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Crack propagation resistance of Zeron 100 weld metal fabricated using the GTA and SMA welding processes

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Abstract

It is envisaged that super duplex stainless steels, as currently used in the offshore oil and gas industries, will find application in the emergent renewable energy sector in areas such as offshore wind, wave and tidal electricity/hydrogen generation. Such applications typically involve engineering components experiencing fluctuating loads. Sub-critical flaws inherent in welded joints are ideal sites for crack initiation and subsequent propagation leading to fast fracture. The current paper investigates the fatigue performance of two Zeron 100 weld metals in a benign environment (laboratory air). The effects of residual stresses and misalignment inherent from the welding process are also considered. The crack propagation threshold and the intrinsic crack propagation resistance of both weld metals was found to be similar to that of the base metal. However, the fracture toughness of the base metal was superior to the GTA weld metal, which was in turn better than the SMA weld metal.

Keywords: Fatigue; Fracture mechanics; Superduplex stainless steel; Weld metals; Residual stresses

1. Introduction

It is widely appreciated that weld joints are critical locations for structural integrity and most failures occur in the vicinity of such joints. Often, fatigue cracks initiate at the edge of the root bead and propagate through the weld metal [1]. Poor root bead geometry acted as a crack initiation site in one particular case [2]. Since NDT inspection intervals are defined on the basis of relevant crack propagation data, studies generating such data while considering residual stresses and weldment misalignment effects are of paramount importance. However, such studies on the crack propagation resistance of commercial duplex and superduplex weld metal are scarce. In the case of one duplex stainless steel, the weld metal performed less well than the base metal due to a high inclusion content [3]. Another particular superduplex weld metal performed similar to its base metal [4]. Unfortunately, the welding method was not stated in either case.

Furthermore, the influence of residual stresses on the fatigue life of superduplex stainless steels in air is not clear. Overall, an insight into the intrinsic crack propagation resistance of commercial superduplex

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weld metals formed by different welding methods is critical. In the current paper, the crack propagation threshold, crack propagation resistance, relative fracture toughness and influence of residual stresses on superduplex weld metal formed by different welding procedures in laboratory air is investigated.

2. Experiments

2.1. Introduction

The weld metals under investigation are the welds of a superduplex stainless steel, Zeron 100 (UNS S32760) supplied by Weir Materials and Foundries (WMF, Manchester, UK). Manual welding was carried out in a pressure vessel fabrication shop by welders working to WMF's comprehensive welding guidelines [5]. The welders had not welded Zeron 100 or similar superduplex stainless steels previously. As such the welds are considered worst-case scenario with regard to the influence of 'welder experience' on the weldment properties. Two wrought plates of Zeron 100 (500 mm × 150 mm × 10 mm) were firstly prepared for a single V butt type weld, by chamfering, and were subsequently welded along the 500 mm length.

Two types of weld process were used to fabricate the weldments tested in the current work. The first was a gas tungsten arc weld (GTA weld). The welding parameters were as follows: 140 A DC current and a 22 V voltage (gas protection with 99.9% argon), the polarity of the tungsten electrode being negative. The GTA welding consumable was a Zeron 100X (overalloyed) welding wire of 2.4 mm diameter (see Table 1). The second type of weld consisted of a GTA weld root and a shielded metal arc weld (SMA weld) fill (referred to as SMA weld from here on). The SMA weld process used a 93 A current and a 17 V voltage – polarity of stick electrode was positive. The 'basic' SMA "Jungo Zeron 100X" welding electrode was 3.2 mm in diameter. In both cases, weld beads were deposited using same direction stringer runs.

The alloy and its weld metals have dual phase microstructures consisting of austenite colonies in a ferrite matrix, Fig. 1(a). The austenite colonies are aligned in the case of the base metal and random in the case of the weld metals.

A macrostructure was also present in the weld metals in addition to the microstructure introduced above. The macrostructure and its formation can be appreciated in Fig. 2. The macrostructure forms when ferrite solidifies from melt in a columnar type fashion. On further cooling a solid-state transformation occurs when a percentage of austenite reforms in the ferrite columns, Fig. 1.

2.2. Initial tests and sample preparation

Before laser cutting and machining fracture mechanics type samples, standard tensile, impact and hardness tests (detailed elsewhere [7]) were car-

Table 1
Base metal and welding consumable composition (wt%) – remainder Fe [6]

Element	Cr	Ni	Mo	Cu	Mn	W	Si	N	C	P	S
BASE	24–26	6–8	3–4	0.5–1	1	0.5–1	1	0.2–0.3	0.03	0.03	0.01
GTA	24.8	9.35	3.8	0.61	0.69	0.6	0.39	0.225	0.018	0.03	0.001
SMA	25	9.5	3.6	0.8	0.7	0.7	0.5	0.2	0.03		

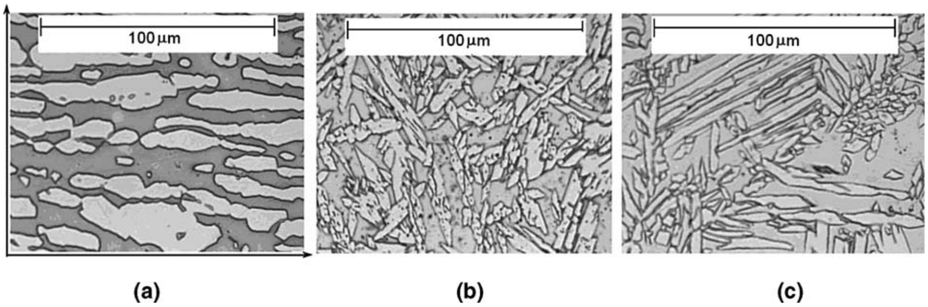

Fig. 1. Base and weld metal microstructures. Evident are the austenite colonies (aligned base metal/random weld metal) in a ferrite matrix. (a) Base metal, (b) SMA weld metal and (c) GTA weld metal.