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A preliminary investigation of strength models for degenerate graphite clusters in grey cast iron

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Abstract

Defects morphology primarily affects the mechanical properties of grey cast iron. In large castings, porosity and clusters of degenerate graphite are heterogeneously dispersed into the ferrous matrix and serve as initiation sites for fatigue and fracture processes. Strength and toughness of nodular cast iron compare to many grades of steel but experiments show that nodular cast iron also exhibits some specific effects, different from those typical of steels and due to cast iron microstructural inhomogeneity. In the present communication, we report on a preliminary investigation aimed at correlating the effect of the graphite microstructure to the mechanical properties of the material via a simplified geometrical description of the defects.

Keywords: Grey cast iron; graphite morphology; defects; stress analysis; interacting ellipitcal holes; stress concentration factor.

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1. Introduction

The mechanical properties of ductile cast iron are highly dependent on its microstructure, consisting of a coherent metallic matrix throughout which particles of graphite are dispersed. Matrix microstructure (ferritic, pearlitic, austenitic or intermediate), free graphite morphology (shape, dimension and distributions) and loading conditions affect the ultimate strength and percent elongation at fracture. Hütter et al. (2015) present a review of experimental studies and constitutive models for nodular cast iron, with an overview on different micromechanisms responsible for damage and failure.

Nomenclature

σ_n	nominal tensile stress
σ_{max}	peak stress in the Inglis' solution (single ellipse)
$\sigma_{max,w}$	peak stress in a plate with finite size (single ellipse)
K_I	mode I stress intensity factor
K_{I0}	reference mode I stress intensity factor
FE	finite element
a, b	elliptical semi-axis
w	plate size
r	polar distance
ϑ	polar angle
ψ	ellipse rotation

In the literature, several different approaches have been reported aimed at understanding the role of free graphite under stressing. Prior investigations into the behavior of cast iron under different loading conditions have shown that the graphite either cracks or debonds at the matrix interface (Dong et al. (1997), Rausch et al. (2010), Mottitschka et al. (2012)). A common approach is to consider the graphite particles as voids or cracks embedded in a metal matrix (cf. Brocks et al (1996), Kuna and Sun (1996), Dahlberg (1997), Costa et al (2010)).

In cast iron, like in most part of natural materials, defects and voids come in a mixture of diverse shapes, as shown in Fig. 1a. A possible simplifying assumption is to replace them by elliptical holes of different shapes and aspect ratios whose distribution could be identified from microstructural information, as done in Fig. 1b. The holes' distribution is expected to have a significant effect on fatigue strength, especially when they are close enough so that interaction occurs depending upon the loading conditions.

Different approaches have been applied to study stress concentrations for interacting holes and a fundamental treatise on the subject was compiled by Savin (1961). Mixtures of holes of different shapes, which are typical in real materials, were analyzed by Tsukrov and Kachanov (1994, 1997) by using the Schwarz's alternating procedure described in Section 2 (cf. also Kachanov (1993), Ting et al (1999), Ukadgaonker et al. (1993, 1995), Zhang et al. (2003)). Tsukrov and Kachanov (1994, 1997) focused on the impact of holes' eccentricities and relative dimensions on the interaction effect and they discussed possible microfracturing patterns in mixtures of defects of different sizes and shapes. Interestingly, when discussing whether the highest tensile hoop stress occurs at the boundary of the smaller hole or of the larger one, they found that the answer depends on the shape of the holes. For two collinear circular holes, the highest concentration factor is found at the boundary of the smaller hole; for two collinear cracks, the opposite is true. For the case of two interacting elliptical holes, which can be considered an intermediate case between the previous ones, the pattern is not obvious and the interaction effect depends on the eccentricities of the holes and on the distance between them.

In Section 3, we present some numerical results on the interaction between two elliptical holes in plane elastostatics. The two elliptical holes have the same size and small eccentricity (0.1) but arbitrary orientation and relative positioning (cf. Fig. 3). Focusing on the hole 1 in Fig.3, our primary goal is to identify a region around the hole 1 outside which placing the hole 2 in order to have a small interaction effect on the first hole. We quantify the smallness by requiring an increase of the stress concentration factor due to interaction smaller or equal to 10%. The identification of the region