# FRACTURE MECHANISMS AND MICROMECHANICAL MODELIZATION FOR AGED DUAL-PHASE STEELS.

C. DUVAL**, D. BAPTISTE*, C. PRIOUL*, D. FRANÇOIS*.

When testing aged austeno-ferritic steels, two different local mechanisms of fracture are observed, depending on the testing temperature . In the first one, the progressive birth and growth of arrays of small parallel cracks in the colonies of ferrite leads to fracture. In the second one, the ferrite and austenite simultaneously break by shearing instability.

A micromechanical model , based on the law of mixtures is proposed to describe the influence of ageing and ferrite content on the stability of the first mechanism. A FEM approach is used to establish a criterion for the initiation of the second one.

Experimental results confirm the requirement of two different approaches to represent the damaging process for different temperatures.

## INTRODUCTION

This work covers the field of the modelization of heterogeneous materials made of two elasto-plastic constituents with different yield stresses. The materials on which we have been working are austeno-ferritic steels containing 20 to 30% ferrite. They have been submitted to experimental accelerated ageing inducing a great change in their mechanical properties (1). The remaining of these materials for a long time within a temperature range of 300°C to 450°C leads to a decrease in ductility coupled with an increase in mechanical resistance. Since our purpose was to establish a failure criterion, we first observe the microstructure and damage mechanisms. Then we evaluate the influence of two microscopic parameters on the stability. Finally we establish a failure criterion for one working condition.

## MICROSTRUCTURE, TESTING TEMPERATURE AND AGEING

Various parameters can influence the damage process in austeno-ferritic steels.

** Electricité De France, Direction des Etudes et Recherches, Dept MTC
BP1, 77250 MORET sur LOING. FRANCE
* Laboratoire MSS-MAT, CNRS URA 850
Ecole Centrale Paris, 92295 CHATENAY-MALABRY Cedex. FRANCE.

Microstructure.

Microscopic observation of metallographic sections at low magnification reveals colonies separated by a continuous austenitic path. The size of these colonies varies from 1 to 5 mm. When testing at 20°C, we can observe networks of parallel cracks in the ferrite with a orientation specific to each colony. Inside a colony each phase forms a continuous network even at very low ferrite contents (5%). As measured by Kossel diffraction, each colony can be divided in three to five areas in which the cristallographic orientation of austenite is uniform. We conclude that the elementary homogeneous volume is millimetric. Another parameter is the mean linear path in one phase, which can be obtained by automatic image analysis, and which depends much on the casting process. The ferrite network is finer in centrifugally cast materials.

Ferrite proportion.

The ferrite plays a strengthening role in the austenitic matrix. In aged specimens the hardness under 50g of the ferrite can reach 900 Vickers whereas the hardness of austenite keeps values approaching 200 Vickers. As in all composites the ferrite content plays an important role on the mechanical behaviour.

Testing temperature.

The effect of temperature on the mechanical properties of austeno-ferritic steels can be seen through its effect on each phase. When the testing temperature varies from 20°C to 350°C the yield strength of the two phases decreases. Moreover, in aged castings the mechanisms of fracture evolve, due to the fact that aged ferrite is in its ductile-brittle transition area.

Ageing.

A macroscopic parameter giving an idea of ageing embrittlement of the steel is the KCU Charpy impact energy which can evolve from 25 daj/cm2 to 1daj/cm2..

If we consider that ageing mainly affects the ferrite as suggested in (1), a way to evaluate the embrittlement is to measure the local hardness. A correlation has been made showing an evolution of the ferrite hardness from 300 Vickers to 900 Vickers (1).

## FRACTURE MECHANISMS

These mechanisms were observed through 'post mortem' metallographic observations and during in situ (inside a Scanning Electronic Microscope) tensile tests. The first mechanism is classical (2) and has been successfully modelized (4).

First mechanism.

It consists in a continuous birth and growth of cracks in the ferrite phase. Inside a given colony, the cracks are parallel with one another and to a direction not far from the perpendicular to the tensile axis (see figure 1). This mechanism was observed at 20°C on 20% and 30% ferrite content steels whose KCU impact energy were 3 and 1 daj/cm2.

Second mechanism.

This mechanism consists in simultaneous shearing of the two phases following the weakest shearing stress plan (see figure 2). No previous crack was observed. The observations were performed at a temperature of 320°C on the same two materials as for the first mechanism.

## INFLUENCE OF AGEING AND FERRITE CONTENT ON THE STABILITY OF THE FIRST MECHANISM

Modelization.

Considering an elementary volume composed of three parallel bars whose relative size respects the ferrite content (see figure 3). Then apply a uniform displacement to it in the direction of the bars. For a few percent of strain, both phases deform following their own stress-strain curve. Then a crack appears in the ferrite and the further deformation is concentrated in triangular areas on each side of the crack. The level of the stress-strain curve of austenite is given by a 18-12 stainless steel and the ferrite one is chosen so that the application of the law of mixtures to the elementary volume produces the original austeno-ferritic stress-strain curve. The resulting behaviour of the cell reveals two significant stress levels: at the occurrence of the crack (level 1 on figure 3. ), and just after this event.(level 3 on figure 3 ). The comparison between those two levels gives an idea of the stability of the first mechanism and can be named the 'instability difference'.

Influence of ferrite content.

For low ferrite contents, the instability difference is low and a progressive crack initiation is possible during increasing deformation whereas for greater ferrite contents the first crack initiation in the ferrite may lead to instability (see figure 4).

Influence of ageing.

If the level of the ferrite stress-strain curve is proportional to its hardness as classically used in mechanics, then we get the influence of ageing on the stability of this mechanism for hardness varying from 300 Vickers to 900 Vickers. For long time ageing, we observe a great noxiousness of the first crack (see figure 4).

## COMPLETE STUDY AT 320°C OF AN AGED STEEL

Experiments.

Tensile tests were performed at 320°C on 39 cylindrical notched specimens whose notch radii were 2,4 and 10 mm on a steel containing 30% of ferrite whose KCU impact energy was 1 daj/cm2. The mean radial deformation in the smallest section measured at maximum load for AE2, AE4, AE10 were respectively: 7.9, 12.5, and 17.0 %.

In each geometry, 4 tests were stopped just after the maximum load was reached. Metallographic observations on the damaged specimens revealed the crack initiation area and the damage mechanism (see figure 5).

FEM analysis and initiation criterion.

A finite element calculation of the state of stress and strain of the three specimens was conducted. Assuming that no significant damage was observed before the maximum load point, we made the hypothesis of an isotropic homogeneous material. We then computed the values of different criteria all over the structures and reached to the conclusion that the best one was the Von Mises stress which gave the good crack intiation area and values in a good agreement whatever the geometry (see figure 6). Other criteria such as the maximum shear deformation or the maximum Tresca stress gave also acceptable results.

## INFLUENCE OF TEMPERATURE ON THE FRACTURE MECHANISM AND ON THE TENSILE RESISTANCE OF ONE AGED STEEL

Tensile tests were performed on specimens containing 30% of ferrite aged up to 1 daj/cm2, at temperatures varying from 200°C to 350°C. Figure 7 shows a discontinuity at 200°C in the evolution of the maximum load on TS8 specimens. This evolution of the maximum load was related to the mechanisms of fracture. The specimen tested at 20°C followed mechanism I. When the temperature increases the number of cracks decreases and the mechanism progressively moves to mechanism II. The transition is progressive due to the variation of the morphology and other parameters through the structure.

## CONCLUSION

Depending on the testing temperature and on the ferrite content, the fracture mechanism of aged austeno-ferritic steels can be of two types requiring two different failure criteria. The first fracture mechanism is similar to that of ductile materials and is rather specific to room temperature tests. The second one is more frequent at temperatures greater than 20°C. The stability of the first mechanism depends on the ferrite content and on the ageing state. The Von Mises equivalent stress is a reliable criterion to describe the initiation of damage in the second mechanism.

## REFERENCES

(1) Bonnet S., Bourgoin J., Champredonde J., and Guttmann D. and M., Mat. Sc. and Tech., Mars 90, to be published.

(2) Slama G., Petrequin P., Mager T., Effect of ageing on mechanical properties of austenitic stainless steel castings and welds., Smirt7 Post conf. Seminar 6, Monterey, Aug. 83.

(3) Cho K., and Gurland J., Met. Trans. A, vol 19A, Aug. 1988, pp 2027-2040.

(4) Pineau A., Joly P., Local versus global approaches of elastic-plastic fracture mechanics. Application to ferritic steels and a cast duplex stainless steel, Symp. on Elas. Plas. Frac. Mech., Fribourg, RFA, 9-12 Oct. 89.

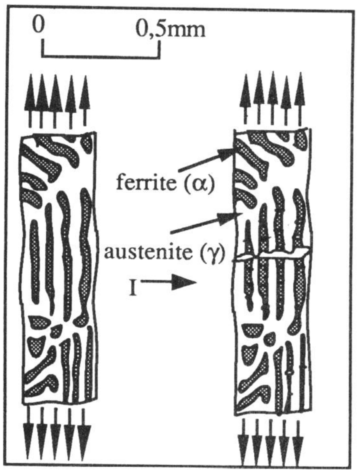


Figure 1: First mechanism.

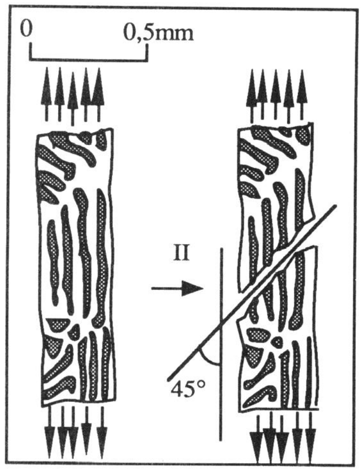


Figure 2: Second mechanism.

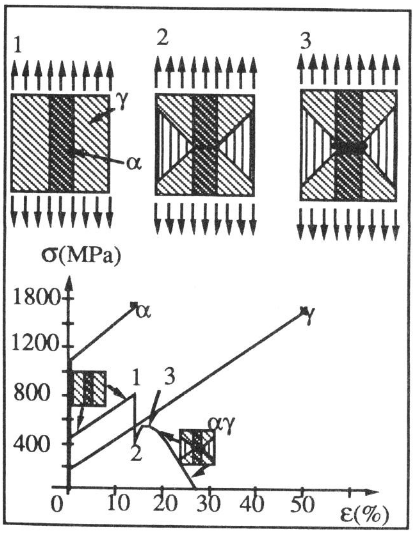


Figure 3: Modelization of an elementary volume.

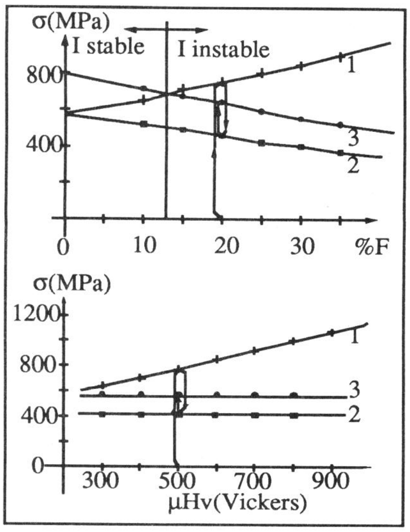


Figure 4: Effect of ferrite content and ageing.

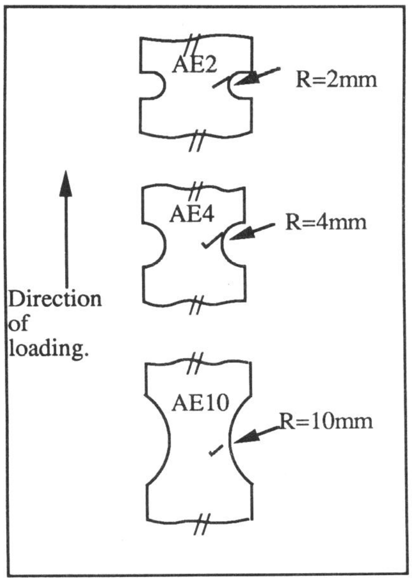


Figure 5 : Position of shearing damage in cylindrical notched specimens.

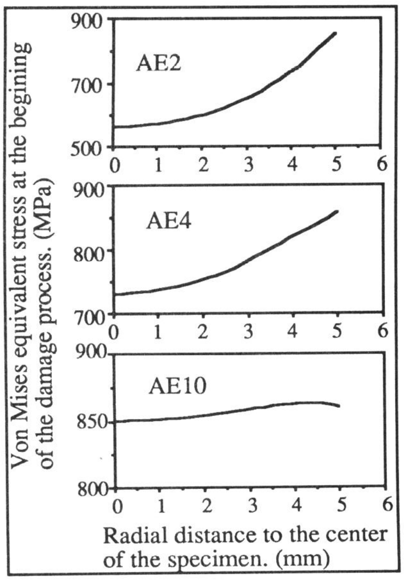


Figure 6: Von Mises stress plotted versus radial distance to the center.

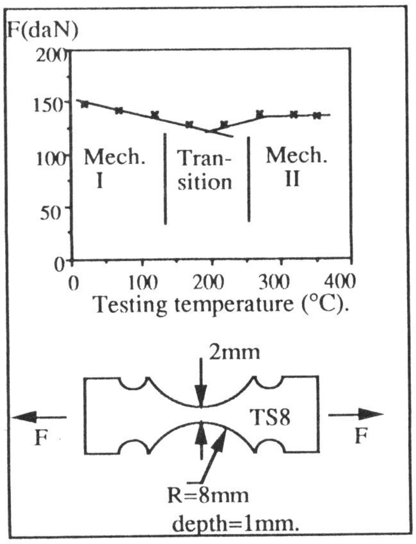


Figure 7: Effect of temperature on maximum load. Plan of TS8 specimens.