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FATIGUE AND CREEP CRACK GROWTH BEHAVIOUR AT HIGH TEMPERATURES FOR WELD METALS OF ALLOY 800 AND ALLOY 617

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ABSTRACT

High temperature fatigue crack growth (FCG) and creep crack growth (CCG) experiments have been conducted in air on weld metal, heat affected zone (HAZ) and base metal of the austenitic Alloy 800 and the nickel base Alloy 617. Tests were performed on specimens machined from pipes, in the temperature range 550-900°C. The crack propagation mode was examined.

At all temperatures and for both materials, FCG of base metal was found to be the highest, whereas the weld metal exhibited the lowest FCG rate. The FCG rate in the HAZ was found to lie in between of those observed for base and weld metal. The crack propagation mode remained transgranular in base metal and transdendritic in weld metal at all temperatures.

CCG behaviour could be described using the energy rate integral C^*. Base metal and weld metal exhibited similar CCG rate at same C^*. The crack propagation mode under CCG condition was found to be intergranular in base metal and HAZ and interdendritic in the weld metal.

1. INTRODUCTION

A great number of experiments concerning the creep crack growth (CCG) and fatigue crack growth (FCG) of the materials Alloy 800 (X10NiCrAlTi3220) and Alloy 617 (NiCr23Co12Mo) have been performed in the frame of several German HTGR development programmes [1, 2]. But most of the work has been done for base metals. On the other hand, weldings of these materials are relevant for components, and therefore a programme has been initiated to study FCG and CCG in weldings and the heat affected zone (HAZ) of these materials.

2. EXPERIMENTAL DETAILS

2.1 Test Material

Both Alloy 800 and Alloy 617 were obtained in the form of pipes. For Alloy 800 several batches of material (named BDZ, AYJ and BCE) were used. The supplied weld pipes were prepared using U groove and welded circumferentially. The welding of roots was made by tungsten inert gas (TIG) welding, whereas subsequent filler passes were made by manual metal arc (MMA) welding in all the pipes. The details of groove geometry, electrodes and current used during welding are given in Table 1. Two welding modes were used for BDZ material. One batch of BDZ specimens was machined from the weld pipe prepared by unidirectional mode of welding, where the filler passes were circumferentially moved from one surface of the U groove to the opposite surface. The other batch of BDZ specimens was machined from the weld pipe prepared by two directional mode of welding, where the filler passes were circumferentially moved from either side of the groove and were joined in the central region of the groove.

2.2 Specimen Preparation

Compact tension (CT) specimens of 1" (material BDZ) and 1/2" size (all other materials) with chevron notch were machined from the base metal and weld metal pipes following ASTM E399-83 [3] with a slightly reduced specimen thickness. All the specimens were machined in L-C orientation (cp. fig. 1) to facilitate the crack growth at high temperatures to remain in the designated specimens metallurgical condition. In the case of HAZ specimens, the saw cut as a starter for room temperature fatigue precracking in the HAZ specimens was machined within approximately 2-3 mm distance from the fusion line corresponding to the outer surface of the pipes (Fig. 2). The chevron notch in the weld metal specimens were machined in the central region of the weld (Fig. 2). In order to avoid tunnelling of the crack front, side groves were used with the CCG specimens, with a depth of 10% of the specimen thickness on each side. Following machining, the specimens were precracked under fatigue loading conditions at room temperature.

2.3. Testing

High temperature tests were performed in air with constant load (CCG) or constant load amplitude (FCG) respectively. FCG and CCG tests were conducted with crack propagation in base metal and weld metal. For Alloy 800 at 550°C additional tests have been carried out with HAZ specimens. The test frequency of 5 Hz and stress ratio of 0.05 were employed during FCG testing. The crack length was measured using D.C. potential drop (DCPD) technique.

The microstructures of the base metal, weld metal and HAZ were examined on specimens prepared by usual metallographic technique and by electrolytic etching using an optical microscope. The tested specimens were sectioned parallel and perpendicular to the macroscopic crack growth direction to obtain information on crack propagation mode and secondary cracks. Fractographic examinations were carried out on specimens fracture surface using a scanning electron microscopes (SEM).

3. RESULTS

3.1 Fatigue Crack Growth

Fatigue crack growth experiments have been carried out between 550 and 900°C for Alloy 800 and between 700 and 850°C for Alloy 617. The results were plotted as da/dN vs. ΔK_I in a double logarithmic scale. In the high ΔK_I region, da/dN vs. ΔK_I obeys the Paris-Erdogan power law [3] $da/dN = C\,(\Delta K_I)^m$ Here only part of the results can be presented but the qualitative behaviour of both materials is similar. A detailed presentation of the data is given in [4]. The results of base metal, weld metal and HAZ for Alloy 800 at 550°C are compared in Fig. 3. Results at 850°C are shown in Fig. 4. The corresponding data for Alloy 617 at 850°C are given in Fig. 5. As can be seen from the three figures, crack growth rate da/dN for base metal was found to be the maximum at all ΔK_I, whereas the weld metal exhibited the lowest FCG rate. The da/dN in HAZ (only measured at 550°C) was found to lie in between of those observed for base and weld metal. The decrease in da/dN in weld metal is more pronounced at low and intermediate ΔK_I and at lower temperatures.

The fatigue threshold, ΔK_{th} was found to be the lowest in base metal followed by HAZ and weld metal. As in the case of base metal [1,2] the fatigue threshold ΔK_{th} of weld metal specimens decreases with increase in temperature.

FCG data pertaining to weld metal showed larger scatter than for the base metal and HAZ. This corresponds to the observation that weld specimens show a rough fracture surface with irregular crack fronts, where as the base metal and HAZ specimens show smooth surfaces (Fig. 6). All the weld specimens exhibited large macrodeviations of the growing crack in either side of the crack plane resulting zig-zag fracture path.

The fracture behaviour of base metal, HAZ and weld metal was transgranular and transdendritic respectively. With increasing ΔK_I from intermediate to high value, striations were observed.

Weld specimens prepared by UTP 70 15 Mo electrode exhibited shear fracture mode at all ΔK_I. The weld metal composition and welding mode did not exhibit a significant effect on FCG resistance of weld metal at the test temperature of 550°C.

3.2 Creep Crack Growth

CCG experiments have been performed between 550 and 900°C for Alloy 800, and at 800 and 900°C for Alloy 617. The crack growth rates da/dt were plotted in double logarithmic scales over the energy rate integral C* [5] and over the stress intensity factor K_I. C* was calculated from $C^* = \eta \dot{v} \sigma_{net}$ (η: specimen geometry dependent constant, $\dot{v}$: COD rate, σ_{net}: net section stress). For the description of CCG rates da/dt, a power law $da/dt = k\ C^{*n}$ has been suggested [5], which gives a linear plot in the double logarithmic scale. As in the case of base metals (cp. [1,2]), also for weld metal, the parameter C* is better suitable than K_I for the description of CCG. As an example, Fig. 7 shows a comparison between base metal, weld metal and HAZ for Alloy 800 at 550°C. More results are given in [6].

Other as in the case of FCG, no influence of welding is found for either of the two alloys, and CCG rates are independent of testing temperature.

The fracture surfaces of base and weld metal specimens are shown in Fig. 8. The weld specimens of both alloys exhibited rough fracture surface in comparison to base metal. SEM examination on the fracture surface of CCG tested base metal specimens showed intergranular crack propagation; weld metal specimens of both alloys exhibited interdendritic crack propagation and interpass cracking at all temperatures.

4. DISCUSSION

At all temperatures, weld metals of Alloy 800 and Alloy 617 exhibited lower FCG rates in comparison to base metals. The decrease in FCG rate of weld metal is more pronounced at low and intermediate ΔK_I and at lower temperatures. The differences between base and weld metal are ascribed to two effects: the presence of residual compressive stresses produced during the welding process and the zig-zag fracture path of weld specimens.

The presence of compressive residual stress at the crack tip will arrest the propagating crack and higher ΔK_I will be needed for crack opening, thus reducing the effective stress intensity at the crack tip. Due to the strong temperature dependence of creep at temperature of 700°C and above majority of the stress is relaxed rapidly, whereas at 550°C there is little relaxation. This suggests that at higher temperatures the most of the residual stress will get relaxed during a short time of heating and the influence of compressive residual stresses vanishes.

In comparison to base metal the weld specimens of both alloys showed large zig-zag fracture path at all temperatures. Presence of such large zig-zag fracture path in weld metal would influence the FCG rate in the following two ways. Firstly, a larger number of cycles will be required for a crack to grow for a particular length of segment in the macroscopic crack growth direction in the presence of zig-zag fracture path than a smooth linear path, thus reducing da/dN at a constant ΔK_I. Secondly, a large zig-zag path will change the local crack geometry and stress mode from ideal mode I loading, resulting a decrease in the local stress intensity at the crack tip, ultimately reducing da/dN.

It was found before for base metals that CCG described in terms of C*, is not dependent on experimental parameters like temperature, grain size etc. [1, 2]. The same independence was also found for weld metals. So the CCG of weld metal of the two alloys can be described by the base metal data.

5. CONCLUSIONS

FCG behaviour of base, weld and HAZ of Alloy 800 and Alloy 617 was successfully described using LEFM parameter ΔK_I. The FCG rate of base metal was found to be the highest at all ΔK_I, where as the weld metal exhibited the lowest. The FCG rate of HAZ was found to lie in between of those observed for base and weld metal. Weld metal exhibited the highest fatigue threshold followed by HAZ and base metal. From these statements, it can be concluded that FCG of base metal can be considered as conservative for weldings.CCG behaviour of base, weld and HAZ of Alloy 800 and Alloy 617 can be described by the energy rate integral C*. No significant differences of CCG rates were found for base and weld metal in either of the two alloys investigated.

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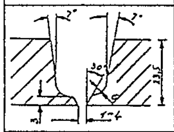
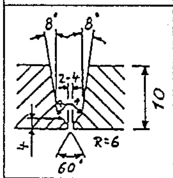
Shape of joints	Location of Specimens	Manufacturer and trade name of electrodes: Root pass TIG	Manufacturer and trade name of electrodes: Filler pass MMA	Welding current in Amp. (electrode dia in mm): TIG	Welding current in Amp. (electrode dia in mm): MMA
	BDZ-IM 11 to 17	Messer Griesheim Grini T NCF 9 R500	Böhler Fox NiCr 70 Nb	90-120 (2-2.5)	70-90 (3.25)
	BDZ-IM 21 to 27		UTP UTP70 15Mo		90-110 (3.25)
	AYJ-GM	Thyssen Thermanit 21/23 SG	Thyssen Thermanit 21/23	120-160 (2-4)	70-110 (3.25)
	BCE-GM				110-140 (4)
	BBP-GM	Nicrofer 5520 Co	Messer Griesheim Gritherm 85R15	120-160 (2-4)	70-100 (3.25)

Tab. 1: Details on welding of Alloy 800 and Alloy 617 pipes

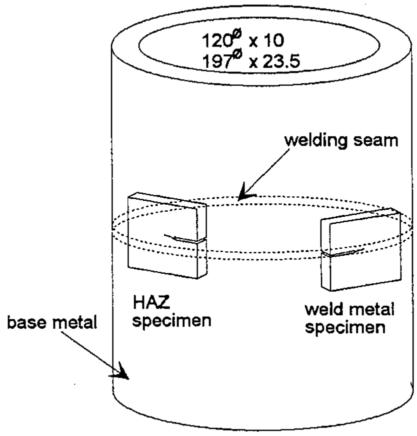


Fig. 1: Orientation of specimens relative to the welding

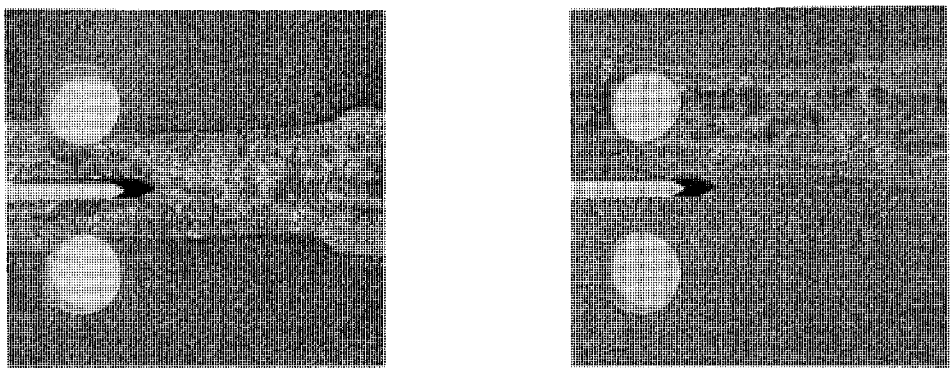
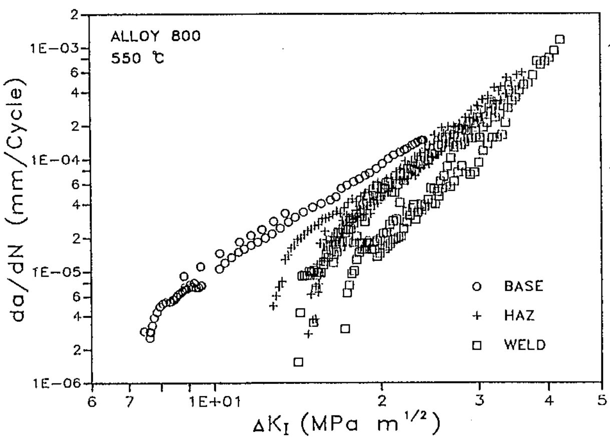


Fig. 2: Position of cracks relative to the welding (left: weld metal, right: HAZ)



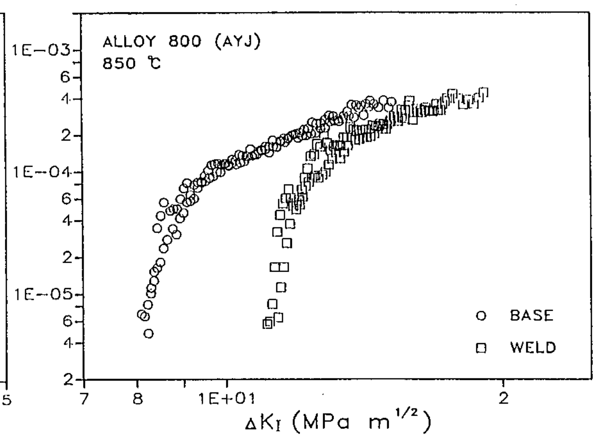


Fig. 3: da/dN vs. ΔK_I plots for base and weld metal and HAZ (Alloy 800, 550°C)

Fig. 4: da/dN vs. ΔK_I plots for base and weld metal (Alloy 800, 850°C)

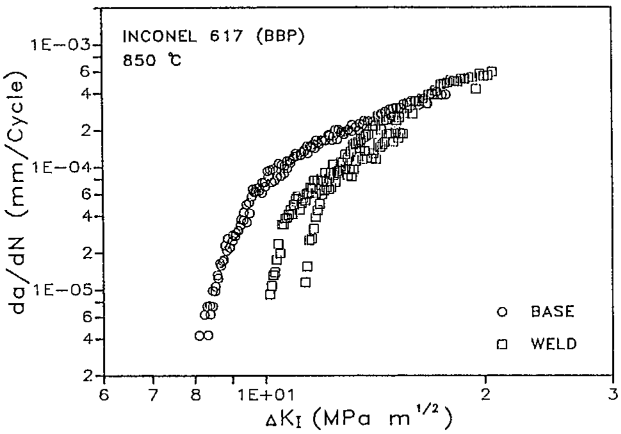


Fig. 5: da/dN vs. ΔK_I plots for base and weld metal (Alloy 617, 850°C)

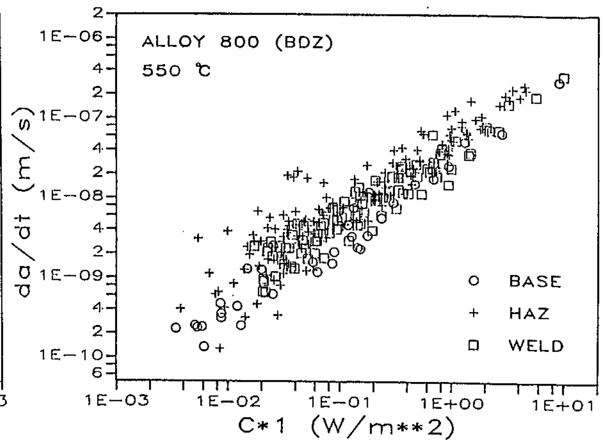


Fig. 7: da/dt vs. C* plots for base and weld metal and HAZ (Alloy 800, 550°C)

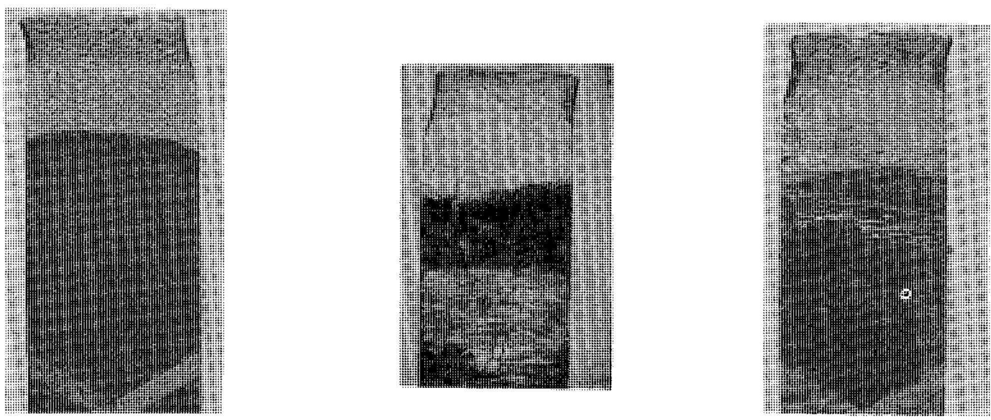


Fig. 6: FCG fracture surfaces of Alloy 800, for base metal (a) and two weld metals (b: Fox NiCr 70 Nb, c: UTP 70 15 Mo)

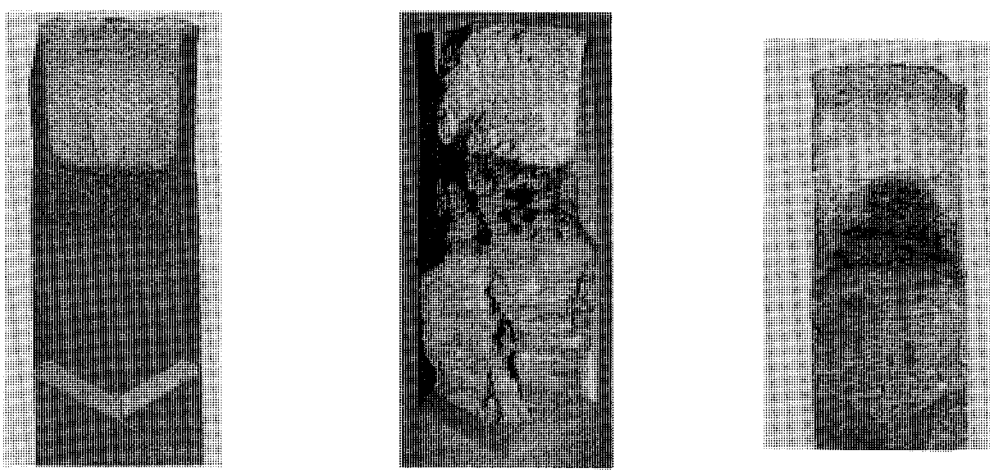


Fig. 8: CCG fracture surfaces of Alloy 800, for base metal (a) and weld metal (b: with side groves, c: without side groves)