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Short Communication

Prediction of crack depth during quenching test for an ultra high temperature ceramic

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ABSTRACT

Quenching test was used to characterize thermal shock properties of ZrB_2–20%SiC_p–10%AlN. It showed that critical temperature difference was 400 °C, and residual strength was a constant while quenching temperature was higher than 400 °C. Inertial stress was investigated under different temperatures, as shown, a higher temperature led to a lower inertial stress. Crack resistance under room temperature was compared with that under 600 °C, as can be seen, a higher temperature led to a higher crack resistance. Dynamic thermal stress intensity factor was investigated at the quenching temperature of 600 °C, and it indicated that stress intensity factor ascended first and descended afterwards, farther crack propagation would not occur when Biot value is in a certain range, such as Biot = 5. Crack would not propagate when Biot = 1, and specimen would be destroyed when Biot = 10.

1. Introduction

Ultrahigh-temperature ceramics (UHTCs), such as borides and carbides, were developed in the 1960s [1]. Among UHTCs, zirconium diboride (ZrB_2) and hafnium diboride (HfB_2) are materials of particular interest because of their excellent combinations of high melting point, low theoretical density, high electrical conductivity, good chemical inertness and superb wear resistance. These properties make them attractive candidates for high temperature applications such as refractory materials in foundries, electrical devices, nozzles and armour [2]. Moreover, ZrB_2 and HfB_2 could be used for high temperature structural applications in aerospace [3,4]. The addition of SiC dispersoids has been proved to improve the mechanical properties and oxidation resistance of diboride matrix composites [3–9]. And the addition of AlN has been proved to improve the properties of sintering. Chamberlain et al. [4] reported that flexural strength increased from 565 MPa for pure ZrB_2 to 1089 MPa for ZrB_2–30 vol.%SiC. Likewise, fracture toughness ranged from 3.5 to 5.3 MPa $m^{1/2}$ over the same composition range. However, reports on thermal shock investigation, especially considering dynamical thermal stress, are limited in the open literature.

In this work, ZrB_2–20%SiC_p–10%AlN (ZS10A) was fabricated, and the processing parameters were reported elsewhere [10] in detail. Based on the results of quenching test, a model predicting depth of thermal shock crack was proposed.

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2. Material fabrication and experimental procedures

Specimens were cut by linear cutting machine. Room temperature water was selected as quenching medium. Mechanical properties of the material were measured using Instron 5569 under room temperature and using Instron 5500 under high temperature. Flexural strength was tested in three-point flexural test on 3 mm × 4 mm × 36 mm bars, using 30 mm span. Crack resistance of the material was characterized in [10].

3. Experimental results

3.1. Results of quenching test

Residual strength of ZS10A after quenching test is given at Fig. 1a. As shown, critical quench temperature is 400 °C. After 400 °C, residual strength is retained for the material. As can be seen from Fig. 1b, when crack reaches certain depth, it will not continue to propagate, but deflect. This can explain why residual strength remained after quenching test.

3.2. Effect of temperature and strain rate on material strength

Material strength of ZS10A under different strain rate is given in Fig. 2a. As shown, material strength decreases with increasing strain rate. It shows that the measured strengths decrease with an increase of strain rate at relatively lower strain rate, and then it gradually approaches to a constant. As the material is linear elastic, the intrinsic strength should be a constant, regardless of strain rate. The reason for the divergence of the material strengths

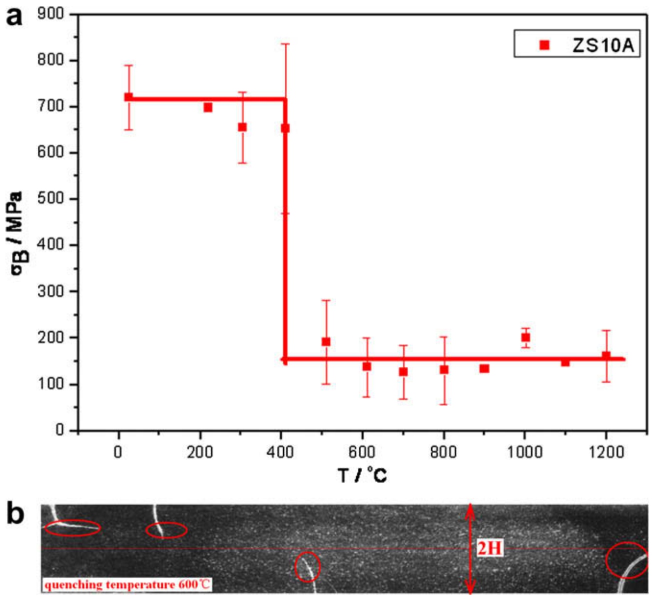

Fig. 1. (a) Residual strength of ZS10A after quenching test and (b) crack propagation during quenching test.

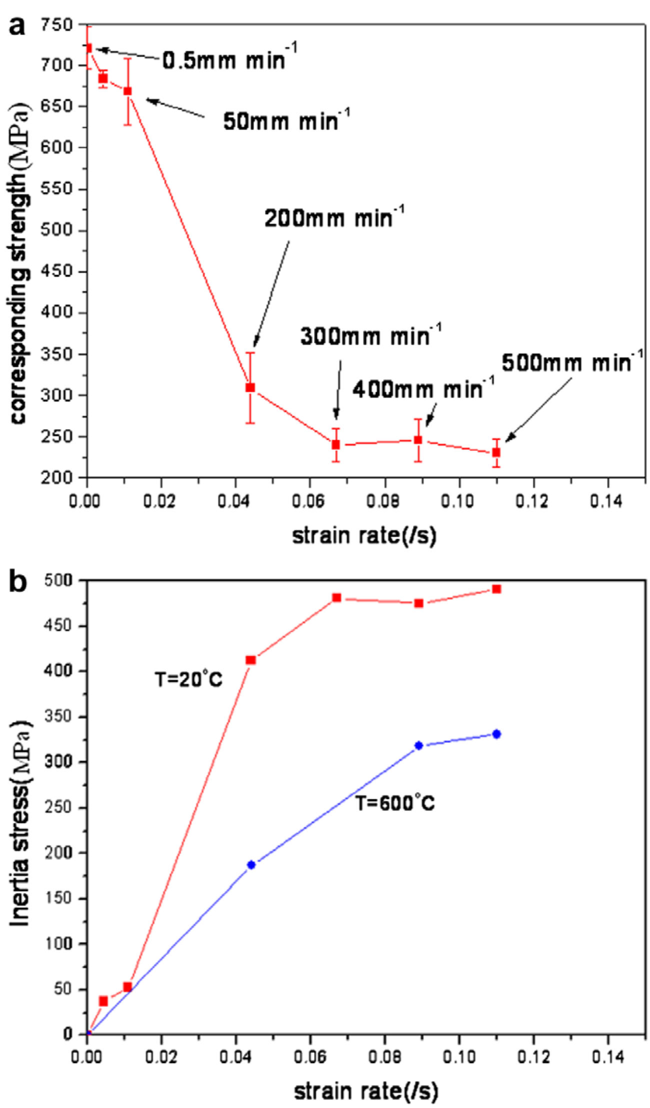

Fig. 2. (a) Effect of strain rate on material strength and (b) effect of temperature on inertial strength.

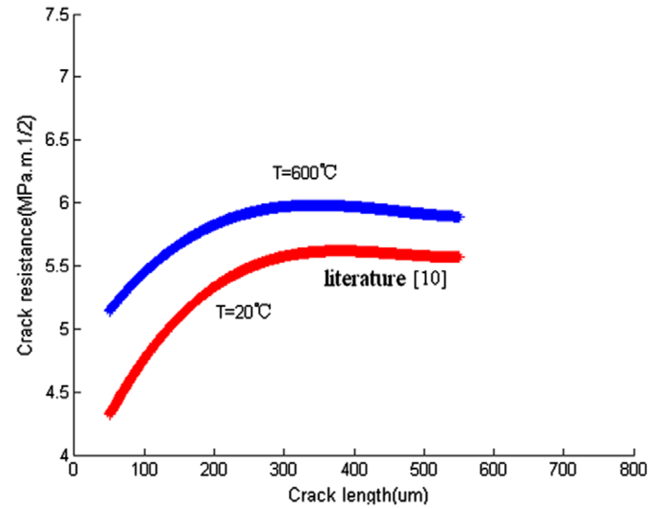

Fig. 3. Crack resistance under different temperatures.

at different strain rates can be explained by the existence of inertial stress [11].

Effect of temperature on inertial strength is given in Fig. 2b. As shown, higher temperature leads to a lower inertial stress.

3.3. Effect of temperature on crack resistance

Effect of temperature on crack resistance is shown in Fig. 3. As can be seen, temperature has a significant effect on crack resistance, and a higher temperature leads to a higher crack resistance. The highest crack resistances are about 5.5 MPa $m^{1/2}$ and 6 MPa $m^{1/2}$ for 20 °C and 600 °C separately.

4. Discussion

Results from Fig. 1a, residual strength tends to a constant while quenching temperature is higher than 400 °C. This can be explained by that quenching crack depth is a constant while quenching temperature is higher than 400 °C. In the following, the quenching crack depth is predicted.

4.1. Model formulation

Physical dimension of specimen is shown in Fig. 4. c is quenching crack depth, and H is half thickness of specimen.

Quasi-static thermal stress during quenching test is given by [12].

$$\bar{\sigma} = \frac{\sigma(z,t)}{E\bar{\alpha}(T_i - T_\infty)} = -2\sum_{n=1}^{\infty} \exp(-\beta_n^2 t') \frac{\sin\beta_n}{\beta_n + \sin\beta_n \cos\beta_n} \times \left\{ \cos\left(\beta_n \frac{z}{H}\right) - \frac{\sin\beta_n}{\beta_n} \right\} \quad (1)$$

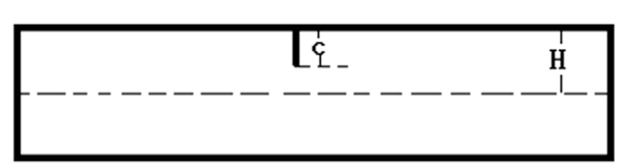

Fig. 4. Physical dimension of specimen.