DAMAGING EFFECTS OF POROSITY ON FRACTURE OF SINTERED NICKEL

Ph. Bompard and D. François

Laboratoire Matériaux, Ecole Centrale des Arts et Manufactures, 92290 - Châtenay-Malabry, France

ABSTRACT

The tensile properties were measured on sintered nickel with 8% to 40% porosity. The initial porosity and its growth during tensile testing were related with the decreease of young's modulus. A good agreement with the mechanical models of cavity growth was found.

KEYWORDS

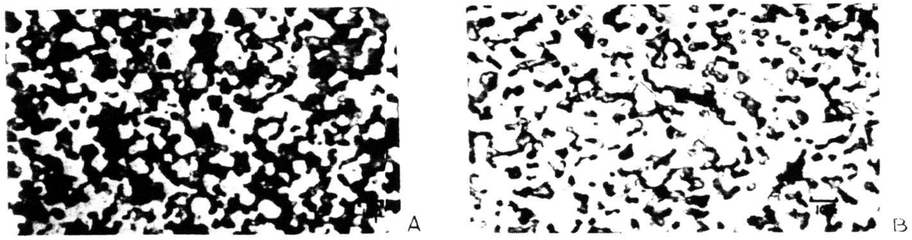
Porosity, nickel, sintered nickel, ductile fracture, damage.

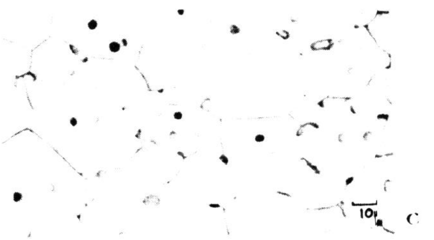
1 - INTRODUCTION

Sintered parts always contain porosities whereas the mechanical properties of porous alloys are not yet well understood. Besides ductile and creep failures are the result of cavity growth and coalescence. It thus seems of interest to study the tensile behavior of a porous material, in order to test cavity growth models of McClintock (1) and Rice and Tracey (2). If experiments in ductile fracture begin to clarify this problem (3, 4, 5, 6), very little is known in porous metals. Yet, in such materials, the initiation stage does not exist and the various initial values of porosity which can be used ought to simplify the interpretations of the results. We studied the tensile properties of sintered nickel, which can be easily produced with a wide range of porositi. We interpreted the results using the damage theory which relates young's modulus to the effective load bearing surface.

2 - MATERIAL STUDIED

We used a carbonyle nickel powder with a particule size between 4 and 6 µm and an impurity level between .05 and .1% (mainly carbon). Compression followed by sintering at 1 373°K, under cracked ammoniac, gave a final porosity ranging from 40% to 7%. Corresponding microstructures are shown in Fig. 1.





× 600

A : 40%, opened porosity
B : 20%, mixed porosity
C : 7%, closed porosity, beginning of grain growth

Fig.1 : Microstructures

Frappier (7) showed that porosities higher than 25%, in sintered nickel, are almost completely opened, while porosities lower than 12% are completely closed. The grain size is equal to the previous particule size for porosities higher than 10%, but grain growth begins to take place for 7% specimens.

3 - EXPERIMENTAL RESULTS

25mm^2 cross section and 35mm length specimens were used and tested on a tensile testing machine at a crosshead velocity of 1mm per mn.

Fig.2 shows three important features of the tensile behavior of sintered nickel :

- the ultimate tensile strength and the fracture strain are both strongly dependent on porosity ;
- the ratio between conventional yield strength ($\varepsilon_p = 2.10^{-3}$) and the microyield strength (2.10^{-5}), previously measured by Morlier (8) is about 2 or 3, which can be accounted for by the stress concentration factor K_T of a "smooth" elliptical hole ;
- the mechanical properties of nickel are strongly dependent on grain size, as previously observed (9, 10), and was also noticed in fatigue (11). Results obtained by Hasegawa (9) on fine grain nickel are consistent with our results on nickel of higher porosity.

Elastic and plastic coefficients are reported on Fig.3. Our experimental values are in close agreement with values measured by Frappier (7). It must be noticed that porosity induces a strong decrease of work hardening and promotes non isovolumic plastic strains.

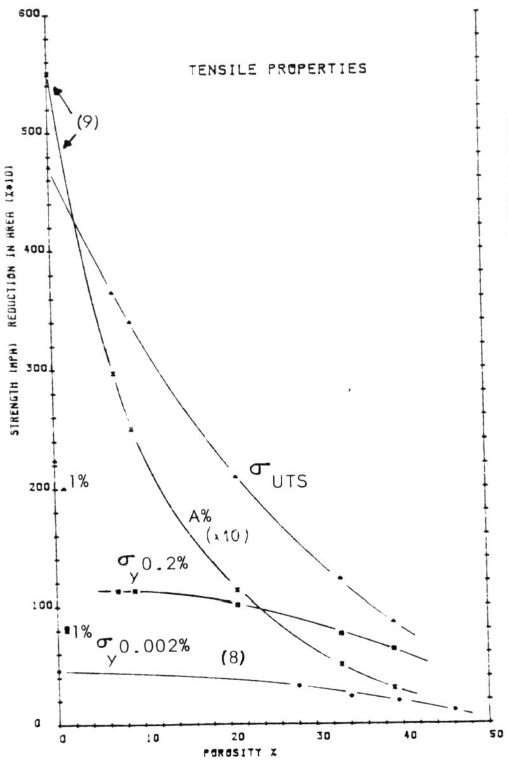


Fig.2 : tensile properties

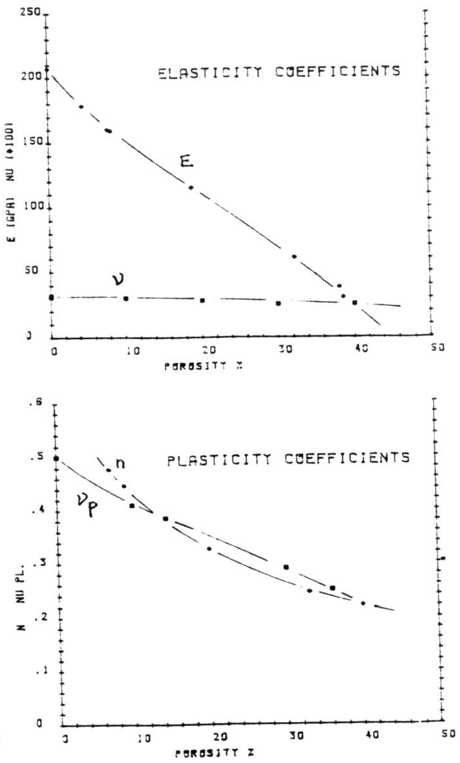


Fig. 3

4 - DISCUSSION

4.1. Porosity effects

The first effect of porosity to be considered is the reduction of the surface on which the stress is applied. This concept of S_{eff} was introduced in terms of damage theory by Kachanov and Rabotnov. Damage is given by :

$$D = 1 - \frac{S_{eff}}{S_o} \simeq \frac{S\ porosity}{S_o}$$

Damage is measured by means of young's modulus, as proposed by Lemaitre and Chaboche (12) :

$$\frac{E\ (\rho)}{E_m} = \frac{S_{eff}}{S_o} = 1 - D$$

where E_m is the Young's modulus of compact nickel and E (ρ) the modulus of sintered nickel (ρ is porosity), as reported on Fig.3. Damage measurements (Fig.4) lead to an "effective" porosity greater than the average one. This fact has been noticed by many authors (7, 11), and is related not only with the local stress distribution, but also with the existence of surfaces of local greater porosity.

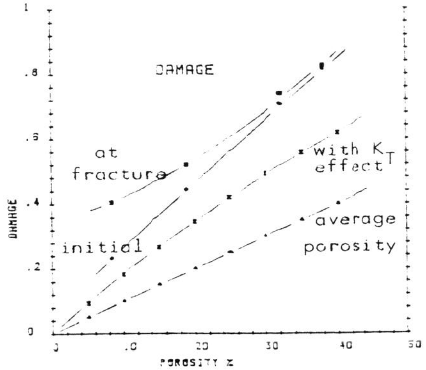


Fig.4 : damage measurements

4.2. Damage evolution

In order to test if the damage could be related to the existence of actual pores, we measured the evolution of E (ρ) during tensile tests, by the unloading method. Assuming that the pore growth is given by the Rice and Tracey's model (2) :

$$\frac{dR}{R} = \alpha \, d\varepsilon_p \exp\left(\frac{3\sigma_m}{2\bar{\sigma}}\right)$$

with α = 0.284 for a single cavity in a perfectly plastic material. The evolution of E is thus given by considering the effective stress on the average load bearing section :

$$E(\rho, \varepsilon_p) = E_m - \left[E_m - E(\rho, 0) \right] \exp(3\alpha \sqrt{e}\, \varepsilon_p)$$

Experimental results (Fig. 5, 6) are in good agreement with this model, and lead to some remarks :

- Values of α for the lower porosity specimens are higher than 0.284. This may be a consequence of the strain hardening behavior of nickel, as previously shown by McClintock (1). It may also be the effect of pores interaction, although the decrease of α for higher porosities specimens does not agree with that interpretation.

- α decreases rapidly for higher porosity specimens, and becomes smaller than 0.284. However what is measured is a decrease in transversal growth rate and it may be the effect of the loss of plastic constraint which becomes important as soon as opened porosity prevails. Still, as decreases as porosity increases, the total porosity growth rate keeps increasing, in agreement with the high α values observed by Sun Yao Qing (4) for mean cavity growth rates in spheroīcal cast iron.

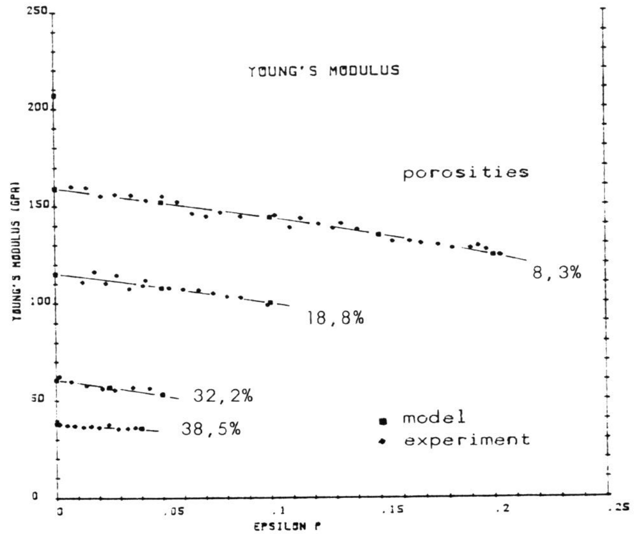


Fig 5 : Evolution of damage during tensile tests

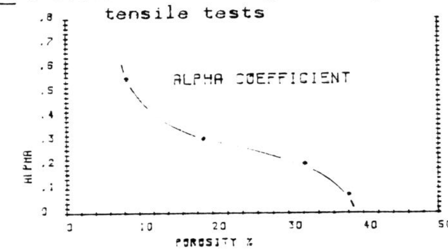


Fig 6 : Evolution of the α coefficient with the initial porosity

The model we propose leads to a damage growth rate given by the evolution of the average load bearing section :

$$\dot{D} = \frac{d}{dt}\left(N \frac{4}{3} \frac{\pi R^3}{V_o}\right) \quad \text{proportional to } R^2\dot{R}$$

This damage behavior would agree with the damage model proposed by Lemaître and Chaboche (12) :

$$\dot{D} = \left[\frac{\sigma - \sigma_D}{S(1 - D)}\right]^s \frac{\dot{\sigma}}{S}$$

where σ_D, S, s are material's constants.

4.3. Ductile failure

Damage measurements lead to values of $(R/R_o)_c$ at failure ranging from 1.21 to 1.01 (Fig.4, 7), with a sharp decrease as soon as the porosity becomes opened. As the growth of the cavities in the applied stress field is very anisotropic, the transversal growth ratio $(R/R_o)_c$ is not the best failure criterion. A better description of the plastic instability between pores would be needed and could lead to the concept of an equivalent cavity.

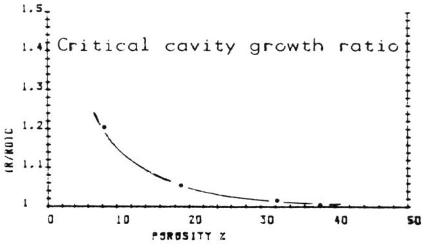


Fig 7 : Evolution of the transversal critical growth ratio with the initial porosity.

5 - CONCLUSION

Tensile behavior of sintered nickel is related with the damage induced by porosity. Evolution of damage with both porosity and plastic tensile strain shows that :

- damage is related with internal surfaces of local greater porosity,
- the growth of pores agrees with Rice and Tracey's model, and is increased by the strain hardening of nickel,
- the total growth is increased, but the transversal growth is decreased by pores interaction, this leading to difficulties in using a critical radius ratio criterion,
- damage growth rate D is proportional to $R^2\dot{R}$, R being the radius of the cavity.

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