MODELLING OF THE CHARPY V-NOTCH TEST AT LOW TEMPERATURE FOR STRUCTURAL STEELS.

M. Tahar † R. Piques †, P. Forget *

Charpy V notch specimens taken out from a pressure vessel steel are tested on a standard instrumented pendulum impact machine at low temperature. Numerical calculations were carried out to model these tests using a plane strain and plane stress analysis. The strain rate effect on the yield stress is investigated. The anvils and the striker are supposed rigid bodies with sliding friction surfaces. A comparison of the load-displacement curves indicate an overestimation by a plane strain analysis whereas a plane stress underesimate the experimental curve. In order to apply the Beremin model (1), attention is payed to obtain correct local stress and strain fields.

INTRODUCTION

The results reported here are part of both experimental program and numerical calculations performed with partners (A. Rossoll et al (2)) in order to investigate a better relationship between Charpy V notch energy and fracture toughness K_{Ic} at low temperatures. The modelling of the Charpy V notch is only investigated in this paper. A two dimensionnal approach is used to model the Charpy test : a comparison of a stress plane and strain plane analysis with an experimental load-displacement curve is made. Dynamic effects on mechanical properties are taken into account but inertials terms seem to be negligible in order to explain the fracture's initiation in this material. The striker and anvil supports are modelled using rigid contact elements. Local stress and strain calculations are discussed in order to apply a critical cleavage stress concept in the framework of Beremin model (1).

† Centre des Matériaux Ecole des Mines B.P. 87 - 91003 EVRY cedex (France)
* Commissariat à l'Energie Atomique (SRMA) 91191 Gif-sur-Yvette (France)

MATERIAL AND EXPERIMENTAL PROCEDURE

Material.

The investigated material is a french pressure vessel steel (A 508 cl. 3 according to the american nomenclature) whose composition is shown in table 1. This mild steel has a tempered bainitic microstructure characterised by an average prior austenite grain size of 30 μm.

All the experimental work is carried out by using specimens whose the longitudinal axis corresponds to the Long Transverse material direction.

Table 1: Chemical composition (weight %)

C	S	P	Si	Mn	Ni	Cr	Mo	Cu	Co	V
0,16	0,004	0,008	0,22	1,33	0,76	0,22	0,51	0,07	0,017	$\leq$0,01

Material behaviour

Many investigators have examined the effects of strain rate and temperature on material behaviour of ferritic steels, for example Ritchie et al (3), Benett and Sinclair (4). They have also suggested a dependance of the yield stress on temperature and strain rate, this dependance is given by

$$\sigma_y = A\left[Tln\left(\frac{\dot{\epsilon}_0}{\dot{\epsilon}}\right)\right]^m \quad with\ \dot{\epsilon}_0 = 10^8 \tag{1}$$

An analysis of the work of Pluvinage and Marandet (5) and Henry et al (6) contributed to identify the parameters m et A for the french pressure vessel steel. In fact, tensile and compression tests made by Pluvinage give a couple of parameters (A = 75866 and m = -0.573), whereas the tensile tests of Henry give an another couple of parameters (A = 35188 and m = -0.487).

An experimental study has been launched to identify these parameters for our steel. It consists on tensile tests in static and dynamic conditions at differents strain rates (10^{-3} up to $50s^{-1}$) and temperatures (77 K to 298 K). First results of dynamic tensile stress are plotted in figure 1. A good agreement appears with the tensile results obtained by Pluvinage and Henry(6). The difference with tensile plus compression yield stress (5) could be related to the strength differential effect (7). In this material, on one hand the hardening effect is low and on the other one it is like insensitive with respect to the strain rate (5).

Charpy V notch tests

Charpy V notch tests have been carried out in a temperature range of -100 to -60 degrees Celsius on a standard pendulum impact machine, which is instrumented in such a way that the force, the striking velocity and the absorbed energy could be recorded versus time during the tests. In this paper, we focused on tests carried out at - 80 degrees Celsius to study the fracture of Charpy V notch specimen at low temperature.

FINITE ELEMENT ANALYSIS

The numerical calculations were performed by using the ABAQUS code. Eight node isoparametric quadratic elements with reduced integration were adopted. Due to symmetry, only one half of both striker and specimen was modeled by using an appropriate symmetry boundary.

As it has been underlined in the material presentation, the A508 steel could be considered as an elastic viscoplastic material. ABAQUS allows the material to have a yield stress being rate dependent ($\dot{\epsilon}$).

The loading process was controlled by prescribing either the striker's displacement for a static analysis or the striker's velocity for a dynamic analysis.

The contacts between the specimen and the anvils or the striker were modeled by defining these parts as rigid bodies with sliding friction surfaces ($f = 0.2$)

RESULTS AND DISCUSSION

Experimental results : The recordings made during the tests show that the load displacement plots are in good agreement at - 80 ° C. The principal difference between curves are the times to rupture corresponding to the scatter of brittle fracture. The scanning electronic microscopic (S.E.M.) observations show that cleavage controls the fracture at this temperature Time to rupture encountered are in a range from $t_1 = 150\ \mu s$ to $t_2 = 400\ \mu s$ corresponding to a deflection of the striker of $d_1 = 0.7$ mm to $d_2 = 2$ mm. Fracture occurs after the slight one or two oscillations observed in the load plot recorded during the tests.

Numerical calculations : A comparison between a plane strain static and a dynamic analysis is made in the figure 2a. On the global curve, load versus time, plasticity damps the amplitude of oscillations. Moreover, the precedent remarks on the weak oscillations observed experimentally seem to indicate that a quasi static analysis of the Charpy V notch test is sufficient for the modelling of the Charpy V notch test.

In the figure 3a, the experimental results are bounded by the plane strain and the plane stress F.E.M. simulations. However, the plane stress calculations show too much plasticity around the notch root to be realistic by comparison with experiments (figure 4).

The evolution of the maximal principal stress (the opening stress) along the ligament is represented in the figure 3b for a static and plane strain analysis. It shows that the maximum occurs at 500 μm up to 1 mm from the notch root. The level of this maximum does not increase consequently during the analysis. It is related to the hardening properties of the material. There is an extent a zone where the maximum stress is constant. In order to propose a better relationship between Charpy V notch energy and fracture toughness using the Beremin model (1), local calculations like those which are shown in figure 3a are in progess.

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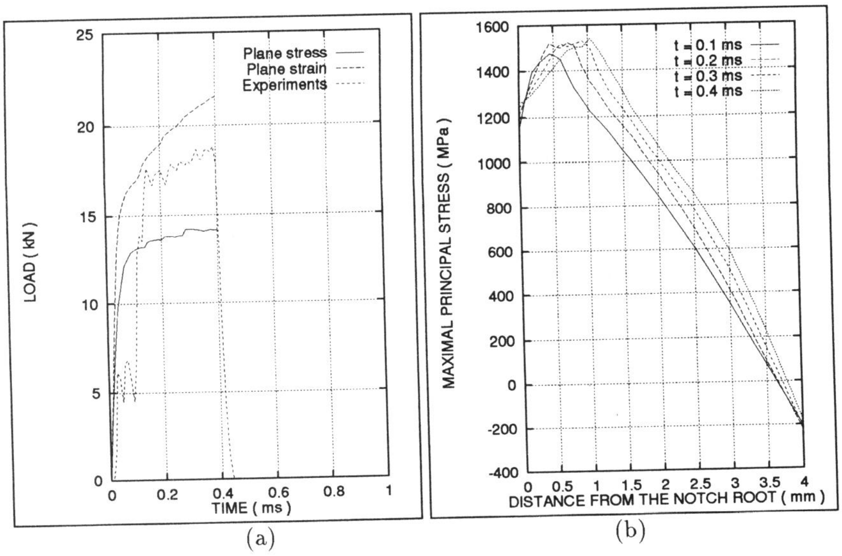

Figure 3 : (a) Finite element simulations and experimental load curves.
(b) Evolution of the maximal principal stress.

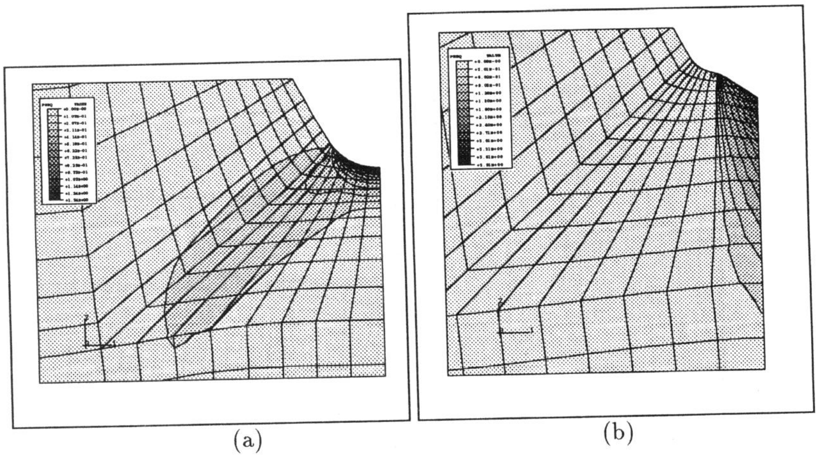

Figure 4 : Comparison of the shape and the size of the plastic zone between a plane strain (a) and a plane stress (b) analysis.

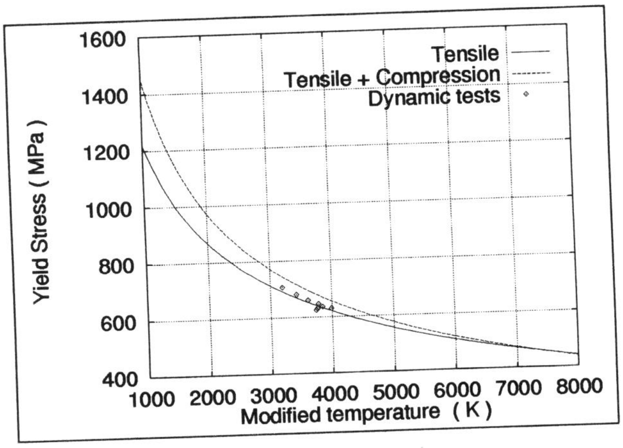

Figure 1 : Yield stress as a function of the modified temperature $T \ln(\frac{10^8}{\dot{\epsilon}})$.

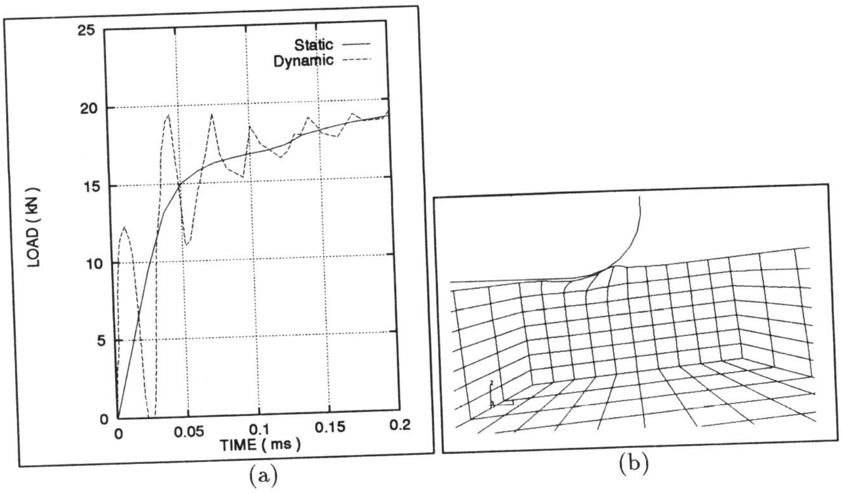

Figure 2 : (a) Comparison between static / dynamic analysis.
(b) View of the deformed mesh at anvil/specimen contact.