# FRACTURE MORPHOLOGY IN COMPACTED GRAPHITE CAST IRON

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ABSTRACT

Results of an investigation on the fracture morphology of as cast ferritic-pearlitic iron with compacted graphite are presented. Materials were characterized by tensile and impact tests. Generally the crack begins in the compacted graphite particles. The fracture surface of the matrix has mainly a ductile morphology. In the iron inoculated by higher-titanium alloy crack propagation in the matrix occurs more frequently by a brittle cleavage mechanism. In this case brittle particles of TiN were detected in the initiation areas of the cleavage. The graphite and matrix fracture modes appear to be independent of strain rate.

KEYWORDS

As cast compacted graphite cast iron for moulds; fracture.

INTRODUCTION

Compacted graphite iron has been known for many years, but only recently consistent methods have been developed to produce castings of this type of iron on a commercial basis (Campomanes and Goller, 1975; Cooper and Loper, 1978a; Evans, Dawson and Lalich, 1976; Sergeant and Evans, 1978; Stefanescu and coworkers, 1980). Often the compacted graphite (CG) morphology is defined as intermediate between those of gray (flake) (FG) and ductile (spheroidal) (SG) iron. Indeed the CG irons are characterized by a peculiar graphite morphology, consisting of shortened and thickened flakes with rounded ends. Moreover these graphite particles are interconnected within the eutectic cells, and are not separated from one another as the spherulites in nodular iron. The physical and mechanical properties of CG iron are to a large extent related to the morphology and interconnection of the graphite. Thermal conduction, machining and casting characteristics approach those of FG irons, because of the interconnected nature of the graphite.
The rounded ends of the compacted graphite confer a higher strength than FG

irons, with a higher strain at failure and appreciable ductility, but not as much as nodular graphite irons, because the graphite is interconnected.
This is confirmed by the stress strain relation of the CG irons, showing an elastical behaviour over a range of stresses, unlike FG irons, having a curvature on the same relation also from low stress levels. This combination of properties in CG irons, giving significant advantages over both gray and ductile irons, has generated much interest in the potential applications of these materials (Lalich and Lapresta, 1978). The physical and mechanical properties and behaviour of CG irons have been thoroughly investigated.
Rather poor information is available as to the behaviour of compacted graphite particles in the fracture process and their influence in the fracture of irons with different matrix structure (Cooper and Loper, 1978b; Hieber, 1978).
In this paper some results of an investigation on the fracture morphology of as cast ferritic-pearlitic CG irons are presented.

## MATERIALS AND EXPERIMENTAL PROCEDURES

The research has been done on cast iron specimens obtained in the electric furnace, with a composition within the limits indicated in Table 1. In order to obtain the compacted graphite iron, inoculants have been employed having the following composition : Si 53,7%; Ca 0,9%; Mg 4%; Ce 0,4%; Ti 8,8 and 4,7%.
The specimens used to determine the mechanical characteristics have been obtained by square castings having dimensions 200 x 200 mm. For the examination of the microstructure and the morphology of the fracture surfaces the light microscopy, SEM and microprobe have been used.

TABLE 1 Chemical Analysis of Cast Iron

| C | Si | Mn | S | P | res.Mg |
|---|---|---|---|---|---|
| 3.68 | 1.98 | 0.42 | 0.015 | 0.1 | 0.022 |

## RESULTS AND DISCUSSION

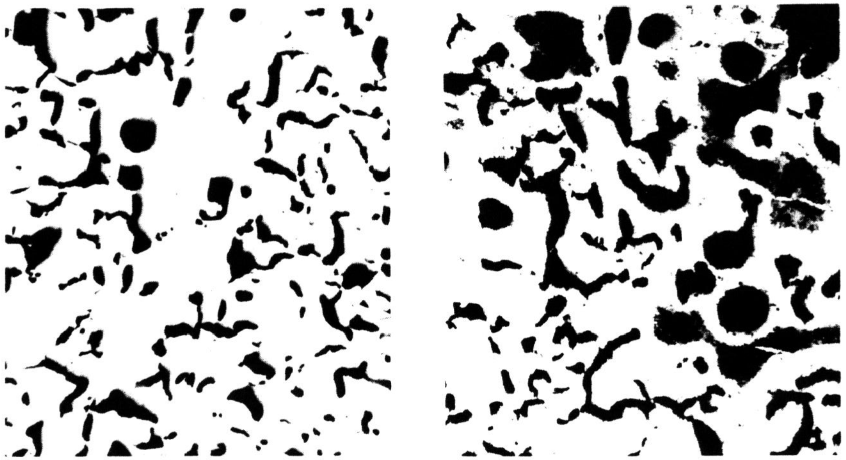
Table 2 shows the results of the mechanical tests : tensile at room temperature, impact strength and modulus. The obtained values fall within the limits which are normally indicated for cast iron with compacted graphite having a ferritic-pearlitic matrix.
The results also point out a quite acceptable homogeneity in the mechanical characteristics of the examined samples.
The small differences are ascribable to the different ferrite/graphite ratio.



TABLE 2 Mechanical Properties (Medium Value of Three Samples).

| SAMPLE | IMPACT TEST $J/cm^2$ | IMPACT MODULUS $J/cm^3$ | PERCENT ELONGATION 1/1 | TENSILE STRENGTH MPa | YIELD STRENGTH MPa | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 |
| 1 | 10.8 | 1.63 | 1.3 | 245 | 200 | 214.6 | 220.5 | 228.3 | 233.2 |
| 2 | 9.8 | 1.53 | 1.8 | 254.8 | 202 | 210.7 | 221.5 | 231.3 | 235.2 |
| 3 | 10.8 | 1.76 | 1.5 | 269.5 | 218.5 | 240 | 250 | 256.8 | 260.7 |

Two examples of the obtained microstructures are reported in the micrographs of Fig. 1. The graphite's morphology was mainly of the compacted type, with presence of shares of spheroidal graphite, whereas the flak graphite was practically absent.



a b

Fig. 1. Representative microstructures of the material tested: a) unetched, b) etched (50x).

As it is evident in Fig. 1, the graphite particles are interconnected, short, thick, contorted and have round boundary edges. The nodules dimension was changeable and their distribution quite casual. The percentage of spheroidal graphite was within 8 and 20% of the total graphite. The matrix was mainly ferri-

tic (pearlite 30%), with presence of minor components such as titanium nitrides and steadite.
Due to the structure's complexity and heterogeneity, also the morphology of the fracture surfaces at room temperature is quite complex(Fig. 2.) From the examination of the fractographies obtained at SEM, it is possible to derive some indications as to the initiation's phenomenology and on the crack's propagation.

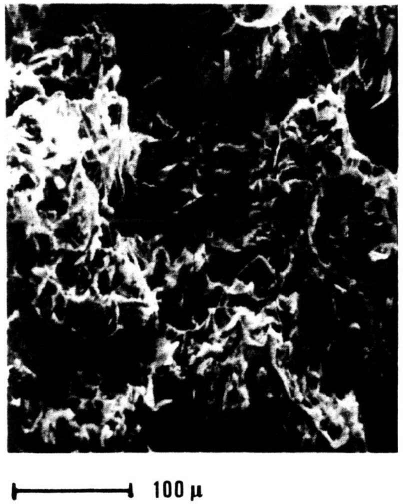



Fig. 2. Fracture surface morphology.


Fig. 3. Fracture surface of a graphite particle.

As far as graphite is concerned, the behaviour of its compacted particles is much more similar to that of flake graphite than to the nodules' one. Still the behaviour of graphite during fracture is not clear, even in the traditional cast iron with flake graphite.
It seems nevertheless certain that the fracture begins inside the graphite, probably in the area next to the graphite-matrix interface (Glover and Pollard, 1971). This is also valid for compacted graphite : as one can see in Fig. 3, the fracture begins in the graphite particle remaining partly adherent to the fracture surfaces, showing up the crystallites forming the particle.
However standing to our observations, it is not possible to make clear whether the beginning of fracture in the graphite occurs in the central part of the particle or in the area close to the graphite-matrix interface.
As to the nodules on the contrary, the cracking at the interface is more evident, as it generally occurs in the nodular cast iron.
The crack spreads from graphite into the metallic matrix which, around the graphite particles, is generally made of ferrite. In both the types of cast iron with compacted graphite examined (obtained by means of alloy at different titanium content) the fracture surface has mainly a ductile morphology, with the typical "cup-and-cone" formations. Zones of brittle fracture by transgranular



cleavage and intergranular decohesion, are also visible (see Figs. 4a and b). On the surfaces with intergranular cracking the presence of phosphorus segregations has been observed. As it can be noticed in Fig. 4a, the cleavage generally develops on different levels, joint by zones with ductile fracture.

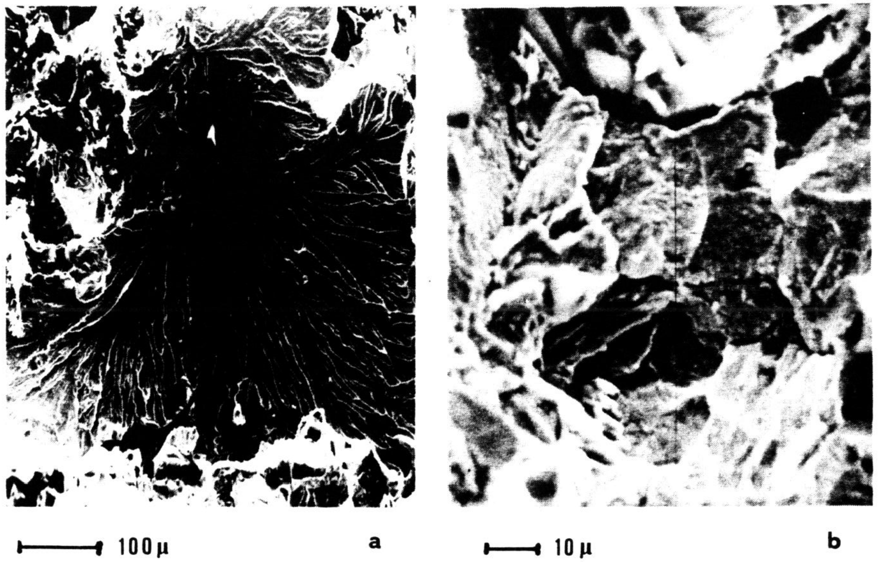



Fig. 4. Brittle fracture zones : a) transgranular cleavage; b) intergranular decohesion.

The cleavage surface is generally smooth, with the typical "delta" shape and well identifiable initiation areas, from which the "river patterns" are issued fan-wise. Other typical and frequent morphologies are the steps between different cleavage levels Fig. 5a, and the so-called tongues Fig. 5b.
As one can notice considering also the previous figures, the most interesting aspect of the cleavage zones is their initiation not seeming to be connected to the graphite particles. In the initiation zone on the contrary small heterogeneus particles are often quite visible. Furthermore, it has been noticed that the cleavage zones are quite more numerous in the cast iron obtained with the inoculating alloy having a higher titanium content. A wide research, carried out by the microprobe on all the examined samples has allowed to enlight and confirm that the particles present in the initiation areas were made of titanium nitrides (and sometimes carbides), whose presence clearly derives from the inoculating alloy employed. A typical example is indicated in Fig. 6a and b, where the cleavage initiation in connection with the presence of heterogeneous inclusion is quite visible, as shown by the titanium distribution map, Fig. 6b, of the same fracture surface.

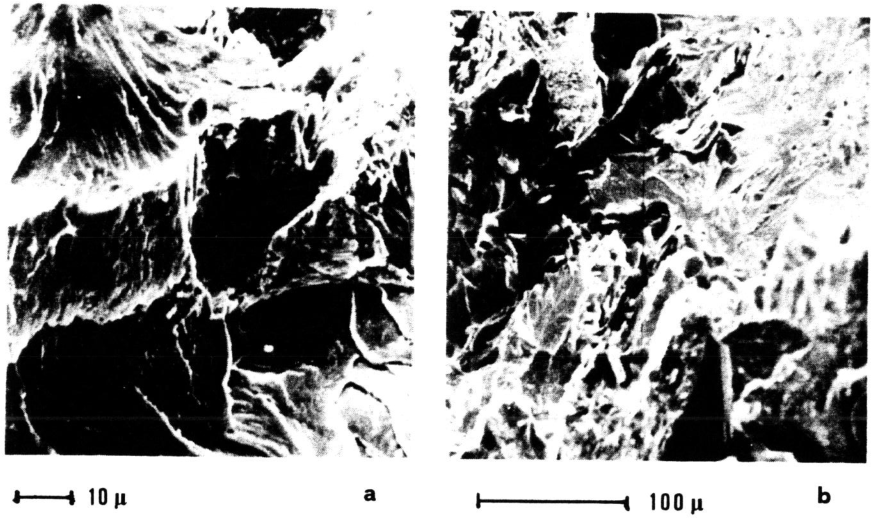



Fig. 5. Typical morphologies of brittle fracture: a) step between different cleavage levels; b) tongues in cleavage areas.

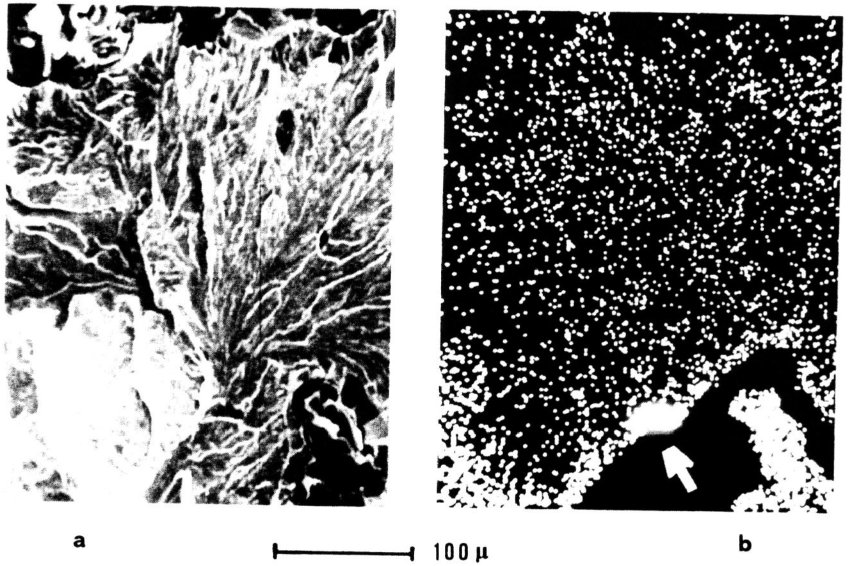



Fig. 6. Typical example on the cleavage initiation area with presence of heterogeneous inclusion: a) cleavage micrographie; b) titanium distribution map.



In the vicinity the presence of a graphite particle is noticed, being surrounded by a narrow ferrite band, encircled by the cleavage surface. This confirms that in many cases, with respect to the cleavage initiation, the effect of the compacted graphite's particles can prove to be secondary if compared with that of other factors as the fracture of small particles of intermetallic compounds is brittler and harder.
This result has a great importance also for what concerns the choice of the criteria of the inoculants suitable for obtaining the compacted graphite.
It is quite known that nitrogen is one of the oligoelements suitable to obtain this type of graphite. But an excessive dose of titanium in the inoculating alloy leads to the formation of nitrides, the fracture of which constitutes initiation zones of brittle fracture in the matrix, even more important than the particles of the compacted graphite.
On the other hand, this outcome indirectly confirms that the compacted graphite has a minor importance, as initiation zone of the brittle fracture, compared with the traditional flake graphite.
This, together with the fact that interconnected compacted graphite causes local reorientation of the propagating crack resulting in a crack branching, can reduce the possibilities of the continuous extension of the crack. These combined effects can contribute to the improvement of the tensile and, in particular, of the impact strenght of the compacted graphite iron castings.

## CONCLUSIONS

Micrographical investigation of the phenomenological aspects of fracture in compacted graphite cast iron, obtained by recently proposed inoculation procedures, indicates that:

1. at room temperature in ferritic-pearlitic iron with compacted graphite fracture has mainly a ductile morphology;
2. crack initiation is located in the graphite particles;
3. crack propagation in the matrix depends on various factors, the most relevant of which being the matrix structure;
4. brittle fracture appears on the surface as transgranular cleavage and intergranular cracking;
5. brittle particles of TiN are often detected in the initiation zone of the cleavage;
6. the mode of fracture, both in graphite and in the matrix, appears to be independent on the strain rate, the same feature being observed on tensile and impact fracture surfaces.

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