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Three-point bending test at extremely high temperature enhanced by real-time observation and measurement

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ABSTRACT

We developed a three-point bending test equipment with a heating chamber to provide a high temperature environment. An observation window was intentionally opened in the chamber wall for image capture. A high speed camera is integrated to record the surface evolution of the specimen through the observation window. The fixture stage for the specimens was made of Al_2O_3 ceramic (>99% pure) and could resist extremely high temperature. This testing platform provides the specimens with an environment that is up to 1600 °C in atmosphere for three-point bending test. Experiments were conducted for refractory alloy and C/SiC (carbon fiber reinforced silicon carbide composites) and the surface evolution of these specimens at high temperature was recorded. The crack propagation of the specimens was captured real-time and provided more detailed information for study of fracture behavior of the materials at high temperature.

1. Introduction

Three-point bending test provides the flexural response of the specimens. From the curves of the flexural response the bending elastic modulus, flexural strength and the fracture toughness, which are of great significance for engineering design and application, can be obtained. Three-point bending test has been widely used for mechanical evaluation of materials such as metals and alloys [1] for engine turbines, mostly for ceramics and coatings in aerospace applications [2–5], and even for dental ceramics [6–7]. It should be noted that test results of three-point bending are sensitive to specimen geometry and strain rate. For instance, based on different notch sizes and shapes, three-point bending test could be further divided into Chevron-notched beam (CNB) method [8,9], single-edge-notched beam (SENB) method [4,10–12], etc.

Meanwhile, with the wide application of non-contact image analysis techniques, such as digital image correlation (DIC) method [13–19], it is of great potentiality to improve real-time and on line measurement for image capture so that the image analysis techniques can be adopted to measure the deformation and strain of the materials or components. However, due to the oxidation at high temperature, the features on the surface or the speckles used for conventional DIC method would disappear and cause this method to be invalid at extremely high temperature. Thus, an improved image processing technique based on Maximally Stable Extremal Regions (MSER) method has been proposed for high temperature image detection and analysis [20–23]. Moreover, high temperature environment also brings about non-uniform air disturbance, strong radiation and light saturation. These factors must be taken into consideration in order to capture clear images for calculation and analysis.

There has been some research using three-point bending test above room temperature up to 500 °C [24–26]. However, the temperature range is still in great need to

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be elevated, especially for experiments at temperatures up to 1600 °C or even higher. Moreover, the real-time observation method is also rarely applied for three-point bending test. In this work, we report experiments on refractory alloy and C/SiC by using the proposed three-point bending test equipment at high temperature, since these two categories of materials are being widely applied in aerospace and turbine engineering, where high temperature is a serious concern for the service of such materials. By using the integrated high speed camera, the fracture process of both samples was captured. The real-time crack propagation of the specimens provides more information to analyze the fracture behavior of the materials at high temperature.

2. Experimental setup and measurement principle

2.1. Experimental setup

Fig. 1 schematically shows the proposed setup of the three-point bending test equipment integrated with high speed camera. The whole loading stage is a conventional tensile testing machine. The fixture stage for the specimens is set up in a heating chamber, which is heated by using Si–Mo bar as the heater. On the wall of the chamber, an observation window with a diameter of 12 mm (in order to reduce the heat loss and to avoid causing large uniformity of temperature distribution, the observation window should not be too large) is intentionally opened for the image capture of the specimens by using the high speed camera, which is located outside of the heating chamber on a tripod. For a better image capture effect, the center of the camera lens, the center of the observation window and the specimen should be kept on a same horizontal level.

It should be noted that for traditional fixture stage made of Ni-based alloy or other alloys, it usually goes through serious creep, oxidation and stress relaxation when the temperature exceeds 800 °C or even higher, causing the failure of the fixture stage and obvious data error in the measurement. In order to overcome the challenge of high temperature, Al_2O_3 ceramic with purity higher than 99% is chosen to be the materials for the fixture stage. The Al_2O_3 ceramic has excellent high temperature mechanical property and stability. The oxidation effect of this new stage could be neglected and its linear expansion is also within the range of error tolerance.

The design of the fixture stage is shown below in Fig. 2. It consists of four parts, the under supporting rod, the top pressing rod, two supporting pins and one pressing pin. The two traditional supporting pins were replaced by two supporting bars here in our design with a slot on each of them, as shown in Fig. 2(b). A convex surface is intentionally designed on the slot in the supporting bar to maintain a line contact between the specimen and both of the supporting bars. Compared to the traditional design, this elaborate design provides uniform loading of the specimen and prevents sliding between the specimen and the supporting pins, especially at elevated temperature. The loading pin has a line contact with the middle line on the upper surface of the specimen as well. A long thin ceramic pin made of Al_2O_3 is placed in the hole of the supporting shaft shown in Fig. 2(b) to tip and sense the deflection of the specimen and transmit the information to the displacement sensor, thus the load and deflection curves are recorded to further calculate the mechanical properties. By using this ceramic pin, the thermal tolerance is also increased for the pin when it engages contact with the bottom surface of the specimen during the loading process. The whole system can provide an environment with temperature up to 1600 °C in air.

2.2. Measurement principle

For the image capture at high temperature, the biggest challenge to be faced with is that the heating chamber would inevitably emit strong radiation from the observation window outwards at high temperature, which would strongly affect the image capture of the camera due to the light saturation. However, since the heated air in the chamber is relatively stable (so we can neglect the air disturbance for observation), the main task left is to filter the high temperature radiation, so that clear images of the specimen surface can be obtained. In order to solve this problem, we have proposed a method utilizing a variety of

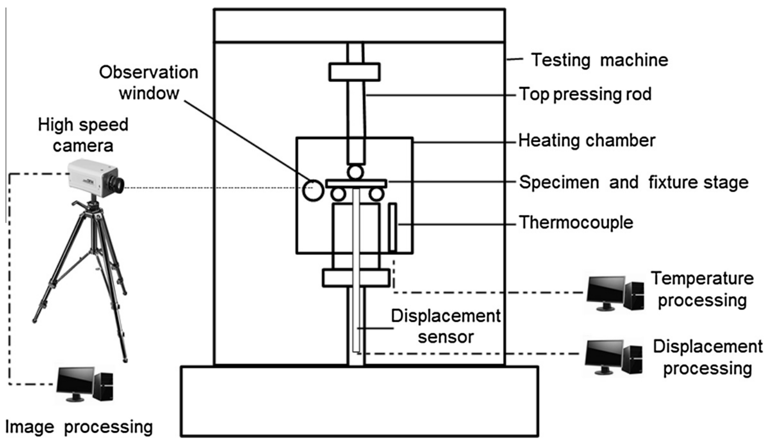

Fig. 1. Schematic of the apparatus for three-point bending test at high temperature integrated with high speed camera.