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Fatigue life prediction of strength mis-matched high strength low alloy steel welds

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Abstract

Welding of high strength low alloy steels (HSLA) involve usage of low, even and high strength filler materials (electrodes) than the parent material depending on the application of the welded structures and the availability of the filler materials. The base material used in this investigation is HSLA-80 steel of weldable grade. Shielded metal arc welding (SMAW) process has been used to fabricate the single bevel butt joints. Centre cracked tension (CCT) specimen has been used to evaluate the fatigue crack growth behaviour of the welded joints. Fatigue crack growth experiments have been conducted using servo hydraulic controlled fatigue testing machine at constant amplitude loading ($R = 0$). A method has been proposed to predict the fatigue life of HSLA steel welds using fracture mechanics approach by incorporating influences of mis-match ratio (MMR), post weld heat treatment (PWHT) and notch location.

Keywords: Shielded metal arc welding; High strength low alloy steel; Mis-match ratio; Post weld heat treatment; Fatigue crack growth; Fatigue life

1. Introduction

Mis-matched welded joints are joints in which the yield strength and or microstructures of the weld metal will be different from that of the base metal and HAZ. The factors, which are responsible for heterogeneities, are welding processes, consumables, joint designs and weld thermal cycles [1]. Under matched joints are used in repair welding, welding of penstocks, pressure vessels and bridges etc. They are used to prevent cracks in the welds, for example an under matched cap pass reduces the weld toe cracking from cyclic plastic bending during reeling [2]. Similarly over matched joints are used in pipe line girth welds, welded offshore structures, cladding and hard facing, etc., for protecting the weld metal failure by effectively shielding the small cracks present in the weld metal [3].

It has been found that very little engineering experience [4,5] has been gained particularly on the performance of high strength steel joints under cyclic loading conditions. Moreover, various codes and specifications require that welded structures such as pressure vessels and offshore platforms be post weld heat treated (PWHT) depending on the type and thickness of the welded joint. Post weld heat treatment reduces the effect of any stresses induced by the welding process and tempers the heat affected zone [6]. Some studies [7,8] have been conducted to study the effect of a long PWHT on the properties of constructional and pressure vessel steel weldment. PWHT may have a beneficial, detrimental or negligible effect on properties (especially toughness) of the weldment, depending on the chemical composition of the steel, welding procedure used and PWHT time and temperature.

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For critical structural applications, both fatigue crack initiation and propagation behaviour are equally important for the purpose of safety. In such situation, the fracture mechanics approach is more appropriate in place of traditional S–N type of approach covered by BS 5400 and IIW Documents, to predict the fatigue life [9]. Accordingly, it is imperative to account both initiation and propagation period for the same using fracture mechanics method. It is customary to predict the fatigue life of a component/welded joint in terms of crack growth parameters such as d*a*/d*N* against ΔK obtained by crack growth experiment [10]. Practically, this type of data merely indicates the fatigue behaviour of the component and does not predict the actual life. As a result, most of the fatigue crack growth data obtained for different components finds a little relevance when the fatigue life prediction is concerned due to the absence of any direct correlation. Hence, in this investigation an attempt has been made to predict the fatigue life of strength mis-matched HSLA steel welds using fracture mechanics approach by incorporating the influences of mis-match ratio and post weld heat treatment.

A unified approach has been proposed by combining Basquin type equation for crack initiation and Paris type equation for crack propagation. The initiation life (N_i) and the propagation life (N_p) of the joints are accounted for, to obtain the total fatigue life (N_f). The fatigue crack initiation life of the load carrying butt joints has been estimated using the equations derived from $\Delta\sigma - N_i$ relationships. The initiation life (N_i) was obtained experimentally using suitable crack initiation criteria. The propagation life of the load carrying butt joints has been evaluated using the numerically developed equations and incorportating an integral factor (I_p) obtained by integrating Paris type crack growth equation. Accuracy of the method has been checked by comparing the predicted fatigue life values with the experimental values and the correlation was found to be fairly close.

2. Experimental work

The base material used in this investigation was HSLA-80 steel, widely used for submarines, bridges, heavy earth moving equipments, pressure vessels and pipelines, ship building and offshore construction etc. Rolled plates of 12 mm thickness has been used as the base material. Single bevel butt joint configuration, as shown in Fig. 1(a), has been prepared for joining the plates. This joint design is so chosen to study the fatigue crack growth behaviour of HAZ region since in this joint design the HAZ region is straight and parallel in one side of the joint. Three types of low hydrogen, ferritic electrodes with different levels of yield strength have been chosen for joining the plates to attain different strength mis-match ratio. The chemical composition and mechanical properties of base metal and weld metals are presented in Table 1.

The welded joints were divided into two groups viz., (i) as welded (AW) joints (without any post weld heat treatment) and (ii) post weld heat treated (PWHT)

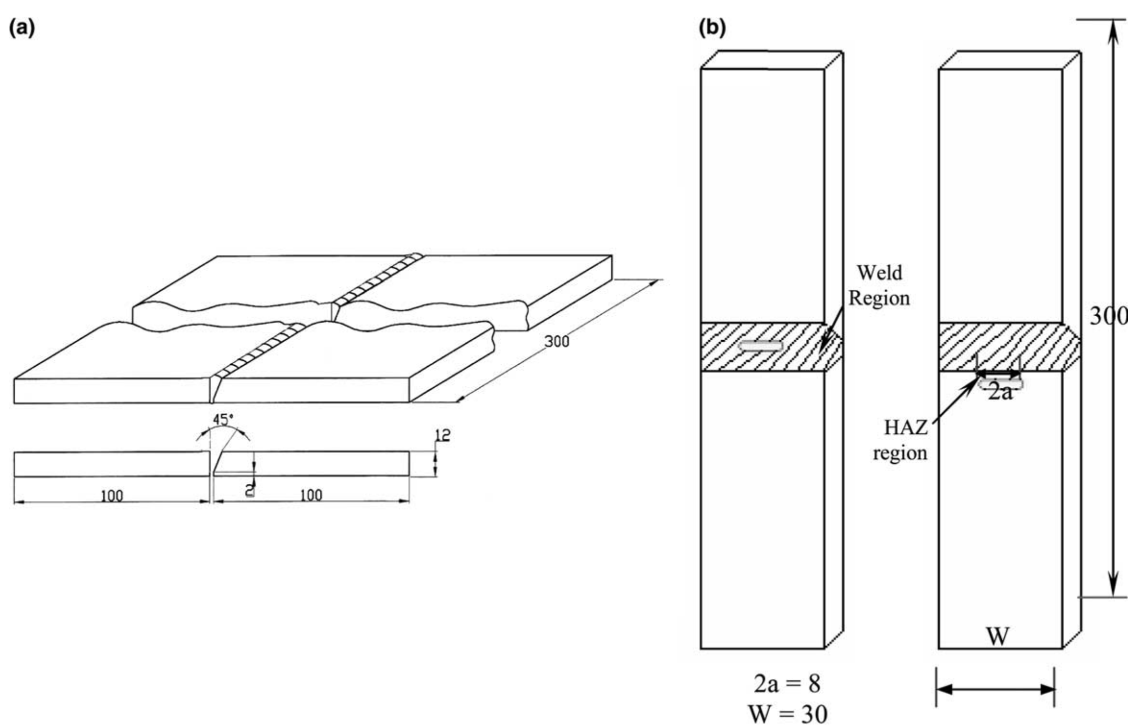

Fig. 1. Joint configuration and dimensions of CCT specimen.