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Non fracture prediction of a C–Mn weld joint in brittle to ductile fracture transition temperature range. Part II: Determination of the stress-based criterion parameters and evaluation of its transferability

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ABSTRACT

This paper evaluates the brittle fracture risk for a C–Mn weld in the brittle-to-ductile transition: the criterion considered is based on a critical stress σ_{th}, with the failure probability related to the volume around the crack where the maximum principal stress exceeds σ_{th}. In Part II, the criterion is calibrated using more fracture tests at lower temperature. The capacity of the criterion to predict the probabilities of failure is validated. Finally, its transferability to another geometry is evaluated and appears to be possible.

1. Introduction

This paper deals with the brittle fracture risk evaluation of a C–Mn weld joint in the brittle to ductile fracture transition temperature range, with the main objective to develop a predictive criterion, able to demonstrate the complete absence of brittle fracture risk: this criterion is a critical stress-based fracture criterion, assuming that the probability of failure is directly linked to the volume around the crack where the maximum principal stress exceeds a critical cleavage stress σ_{th}. The aim of the work is the validation of the criterion applicability and transferability to analyze the risk of failure of a crack in a C–Mn weld joint.

A previous paper [1] introduced the criterion, some experiments supporting this work and the F.E. analysis (F.E.A.) of these experiments. The analyzed weld shows a complex microstructure with two types of zones: Re-Heated Melted Zones

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Nomenclature

BM	Base Metal
WM	Weld Metal
HAZ	Heat-Affected Zone
RHMZ	Re-Heated Melted Zone
JSMZ	Just Solidified Melted Zones
NT	Notched Tensile specimen
CT	Compact Tension specimen
SEM	Scanning Electron Microscopy
CMOD	Crack Mouth Opening Displacement
J_{IC}	rice integral at failure
K_J	elasto-plastic stress intensity factor
a_0/W	pre-crack length
SENT	Single Edge Notch Tension specimen
F.E.A.	Finite Elements Analysis
V_{th}	cumulative critical volume
σ_{th}	critical stress

(RHMZ) by the following bead, re-austenitized and then transformed in ferrite and pearlite, with a ferrite mean grain size of 25 μm and Just Solidified Melted Zones (JSMZ), which are zones not affected by the heating of next bead, and consisting of ferrite and bainite, with large and elongated ferrite grains of about 100 μm in the solidification direction. From SEM observations of failure surfaces of the specimens (Notched Tensile bar at −175 °C and Compact Tension specimens between −30 and 20 °C), it has been showed that the main cleavage sites are located in the coarse grain zone (JSMZ), usually at the vicinity of an inclusion which initiates the brittle fracture. Through the F.E.A., it was demonstrated that a local K, depending on the stress in the inclusion area, is not a relevant parameter to characterize the fracture initiation process because the values are very different for the two types of specimens (NT and CT specimens). Nevertheless, it appears that the values of the maximum principal stress at cleavage initiation sites are similar for both of them, that is to say there is a good consistency with the critical stress between the two types of specimens: this indicates that a simple model based on the maximum principal stress is valuable for cleavage initiation risk evaluation. A threshold stress below which cleavage is not possible has been defined (σ_{th} = 1300 MPa).

In this paper, new experimental tests on CT specimens (at −70 and −130 °C) analyzed through F.E. are presented. They are used to define and calibrate the stress-based criterion for the whole brittle-to-ductile transition. Afterwards, the criterion is used to predict the brittle fracture of the CT specimens and its relevance is evaluated. More fracture tests are performed on Single Edge Notch Tensile specimens at −70 °C and −130 °C. The first objective of this step is to better understand if the cleavage always starts in a JSMZ from an inclusion because of more severe loading conditions due to a higher yield stress than in the RHMZ, or because they are the weakest zones with a lower critical cleavage stress σ_{th}. Indeed, two different tensile curves have been defined for the RHMZ and the JSMZ. Also, two different sets of specimens are used with two crack tip orientations in the weld: for the first type, the crack tip crosses the RHMZ and the JSMZ whereas, for the second type, the crack tip only crosses the JSMZ. As for the second objective, it is to evaluate the transferability of the stress-based criterion from one geometry to another. As a matter of fact, the criterion calibrated with the CT specimens is used to predict the failure of the SENT specimens in function of the load. The results will allow concluding if the stress-based criterion is able to predict the maximum acceptable load without any risk of fracture in the brittle-to-ductile transition and if it can be calibrated with laboratory tests to be applied on an actual structure.

2. Stress-based criterion

In order to evaluate the brittle fracture risk, three PhDs [2–4] have been performed in CEA (French Alternative Energies and Atomic Energy Commission) to develop and validate a criterion following major objectives:

- the criterion has to be simple enough to be fitted on a small number of specimens;
- the criterion has to be simply applicable to large components and taking benefit from the related geometry, constraint, etc.;
- the criterion has to be capable to exclude the brittle fracture risk;
- the criterion has to be slightly conservative.

The work was initially based on the interpretation of test series on A508 steel [5,6] and then used for the materials considered in this paper.