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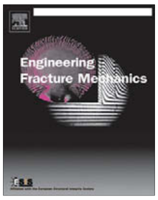

Analysis of creep lifetime of a ASME Grade 91 welded pipe

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ABSTRACT

A multi-material local approach to creep damage was applied to a ferritic-martensitic ASME Grade 91 steel welded joint at 625 °C. Focus was made on the detailed analysis of the most sensitive area of the weld i.e. the intercritical heat affected zone. Prediction of creep failure of the weld well agrees with experimental results. The model was then applied to the case of a seam-welded pipe exhibiting a roof defect, creep tested at 580 °C, showing consistent results with a more classical engineering assessment.

1. Introduction

The integrity of welded structures has focused the attention of both engineers and researchers so that simple design principles were introduced in design codes fifty years ago. It has been previously evidenced [1–6] that welding has a large effect on the creep strength of 9Cr1Mo–NbV steels. Rupture occurs in the heat affected zone (type IV failure) which is a relatively weak but ductile area delimited by the base metal on one side and the weld metal on the other side. As both the base and weld metals are stronger than the heat affected zone (HAZ), there is a constraint effect on the deformation of the type IV region so that this region is submitted to complex multiaxial loading conditions.

Due to these constraint effects, it was evidenced [7] that the use of simple design criteria as these proposed in the ASME [8] and R5 procedure did not allow good predictions of weld creep lifetime. Therefore, attention was focused on performing finite element modelling of creep flow and damage behaviour of welds with taking heterogeneities in materials properties into account [7]. Despite the complexity of the HAZ microstructure, the weld is classically simplified using a three materials representation i.e. the weld metal (WM), the weakest HAZ, and the base metal (BM) [9–11]. Note also that some authors [12] considered four main areas as they divided the HAZ into two main parts. The determination of creep flow properties of each part of the weld requires numerous time consuming experiments. Moreover, to study the creep properties of the weakest HAZ, it is necessary to reproduce its microstructure on bulk specimens after having determined the thermal cycle to which this part of the HAZ is submitted during the welding procedure.

To overcome these difficulties, it was proposed [13] to modify the creep constitutive equations of the base metal to account for creep flow and damage behaviour of the HAZ and the weld metal. Whenever practical, this method implicitely postulates that the physical mechanisms responsible for damage are the same in the HAZ, the base metal and the weld metal, which is not necessarily true. Some other authors [14–16] determined the creep flow and damage properties of the HAZ from

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multi-material FE calculations to account for the experimentally measured weld creep lifetime. However this method also neglects the determination of the physical mechanisms responsible for creep flow and damage.

In this study, a ASME Grade 91 weld is studied following the methodology proposed in [11]. It is based on a "local approach" description of fracture [17,18] which relies on detailed evaluations of stresses, strains and damage in fracture process zones. In the case of welds, and following [11], it is based on three main steps:

(1) Characterisation of creep flow and damage mechanisms in the weld using creep tests on cross-weld specimens. The analysis of the tested specimens especially allows the determination of creep strain gradients and the rupture location in the weld.
(2) The experimental characterisation of the creep flow and damage behaviour of various regions of the weld chosen from the analysis of the creep response of the weld (three regions i.e. the weakest HAZ, the weld metal and the base metal in the present study).
(3) Finite element modelling off all regions, then of the welded joint integrating the heterogeneities in material creep properties to evaluate lifetime of laboratory samples and of actual industrial parts.

A strong effort was also made to understand the origins of the microstructural changes in the HAZ during welding before choosing a weld thermal cycle to reproduce the HAZ microstructure on bulk specimens [6] (Section 2). By comparison with the work in [11], the present study is supported by a finer analysis of the HAZ creep properties based on a larger experimental database. Creep tests on various type of U-notched axisymmetric specimens were especially included in the experimental database to investigate the effects of the stress triaxiality ratio on damage kinetics. Creep tests were carried out up to 7000 h (Section 3). The base metal was characterized in [19]. Modelling of the creep response is based on a model integrating multiple deformation and damage mechanisms [19], which allows a description of the creep response from high to low stress while taking into account the changes in both deformation and damage mechanisms. These constitutive equations representing each material are then used to represent the experimentally observed creep lifetime of cross-weld notched and un-notched specimens (Section 5). Finally the model is applied to predict the lifetime of a pipe with a seam weld containing a roof defect (Section 6)

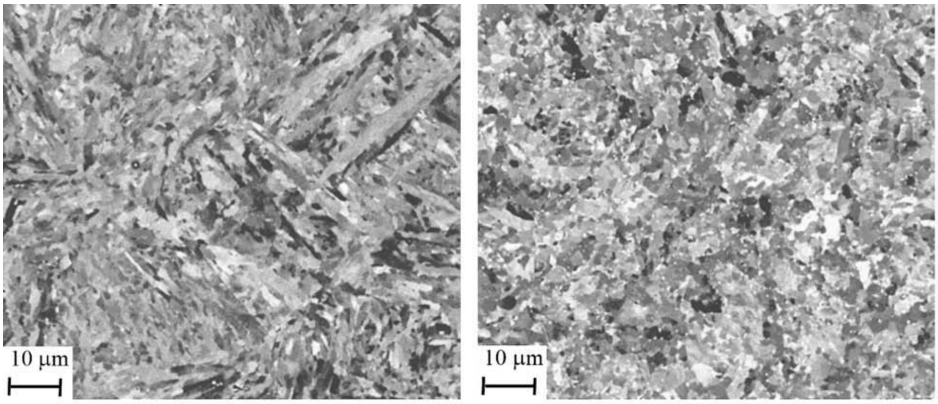
2. Materials

2.1. Base metal

The chemical composition of the ASTM Grade 91 steel used in this study is shown in Table 1. The material was supplied as a pipe of 295 mm in outer diameter and 55 mm in thickness. This pipe was austenized at 1065 °C for 1 h, cooled and then tempered at 765 °C for 2 h. The resulting microstructure (Fig. 1a) is lath martensite arranged in packets (30–40 μm in size)

Table 1
Chemical composition of the base metal and of the filler metal in wt%.

	C	Si	Mn	P	S	Al	Cr	Ni	Mo	V	Nb	N	Cu
Base metal	0.09	0.31	0.41	0.014	0.005	0.016	8.56	0.26	0.92	0.21	0.065	0.042	–
Filler metal	0.09	0.37	0.41	0.028	0.013	0.07	8.44	0.27	0.92	0.24	–	0.038	0.04



(a) BM (b) $\mathrm{ICHAZ_{sim}}$

Fig. 1. (a) Backscattered electron SEM micrograph of (a) the ASME Grade 91 base metal and (b) the ASME Grade 91 $ICHAZ_{sim}$ (Colloidal silica polishing).