Creep Cracking in Austenitic Weld Metal

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ABSTRACT

Investigations have been carried out to study the crack growth behaviour in type 308 Cb stainless steel weld metal under constant load creep conditions in the temperature range of 600°C to 800°C. At 600°C the load point deflection (LPD) rate is proportional to the creep crack growth (CCG) rate. At 700°C and 800°C it is dependent on both crack growth rate and the applied load. The parameter C* appears to describe well the CCG rate. At 600°C the crack growth takes place along the interphase between austenite and the primary arms of the delta ferrite. At 700°C and 800°C sigma phase formation takes place and the crack growth is through the interphase between austenite and sigma phase.

KEYWORDS

Creep crack growth, weld metal, C*-integral, Type 308 stainless steel.

INTRODUCTION

Austenitic stainless steels are being extensively used for structural components in high temperature applications because of their good elevated temperature properties, corrosion resistance and ease of fabricability. Welding is widely employed in these applications. During the operation the alloy in both wrought and welded conditions, is exposed to elevated temperature for a long period. Generally the austenite welds contain 3 - 8 % delta ferrite in the deposit. On exposure to high temperature the metastable delta ferrite transforms to secondary phases like carbides, sigma etc., (Marshall, 1984). In high temperature applications weld joints are the most critical parts of the component and creep cracks can initiate and grow under the applied load. Haigh and Laidler (Haigh and Laidler, 1980) examined the creep crack growth behaviour in type 316 stainless steel weld metal at 538°C and the COD parameter was successfully used to describe the CCG rate. Lloyd et al (Lloyd et al, 1985) have studied the CCG rate in type 316 stainless steel weld metal in the temperature range of 550°C to 625°C and found that the C* parameter gave the least scatter. The metallographic examination showed cracking to occur preferentially along the delta ferrite-austenite boundaries. The vermicular (network) delta ferrite is particularly susceptible to cracking and secondary cracks were often noted in favourably aligned delta ferrite behind the main crack.

The present investigation has been undertaken to study the cracking behaviour of type 308 stainless steel weld metal when subjected to elevated temperature of 600°C to 800°C.

EXPERIMENTAL

The material used in this investigation is type 308 Cb stainless steel containing 4 FN delta ferrite. The chemical composition of the material is C= 0.035 %, Cr= 22.5 %, Ni= 13.18 %, Mn= 2.4 %, Si= 0.49 % and Nb= 0.7 %.

Creep experiments have been carried out in a tensile creep testing machine with loading lever arm of 1:10. The specimens were in the form of rectangular sheets of 150 mm long, 15 mm wide and 1.0 mm thick. A sharp edge notch of depth of 2 mm has been introduced at the centre of the specimen where the weld region is located, in order to localise the crack growth in the weld.

The specimen was heated by means of a tubular furnace and the specimen temperature was measured and controlled by a chromel-alumel thermocouple within ± 3°C. The experiments were carried out at specimen temperatures of 600°C, 700°C and 800°C. The crack region was illuminated suitably and the growth was measured by means of a travelling microscope with an accuracy of 0.01 mm. The load point deflection was measured by means of a dial gauge with an accuracy of 0.01 mm. Metallographic examinations of the fractured specimen were carried out with different etchants (10% oxalic acid, modified Murakami etchants) to identify the phases. X-ray analysis was carried out to study the phase changes that might have occurred during the high temperature exposure.

RESULTS AND DISCUSSION

Fig.1. shows the relation between the crack growth rate, da/dt, and the load point deflection rate, d /dt, onthe log-log plot for the three temperatures investigated. At 600°C the relation appears to be independent of the load and an equation of the type

$$da/dt = A\ (d\ \ /dt)^{q} \tag{1}$$

can be used to describe the behaviour. A and the exponent q are constants and are independent of the load at 600°C. At 700°C and 800°C the relation is dependent on the load P. For a given load point deflection rate the CCG rate increases with increasing load. This indicates that the constant A increases with load. The exponent q appears to be independent of load at 700°C, but is dependent on load at 800°C. It should be noted that the material is of composite in nature in the sense that the crack growth takes place in the weld and the load point deflection, measured far away from the crack, is predominantly contributed by creep deformation taking place in the base metal. The base metal deformation is much more than that in the weld metal specially at higher temperatures.

The energy rate line integral C* defined as

$$C^{*} = \frac{n}{n+1}\quad \frac{P}{B\ (W-a)} \tag{2}$$

has been tried to correlate the creep crack growth data in the weldment. The constant n is the stress exponent in creep rate relation. B is the thickness and W the width of the specimen. The integral has been evaluated and the relation between the CCG rate and the C* integral is shown in Fig.2., on log-log plot. The parameter appears to give a good description of the experimental data. However, it can be noted that data points at higher temperatures namely, 700°C and 800°C, show more scatter than those at 600°C. It has been shown (Radhakrishnan and Kamaraj, 1987) that for stainless steel under plane stress loading condition at 600°C, C* can be effectively used to describe the CCG rate. This has also been found to be valid in the present case. At this temperature the overall deformation is rather small and the CCG rate is proportional to the LPD rate. In such cases C* can be used as an effective parameter. At higher temperatures the overall deformation is comparatively large. This is also reflected in the relation between CCG rate and the LPD rate. The crack is growing in a comparatively brittle medium, namely, the weld metal and the LPD is contributed by the deformation in the parent metal. This may be the reason for the scatter observed in the high temperature ranges.

Fig.3. shows the growth of a crack in the composite material, the crack being located in the weld region and the LPD being measured in the base metal region. The ferrite content of the as-welded condition of 308 Cb material as determined by the ferritescope lies in the range of 5 to 6 per cent. Fig.4. shows the microstructure of the as-welded metal which consists of austenite and interdendritic delta ferrite having a discontinuous vermicular morphology with randomly distributed inclusions. The ferrite content of the weld after the creep crack growth tests was found to be less than 1.5 %. X-ray analysis of the fractured samples at the three test temperatures is shown in Fig.5. The analysis indicates the formation of sigma phase in the weld metal after prolonged creep testing. The reduction in delta ferrite in the weld material is mainly due to the transformation of delta ferrite to secondary austenite, non-magnetic intermetallic phases and carbides (Edmonds <u>et al</u>., 1978). On exposure to elevated temperature the ferrite in austenitic weld undergoes two structural changes, namely, i) the partial dissolution of ferrite and ii) transformation of ferrite to sigma phase (David, 1981).

The crack growth morphology was determined by opticalmicroscope. At 600°C the crack initiation and advancement take place in a step-wise manner as indicated in Fig.6(a). Micro-cracks just ahead of the primary crack can be seen to nucleate during creep and cracking is developed at the interphase between austenite and primary arm of the delta ferrite as shown in Fig.6(b). Near the crack front sigma particles were observed. Growth of the primary crack takes place by linking of these secondary cracks with the primary one.

Observations of crack growth at 700°C showed that the crack front was somewhat irregular as shown in Fig.7(a). However, the total crack path was within the weld metal. The micro-cracks were more at 700°C than at 600°C. At 700°C the ferrite dissolution reaction takes place in shorter time leading to decrease in ferrite content. Further exposure results in sigma phase formation. The micro-cracks were found between the austenite- sigma interphase. The morphological instability of ferrite on exposure to 700°C can be seen in the structure shown in Fig.7(b).

At 800°C, specimens tested at low stress levels showed crackinitiation at the fusion line. Exposure at 800°C results in the vermicular ferrite breaking into spherical particles. Figs. 8(a) and (b) show the crack growth and breaking of delta ferrite and formation of spherical particles. Secondary cracks have been observed between the austenite-sigma interphase. In all the cases no carbide formation has been observed, as confirmed by

X-ray analysis. This may be due to low carbon content of the metal.

In all the cases it has been observed that there is little plastic deformation at the crack front, as the crack is growing in the weld metal. At comparatively low temperature, the overall deformation is also small in the presence of a moving crack, as can be seen at 600°C. In such cases, a unique relation between CCG rate and LPD rate can be obtained and the C* integral can be successfully employed as a parameter for creep crack analysis (Radhakrishnan, 1987; Radhakrishnan and Kamaraj, 1987 a.). At 700°C and 800°C the deformation of the parent metal is more pronounced than that of the weld metal. The metallographic examinations clearly indicate the possible reasons for the brittle type of crack growth in the weld metal due to the formation of sigma phase. However, due to the overall deformation of the entire composite material a unique relation as given by eqn.(1) is not obtained in these cases. Application of C* parameter in such cases has to be carefully examined, as can be seen by the scatter of data obtained at these temperatures.

CONCLUSIONS

From the experimental investigations carried out on type 308 Cb stainless steel weld metal to study the crack growth behaviour in creep at 600°C, 700°C and 800°C, the following conclusions are arrived.

1) The load point displacement rate bears a simple relation with the crack growth rate on the log-log plot at 600°C, which appears to be independent of the load. At the other two temperatures the relation is dependent on the load.

2) The energy rate line integral C* appears to give a good correlation with the experimental data, specially at 600°C. At higher temperatures the data points show scatter.

3) In the weld metal the crack growth takes place in a step-wise manner. Secondary cracks form just ahead of the main advancing crack and subsequently join the main crack. Crack growth at 600°C takes place along the inter - phase between austenite and the primary arm of the delta ferrite.

4) At 700°C the ferrite dissolution reaction takes place in shorter time leading to decrease in ferrite content. Further exposure of the metal results in sigma phase formation. The micro-cracks were found between the austenite-sigma interphases which appear to be weaker. At 800°C, the vermicular ferrite breaks into spherical particles. Here also secondary cracks have been observed between austenite-sigma interphase.

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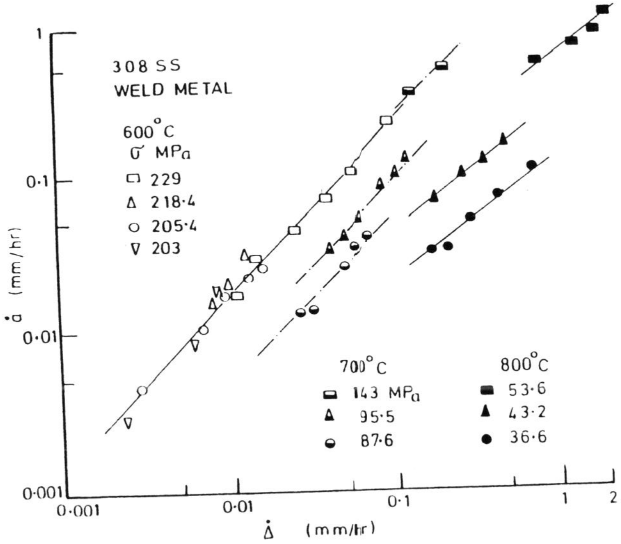

Fig. 1. Relation between creep crack growth rate and the load point deflection rate.

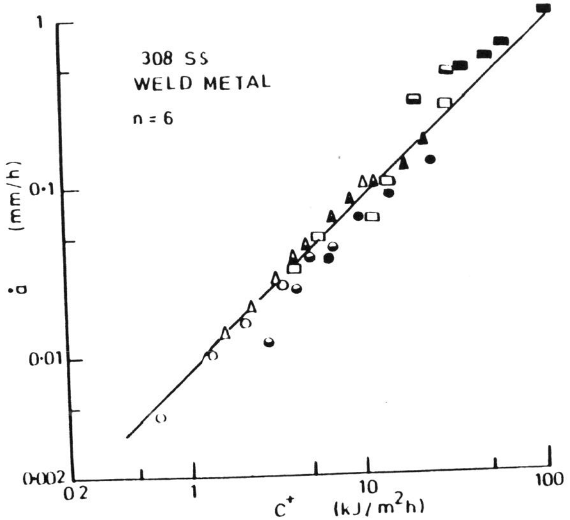

Fig. 2. Relation between creep crack growth rate and the energy rate line integral C*.

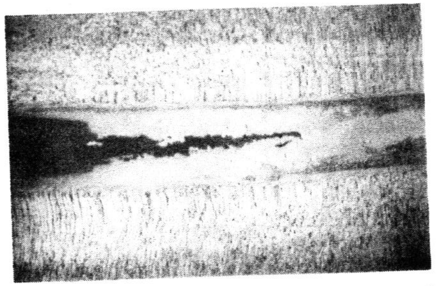

Fig. 3. Crack growth in weld metal.

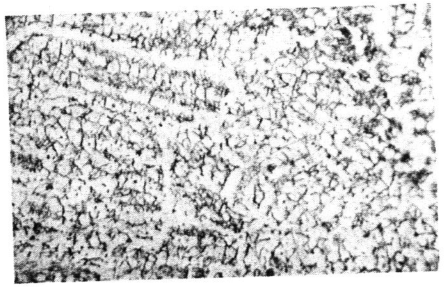

Fig. 4. Microstructure of as-weld metal. (X 500).

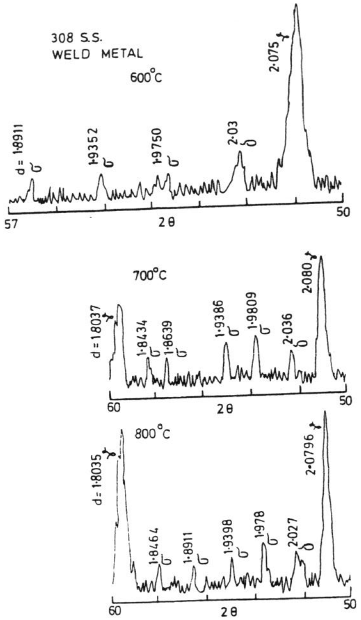

Fig. 5. X-ray diffractogram.

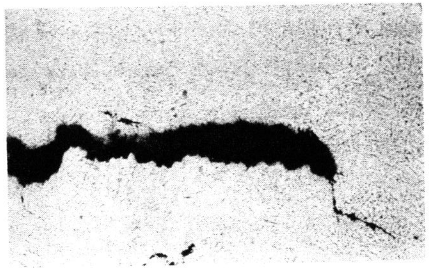

Fig. 6a. Crack growth in weld metal at 600°C. (X 200)

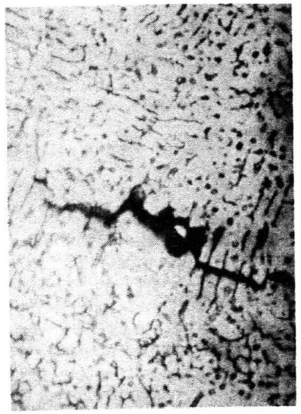

Fig. 6b. Cracking at the interphase between austenite and primary arm of delta ferrite. (X 1000).

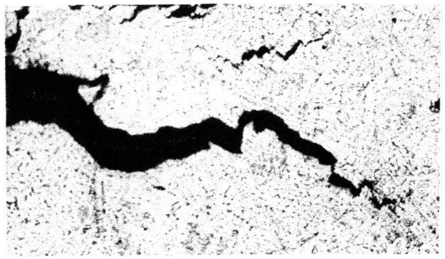

Fig. 7a. Crack growth in weld metal at 700°C (X 200)

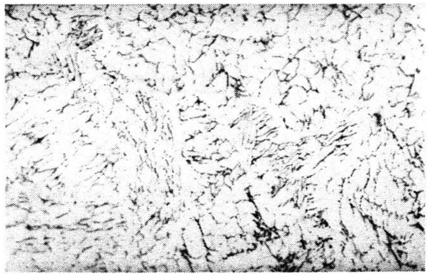

Fig. 7b. Micro-structure of weld metal exposed to 700°C. (X 500).

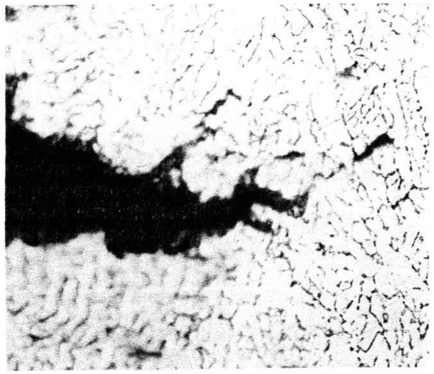

Fig. 8a. Crack growth in weld metal at 800°C. (X 500).

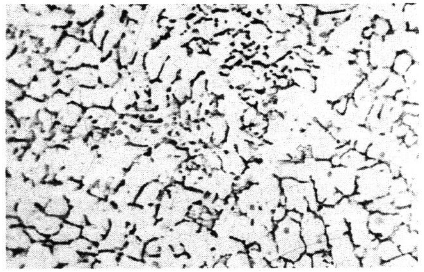

Fig. 8b. Micro-structure of weld metal exposed to 800°C. (X 1000).