EFFECTS OF POROSITY ON FATIGUE CRACK PROPAGATION IN SINTERED NICKEL

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ABSTRACT

Fatigue crack propagation rates were measured between 10^{-6} and 10^{-3}mm/cycle in sintered porous nickel with porosity ranging from 1% to 40%. The usual power law was observed with an exponent which did not change much with porosity. However the crack velocity for a given stress intensity factor was multiplied by a very large factor when the porosity was increased. A damage model based on the reduction of the load bearing area and thus related to the change of Young's modulus was enough to bring together the experimental results, morphology effects playing only a minor role.

KEYWORDS

Porosity, nickel, sintered nickel, fatigue, fatigue crack propagation, damage.

I-INTRODUCTION

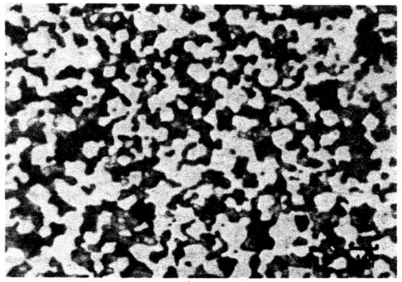
The good performance of sintered steels in automobile applications cannot be explained by considering their rather poor tensile mechanical properties alone. Their behavior is similar to that of spheroïdal cast iron. Many authors (2,5,6) showed that the fracture toughness of sintered steels increases proportionaly to the increase of their yield strength, the last one being related either with a decrease of porosity, or an increase of alloying elements. The toughness was found independant of the thickness of specimens (1, 2), because the porosity induces plane-stress conditions near the crack tip. The fatigue limit of sintered alloys decreases rapidly with increasing porosity (1,4).

Fatigue crack propagation rates in sintered low alloyed steels (1), with a porosity ranging from 11% to 17%, are found to be at least ten times faster than in a fully dense steel of similar tensile properties.

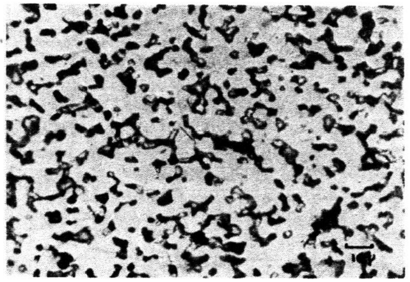
In order to elucidate the role of porosity on the fatigue properties and to try to reach a more quantitative description, we chose to study pure sintered nickel, a material which we can be easily produced with a wide range of porosities. We concentrated on the crack propagation behavior.

II-MATERIAL STUDIED

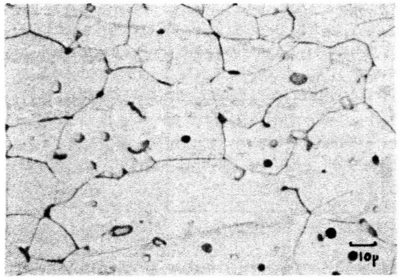
We used a carbonyle nickel powder with a particule size between 4 and 6 μm, and an impurity level between 0.05 and 0.1% (mainly carbon). Compression followed by sintering in an atmosphere of cracked ammonia at 1373 K gave a final porosity in the range 7% to 40%. Hot-forging of 7% porosity specimens, at 1600°K, reduced the porosity to 1%. Corresponding microstructures are shown in Fig.1.



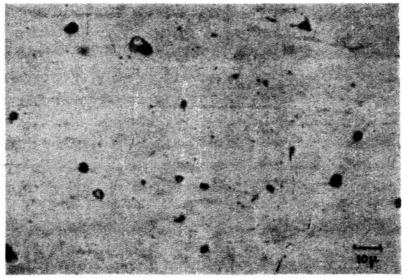
40% : opened porosity



20% : mixed porosity



7% : closed porosity.



1% : large grain size (≏ 1 mm)

Frappier (7) showed that porosities higher than 25%, in sintered nickel, are almost completely opened, and porosities lower than 12% are completely closed. We did not measure the morphology, however previous work by Wakanabe (8) on sintered pure copper showed that both anisometry (excentricity of equivalent ellipse) and bulkiness (ratio of ellipse area to pore area) increase monotically with porosity. The grain size remains equal to the previous particule size for porosities higher than 10%,but grain growth begins to take place for 7% specimens. The grain size of 1% specimens is very large (≃ 1mm).

The tensile properties were first studied and are described in another publication (Bompard, François, this conference). Figures 2 and 3 give the main results.

FATIGUE CRACK GROWTH RATES.

Fracture mechanics RCT specimens (50mm in diameter, 20mm thick) were tested with a R ratio of 0.1. Crack length was measured optically . Frequency ranged from 5 Hz (high propagation rates) to 90 Hz (lowest rates), without detectable frequency effect at a given ΔK value. Fig. 4 shows that, in the range 10^{-6} to 10^{-3} mm/cycle, all sintered nickel specimens follow the usual power law with an exponent nearly constant and C ranging between 10^{-13} to 10^{-7}. Owing to its large grain size, 1% porosity nickel shows a threshold behavior up to 10^{-5} mm/cycle, and only little improvement in medium propagation rates compared to 7% nickel. Our results are in good agreement with those of Speidel (9), who tested fine grain compact nickel at a load ratio of zero.

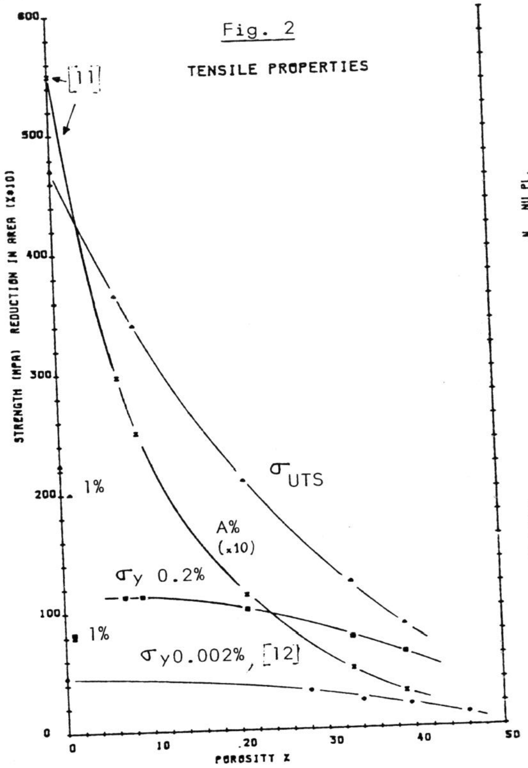


Fig. 2

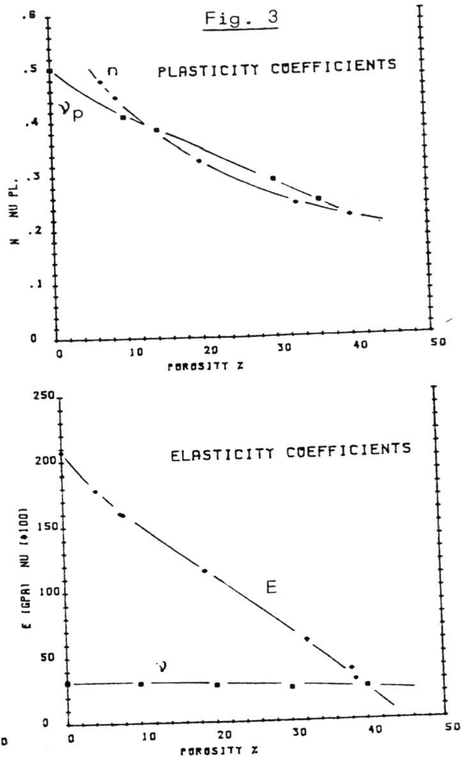


Fig. 3

σ_{uts} : ultimate tensile stress, MPa
$\sigma_{y0.2\%}$: 0,2% offset yield stress, MPa
$\sigma_{y0.002\%}$ = 0,002% offset microyield stress, MPa
E = Young modulus, GPa
ν = Poisson's ratio (elastic)
n = hardening coefficient
ν_p = Poisson's ratio (plastic)

DISCUSSION

The effective load bearing section S_{eff} is reduced by the pores (Fig.5). This leads to : a/ an increase of the local stress, that is to say of the local ΔK :

$$\Delta K_{eff} = \frac{\Delta K}{1 - D} \qquad (1)$$

Where D is the Kachanov's damage defined as :

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

S_{eff} : effective load bearing section.

S_o : total section.

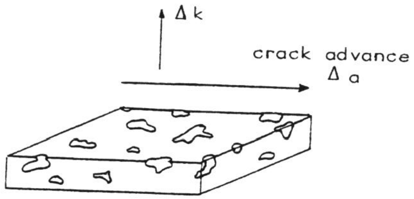


Fig. 5 : Reduction in load bearing area by porosity

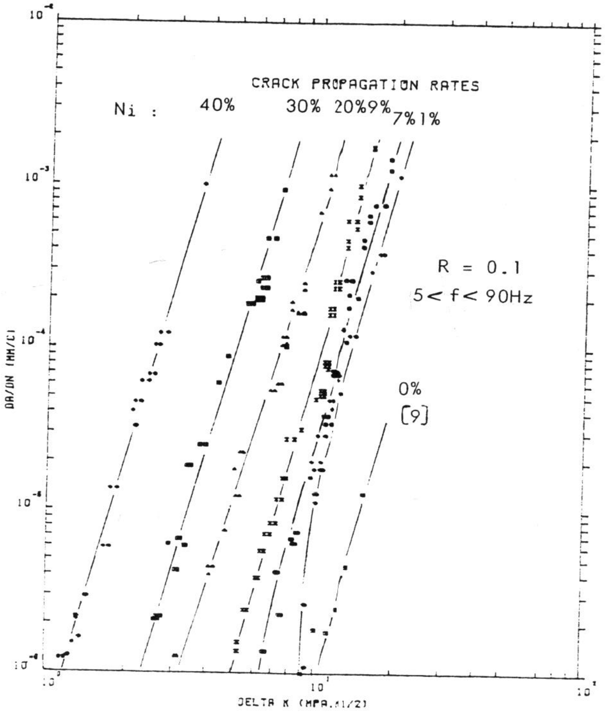


Fig.4: Fatigue crack propagation rates

b/ an increase in crack propagation rate, since it is assumed that the crack tip can jump instantaneously across a pore. Hence,

$$\left(\frac{da}{dN}\right)eff = (1 - D)\,\frac{da}{dN} \qquad (2)$$

Observations show that the Paris law is obeyed for fully dense nickel :

$$\frac{da}{dN} = C_o \,.\, \Delta K^{mo} \qquad (3)$$

We may then predict crack growth rate for porous nickel from equations (1), (3), yielding :

$$\frac{da}{dN} = \frac{C_o}{(1-D)^{m_o + 1}}\,\Delta K^{m_o} \qquad (4)$$

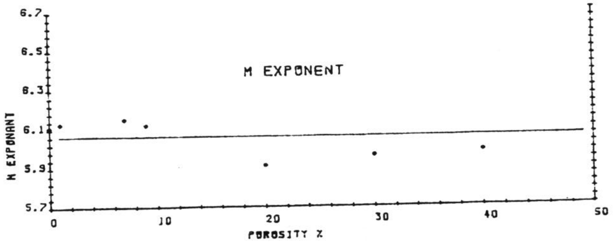
where C_o and m_o are the coefficients for pure fine grain compact nickel.

Using modulus measurements of D, we found a good agreement of equation (4) with experimental results :

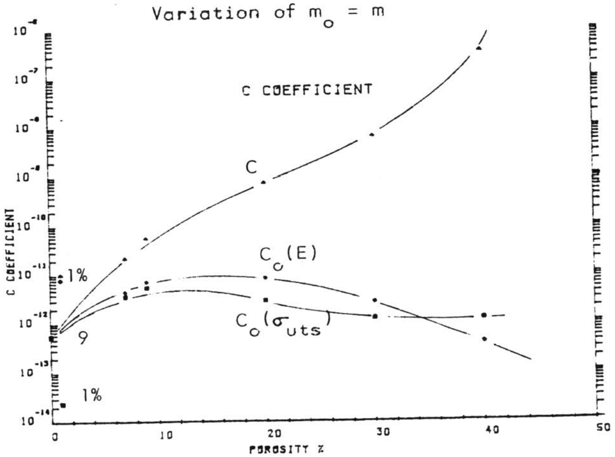
- m_o is nearly constant
- $C_o = C(1-D)^{m_o+1}$ is in the range 1 to 10, although C itself is in the range 1 to 10^6 (Fig. 6).

Another definition of damage related to the decrease of the ultimate tensile strength can also be used. It gives comparable results (Fig.6).

Fig.6



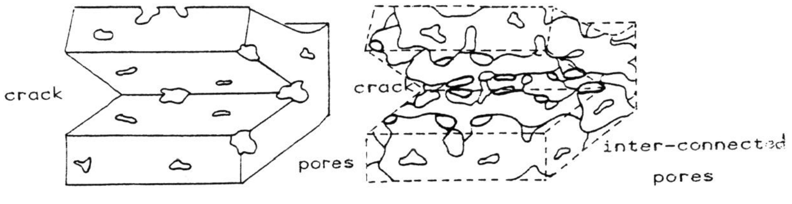
Variation of $m_o = m$



Variation of $C_o = C(1-D)^{mo + 1}$

Reduction of the effective load bearing section is shown to be the main effect of porosity on fatigue crack propagation rates, in agreement with (10). The variation of C_o with porosity is due to changes in morphology, as follows :

- at low porosities, the stress concentrating influence of the pores is high, leading to accelerated growth and a high C_o.
- at higher porosities, the pores interconnect, leading to blunting of the crack tip ; plastic constraint is also reduced. The net effect is a reduction in growth ratio and lowered C_o. Refer to Fig. 7.



Closed porosity Opened porosity

The low value of C_o for 1% Nickel is a consequence of the large grain size of that nickel, which induces a sharp decrease of the ultimate tensile strength (Fig.2) and a smaller increase of intermediate crack propagation rates (Fig.4). At lower rates, as the plastic zone size becomes smaller than the grain size, the cristallographic dependence of slip bands leads to a threshold behavior : crack can be easily stopped by uncorrectly oriented grains or annealing twins (Fig.8).

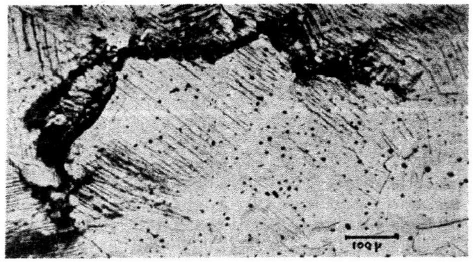


Fig.8. : 1% Ni. 10^{-5} mm/cycle
near threshold behavior

CONCLUSION

The porosity does not change the exponent of the fatigue crack propagation law whereas it increases considerably the crack velocity for a given Δ K.

This can be explained almost entirely by the reduction of the load bearing section by the porosity.

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