FATIGUE LIMIT OF NODULAR CAST IRON CONTAINING CASTING DEFECTS

Y. Nadot* J. Mendez* N. Ranganathan* and A.S. Béranger**

In the present study, the high cycle fatigue behaviour of a nodular cast iron has been investigated. The influence of casting defects has been analysed by considering two different types of defects : surface and internal microshrinkages. It has been shown that the fatigue limit is strongly dependent on defect size and position. Long fatigue crack propagation thresholds, experimentally determined in air and in high vacuum, were used to evaluate the fatigue limit associated with surface or internal defects considered as pre-existant cracks. This approach appears to be not relevant even for large defects. This tends to support that casting defects cannot be identified as cracks and that the initiation period cannot be neglected.

INTRODUCTION

Nodular cast iron is a useful material for automotive components : mechanical properties are similar to steels and castability is better. It is therefore used for many components as crankshafts or supension arms. Casting process introduces microstructural heterogeneities which can be located at the surface of the castings or distributed within the bulk. It is well known that defects have a strong influence on fatigue strength (1). Therefore, a great interest is given account for these defects for the estimation of the upper loading conditions permitted to ensure in service security requirements. The most commun method to evaluate the fatigue limit of a material containing defects is to assimilate the defect as a pre-existant crack. However, it is not very clear from the experimental published data if this approach could be relevant. Different questions arise which are very similar to those encountered for small natural cracks about the accuracy of the calculation of the stress intensity factor or the applicability of the threshold value established for long cracks to the behaviour of rather small defects. Morever, the role of internal defects are poorly documented in particular with respect to difference in the environnement damage interaction depending on the location of the defect initiating the fatal crack.

*Laboratoire de Mécanique et de Physique des Matériaux - UMR CNRS n°6617
ENSMA, Téléport 2, BP 109, 86960 FUTUROSCOPE cedex, France
**RENAULT, Service 60 503, API : CTR B12 0 10
67, rue des bons raisins, 92 500 Rueil Malmaison, France

This paper is focussed on the following points :
- Experimental evolution of the fatigue limit with defect size for surface and internal defects. Fatigue mechanisms above endurance limit are discussed.
- Endurance limit calculation using effective threshold concept in air for surface defects and in vacuum for internal defects.

MATERIAL AND EXPERIMENTAL DETAILS

RENAULT has provided nodular cast iron used in the present study. The matrix fully ferritic is obtained as cast without any heat treatment. The volume fraction of nodules is 10% with a mean size of 15 µm and a ferrite grain size of 50 µm. The bulk matrix exhibits a homogeneous distribution of nodules in the ferrite matrix. The purpose of this study is to identify the influence of one type of defect (microshrinkage) on fatigue strength. Thus, samples are taken off the bulk of a casting block ; the only defects present in the fatigue samples are microshrinkages of size varying from 50 to 2200 µm, which can be located at the surface or in the bulk of the sample. Mechanical properties are : E = 180 GPa, $R_{P0.2}$ = 380 MPa and R_m = 510 MPa. Tests are conducted on smooth polished cylindrical samples at 35 Hz using a sinusoidal signal in uni-axial tension-tension with a load ratio R = 0.1. In order to determine the evolution of fatigue limit with defect size, the following procedure has been used. A sample is loaded up to 10^7 cycles, if it does not fail, load is increased and the sample is loaded again up to 5 10^6 cycles. This sequence is repeated step by step up to failure. The defect size is measured on the fracture surface after failure. Thus the fatigue limit is established for a size and position of an identified critical defect.

EXPERIMENTAL RESULTS

Fatigue test results

The fatigue limit value determined for surface and internal defects with the step loading procedure described before is reported in figure 3 versus the parameter $\sqrt{area}$. All samples were observed after failure. Defect location was noted and it's size measured and converted into the $\sqrt{area}$ defect parameter proposed by Murakami (1). Typical example of surface and internal critical microshrinkages are presented on figure 1 and 2. It can be noted that microshrinkages located at the surface of the specimen have been obtained by machining samples from the bulk of the casting block. Results are clearly dependent on defect position : for the same fatigue limit (σ_{max} = 300 MPa), the corresponding surface defect is 250 µm while the internal defect is six times bigger. For big surface defects, extrapolation of fatigue limit curve shows that for a defect of 1000 µm, surface defects give rise to fatigue limit of 220 MPa while fatigue limit for internal defect of the same size is 330 MPa. Results are also highly dependant on defect size since fatigue limit vary from 350 MPa for a 100 µm surface defect to 220 MPa for a 1000 µm surface defect. The evolution is similar for internal defects. As shown on the curve corresponding to surface defects, it is assumed that the defect size has no influence on fatigue limit for a size smaller than 100 µm.

Fatigue threshold

In order to calculate fatigue limit for surface and internal defects using the threshold concept, threshold stress intensity factor has been experimentally determined. A study has been conducted to determine the long fatigue crack threshold both in air and in vacuum with crack closure measurements for different loading conditions. Principal results are shown on figure 4 but further details about this study are presented in ref. (2) and (3). Effective threshold has been taken off from this analysis and results are :

$$\Delta K_{th\ air} = 3.75\ MPa\sqrt{m}$$
$$\Delta K_{th\ vacuum} = 6.5\ MPa\sqrt{m}$$

FATIGUE LIMIT CALCULATION

In order to calculate the endurance limit using the threshold value, the following formula have been used for both internal and surface defects :

$$\Delta K_{th} = \Delta\sigma_D \sqrt{\pi\sqrt{area}} \qquad (1)$$

No shape factor is used because Murakami (1) shown that Kmax is not dependant on crack shape when using the $\sqrt{area}$ parameter. The calculation which considers the defect as a fatigue crack gives a poor agreement with experimental results (see figure 5). In the case of very small defects (less than 100 µm), this is not surprising because similitude conditions (mechanical and metallurgical) do not exist : Linear Elastic Fracture Mechanic (LEFM) is not applicable for very small cracks (4). Nevertheless, agreement is not obtained for large defects even if LEFM concept can be applied in this case. In air, calculation seems to be valid for defects between 100 and 300 µm. For bigger defects, experimental fatigue limit is higher than calculated with long crack threshold value for both internal and surface defects. This tends to show that we cannot consider the defect as being equivalent to a crack : initiation stage of the crack around the defect has to be taken into account. For example, non-propagating cracks were observed on a sample cycled just below the fatigue limit up to 10^7 cycles and broken at higher stress level in vacuum. The difference of fracture mechanisms in air and in vacuum acts as a crack front marker permitting to determine the damage created in air below the fatigue limit (5). Even if the non-propagating crack is long on the surface of the sample, cracked area around the defect in the bulk is very small (see fig. 6). It seems therefore difficult to consider the defect equivalent to a crack.
This study brings out that the threshold concept does not seems to be relevant to describe experimental evolution of fatigue limit with defect size for surface and internal microshrinkages. A period to initiate a crack totally surrounding the defect has to be considered, and especially for large defects.

CONCLUSION

The evolution of fatigue limit with defect size has been experimentally established for surface and internal defects. Effective threshold for long cracks in nodular cast iron has been determined in air and in vacuum and this concept has been used to calculate fatigue limit. Results shows that even if surface damage observations show the existence of non-propagating cracks below the fatigue limit, threshold concept is not relevant in air and in vacuum to estimate fatigue limit. It is therefore impossible to consider microshrinkages as being equivalent to cracks to determine fatigue limit in nodular cast iron. A period to initiate a crack around the defect has to be considered to assess fatigue strength for such a material.

ACKNOWLEDGEMENTS

The financial and technical support of RENAULT is gratefully acknowledged.

SYMBOLS USED

E	Young modulus
R	Stress ration ($R = \sigma_{min}/\sigma_{max}$)
R_m	Tensile strength
$R_{p0.2}$	Conventional yield strength
ΔK_{th}	Threshold stress intensity factor range
σ_{min}	Minimum stress level in the fatigue cycle
σ_{max}	Maximum stress level in the fatigue cycle
$\sqrt{area}$	Defect size parameter proposed by Murakami (1)

REFERENCES

(1) Murakami Y. and Endo M., 'The $\sqrt{area}$ parameter model for small defects and non-metallic inclusions in fatigue strength : experimental evidences and applications', Theoretical concepts and numerical analysis of fatigue, Blom A.F. and Beevers C. J. editors, 1992, p. 51-71.

(2) Nadot Y., Ranganathan N., Mendez J. and Béranger A.S., 'fatigue crack propagation in Spheroidal Graphite castr Iron (SGI)', Proceedings of the conference : 'fatigue 96', G. Ludgering and Novak editors, vol.3, P.331.

(3) Nadot Y., Mendez J., Ranganathan N. and Béranger A.S., 'fatigue damage in Spheroidal Graphite castr iron (SGI)', Proceedings of the conference : 'ECF 11', J. Petit editor, vol.1, P.1155.

(4) Kitagawa H. and Takahashi S., 'Applicability of fracture mechanics to very small cracks or the cracks in the early stage', Int. Conf. on Mech. Behav. of Materials (ICM-II), Boston, 1976, 627-631.

(5) Nadot Y., Ranganathan N., Mendez J. and Béranger A.S., 'A study of natural cracks initiated on casting defects by crack front marking', Scripta Materialia 37 (5), 1997, 549-553.

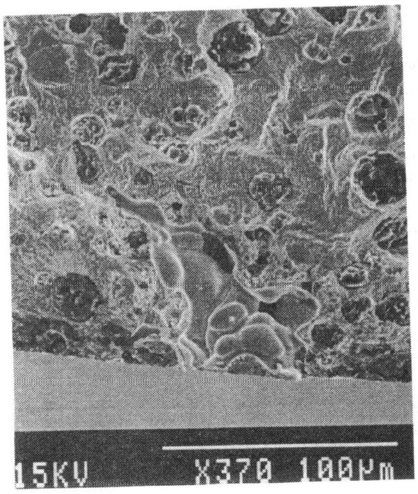

Fig. 1 : Microshrinkage located at the surface of the sample.

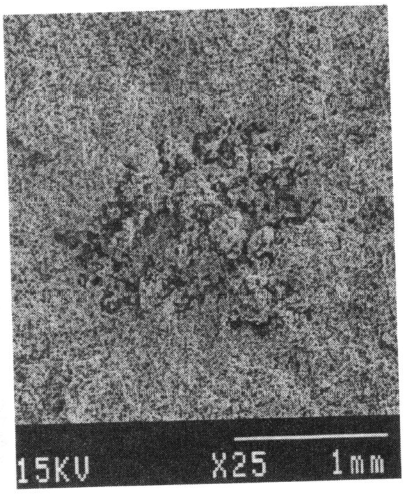

Fig. 2 : Microshrinkage located in the bulk of the sample.

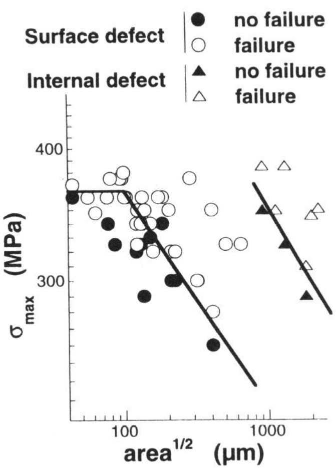

Fig. 3 : Fatigue limit evolution with defect size for surface and internal defects.

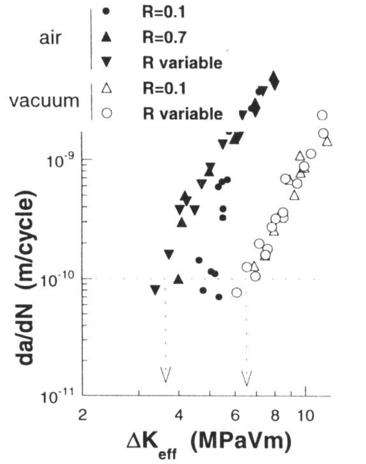

Fig. 4 : Effective long crack threshold behaviour in air and in vacuum.

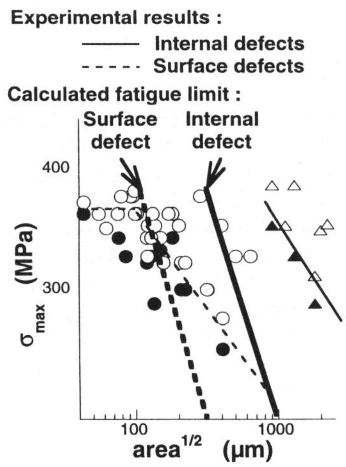

Fig. 5 : Comparison between experimental results and calculated fatigue limit.

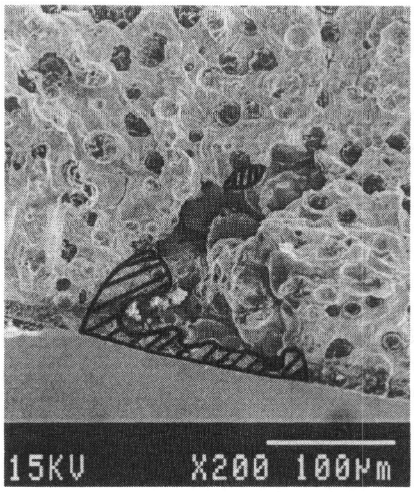

Fig. 6 : Non-propagating cracked area around the defect.