ON FFM/PFM FAILURE CRITERIA FOR METALS UNDERGOING SSY – NEW INSIGHTS AT V-NOTCH TIPS

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Abstract
Structures made of steel alloys may fracture at V-notch tips at which a small plastic zone usually evolves. Failure criteria for predicting fracture loads for such quasi-brittle alloys, as a function of the V-notch opening angle are very scarce and have not been validated, to the best of our knowledge, by a set of experimental observations. Neither the FFM coupled criterion (FFMCC) for brittle fracture nor two phase-field models (the classical AT1 for brittle materials and a ductile version) could predict the increase of the crack nucleation force observed in the four-point bend (4PB) experiments performed on AISI 4340 specimens as the opening angle increased. Extension of the FFMCC to account for the small plastic zone and further 4PB experiments on a new steel alloy (H13) are being considered to improve the failure criterion.

1. Introduction
A set of experiments were performed on AISI 4340 steel alloy specimens with three different V-notch opening angles and three different tempering temperatures, loaded in mode I [1]. The FFMCC for brittle materials [2] was shown to predict reasonably well the failure load for small V-notch opening angles (30^o) for which the plastic area is very small (~20% which is within the experimental error range). The under-prediction of the failure load constantly increases to ~50% as the V-notch angle increases to 90^o and plastic area increases to ~0.5 mm^2 (for a V-notch depth of 5 mm).

At the same time, the AT1 PFM was also considered to predict the failure load and the plastic zone area. We provide results using both AT1 for brittle materials as well as a recently-developed PFM for ductile materials. Importantly, both models tie crack nucleation to critical values of energy, and both are shown to be lacking in their accuracy to varying degrees [3].

2. Results
Following a set of 4PB experiments on AISI4340 4PB specimens with 30^o, 60^o, 90^o V-notches as shown in Figure 1, we compared the load to fracture predicted by the FFMCC for brittle materials and PFM, with the experimental measure load. For V-notch openings of 30◦ and below, and a plastic area of less than 0.25 mm^2, it is useful to use the brittle version of FFMCC, predicting an underestimation of the failure load by about 20%. However the predictions deteriorate as the V-notch angle increases up to 50% underestimation at a V-notch angle of 90◦.

Neither the AT1 brittle nor the ductile phase-field models for fracture could predict the increase of the failure load observed in the four-point bend experiments as the opening angle increased. After calibrating the regularization parameter using specimens with the 30◦ V-notch angle, the error increased by 18% when predicting the 60^o specimens and then 34% when predicting the 90^o specimens.

To further investigate the influence of the SSY on the failure load, V-notched specimens made of another steel H13 were fabricated (see Figure 2) and experiments are ongoing. In parallel, theoretical extensions of the FFMCC [4] and PFM are being developed to better consider the SSY and its influence on the predicted failure load. These results will be presented in this talk.

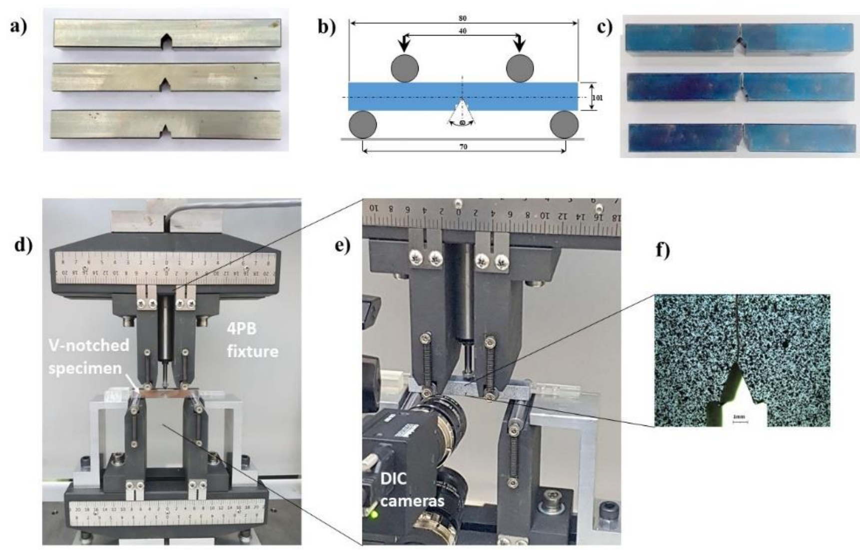

Figure 1 - *Experimental system and specimens. a) AISI4340 specimens with V-notches of 30^o; 60^o and 90^o . b) Dimensions of specimens. c) Fractured specimens. d) 4PB fixture in loading machine. e) Zoom at specimen and DIC system. f) DIC view at V-notch tip.*

3. Conclusions

An attempt to extend the FFMCC to cases where small-scale yielding plasticity is evident at the V-notch tips was theoretically presented in [4]. By measuring the plastic zone size by DIC and recording the failure load we use the Ramberg-Osgood law to model the plastic zone evolution and thus stresses still exhibit a singular behavior when approaching the notch root like the Rice and Rosengren model. When crack nucleates, an elastic unloading phase is assumed.

We shall present our analysis to enhance the FFMCC in cases where a small-scale yielding zone develops prior to crack initiation at the V-notch tip, and validate it by extending the experiments by a new experimental investigation where another metallic allow is considered – H13 – to investigate whether material properties affect the predicted failure load.

Figure 2 - *Left) H13 specimens with V-notches of 30°; 60° and 90° . Right) H13 specimens for experiments required by a triaxiality fracture theorem.*

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