An experimental method for determination of dynamic mechanical behavior of materials at high temperatures with high speed imaging

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Abstract. An experimental method for measuring dynamic behavior of materials at high temperatures (up to 1600°C) was proposed in this work. The experimental device includes a Split Hopkinson pressure bar with double-synchronically assembled system and an MoSi2 heating source for achieving high temperature. High speed camera was employed to record the image of specimen during testing through a window in the heating furnace. Experiments were conducted on TC4 alloy (strain rate of 2000 1/s) and SiC (strain rate of 200 1/s), at temperatures ranging from 20 to 1600°C. High temperature inorganic glue was used to made high temperature speckle on SiC. The result of high speed imaging was employed to analysis the failure mode of TC4 alloy and SiC at elevated temperature. This opens up new perspectives in the quantitative use of full-field measurements for dynamic test at high temperature.

Introduction

Mechanical properties of materials under the combined effects of high temperatures and high strain rates have been an important and challenging issue for decades. The split Hopkinson pressure bar (SHPB) has been widely used for the determination of the dynamic mechanical properties of materials at high strain rates (100 1/s to 10000 1/s). Knowledge of the dynamic behaviour of materials at various temperatures is crucial to their application. Many researchers[1,2] opted to heat the specimen individually while both the incident and the transmitted bars were kept out of the heating furnace and separated from the specimen during heating. After heating the specimen to the desired experimental temperature, the bars were moved towards the specimen so that the specimen is sandwiched just before the dynamic compression.

Traditionally with this technique, the strain in the specimen during a test is determined from the recorded waves in the incident and transmitter bars using elastic wave theory. Camera based computer vision techniques to measure full-field strains in deformed solids are now widely used throughout the scientific community working on mechanics of materials and structures[3]. The introduction of Digital Image Correlation (DIC) and the availability of digital high speed cameras have provided means for full field measurement of the deformation directly on the specimen during a SHB experiment. Researchers[4] have proposed a method to obtain the images of the sample surface at high temperature and calculated the strain of the sample using DIC method (low speed). However, for very high speed events (Hopkinson bar tests) at high temperature, this area of DIC research is still very much in its infancy. There is strong need for full-field measurements in such dynamic tests at high temperature.

In the present work, combined with a high speed camera, a method equipped with a double-synchronous assembled system was developed to determine the dynamic properties of materials at temperatures up to 1600°C. With the aid of high speed camera, the dynamic process of the deformation at high temperatures can also be captured. High speed imaging for dynamic mechanical testing of materials at high temperature (up to 1200°C) was proposed.

SHPB tests with high speed imaging at high temperature

In order to investigate the dynamic properties of materials at high temperatures, in the present work an improved split Hopkinson pressure bar with a high temperature heating furnace, a double-synchronous assembled system, and a high speed camera was developed, as shown in Fig. 1.

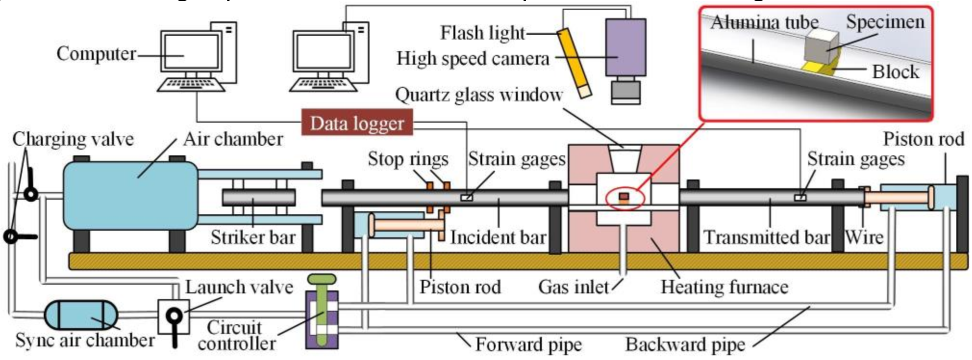

Fig. 1 Schematic illustration of the high temperature split Hopkinson pressure bar with a double-synchronous assembled heating system and a high speed camera.

Two piston rods that could make the bars move forward and back automatically were used to form the double-synchronous assembled system. During the experiment, as soon as the striker bar moves to impact the free end of the incident bar, the incident and transmitted bars are pushed towards the specimen by the push rod of the pistons simultaneously. The protective gas (Argon) could be imported into the furnace through the gas inlet in the furnace to prevent the specimen from oxidation. To enable observation during experiment, the viewing port is equipped with a quartz glass, and the high speed camera was employed to obtain the image of the specimen during the dynamic testing. The maximum temperature of the heating system is up to 1650 C when the viewing port is plugged up with insulation. The specimen was supported by high temperature block, which was made of polycrystalline mullite fibers and can bear high temperature up to 1800 C, and a semi-alumina ceramic tube (see Fig. 1).

Based on the method, we characterized the high strain rate behaviour of TC4 and SiC at high temperatures with high speed camera (frame rate of 0.1~1MHz).

TC4 alloy was compressed at the strain rate of 2000 1/s at experimental temperatures ranging from 20 to 1400°C. The peak flow stress drops from 1.6GPa at room temperature to 150MPa at 1400°C. Almost all materials tend to react with oxygen at high temperatures, which may affect the accuracy of the experiments. To avoid oxidation of the specimen during the preheating process, argon was imported into heating furnace. Fig. 2(a) shows the stress-strain curves and image at 2000s^{-1} and 1100 C in different environments (frame rate of camera is 200,000Hz). The oxide layer on the surface of sample cracked at 40μs and separated from the sample at 100μs under the environment of air. But there is no oxide layer on the surface of sample cracked and separated under the environment of argon. It can be seen that the flow stress under the environment of argon (~361MPa) is higher than that (~332MPa) in air, indicating a negative effect from the oxidation of the specimen during preheating on the experimental results.

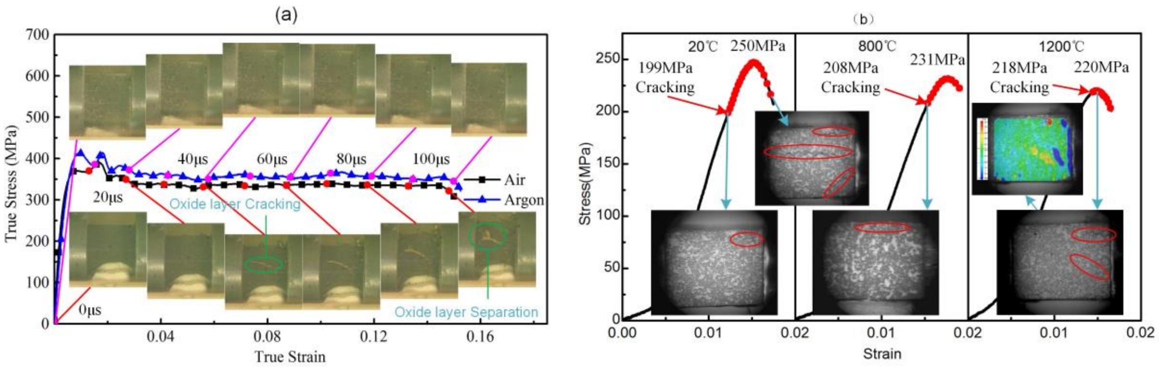

Fig. 2 (a) Stress-strain curves and image at 2000 1/s and 1100 C in different environments; (b) true stress vs. true strain at different temperatures (at the rate of 200 1/s)

SiC was compressed at the strain rate of 200s^{-1} at temperatures ranging from 20 to 1600℃ with high speed camera (frame rate of 1MHz, 924*768).

The compressive strength of SiC decreases monotonously with increasing temperature (250MPa at room temperature, 176MPa at 1600°C), indicating that the SHPB equipped with the double-synchronous assembled system presented in this work is capable of measuring the dynamic material properties at high temperatures (up to 1600°C). In addition, a simple speckle pattern is developed by blending white Alumina powder with a liquid composition of a high temperature inorganic glue (max temperature is 1200°C) on SiC. It should be pointed out that the initial cracks produced at 79% of the compressive strength (199Mpa/250Mpa) at room temperature. But with the increase of temperature, the location where the crack begins to appear is approaching the compressive strength (218Mpa/220Mpa at 1200°C). Fig. 2(b) shows a DIC frame at the max stress of a test at 1200°C. Notice, the deformation is quite uniform throughout the test until the specimen fracture. But, the strain determined by using DiC less than that obtained based on the traditional Hopkinson bar theory.

Conclusion

A new experimental method for measuring the dynamic behaviour of materials with high speed imaging at high temperatures (up to 1600 C) was proposed. To verify the ability of the proposed method to operate at high temperatures, experiments were successfully conducted on TC4 alloy with experimental temperatures ranging from 20 to 1400°C at the strain rate of 2000 1/s, and on SiC at temperatures ranging from 20 to 1600°C at the strain-rate of 200 1/s. The use of DIC in SHPB experiments at high temperature significantly improves the quality of the data that is obtained. This method can be used for studying failure under dynamic conditions at high temperature when the deformation is not uniform before failure.

References

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