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Strain capacity of SENT specimens – Influence of weld metal mismatch and ductile tearing resistance

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ABSTRACT

In this paper results from experimental investigations and numerical modeling of the strain capacity in SENT (Single Edge Notched Tension) specimens are presented. Both SENT specimens with defects in the pipe base material and in weldments are considered. The weld metal is about 10% overmatched compared to the base material. The results show that the overmatching on average leads to an increase in strain capacity, however, a much larger scatter in the results is observed for specimens with the defect in the weld material. The paper also demonstrates that 3D FE simulations are very well capable of reproducing the physics observed in the experiments.

KEY WORDS: Pipelines, fracture, strain capacity, weld metal mismatch, ductile tearing, numerical modeling

INTRODUCTION

Prediction of strain capacity of pipelines with defects is an important part of strain-based fracture assessment. The strain capacity can be influenced by several different parameters, e.g. defect size, weld metal mismatch, and crack growth resistance. The scatter in these parameters also plays an important role, and will have an effect on how to define appropriate safety factors. A thorough understanding of the influence played by the different factors is vital in order to obtain robust strain-based fracture assessment schemes. SENT specimens have recently been proposed as an interesting candidate for fracture mechanics testing of pipelines and associated weldments (see Nyhus et al. (2003)). The SENT specimen displays a similar ligament deformation pattern and constraint level as found for cracks in pipes. In this paper we apply testing of SENT specimens to investigate some of the above mentioned factors, comparing results from pure pipe material specimens with specimens with defect in a slightly over-matched weld metal. The effect of weld metal overmatch on the crack driving force has been discussed by several authors, and examples can be found in Kim et al. (2000), Liu et al. (2007), Gioielli et al. (2007), and Motohashi and Hagiwara (2007). An important challenge in including mismatch effects in fracture assessment is to cope with the scatter due to the inhomogeneous material properties in the weld. Below results demonstrating how this scatter can influence the strain capacity are presented. Further, understanding of the influence of crack growth resistance is also of importance. Østby et al. (2007), Østby and Hellesvik (2007), and Minnaar et al. (2007) have shown the importance of explicitly including the effect of crack growth in strain-based fracture assessment. In this paper it is shown that the effect of accounting for the ductile tearing depends on the crack growth resistance curve level. The paper also demonstrates that 3D FE modeling very well captures the physics observed in experiments. Thus, it provides a very powerful tool for running e.g. parametrical studies as a support to experimental work, and could be used in relation to calibration of safety factors.

MATERIALS AND TESTING CONDITIONS

The pipe considered in the experimental work was an 12” X65 seamless pipe with 14.9 mm nominal wall thickness. Engineering stress-strain curves in the axial direction extracted at 4 different positions around the circumference of the pipe base metal (BM) are shown in Fig. 1. As can be seen the pipe material had a yield stress of about 500 N/mm^2 and a distinct yield point. The length of the Lüders plateau varied from about 0.012-0.018, however, only small variations in the yield stress were observed. The weld metal was chosen to give about 10% overmatch compared to the pipe material. The weld groove had a root opening of about 3 mm and bevel angle of 20°. Stress-strain curves of the weld metal were obtained using notched tensile specimens (see Zhang et al. (2002)). Weld metal (WM) stress-strain curves measured at 4 different positions (3, 6, 9, and 12 o’clock) around the circumference are shown in Fig. 2. A pipe base metal curve is included in this figure as a reference. The following features of the WM stress-strain curves are noted: 1) The curves are on average about 10% higher than for the base material. 2) The weld metal curves do not display a Lüders plateau. 3) There is a scatter of about 50 N/mm^2 between the upper and lower WM stress-strain curves.