CP429, *Shock Compression of Condensed Matter - 1997*
edited by Schmidt/Dandekar/Forbes

EXPERIMENTAL STUDY OF INTERFACE DEFEAT IN CONFINED CERAMIC TARGETS

N.S. Brar[‡], Horacio D. Espinosa[†], G. Yuan[†], and P.D. Zavattieri[†]

[†] *School of Aeronautics and Astronautics, Purdue University, West Lafayette, IN 47907*
[‡] *Impact Physics Laboratory, University of Dayton Research Institute Dayton, OH 45469-0182*

Recent experimental studies by Hauver et al. reveal that the ballistic performance of ceramic targets depends entirely on how the ceramic is confined in a composite target. If the ceramic confinement is preserved, the penetrator is consumed by lateral flow at the ceramic-cover plate interface; this mechanism is known as interface defeat. A number of variables are important in achieving optimum ballistic performance. The most relevant are: shock attenuation through the use of an attenuator plate, ceramic-cover plate interface, ceramic confinement pre-stress, ceramic-back surface interface properties, and shear localization sensitivity of the cover plate and penetrator materials. In this work several diagnostic tools are used to gain insight of the ballistic performance of ceramic targets. Stress histories produced at the cover plate-ceramic interface and ceramic-back plate interface are recorded with in-material gauges. Velocity measurements, at the back plate free surface, are recorded with velocity interferometry.

INTRODUCTION

There have been a number of investigations to utilize the high compressive strength and low density properties of ceramics to make light weight armor. On the other hand, ceramics fracture upon impact because of their low tensile and spall strength. Thus, in order to design an effective ceramic armor, an optimum confinement is needed to avoid ceramic flow during the penetration process. Bless et al. investigated the effect of confinement on the ballistic performance of 3-inch square 1-inch thick TiB_2 tiles against tungsten heavy alloy (WHA) projectiles shot at 1.5 km/s (1). In these shots the ceramic plate was inserted in a well of the same size as the ceramic machined in 4340 steel block and the confinement on top of ceramic was provided with a HSLA steel (SAE 4130, BHN 480) cover plate. In this configuration most of the penetrator flowed laterally at the cover plate-ceramic interface and there was only 5 mm penetration in the substrate below the ceramic. This phenomenon was identified as interface defeat (surface magic). Hauver et al. (2-3) investigated this phenomenon further and showed that WHA penetrators, shot at velocities up to 1.6 km/s, can be defeated with improved cover plate configuration. They investigated the performance of a number of round and square, 25 mm thick ceramics (tungsten carbide, titanium diboride, boron carbide, alumina, etc.). They concluded that in targets containing WC/Co or TiB_2, can defeat 93% WHA, L/D =20 penetrators (diameter=0.194") at the 4340 steel cover plate-ceramic

interface. Little damage to the ceramics was observed in both the cases. In the case of alumina and boron carbide the targets did not perform as well. In this study no quantitative measurements, such as stress/strain-histories at the ceramic front or back interfaces were made. In this paper we present the results on stress/strain-histories measured at the ceramic-cover plate interface and ceramic-back surface plate with in-material embedded gauges. The ballistic targets were assembled following the configuration used by Hauver et al. (2-3). The first two shots in this series were performed on relatively simpler targets to gain experience in using stress/strain gauges. Measured values of stress/strain and the post shot length of the remaining penetrator were compared with numerically simulated results (4).

EXPERIMENTAL METHOD

Materials Properties

Three types of ceramics were used in the present study. Nominal dimensions, density, and source of the ceramic plates are summarized in Table 1.

Target Configuration and Assembly

Four targets, 7-1795, 7-1796, 7-1797, and 7-1798, were configured and assembled as follows; 7-1795: A manganin/constantan gauge of Type MN/CN-50-EK (Dynasen) was glued on top of 50-mm thick and 150-mm in diameter 4340 steel plate. The gauge was covered with a 25 mm thick mylar sheet. A 13-mm thick steel plate

TABLE 1. Dimensions and density of ceramics.

Ceramic	Shape Dim.(mm)	ρ (g/cc)	Source
Alumina	Square 63x63x13	3.95	Babcock &Wilcox
Ebon-A Alumina	Round ϕ=72; th.=25.7	3.97	Cercom
TiB_2	Round ϕ=72; th.=25.7	4.5	Cercom

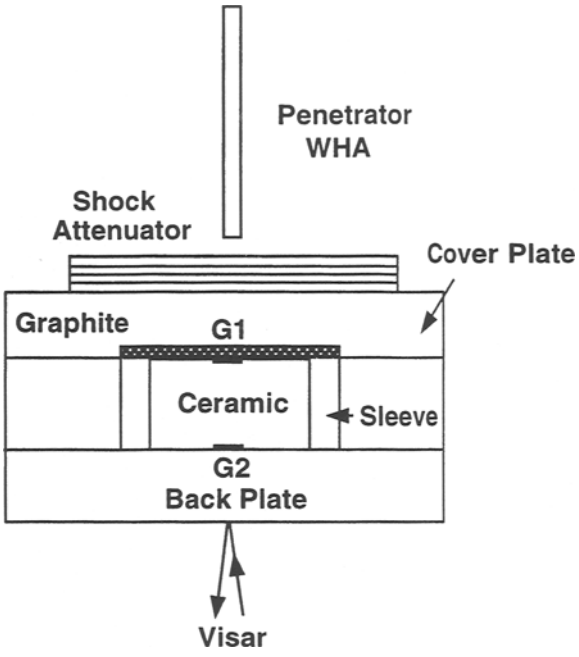

FIGURE 1. Schematic of targets 7-1797 and 7-1798.

was glued on top of the gauge. A shock attenuator block, consisting of 12 alternate layers of 0.8 mm thick 2024 aluminum and plastic, was glued on top of the 12.7 mm thick steel plate. 7-1796: This target was assembled with a 12.7-mm thick alumina plate (Babcock and Wilcox) set in a well machined in 50-mm thick and-150-mm in diameter 4340 steel plate. A Dynasen stress/strain gauge was glued on top of the alumina plate to record the stress/strain histories during the penetration process. On top of the gauge a 13 mm thick steel plate and a shock attenuator of the type in target 7-1795 were glued. 7-1797: This target was designed following Hauver et al. (2-3) and consisted of three plates, as shown schematically in Fig. 1. The top 25.4-mm thick 150-mm in diameter 4340 steel plate had a well machined on the bottom to accept a 2.4-mm thick and 73-mm in diameter graphite disk. The middle disk consisted of Cercom Ebon-A alumina disk shrink fitted in a 5mm wide 17-4 PH steel ring. The steel ring was further shrink fitted into a 25.5-mm thick 4340 steel ring. The

bottom plate was 25-mm thick 4340 steel plate. Both the faces of the ceramic containing steel plate, the lower face of the top steel plate, and the upper face of the bottom plate were lapped to ascertain flatness at the interfaces. Two Dynasen stress/strain gauges, one on top of the Ebon-A alumina ceramic and another on top of the bottom 4340 steel plate, were glued to record the stress/strain histories during the penetration process. The three plates were bolted together using 12 grade-8 bolts. A shock attenuator block, consisting of 24 alternate sheets of 0.8-mm thick 2024-aluminum and plastic, was glued on top of the target assembly. A VISAR was set up to measure the free surface motion of the back steel plate. 7-1798: This target was prepared and assembled in the same way as the target 7-1797, replacing Ebon-A alumina disk with the Cercom TiB_2 disk.

Ballistic experiments

Penetrator rods were machined from the Teledyne X21 93% tungsten stock and were launched using a Lexan sabot. Shots 7-1795 and 7-1796 were performed with 6.35-mm diameter L/D=10 penetrators. Shots 7-1797 and 7-1798 were performed with L/D=20 penetrators, (D=4.93-mm), which are similar to those used by Hauver et al. (2-3). Lexan sabots were stripped using a specially designed sabot stripper. The shot data is summarized in Table 2. The outputs of the stress/strain gauges were recorded using a Dynasen pulsed power supply. Strain and stress values were determined following the Dynasen manual (5).

RESULTS AND DISCUSSION

In shots 7-1795 and 7-1796 both stress and strain gauge profiles were obtained. In 7-1795 strain was less than 0.5% until the penetrator arrives at the gauge location. The stress profile from this shot is shown in Fig. 2. The stress increases to a level of 0.4 GPa and remains at this level for about 5 μs. After this, the stress level jumps first to about 2 GPa and then continuously increases to 10 GPa until gauge failure. The jump in stress may possibly be due to the effect of the approaching penetrator to the gauge location. For numerical predictions of in-material stress histories in ballistic simulations, see (4). The stress history obtained in shot 7-1796 is shown in Fig. 2. Strain was zero until the penetrator arrives at the gauge location. The stress profile shows a slow increase in the

TABLE 2. Summary of the shot data.

Shot No\	Impact Vel. (km/s)	Penet.	Interface Defeat
7-1795	1.3	complete	NA
7-1796	1.41	complete	partial
7-1797	1.7±0.1	complete	partial
7-1798	1.7±0.1	complete	partial

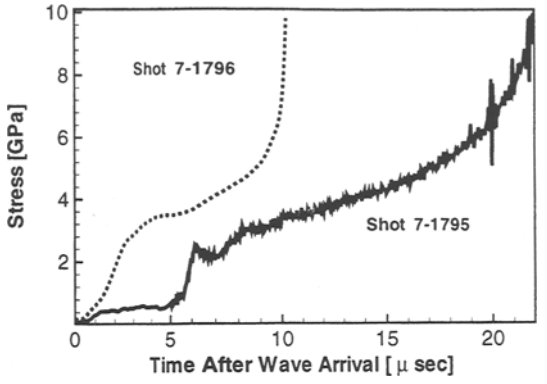

FIGURE 2. Axial stress histories.

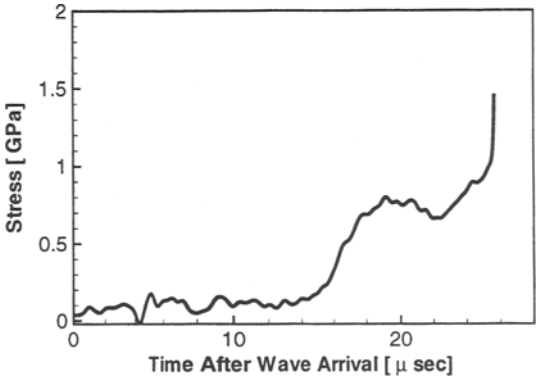

FIGURE 3. In-material stress history in shot 7-1797.

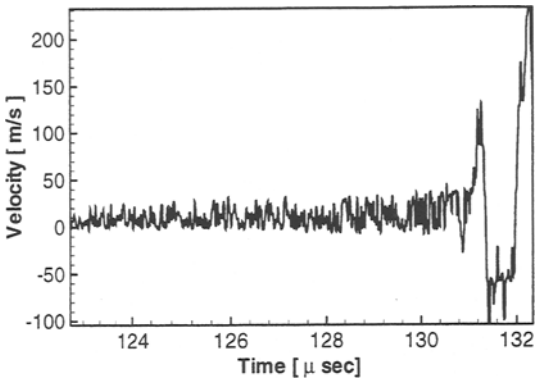

FIGURE 4. Back surface velocity history in shot 7-1797.

form of a ramp to about 4 GPa over a period of 2 μs and continues to increase to about 8 GPa before the gauge fails. The slow increase in the stress level in the form of a ramp is likely due to the penetrator interaction with the attenuator block. The strain and stress gauge failure, at the same time, can be interpreted as due to the arrival of the penetrator at the gauge location. Strain histories recorded at two locations, see Fig. 1, in targets 7-1797 and 7-1798 showed that strain was almost zero before the failure of the gauges on arrival of the penetrator. Stress histories recorded with manganin gauges on top of the ceramics (gauge 1) in both shots, 7-1797 and 7-1798, were not meaningful. The stress history, shown in Fig. 3, is from manganin gauge at location 2, see Fig. 1, in shot 7-1797. There is a slow rise in the stress level to about 1 GPa over a time of 10 μs. Figure 4 shows the back plate free surface velocity. This velocity history represents the early part of the target motion as inferred from numerical simulations (4). An optical micrograph showing *partial interface defeat* is shown in Fig. 5. This phenomenon was observed in both Al_2O_3 and TiB_2.

ACKNOWLEDGMENTS

The research reported in this paper was supported by the Army Research Office through

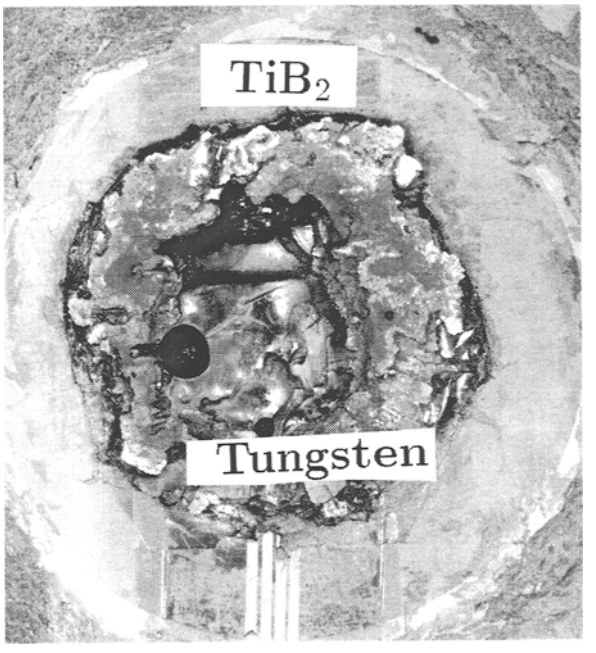

FIGURE 5. Photograph showing penetrator lateral flow at the ceramic-graphite interface.

Purdue MURI grant No. DAAH04-96-1-0331.

REFERENCES

1. Bless, S., Ben-yami, M., Apgar, L, and Eylon, D., "Impenetrable targets struck by high velocity tungsten long rods," Proc 2nd Int. Conf. on Structures under Shock and Impact, Portsmouth, UK, 16-18, June, 1992.
2. Hauver, G., Netherwood, P., Benck, R, and Keoskes, L., "Enhanced Ballistic Performance of Ceramics," 19th Army Science Conference, Orlando, FL, 20-24 June, 1994.
3. Rapacki, E., Hauver, G., Netherwood, P., and Benck, R., "Ceramics for Armors - A Material System Perspective," 7th Annual TARDEC Ground Behicle Survivability Symposium, 26-28 March, 1996.
4. Espinosa, H.D., Dwivedi, S., Zavattieri, P.D., and Yuan, G., "Numerical Investigation of Penetration in Multilayer Material/Structure Systems," submitted to *Int. J. Solids and Str.*, 1997.
5. Charest, J. Personal Communication, 1997.