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NOTCH STRENGTH OF SPHEROIDAL GRAPHITE CAST IRON UNDER TENSION LOADING

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ABSTRACT

Experiments are carried out in this study to determine the notch strength of spheroidal graphite cast (SGC) iron by using notched specimens with various stress concentration factors. Test results show that only the uniform elongation but no necking occurs when the smooth test specimens of SGC iron fracture. Thus, the SGC iron belongs to the kind of low-ductility materials. Test results also show that the notch strength of SGC iron decreases with increasing stress concentration factor investigated. Analysis shows that the notch strength σ_{tN} of SGC iron can be expressed by following equation: $\sigma_{bN} = 0.64(E\sigma_f\varepsilon_f)^{1/2}/K_t$ The notch sensitivity of SGC iron is quantitatively assessed by the notch sensitivity factor, which value is also given.

KEYWORDS

Spheroidal graphite cast iron, Low-ductility materials, Notch strength, Notch sensitivity.

1. INTRODUCTION

Spheroidal graphite cast (SGC) iron has been widely applied in machine-building industry due to its high strength and certain ductility, excellent casting ability and low price [1-3]. The SGC iron bars with various profiles and dimensions have been produced by using continuous-casting technique, which was developed in China in 1980s. The continuous-casting SGC iron bars have higher strength because of the fine and well-distributed graphite spheroids and less defects. As a result, the SGC iron bars can be used to produce the machine elements subjected to heavy loads. In addition, the cost of SGC iron elements can be reduced when the continuous-casting SGC iron bars are used. The reason is that the utilizing efficiency of continuous-casting SGC iron bars is higher and the price is lower than that of steels with the same level of strength. Thus, SGC iron bars have better prospect in engineering applications. Usually, the fetter holes, stages and ditches always exist in machine elements. These geometry discontinuity, which may be referred to as the notch, will induce the stress concentration and change the stress state at the notch tip[4]. Consequently, the strength and the ductility may be decreased. Therefore, it is necessary and important to investigate the effect of stress concentration of notch on the strength, i.e., the notch strength and notch sensitivity of SGC iron. However, the report on the notch strength of SGC iron has not been found in open literature, to authors' best knowledge. In the present study, experiments are carried out to determine the notch strength and the notch sensitivity of SGC iron produced by continuous-casting technology, and the test results are analyzed by using the formula for notch strength developed by one of the authors[5].

2. EXPERIMENTAL PROCEDURE

The continuous-casting SGC iron bars of 38 mm diameter produced by Xi'an Huayu Cast Iron Factory are taken as the test materials. The composition of bars tested is as follows (wt%): 3.22% C, 2.88% Si, 1.31% Mn, 0.04% P, 0.02% S, and balance Fe. The SGC iron bars were normalized in stairway, firstly heated to 960℃ and holding for 4 hours, then cooled in furnace to 800℃ and holding for 1.5 hours, and finally cooled to room temperature. After normalizing, the bars were longitudinally cut into two pieces, and then turned into smooth cylindrical tension specimens. The circuferntial notch were made in the middle of the specimen on the optical grinder, as shown in Fig. 1. The notch depth is 1.0 mm, and the notch radii are 0.22mm, 0.375mm, 0.75mm and 1.02mm, respectively. Correspondingly, the tensile stress concentration factors of the notched specimens, K_t are 4.3, 3.3, 2.8 and 2.1, respectively [6].Tension tests were carried out on a universal testing machine of type WE-30.

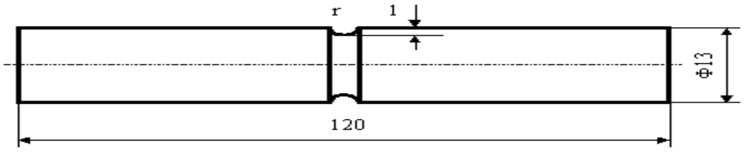

Figure.1: Geometry of the tensile notched specimen

3. TEST RESULTS

3.1 Fractograph

Fig. 2 shows the macrograph of the fracture of the notched and smooth specimen of SGC iron under tension loading. As it may been seen, the fractured surface of both the smooth and the notched specimens are nearly the planes perpendicular to the axis of specimens without any shear tip. The fracture surfaces of the notched specimens are located within the notch. However, the fracture surfaces are rough as shown in Fig. 3. On the other hand, only the uniform elongation but no necking was observed after final fracture of the smooth specimens of SGC iron. Therefore, the SGC iron displays the brittle fracture characteristics but has small ductility. Consequently, it may be thought that the SGC iron is one of the low-ductility materials [4].

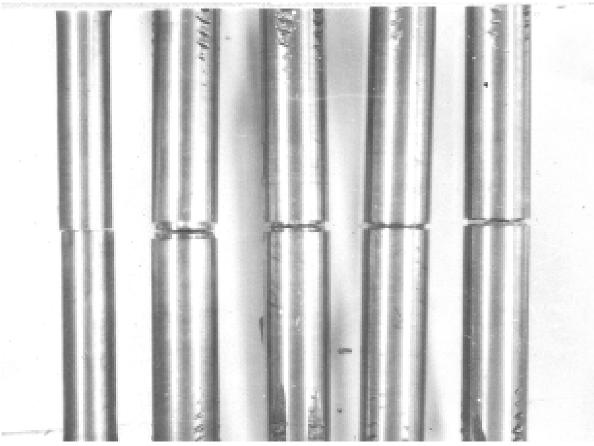

Fig. 2 Topography of notched and smooth specimens

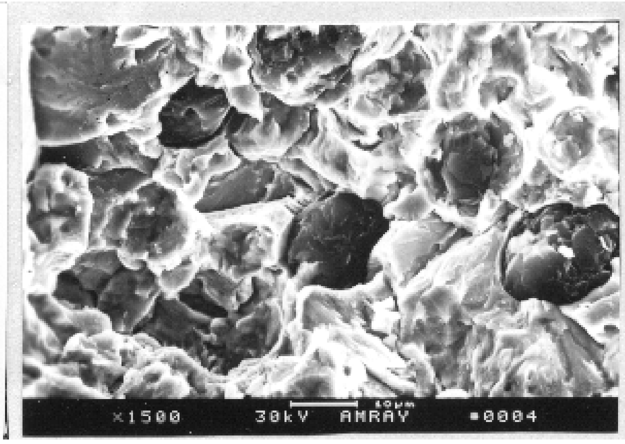

Fig. 3. Fractography of fracture surface of notched specimen under SEM

3.2 Test results of tensile notch strength

According to fracture characteristics of notched and smooth specimens, the notch strength (σ_{bN}) can be calculated by following expression:

$$\sigma_{bN}=P_f/0.25\,\pi\,d^2 \tag{1}$$

where, P_f is the load of fracture, d is respectively, the minimum diameter of notch root for notched specimens, and the diameter of smooth specimen in gauge length. Test results of notch strength were listed in Table 1. It can be seen from Table 1 that the tensile notch strength of SGC iron decreases with increasing stress concentration factor (K_t).

4. BRIEF DISCUSSIONS

4.1 On the expression for notch strength

Based on the strain analysis of notch root and normal stain fracture criterion, an expression between the tensile notch strength (σ_{bN}) and stress concentrate factor (K_t), was developed as follows[5]:

$$\sigma_{bN}=\alpha(E\sigma_f\varepsilon_f)^{1/2}/K_t \tag{2}$$

where, α is a constant related to the stress state at notch root, α=1 for the stress state and α=0.64 for the plane strain state; E is Young's modules; σ_f and ε_f are, respectively, the fracture strength and fracture ductility of smooth specimens, and may be estimated by ultimate tensile strength (UTS) and percentage elongation (EL) for low-ductility materials such as SGC iron as follows:

$$\sigma_f = \sigma_b(1+EL) \tag{3}$$

$$\varepsilon_f = \ln(1+EL) \tag{4}$$

TABLE 1

TEST RESULTS OF TENSILE NOTCH STRENGTH OF SGC IRON

Radius /mm	K_t	d /mm	σ_{bN} /MPa		
0.22	4.3	13.12	547.3	510.4	569.3
0.375	3.3	13.15	799.2	621.6	732.7
0.75	2.8	13.02	712.5	784.8	799.0
1.02	2.1	13.03	821.6	776.4	870.6
∞(smooth)	1.0	11.90	910.4	931.1	926.7

It was pointed out in Ref.[7] that for low-ductile materials, α can be taken to be 0.64 even for thin sheet tested. Since SGC irons are low-ductile materials. α can be taken 0.64. Thus, the tensile notch strength can be expressed as:

$$\sigma_{bN}=0.64(E\sigma_f\varepsilon_f)^{1/2}/K_t \tag{5}$$

For SGC iron, E = 180 GPa[8]. the value of σ_f for K_t=1.0 in table 1 can be taken as the fracture strength σ_f in equ(3). The value of the elongation was approximately taken to be is 4~6% because it is very difficult to accurately measure the value of elongation of the test specimen with brittle fracture characteristic. Substituting the value EL into equ (4) yields the value of σ_f of SGC iron. Put the above data into equ(5), the expression of tensile notch strength SGC iron can be obtained as follows:

$$\sigma_{bN} = (1666\sim2050)/K_t \tag{6}$$

The predicted lines of notch strength of SGC iron are drawn according to equ(6) and shown in Fig. 4. As it may be seen, the predicted notch strength of SGC iron are in agreement with test results within the range of K_t investigated.

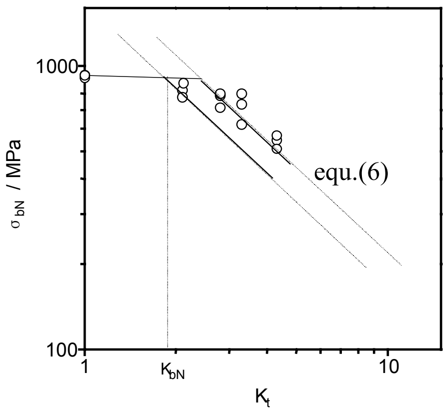

Figure. 4: Predicted line according to equ(6) and test results of notch strength of SGC iron

4.2 On the notch sensitivity of SGC iron

In the early research, the notch strength ratio, NSR, was adopted to evaluate the notch sensitivity of materials. NSR was defined as the value of the ratio of the notch strength to the ultimate strength, i.e., σ_{bN}/σ_b, where the notch strength was determined by using notch specimen with K_t less than 4 [4]. The materials would be notch-brittle, i.e., notch sensitive when NSR< 1.0, while materials would be notch ductile, i.e. notch insensitive when NSR $\geqslant$ 1.0, Obviously, NSR is not a material constant, and can not thus be applied to quantitatively assess the notch sensitivity. This is because it is difficult, even impossible to predict the notch strength and the value of NSR when the profile and thus the value of K_t of notched elements are changed. In ref.[5] a new material constant, i.e., the so-called notch sensitivity factor K_{bN} was defined as follows:

$$K_{bN}=0.64(E\sigma_f\varepsilon_f)^{1/2}/\sigma_b \tag{7}$$

For SGC iron tested,

$$K_{bN}=0.64(E\sigma_f\varepsilon_f)^{1/2}/\sigma_b =(1666\sim2050)/923\approx1.8\sim2.22 \tag{8}$$

In Fig 4 the location and its practical significance of K_{bN} are shown. When K_t of elements is greater than K_{bN}, i.e. $K_t>K_{bN}$, the notch strength is lower than σ_b, and varies according to equ(6), i.e., NSR $<$ 1.0, while the notch strength is equal to or higher than σ_b, i.e. $\sigma_{bN}\geqslant\sigma_b$, NSR$\geqslant$1.0 and equ(6) can not be used to predict the notch strength. Therefore, in the design of mechanical elements, the K_t of the elements should be controlled lower than K_{bN}, i.e. $K_t\leqslant K_{bN}$, and the elements will be safe when the allowable stress of the elements is controlled lower than σ_b. For the SGC iron tested in this study the K_t should be controlled lower than 1.8 theoretically.

4.3 On the dispersion of experimental results

For brittle materials there are high dispersion of the test results of strength and notch strength. So experiments containing big sample size and statistical analyze of the test data are required[9,10]. Test results of the notch strength of low-ductility AL-Li alloy sheets also displayed some dispersion [7]. For SGC iron, the size, the shape and distribution of graphite are varied. It is obvious that strength of SGC iron should have some dispersion. It can be seen from Table 1 and Fig. 6. The test results of strength distributed in a wider scatter band. Therefore, big sample size and statistical analysis of the test results of notch strength should be adopted in further work to provide reasonable basis for the design and reliability assessment of elements of SGC iron.

5. CONCLUSIONS

(1) SGC iron displays the brittle fracture characteristics but has some ductility. It may be thought that SGC iron is low-ductility material.

(2) In the range of K_t investigated the notch strength can be predicted from the tensile properties according to the following equation: $\sigma_{bN}=0.64(E\sigma_f\varepsilon_f)^{1/2}/K_t$ .The theoretically predicted lines agree well with test results.

(3) The theoretically predicted value of notch sensitivity factor (K_{bN}) of SGC iron is about 1.8~2.2, i.e. K_{bN}=1.8~2.2. Therefore K_t should be kept lower than 1.8, i.e. $K_t < 1.8$ in the design of mechanical elements made of SGC iron produced by continuous casting technology.

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