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Giga-cycle Fatigue Properties for Spheroidal Graphite Cast Iron

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In this study, Giga-cycle fatigue properties were investigated for spheroidal graphite cast irons of FCD400 and FCD800. Fatigue tests were carried out by ultrasonic fatigue testing at 20 kHz and conventional servo-hydraulic fatigue testing at 30 Hz using specimen with 3 and 6 mm diameters under stress ratio of R = -1. The results of the ultrasonic fatigue testing showed negligible difference from those of conventional fatigue testing. Accordingly, ultrasonic fatigue testing applicable to spheroidal graphite cast iron. Decrease of fatigue strength in the giga-cycle region was in range from 10 to 20%, namely, fatigue limit was not confirmed even up to 1×10^{10} cycles.

Keywords: *Spheroidal Graphite Cast Iron, Giga-cycle fatigue, Micro shrinkage*

1. Introduction

Fatigue properties for spheroidal graphite cast iron were mainly investigated up to 10^7 cycles conventionally. On the other hand, it is known that fatigue limit becomes disappear and internal fracture from inclusions appears in more than 10^7 cycles for high strength materials such as spring steel. This is so-called Giga-cycle fatigue. Although graphite and micro shrinkage of spheroidal graphite cast iron leads similar internal fracture possibly, their giga-cycle fatigue properties were not investigated enough.

In this study, giga-cycle fatigue properties for graphite cast irons of FCD400 and FCD800 were investigated with ultrasonic fatigue testing.

2. Material and experimental procedure

Materials used in this study were spheroidal graphite cast irons FCD400 (3.6C -2.2Si- 0.09Mn -0.031Mg) and FCD800 (3.2C -3.09Si -0.35Mn -0.37Cu -0.036Mg). Tensile strength were 401 MPa and 867 MPa respectively. Microstructure of these materials were shown in figure 1. Base metal were composed by ferrite for FCD400 and perlite for FCD800. FCD800 were normalized and stress relief heat treated before machining fatigue specimen.

To evaluate size effect, two types of fatigue specimen with different risk volume (region subjected to a stress amplitude above the 90 % of the maximum stress) were prepared. One was hourglass type 3 mm diameter and the other was straight type 6 mm diameter specimen. Specimen risk volume were 33 mm^3 and 504 mm^3 respectively.

Fatigue tests were carried out by ultrasonic fatigue testing at 20 kHz and conventional servo-hydraulic fatigue testing at 30 Hz. The specimen were air-cooled to suppress any temperature increase during ultrasonic fatigue testing.

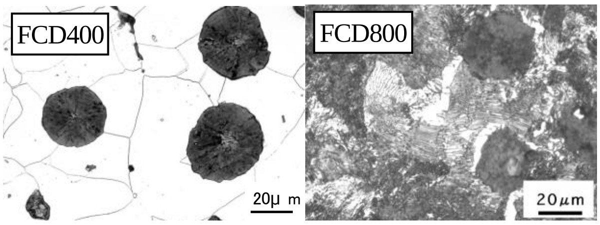


Fig. 1 Microstructures.

3. Results and discussion

Figure 2 shows S-N diagram. The results of the ultrasonic fatigue testing showed negligible difference from those of conventional fatigue testing for FCD400 and FCD800. However specimen were broken even up to 10^8 cycles and obvious fatigue limit was not confirmed. In addition fatigue strength of ϕ6 mm specimen were lower than that of ϕ3 mm specimen related to existence probability of larger defect as described below.

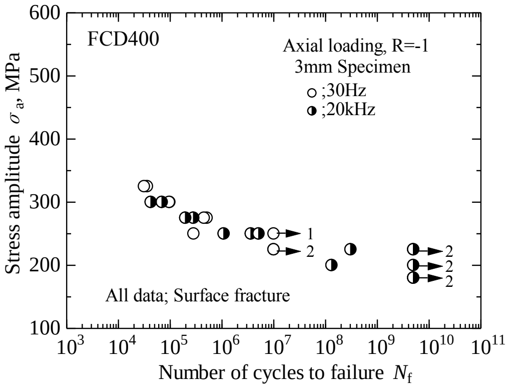
Figure 3 shows typical fracture surface image for crack initiation site. Fracture origins were mainly micro shrinkage at specimen surface, while several internal origin and graphite origin fracture were appeared in FCD800.

Authors pointed out that ultrasonic fatigue testing is applicable for materials which fractured from small defects (e.g. [1]). This report clarified that ultrasonic fatigue testing is applicable for graphite cast iron which also broken from small defect.

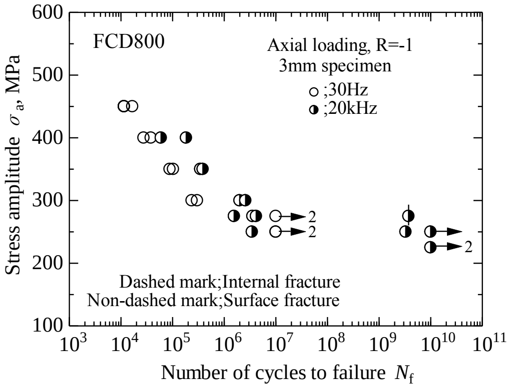
Fig. 4 shows Fatigue limit (10^{10} cycle fatigue strength) versus tensile strength. Although fatigue strength of FCD800 was decreased by micro shrinkage, FCD400 shows fatigue strength as excellent as hot rolled materials which has no defects.

Table 1 shows predicted maximum $\sqrt{area}$ size of micro shrinkage and fatigue limit. Fatigue limit were calculated with $\sqrt{area}$ parameter model proposed by Murakami [2]. Maximum $\sqrt{area}$ size were calculated by Gumbel probability plot evaluation for each risk volume [2] based on micro shrinkage size observed at crack initiation site of fracture surface. Predicted fatigue limit is reasonable for FCD800, while it is too much lower than test results for FCD400. This results indicate that FCD400 has excellent fatigue resistance for small defects.

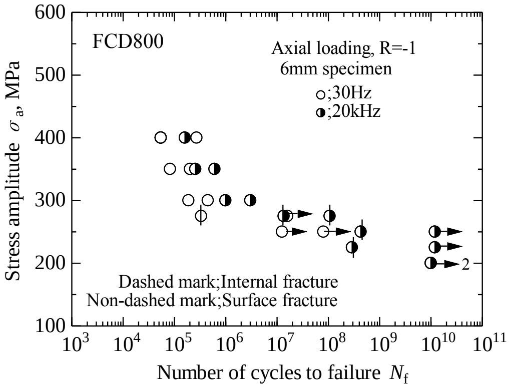
In summary, applicability of ultrasonic fatigue testing for spheroidal graphite cast iron and its giga-cycle fatigue properties which has no fatigue limits were clarified. Furthermore, excellence of fatigue strength of FCD400 were indicated by fatigue limit prediction based on $\sqrt{area}$ parameter model and Gumbel probability plot evaluation.



(a) FCD400, 3mm specimen



(b) FCD800, 3mm specimen



(c) FCD800, 6mm specimen

Fig. 2 S-N diagram.

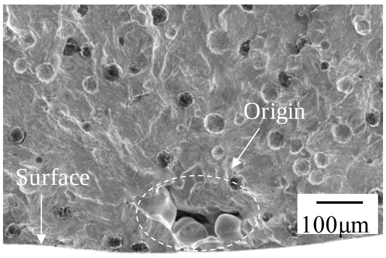


Fig. 3 Typical fracture surface image (FCD800, N_f=1.6×10^5).

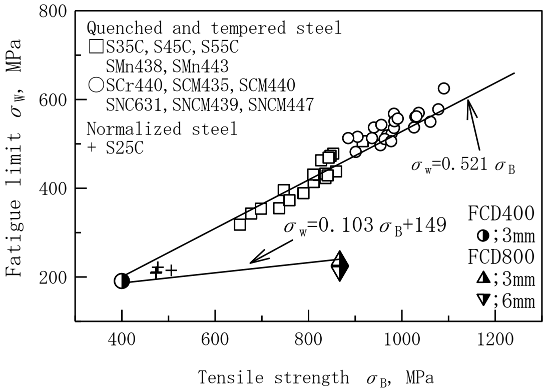


Fig. 4 Fatigue limit versus tensil strength.

Table 1 Predicted maximum $\sqrt{area}$ size of micro shrinkage and fatigue limit.

	Specimen type	Risk volume (mm^3)	Predicted $\sqrt{area}_{\max}$ (μm)	Predicted σ_w (MPa)	[4]Experimental σ_w (MPa)
FCD400	φ3mm	[1]825	214	[2]155	190
FCD800	φ3mm	[1]825	289	[2]217	238
	φ6mm	[1]12600	434	[3]225	213

[1] Equivarent to total risk volume for 25 specimen

[2] Calucrated from surface origin model equation

[3] Calucrated from internal origin model equation

[4] 10^{10} cycle fatigue strength

References

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