impact testing machine (Enkay, India) at room temperature. The amount of energy absorbed in fracture was recorded. The absorbed energy is defined as the impact toughness of the material.

Vicker's microhardness tester (Make: Shimadzu, Japan and Model: HMV-2T) was used for measuring the hardness distribution across the welded joint along with mid thickness region with a load of 0.5 N. The specimen for metallographic examination was sectioned to the required size from the joint comprising weld metal, HAZ (heat-affected zone), and base metal regions, and polished using different grades of emery papers. Final polishing was done using the diamond compound (particle size of 1 μm) on the disc polishing machine. The specimens were etched with 2% of Nital solution to reveal the microstructural features of joints. Microstructural examination was carried out using an optical microscope (Make: MEJI, Japan; Model: MIL-7100) incorporated with an image