A dynamic three-point bending test method at high temperatures

Chao Zhang[1], Tao Suo[1,2,3,a], Kun Jiang[1], Yulong Li[1,2,3]

[1]School of Aeronautics, Northwestern Polytechnical University, China, [2]Joint International Research Laboratory of Impact Dynamics and its Engineering Application, China, [3]Shaanxi Key Laboratory of Impact Dynamics and its Engineering Application, China

[a]suntao@nwpu.edu.cn

Abstract., A dynamic three-point bending test method at high temperatures was developed based on Split Hopkinson bar in this work. The experimental device includes a Split Hopkinson Pressure Bar (SHPB) with double-synchronically assembled system and an $MoSi_2$ heating source for achieving high temperature. Based on the method, we characterized the dynamic bending mechanical properties of 2D C/SiC at high temperatures. The Flexural strength of specimens has an obvious strain rate effect. The Flexural strength of 2D C/SiC increases with increasing temperature, and then drop at temperature above 1400 C, at dynamic test and quasi-static test.

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. Knowledge of the dynamic behavior of materials at various temperatures is crucial to their application. A lot of researchers have paid much attention to the dynamic mechanical behavior of materials at high temperatures using SHPB since 1960's. Researchers proposed that it was practical to heat the specimen and a small portion of the pressure bar adjacent to the specimen. However, a temperature gradient would be established in the two elastic bars since the far ends of the bars are still at room temperature.

Many researchers 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[1,2]. 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. However, this dynamic process should be finished within an extremely short time. But, the experimental method for dynamic three-point bending at high temperature is lacking.

Thermal structural materials such as ceramics, ceramic matrix composites and super alloys have been widely used in structures of hypersonic vehicles and aero engines which usually bear extremely 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 bending properties of materials at temperatures up to 1600 C. Based on the method, we characterized the dynamic bending mechanical properties of 2D C/SiC at high temperatures.

Experimental Procedure

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

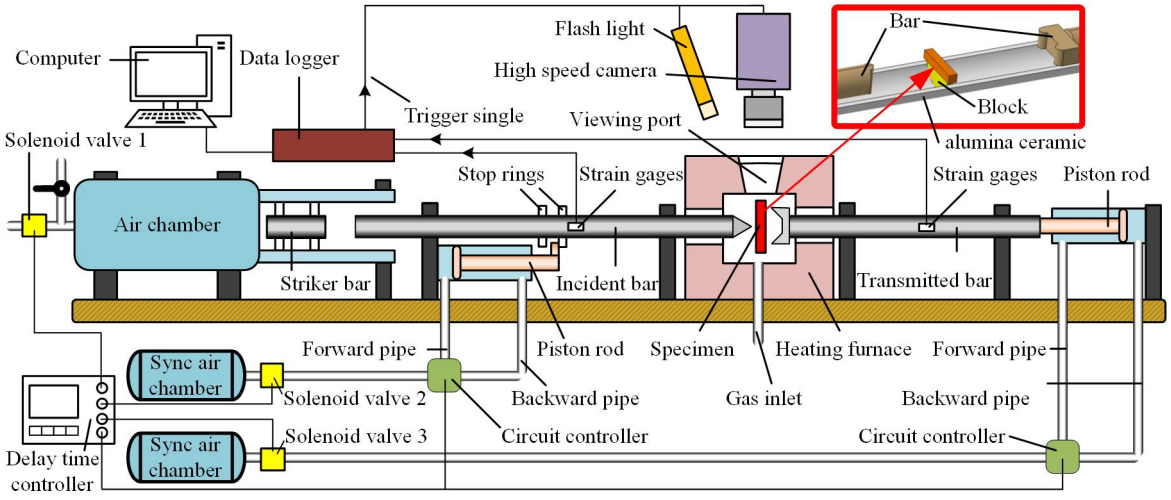

Fig. 1. Schematic illustration of the high temperature split Hopkinson pressure bar with a double-synchronous assembled heating system and a high-speed camera.

In the set-up, two pistons that could make the bars move forward and back automatically were employed to bring both the incident and the transmitted bar into contact with specimen simultaneously[3]. To shorten the cold contact time and to avoid permanent deformation in the specimen with the assembly, the delay time

controller was used to control the air chamber and the sync air chamber simultaneously, enabling activation of the two piston rods and firing the striker bar at the right time. 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. As soon as the specimen is loaded, pressured air flowing into the sync air chamber via the backward pipes activates the push rods of the pistons backwards and brings the incident and the transmitted bars away from the heat furnace, avoiding heating of the loading bars. During the experiment, in case the incident Stress pulse arrives before the contact between the loading bars and the specimen, it will reflect into the incident bar without loading the specimen. On the other hand, if the incident Stress pulse fails to reach the specimen shortly after the contact between the loading bars and the specimen, longer cold contact time and larger temperature difference between the specimen and the loading bars may lead to marked thermal dispersion and temperature drop within the specimen.
The amount of time after the loading bars come to close contact with the specimen but before the incident pulse arrives at the bar-specimen interface is referred to as the cold contact time (CCT). During the CCT, the heat can conduct away from the high temperature specimen into the cold loading bars, leading to temperature reduction in the specimen. Therefore, the CCT should be minimized. In the developed method, the CCT can be controlled within 10ms through adjusting the delay time controller by using the double-synchronous assembled system developed in this work.

Dynamic experimental results

The compressive loading direction was along with the thickness direction of the 2D C/SiC plate. In the dynamic experiment, in order to validate the equilibration force state, a copper pulse shaper was used to ensure force equilibrium and constant loading speed[4]. The development of the force equilibrium coefficient in the test is given in Fig. 2(a). During quasi-static experiments, the loading speeds were controlled at 0.002mm/s. The flexural behavior of 2D C/SiC composites under different loading rate was compared. Fig. 2(b) shows the typical force-displacement curves of 2D C/SiC composites under out-plane bending loading at load speeds of 0.002mm/s and 2000mm/s. 2D C/SiC composites exhibit apparent non-linear behaviour. Both cures can be roughly divided into four deformation phases according to the variation of curve slope[5].

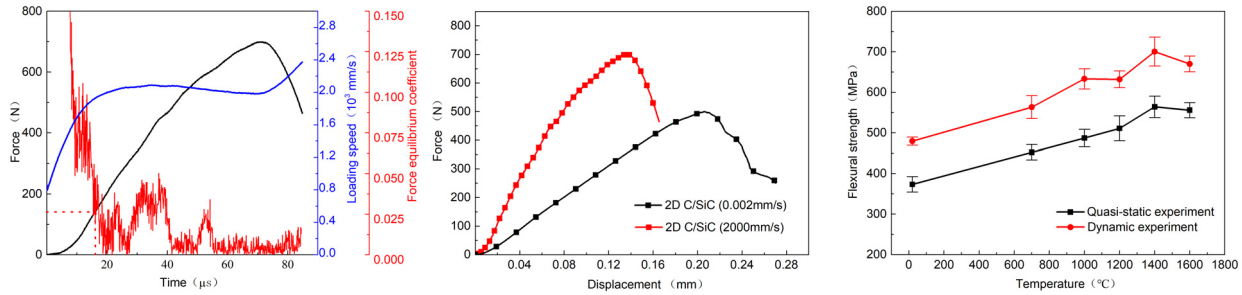

Fig. 2. (a) Stress equilibrium coefficient vs. time, Stress vs. time and Strain rate vs. time. (b) typical force-displacement curves of 2D C/SiC composites under out-plane bending loading at load speeds of 0.002mm/s and 2000mm/s. (c) Flexural strength vs. temperature at different rates under the environment of argon.

To clarify the effect of high temperature test environment on the 2D C/SiC composites, and to avoid oxidation of the specimen during the preheating process, argon was imported into heating furnace. Fig. 2(c) present the flexural strength vs. temperature at different loading rates under the environment of argon. The Flexural strength of the 2D C/SiC specimen has obvious strain rate effect at different temperatures. It should be pointed out that the flexural strength of 2D C/SiC increases with increasing temperature (420MPa at room temperature, 141MPa at 1400 C), and then drop at temperature above 1400 C. The release of residual stress causes the flexural strength of the material to increase first and then decrease with increasing temperature.

Conclusion

A dynamic three-point bending test method at high temperatures (up to 1600 C) was developed based on Split Hopkinson bar in this work. The loading speeds were controlled at 0.002mm/s and 2000mm/s during the quasi-static experiments and dynamic experiments. The Flexural strength of 2D C/SiC increases with increasing temperature, and then drop at temperature above 1400 C caused by the release of residual stress.

References

[1] Suo T, Fan X, Hu G, Li Y, Tang Z, Xue P. Carbon, 62 (2013), p. 481-92.
[2] Song B, Antoun B R, Nie X, Chen W. Experimental Mechanics, 50 (2010), p. 553-60.
[3] Zhang C, Suo T, Tan W, Zhang X, Liu J, Wang C, Li Y. International Journal of Impact Engineering, 102(2017), p. 27-35.
[4] Wang Y, Li Y, Suo T, Luan X, Zhou D, Muhammad Zakir S, Chen C, Liu H, Duan Y. Ceramics International, 44(2018), p. 2058-68.
[5] Hatta H, Taniguchi K, Kogo Y. Carbon, 43(2005), p. 351-58.