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EFFECT OF GRAPHITE MORPHOLOGY ON COMPACTED GRAPHITE IRON THERMOMECHANICAL FATIGUE PROPERTIES

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ABSTRACT

Graphite particles, in Compacted Graphite Iron (CGI), behave as internal notches when a component made of this material is mechanically loaded. The effect can be critical because of the severe loading conditions in specific areas of a heavy truck cylinder head such as the Valve Bridge (VB) located on top of the engine cylinder head. The condition in the VB leads to formation of Thermomechanical Fatigue (TMF) cracks, as a consequence of engine startup and shout down repititive cycles. During engine operation, the VB is thermally restricted and retained, developing compressive and tensile loads. In this research, the TMF crack path developed under different uniaxial loading conditions was studied. The material under investigation is CGI with a heterogeneous shape distribution of the graphite particles. It is found that loading regimes do not have influence on the crack initiation neither on secondary crack formation. Instead, the crack initiation is dominated by graphite size, whereas the propagation is governed by graphite distribution. It was also observed that the secondary cracks are controlled by graphite clustering.

Keywords: graphite, microstructure, thermomechanical fatigue.

INTRODUCTION

Research on engine cylinder heads pays special attention to areas such as the VB (COLLIN 2014), because, these are constrained by their surroundings during thermomechanical cycles associated with engine start up and shout down. The thermal load together with mechanical restrictions gives rise to the phenomenon known as TMF (J. Okrajni, 2006). The phenomenon is largely affected by the microstructure of the graphitic cast iron, because the graphite particles behave as internal notches initiating cracks that later propagate. This behavior has been tested and described using TMF setups with a homogeneous CGI microstructure (Ghodrat, 2013). However, the influence of a heterogeneous microstructure under severe loading conditions on crack formation and lifetime has not been investigated.

The aim of this study is to understand the influence of heterogeneity of the CGI microstructure (graphite length and spatial distribution) on TMF crack formation and lifetime, under different TMF loading conditions.

It has been reported that in TMF out-of phase condition, the samples are under compression during heating cycles, and they return to the initial length during cooling cycles (Buni, Raman et al. 2004, Wu, Quan *et al*., 2015; Kalra, 2016). The amount of constraint γ (cf. equation 1) can be defined as the thermal strain (cf. Equation 1) converted into mechanical strain (ε_m), cf. Equation 2. If γ = 1 one speaks of full constraint conditions, whereby the full thermal strain is converted to mechanical strain. The actual constraint levels used in this research are 75%, 100%, and 125% applied to notched specimens in order to speed up the TMF failure.

$$\gamma = -\frac{\varepsilon_m}{\Delta\varepsilon_{th}} \quad (1) \qquad \Delta\varepsilon_{th} = \alpha(\Delta T) \quad (2)$$

RESULTS

Microstructural Characterization

Samples were extracted from the VB area of a truck engine and compared to samples that were extracted from a Y-shape cast shape with identical chemical composition.

Table 1 quantifies the graphite particles in the TMF tested samples as well as the VB areas. The calculated standard deviation in graphite density is an indication for clustering of graphite particles in TMF specimens.

Table 1 - Graphite particles characterization

Graphite characteristic		**TMF (Std dev)**	**VB (Std dev)**
Density [particles/mm2]		290.12 (63.8)	259.08 (7.6)
Compact / Flake	length [µm]	44.67 (39)	40.86 (29)
Nodules	diameter [µm]	19.0 (10)	18.86 (5.8)

Graphite Length Distribution

Figure 1 shows the flake graphite length distribution frequency for TMF Samples, engine VB samples, and two other randomly selected regions containing graphite clusters (cf. Figure 2 A and B) from TMF samples. The comparison between TMF and VB samples indicates that the average graphite length is similar in both samples. Nevertheless, the comparison of TMF and selected regions shows that the percentage of long graphite particles may be significantly increased within certain clusters.

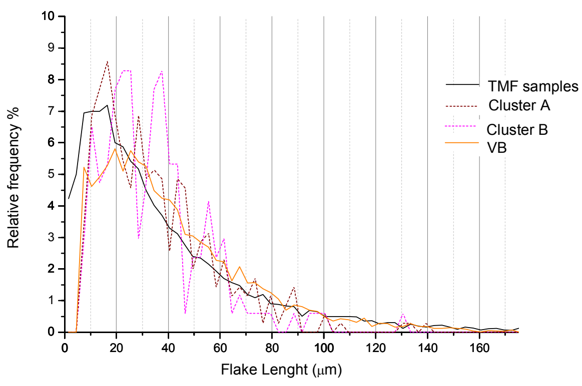

Fig. 1 - Flake graphite length distribution

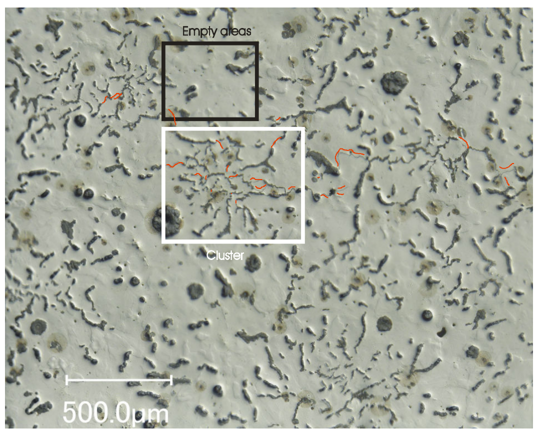

Fig. 2 - Example of CGI with graphite clusters and empty areas

Crack Path Analysis and Crack Branching

Figure 3 presents an overview of the TMF failed samples as function of constraint level and notch size. It was observed that cracks were mainly initiated from notches larger than 0.2 mm. In contrast, cracks did not originate exclusively from the notch in the samples with 0.1 mm notches. In addition, it was observed that the cracks have propagated from one flake particle to the closest (flake) particle and largely avoiding the clusters of nodular particles as well as the graphite-free areas of the matrix. Finally, it was detected that inside the graphite clusters the main crack is locally divided into short cracks or branches (c.f. Figure 2), which grow over a wide range of lengths in all constraint levels, irrespective of the notch size.

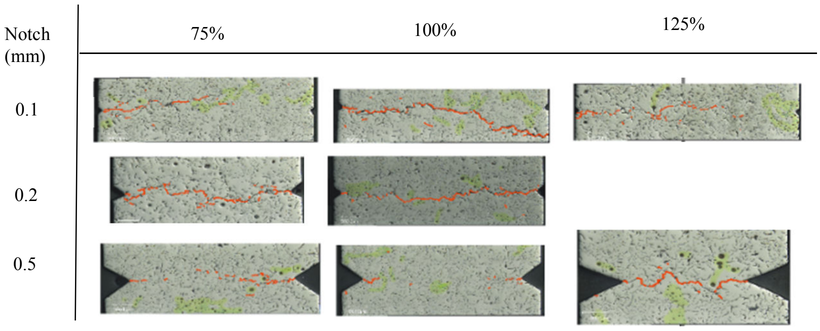

Fig. 3 - Abstract of TMF failures sorted by setup and notch size

CONCLUSION

It was found that crack branching is a phenomenon not related to loading conditions or notching. Instead, it was found that the crack was split in two or more branches only within graphite clusters. Furthermore, it was detected that the crack propagates avoiding graphite-free areas, this show that propagation is governed by graphite distribution. Conversely, the crack in the 0.1 mm notched sample was not limited to the notch area, indicating that the small number of large graphite particles behave as 0.1 mm notches where cracks initiate. Finally, the graphite length comparison of TMF samples with the VB microstructure showed that the average distribution does not capture the graphite clustering; the behavior was only detected when small areas were quantified.

ACKNOWLEDGMENTS

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