FRACTURE TOUGHNESS TESTING OF A PEARLITE DUCTILE CAST IRON

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ABSTRACT

Fracture toughness tests were conducted on a ductile pearlitic cast iron within the temperature range $[-20,100]$°C. It was found that the pearlitic irons gave K_{IC} values from -20°C until 50°C. Comparisons were made between these thoughness results and unnotched Charpy test values at the same temperature range.Based on electron fractography, mechanisms of crack extension were established. While up to 50°C ductile features are scarce or even non existent at the fracture surfaces, after that temperature dimple lips are surrounding many graphite spheres. For the dynamic Charpy tests only after 80°C some dimples were observed at similar locations.

1 - INTRODUCTION

Fracture mechanics tests on ductile cast irons have been made extensively popular due to two basic factors. First they are essential to predict the defect sizes of many components. Also they would allow a prediction of the design stress as a funcion of the maximum defect size that may escape detection. Secondly, since fracture mechanics results are used as a design criterion in other materials competiting with ductile cast irons, cast steels for example, it seems that this data would be essential for a materials selection procedure.

It has been shown [1] [2] [3] that K_{IC} calculations are too conservative for ferritic cast irons, perhaps with the exception of very heavy sections or very low temperatures (< -150°C). On the other hand K_{IC} data is quite useful as a design criterion for pearlitic cast irons at least at room temperature, as it has been reported in refs. [4] [5].

The main objective of the present paper is to present fracture toughness values obtained in a pearlitic graphite cast iron and to describe the mechanisms of fracture involved on slow and fast bend (Charpy) tests within the temperature interval already mentioned.

2 - EXPERIMENTAL PROCEDURES

2.1 - Material and Tensile Mechanical Properties.

Table 1 provides the chemical composition of the ductile cast iron used

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within this study. Table 2 gives the more important mechanical properties
obtained at room temperature. Low and high temperature yield strength va-
lues used for toughness behaviour were obtained from reports on nodular
irons [6] [7]. All specimens were obtained from commercially produced cast-
ings of a local large production facility. They were obtained from keel -
blocks following ISO 1083 and were tested in an as cast condition. This mate

TABLE 1 - CHEMICAL COMPOSITION

C	Si	Mn	P	S	Cu	Cr	Mo	Sn	Mg
3.0 3.6	3.0.. 3.3	0.4... 0.8	0.03... 0.04	0.03... 0.04	0.2	0.1	0.5	0.2	0.1

TABLE 2 - MECHANICAL PROPERTIES AT ROOM TEMPERATURE

$\sigma_{0.2}$ [MPa]	σ_{UTS} [MPa]	ε_r [%]	HRB Hardness	E [GPa]
400	600	2	100	161,3

rial is practically inside 600-3 class of material considered in ISO 1083.
Microstructure is composed of a pearlitic matrix, where most of the graphite
nodules are surrounded by ferrite rings. That amounts to aproximatly 15% of
ferrite. The diameter of spheroidal graphite is 30 μm with a nodule density
of aproximately 170 nodules per mm^2.

2.2 - Specimens

Fig.-1. depicts the SENB specimens used for fracture toughness testing.

For impact tests unnotched (10x10) Charpy specimens were used. The specimens were sectioned and examined metallographically to characterize microstructural features. Scanning electron microscopy of the fracture surfaces have been performed in all bend and impact specimens.

2.3 - Methods of Testing

Fracture toughness testing was performed in accordance with B.S. Standard 5447. All SENB specimens were fatigue precracked and pulled to fracture on a Universal EMEC Testing System. Charpy tests were performed using a pendulum machine with maximum height of 152.4mm, and a maximum potential energy of 40.6 J. Test temperatures below 20°C were obtained with a mixture of alchool and liquid nitrogen. Temperatures above 20°C were obtained through continuous imersion heating in oil at the desired temperature.

3 - EXPERIMENTAL RESULTS

It is a well documented fact that all ferrous materials other than austenitic
ones show a transition from ductile to brittle failure as the testing tempera
ture is lowered. However this transition temperature depends upon the type of
test and is particularly sensitive to the speed of the test e.g. strain rate.
In order to check this point as far as the pearlitic ductile irons are con-
cerned a program of Charpy tests was set up. Unnotched specimens were used be
cause higher energy values than notched specimens are predicted and hence
greater selectivity is expected.

3.1 - Impact Tests

Fig.-2. depicts the absorved energies in impact Charpy tests as a func
tion of the temperature. A transition temperature based on absorved energy
values of 20 J was evaluated at aproximately 80°C. This value is sufficiently
close to other values found in the literature for this type of ductile cast
irons [8].

3.2 - Fracture toughness results.

The results of the fracture toughness tests at the temeprature range
[-20°C, 90°C] are shown in Table 3. Load-COD curves from fracture toughness
tests were analysed for P_{max} (maximum load sustained) and any pop-in loads.
Crack lenghts were measured for each specimen and values of K_Q at pop-in,K_{max}
at the maximum load and $\beta = 2.5(K_Q/\sigma y)^2$ were computed according to standard
procedures. All but one (90°C) fracture toughness curves presented "pop-in"
points followed by evidence of decreased complicance of the system. At this
temperature the test showed excessive plasticity as evidenced by roundhouse

TABLE 3 - RESULTS OF FRACTURE TOUGHNESS TESTING

T [°C]	K_Q [$MP_a\sqrt{m}$]	K_{max} [$MP_a\sqrt{m}$]	δ_m [mm]	$\beta = 2.5\ (K_Q/\sigma_Y)^2$
-20	18.5	23	1.0E -2	5.3
- 6	23.4	26	1.3E -2	8.6
20	31	34	1.6E -2	14
50	37	43	2.1E -2	20
60	29	30	2.2E -2	-
80	34	36	2.9E -2	-
85	36	44	3.2E -2	-
90	-	31	3.3E -2	-

behaviour of load - COD curves. At temperatures below 90°C, curves showed
"pop-in" steps and at lower temperatures sharp rapid fracture occurs. Valid-
ation of most of these results as K_{IC} values is not a straight forward task
in light of standard procedures such as BS 5447. The basic problem on the
application of these standard rules to cast irons is related to the nonli-
near elastic response of these materials. Therefore separation of elastic
and plastic deformations become more difficult and cannot be fulfilled on si
milar basis as for non homogeneous materials such as steels. Based on cri-
teria which will be discussed later, K values were obtained within the tempe
rature range [-20,50]°C. Fig. 3 depicts these results. Above 50°C there
was evidence of extended plasticity before pop-in points which invalidated
the results as K values. Alternatively crack opening displacements were com-

puted according to BS 5762. Fig. 4 depicts these results, and for comparison this plot includes COD values below 50ºC.

4 - DISCUSSION OF RESULTS

It has been shown that K_{IC} values can be measured at low temperatures for ferritic ductile cast irons [1] [2] [3]. On the contrary for pearlitic irons the situation is less strict. In fact "K" values have been measured at room temperatures [4] [5]. The toughness results which have been presented above showed that we can extend this situation to higher temperature e.g. up to 50ºC. However care must be taken both in validation and use of these results Normally for its validation several points ought to be obeyed. First, one must check that plasticity at the onset of the pop-in is reduced. Plasticity is related to curvature of load-displacement records but this cannot be straightly applied to cast irons. Non linear elasticity behaviour of these materials requires carefull examination when elastic-plastic strain separation is necessary. As specimens elastic compliance is changing throughout the test, one must decide what elastic modulus must be used for the purpose of that separation. Tests made within [50, 100] ºC which included loading and unloading at several points of the load-displacement records showed that no plasticity could be detected before aproximately 70% of first "pop-in" load. Hence tangents at this point were used for elastic-plastic strain separation, and COD computations. Below 50ºC no plasticity is expected to occur until the first "pop-in" appears at the convenient record and therefore no separation is necessary.

The validation test requires that the specimen thickness (B) is such that:

$$B \geq 2.5\ (K_{IC}/\sigma_y)^2$$

This condition insures that plasticity ahead of crack front is limited. Although insufficient thickness B values were found above room tempetature there was no evidence of extended plasticity as seen in fracture surface by electron microscopy below 50ºC (Fig. 5). Then thicker specimens are recommended specially in toughness tests between room temperature and 50ºC.

One interesting feature concerning the plasticity at the fracture surfaces is related to the amount and concentration of dimples at the range under study.

At higher temperature values most dimples were found specially around graphite nodules (Fig. 6 and 7). Hence decohesion between nodule and matrix is clearly seen at the same SEM fractographs.

At the lower temperature range graphite nodule within a cleavage type surface could be found as shown in Fig. 5. A similar situation was found for the Charpy unnotched fractures as seen in figs. (8) and (9).

Finally care must be taken when applying these results to heavier sections. Here microstructure homogenity throughout thickness may vary and this may well exert an effect on K_{IC} values. Test records on representative material is obviously a strong requirement in these practical applications.

5 - CONCLUSIONS

1 - K_{IC} is a suitable parameter to describe toughness behaviour of pearlitic ductile cast irons below room temperature

2 - Between room temperature and 50ºC there is evidence that K_{IC} is still the best parameter to describe the behaviour of this material, although slightly larger specimens ought to be used in order to obtain results for plane strain conditions (B > 2,5 $(K_a/\sigma_y)^2$)

3 - Above 50ºC there is plasticity occurring ahead the crack front. Then K_{IC} is no longer the correct parameter for toughness charaterization. The COD approach can be used but difficulties in partitioning the total strain in its elastic and plastic components imply a previous study of elastic behaviour of the material at the temperature of interest.

4 - The Charpy unnotched impact tests gave higher values of the transition temperature. The fracture mechanics tests indicated a transition temperature of about 50ºC. This represents the temperature at which some plasticity was detected at the fracture surfaces. For the Charpy tests plasticity was detected at higher temperatures ($\simeq$ 80ºC) and the transition temperature, based on a energy level of 20J, was found to be approximately 80ºC.

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REFERENCES

1 - François, D., Wagner, D., Hecht, M. and Chevallier, J., La Mécanique de la rupture appliquée aux fontes à graphite spheroidal ferritiques, 47eme Congrès National de Fonderie, Paris, 13-15 May, 1981

2 - Donaron, A., Laport, R., Poulain, D. and Cloitre, C., Fracture toughness of ferritic spheroidal graphite cast irons, 5th International Conference on Fracture, Cannes, France, 29th March - 3 April, 1981

3 - Holdsworth, S.R., PhD thesis, Saldford University, UK, 1973

4 - Nanstad, R.K., Wonzala, F.J. and Lopes, C.R., Static and Dynamic Toughness of ductile irons, AFS Transactions, Vol. 83, 1975

5 - Holdsworth, S.R. and Jolley, G., the fracture toughness of pearlitic and ferritic spheroidal cast irons, British Foundryman, 67, p. 77, 1964

6 - Laplanche, H., Les fontes et leurs traitements thermiques, Tome 2, PYC Edition, Paris, 1976

7 - ASM - Metals Handbook, Eight Edition, Volume 1, Properties and Selection

8 - Pelleg, J., Influence of silicon on ductile cast iron, AFS Transactions, Vol. 71, 1963

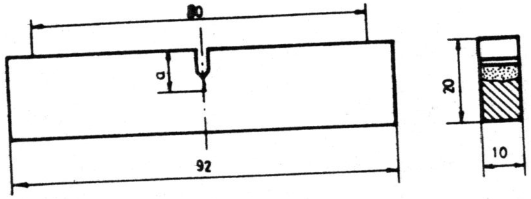

Fig. 1 SENB specimen

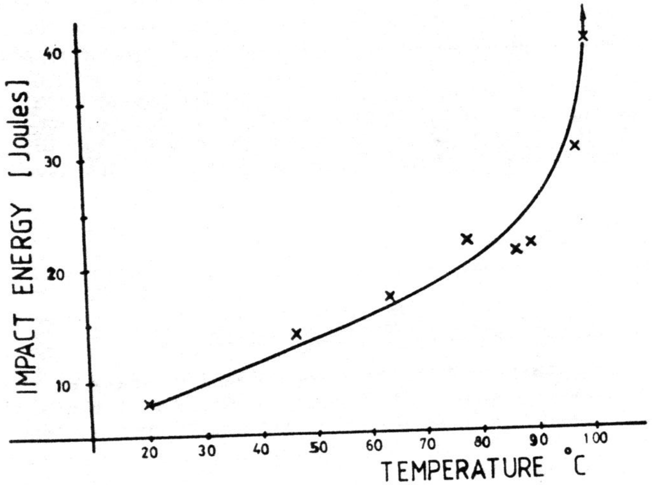

Fig. 2 - Absorved energy in unnotched Charpy tests versus temperature

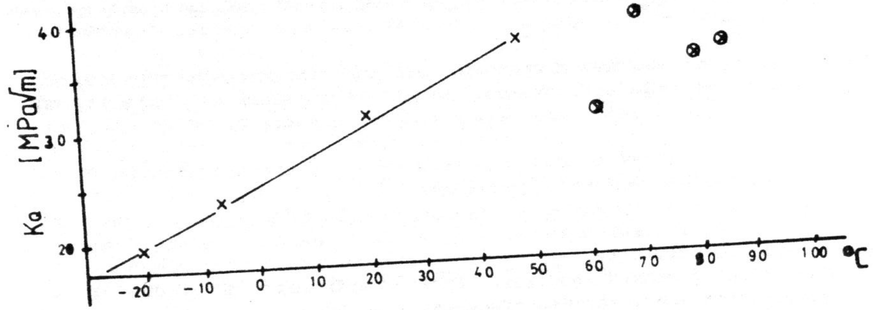

Fig. 3 - K values at the first pop-in

× - Below 50°C K_{IC} values can be assumed.

⊗ - Above 50°C there is extended plasticity. K_{IC} values cannot be assumed.

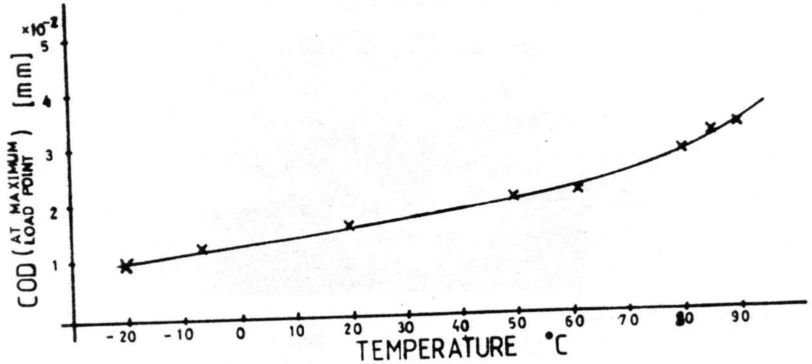

Fig. 4 - COD values at maximum force

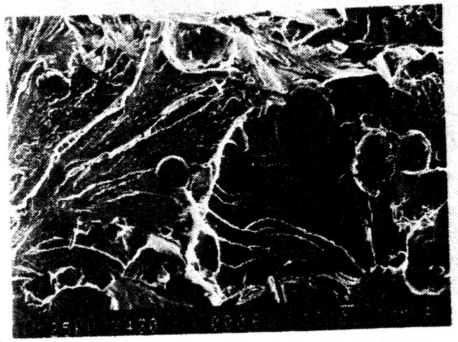

Fig. 5 - SEM fractograph. Specimens tested below 50°C showed this type of fracture. This one was obtained at -19°C

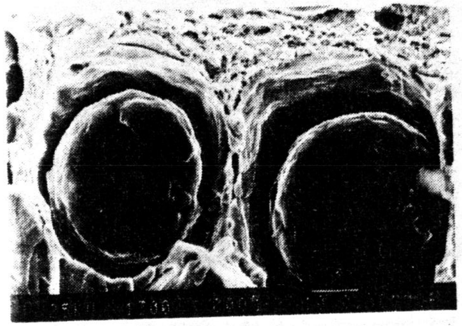

Fig. 6 - SEM fractograph. Specimen tested at 90°C. Note the clear dechoesion nodule-matrix. All specimens tested above 50°C showed this kind of dechoesion

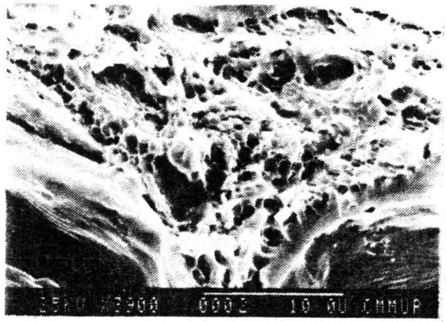

Fig. 7 - Same as Fig. 6, higher magnification, showing the dimple lips apearing ahead the crack front.

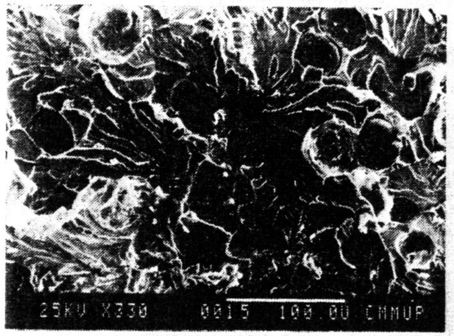

Fig. 8 - Unnotched Charpy fracture surfaces obtained at 47°C. No dimples can be seen.

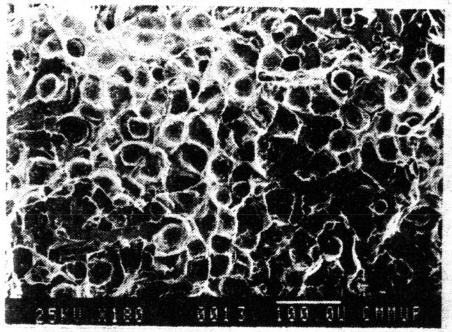

Fig. 9 - Dimples appearing at the fracture surface of an unnotched charpy specimen. Testing temperature 98°C.