Available online at www.sciencedirect.com

ScienceDirect

Journal of the European Ceramic Society 30 (2010) 875–887

www.elsevier.com/locate/jeurceramsoc

Influence of panel/back thickness on impact damage behavior of alumina/aluminum armors

Zhang Zuoguang[a,*], Wang Mingchao[a], Song Shuncheng[b], Li Min[a], Sun Zhijie[a]

[a] *School of Materials Science and Engineering, Key Laboratory of Aerospace Materials and Performance (Ministry of Education), Beihang University, Beijing 100191, China*

[b] *School of Mechanics and Engineering, Southwest Jiaotong University, Chengdu 610031, China*

Received 7 December 2008; received in revised form 20 August 2009; accepted 27 August 2009
Available online 6 November 2009

Abstract

Using modified SHPB device, damage behaviors of alumina/aluminum armors under impact load were studied. The influences of panel/back thickness on the target damage characteristics were investigated. The transmitted stress wave increased and the reflected stress wave decreased distinctly with the increase of back thickness, while the panel thickness variation had little influence on the stress wave propagation features. The vertex angle of ceramic inverted cone increased with the increase of back thickness and decrease of panel thickness, but the number of radial cracks reduced with the increase of back thickness and the decrease of panel thickness. Furthermore, the failure mechanism of the ceramic panels, including the cone and radial cracks formation mechanism was analyzed. A "composite beam" model has been established to estimate the local bending stress. The model calculation showed that the local bending stress is related to the panel thickness, back thickness and the panel/back moduli ratio.

Keywords: Armor; Impact; Split Hopkinson pressure bar; Stress wave; Damage mechanism

1. Introduction

Ceramic composite armors have lower density and higher level of protection ability compared to traditional metal armors. They can enhance the viability and battle efficiency of the weapon systems by reducing weight and increasing mobility. Therefore, the ceramic composite armors have been widely used in aircrafts, ground vehicles, ships, individual protections and some other fields in last several decades. Since the damage mechanism of ceramic armors under impact loads is a key for armor structure design and ballistic performance evaluation, great efforts have been put into the impact damage mechanism study for ceramic armors.[1–7]

The velocity of bullet hitting on armor is usually of 500–1500 m/s, which falls into the range of high-speed dynamic impact, so the quasi-static mechanical properties of materials can not be used directly in armor design. In practice, the ballistic impacts have to be carried out for armor structure design and ballistic performance evaluation.[8,9] However, ceramic armors are usually destroyed severely by high-velocity-projectile and little usable information can be gathered after attack. For this reason, the damage mechanism study of ceramic armors by using ballistic impact is very difficult.

Hopkinson bar experimental technique has been commonly used in dynamic mechanical property study of engineering materials.[10–13] Hopkinson bar can provide different impact velocities and record the complete stress wave information during impact, so it is very suitable for impact damage mechanism study. In addition, since the velocity of incident bar is usually several to dozens of meters per second, the penetration of incident bar into ceramic armors causes less damage. This will be beneficial for the damage appearance maintenance and failure mechanism analysis.

In the present work, the impact damage behaviors of alumina/aluminum armors were studied by using the split Hopkinson pressure bar (SHPB) device. Especially, the influences of panel/back thickness on the damage characteristics and stress wave propagation of the composite armors were investigated in

---

* Corresponding author.
E-mail address: zgzhang@buaa.edu.cn (Z. Zuoguang).

0955-2219/$ – see front matter. Crown Copyright © 2009 Published by Elsevier Ltd. All rights reserved.
doi:10.1016/j.jeurceramsoc.2009.08.023

Table 1
Structure of alumina/aluminum composite armors.

Target	Panel thickness/mm	Back thickness/mm	Target	Panel thickness/mm	Back thickness/mm
A4A3	4	3	A4A6	4	6
A5A3	5	3	A5A6	5	6
A6A3	6	3	A6A6	6	6
A9A3	9	3	A9A6	9	6
A6A4	6	4	A6A9	6	9

detail, and the damage mechanism of the ceramic panel was discussed. The results will be very useful to the ceramic composite armors design.

2. Experimental

2.1. Targets preparation

The square composite armor targets were composed of alumina panel and 2A12 aluminum alloy back. The sides of the target were 50 mm long. Structures of the targets studied are listed in Table 1.

2.2. Modification of SHPB device

In order to simulate the behavior of projectile impacting target better, the incident bar and the transmitted bar of the SHPB device were modified before test. A schematic drawing of the modified SHPB device is shown in Fig. 1. The front end of the incident bar was machined to cone shape. The diameters of the projectile and incident bar are both 14.5 mm. The lengths of the projectile and incident bar are 200 mm and 400 mm, respectively. The end contacting with target of transmitted bar was machined into tubular structure with 36 mm outside diameter and 32 mm inside diameter. The modification of incident bar helps to provide a concentrated load on the composite armor target. The tubular structure design can avoid the infinite support against the target. If using a solid transmitted bar, the target is equivalent to be supported by an infinite back and cannot flex freely. When supported by the tubular transmitted bar, the target can flex locally under impact load, which is more similar to the real behavior of bullet impact on composite armor. A picture of part of the modified SHPB device is shown in Fig. 2.

The modification of incident bar and the transmitted bar changed the one-dimensional stress state in incident bar, sample, and transmitted bar. Therefore, the stress state of tested sample cannot be calculated simply by subtracting the transmitted stress from the incident stress. Although the stress state in the samples cannot be calculated accurately, the difference of stress propagation and absorption between different samples can be obtained by comparing the incident stress and transmitted stress.

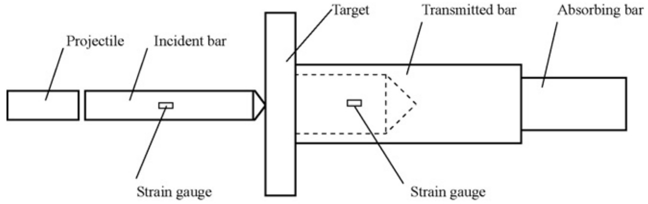

Fig. 1. A schematic drawing of improved SHPB device.

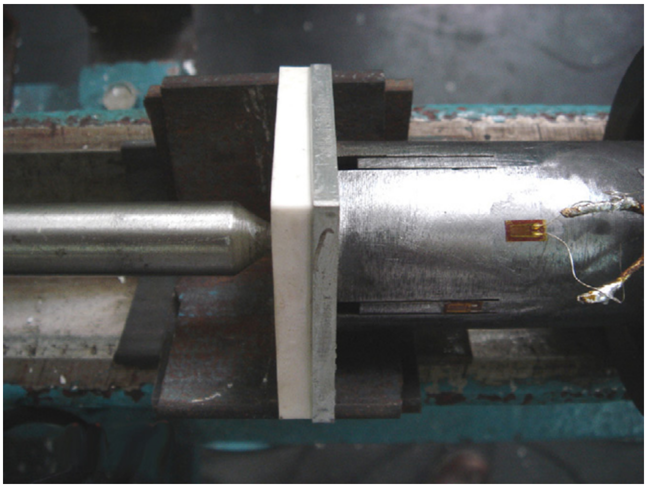

Fig. 2. A photograph of partial improved SPHB device.

2.3. Stress wave characterization

The impact tests were carried out with the projectile velocity of 15 m/s. A series of typical experimental stress waves are shown in Fig. 3. The wave (a) is the incident compression stress wave formed during projectile impact on the incident bar, which wavelength is two times of the projectile length. When

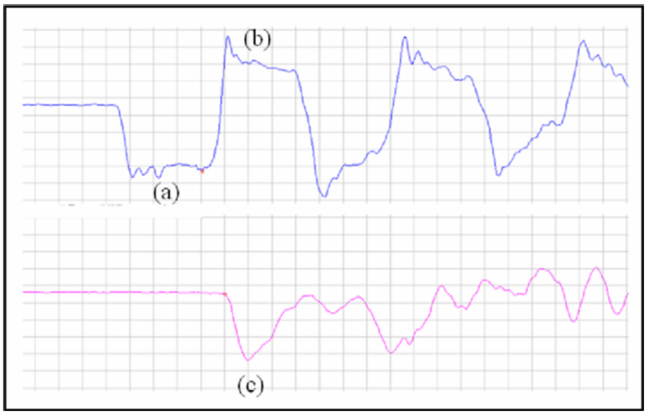

Fig. 3. The stress waves recorded during impact, (a) incident wave; (b) reflected wave; (c) transmitted wave.