PRELIMINARY STUDY OF THE TOUGHNESS DEPENDENCE ON THE HEAT TREATMENT OF A NODULAR CAST IRON

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The use of nodular cast iron in structural components depends to a large extent on its mechanical properties, particularly strength level as well as fracture resistance. This paper presents the results of the fracture toughness of a nodular cast iron type GGG-50, as evaluated by the J_{Ic} parameter, for different pearlite-ferrite ratios. Appropriate heat treatments were applied to alter this ratio and pertinent aspects of the resulting microstructures were defined by an image analysis technique. The toughness values are then discussed in terms of the pearlite-ferrite ratio as well as the corresponding strength and ductility levels.

INTRODUCTION

Ductile cast iron contains graphite in the form of nodules which develop during solidification when alloying elements, such as magnesium, are added to the melt. The as-cast microstructure normally consists of graphite nodules surrounded by ferrite in a matrix of pearlite which may also contain some free cementite.

Nodular cast irons have interesting characteristics from the engineering viewpoint; they exhibit high strength and ductility levels and hence can be indicated for structural applications with the additional advantage of allowing the parts to be in the as-cast condition (Martinez and Sikora (1)). Accordingly, their use with a good margin of safety against in-service failure requires the prior knowledge of their fracture toughness. Fracture in nodular cast irons occurs predominantly in a ductile mode (Shi et al (2)) by growth and linking of voids initiated at the graphite matrix

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interface. The plastic strain at fracture initiation therefore corresponds to the strain level required for void coalescence to occur and depends strongly on the stress triaxiality ((2), Ritchie et al (3), MacKenzie et al (4) and Hancock and MacKenzie (5)). Ahead of the tip of sharp cracks in thick fracture test pieces, where a highly triaxial stress state prevails, the critical strain for failure initiation is expected to be considerably lower than the uniaxial tensile ductility ((2), (3), (4) and (5)). This reduction in ductility, brought about by stress triaxiality, depends on the graphite content, size distribution of the spherical nodules as well as the microstructural condition of the matrix. A change in the matrix constituents, i.e. ferrite-pearlite ratio, could therefore have an influence on the material's toughness.

The main aim of the present study is to evaluate the toughness of a nodular cast iron by determining the J integral value at fracture initiation J_{Ic}. Appropriate heat treatments were applied to alter the as-cast ferrite-pearlite ratio and the corresponding J_{Ic} values were obtained in accordance with an elasto-plastic fracture mechanics methodology (ASTM (6)). An image analysis technique (Russ (7)) was adopted in order to define pertinent microstructural aspects, which were then related to the toughness levels obtained for the material.

EXPERIMENTAL

A ductile nodular iron type GGG-50 in the as-cast condition (condition A) with an equivalent carbon content of about 4.5% was considered for this study. The material had a yield and ultimate strength of 300 and 500 MPa respectively and its microstructure consisted of a pearlitic matrix with ferrite rings of varying thickness surrounding the graphite nodules. A second microstructural condition (condition B), with an increased pearlite content, was developed by subjecting the as-cast iron to a heat treatment at a temperature of 870°C during 5 hours followed by cooling in air. In order to increase the ferrite content (condition C), a different heat treatment was carried out. This consisted of keeping the material at 900°C for 4 hours and then cooling it down to 680°C, where it was kept for one hour, before cooling in air. The pearlite and ferrite contents of the three different conditions were determined making use of an image analysis technique and a suitable software (7).

Three point bend specimens of 10mm thickness were machined from the materials and fatigue precracking was carried out according to (6). Fracture mechanics tests were performed at room temperature on specimens loaded monotonically up to different levels, according to the resistance curve methodology (6). Fracture resistance was then evaluated by determining the J integral at fracture initiation (6).

RESULTS

Table 1 shows the mechanical properties and fracture resistance for the three different conditions, while the graphite nodules, pearlite and ferrite volume fractions are presented in Table 2.

TABLE 1 - Mechanical properties and fracture resistance for the different conditions.

Condition	σ_Y (MPa)	UTS (MPa)	ε_f (%)	J_{Ic} (kPa.m)
A	300	500	9.6	30.0
B	410	720	7.4	18.0
C	250	380	19.4	42.0

TABLE 2 - Materials' microstructural contents (volume percentages).

Condition	Graphite Nodules (%)	Pearlite (%)	Ferrite(%)
A	11.0	67.4	21.6
B	10.6	87.8	1.6
C	11.3	63.7	25.0

DISCUSSION

As one my expect, an increase in the matrix ferrite content implies in an improvement in the material's toughness. This is borne out by the results reported in Table 1, where, on the one hand, the C microstructural condition is seen to be associated with a toughness level that is 40% higher than that corresponding to the A condition. On the other hand, B condition, which contains a considerably higher pearlite proportion compared to the as-received material, exhibits a correspondingly 40% lower toughness.

Fractographic analysis of the as-received fracture surfaces has revealed the predominance of a typically ductile fracture micromechanism (Fig. 1). However, some cleavage facets, originated at pearlite regions (Ferraz (8)), were seen to be present for the B microstructural condition (Fig. 2), consistent with the toughness values listed in Table 1. For strain controlled fracture, as is the case for ductile failure, the initiation toughness, represented by J_{Ic}, is proportional to the material's plane strain tensile ductility ((3), (4) and (5)). For nodular cast iron, the ductility is expected to decrease as the pearlite content increases. This can be attributed to the pearlite's lower capacity for plastic deformation as compared to that of pure ferrite and to the higher plastic constraint set up on the remaining ferrite as the pearlite content increases. Although no attempt has been made in this work to evaluate the effect of stress state on the ductility, the uniaxial tensile test results (Table 1) give a clear indication of the negative effect of increased pearlite content on the material's capacity for plastic deformation. At this point it is also important to add that cleavage fracture, which accompanies the ductile failure mode in both A and C microstructural conditions, represents an essentially stress controlled fracture mechanism (3). Fracture resistance related to such mechanism is expected to decrease as the strength level increases (Malkin and Tetelman (9)), again in agreement with the toughness and mechanical strength data. The variation of J_{Ic}, σ_Y and UTS with the pearlite percentage is depicted in Fig. 3.

FINAL REMARKS

In summary, it can be stated that an increase in pearlite content results in a reduction in the matrix ductility and this, for strain controlled fracture initiation, is considered to be detrimental to toughness. This increase in pearlite content also leads to higher strength level and fracture initiation occurs in a mixed mode, accompanaid by a deterioration in the toughness level.

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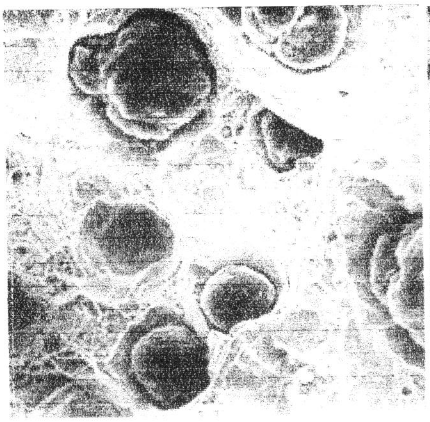

Figure 1 SEM of the as-received cast iron (condition A), 500X

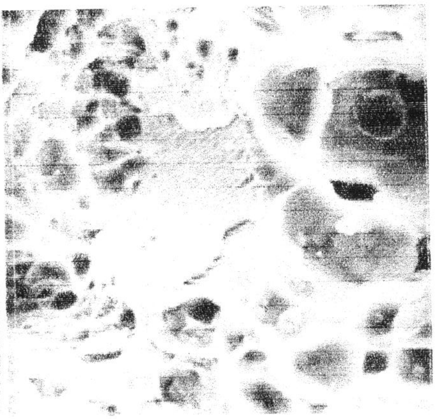

Figure 2 SEM of the material tested in the B microstructural condition, 5000X

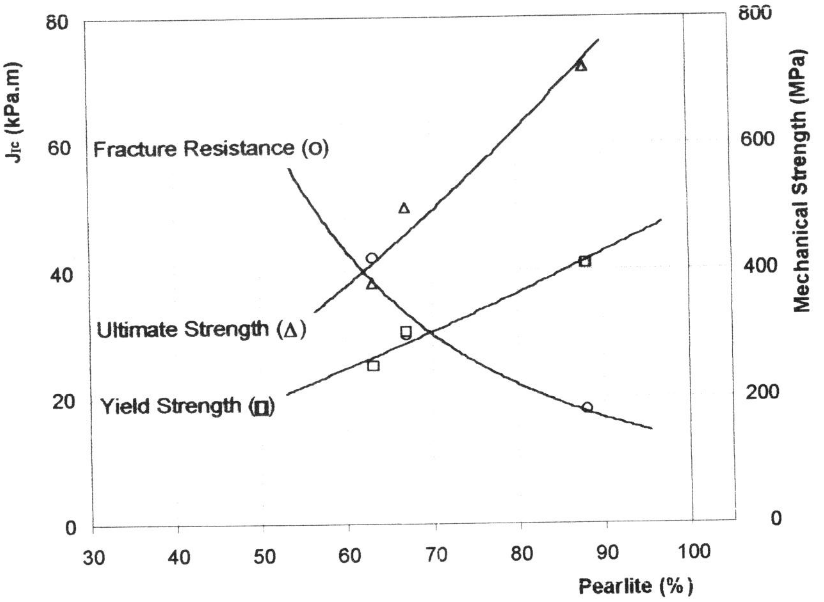

Figure 3 J_{Ic}, σ_Y and UTS as functions of pearlite content