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Experimental investigation on the ballistic resistance of polymer-aluminum laminated plates

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ABSTRACT

An experimental investigation on four kinds of polymer-aluminum laminated plates impacted by blunt- and ogival-nosed projectiles was carried out. The polycarbonate (PC) layer (2 mm) and the polymethyl methacrylate (PMMA) layer (2 mm) were used to make an array with the AA2024-T4 layer (2 mm), respectively, constituting these double layered polymer-aluminum laminated plates with no adherence. To better understand the strength and ductility difference among these materials, quasi-static tensile tests were conducted for them. The impact tests of pure AA2024-T4 layer (3 mm) which has close areal density with the bi-layered plates were compared in ballistic resistance. In each impact test, the projectile was driven by a gas-powered gun at impact velocities above and below the ballistic limit velocity of the target plates, mainly ranging from 60–150 m/s. And the initial and residual velocities of the projectiles impacting the targets were measured by a Photron FASTCAM SA5 high-speed camera. Based on these results, the ballistic limit velocities of seven kinds of structures (including three kinds of different thickness aluminum layer) impacted by blunt- and ogival-nosed projectiles were obtained. And after the impact tests, the plastic deformation of the aluminum alloy in each bi-layered structure was measured.

It is shown that the polymer layer order, nose shape and polymer mechanical behavior affects the performance of the polymer-aluminum laminated plates. The PC is much better than the PMMA in the bi-layer plates in terms of improving the ballistic resistance of the aluminum. Furthermore, the structures with the polymer placed in the impact side performed better than that in the back side for blunt-nosed projectiles, which is opposite to that for ogival-nosed projectiles. And the polymer-aluminum laminated plates with the PC placed in the impact side for blunt-nosed projectiles have advantages comparing with pure aluminum alloy at same mass in this study.

1. Introduction

Light-weight materials are widely used in modern protective structures, with the ability to perform effectively and practically against ballistic, blast and other impact events at a relatively low weight compared with steel structures. Therefore, as an important component of light-weight structures, aluminum and its alloy have been comprehensively researched and designed. To further improve the ballistic performance of the aluminum substrate materials, an increasing interest has been paid in the polymer-aluminum combined structures.

Currently, most of the studies have focused on the polyurea as a coating in improving the ballistic and blast resistance of the metallic plates. Xue et al. [1] investigated the DH-36 steel with the polyurea layer backed and sandwiched structures impacted by pointed and flat strikers. They found that the thick polyurea coating increases the energy absorption of the steel substrate and thus improves the target performance when backed, while sandwiched configuration of the plate has no advantage to penetration resistance. Roland et al. [2] investigated the composite array of elastomer–steel panels. They concluded that the break up and dissipation of the pressure wave by the polymers due to impedance mismatching leads to large increases in ballistic penetration resistance of the structures. Mohotti et al. [3, 4] have investigated the polyurea coated aluminum plates subjected to high and low velocity ballistic impact. A higher residual velocity reduction per unit areal density was found with the polyurea appropriately arranged than pure aluminum alloys. Amini et al. [5, 6] studied the dynamic response of monolithic steel and pollyurea coated steel plates subjected to impulsive loads. They conducted a series of experiments in which they found that polyurea layer can mitigate the failure of the steel and absorb more impact energy when backed. And while it was placed at the impact side, a severe damage occurred at the steel plate. Rijensky and Rittel [7] investigated the polyurea coated aluminum plates under hydrodynamic loading. 3D-DIC (digital image correlation) technique was adopted to analyze the deflection history of

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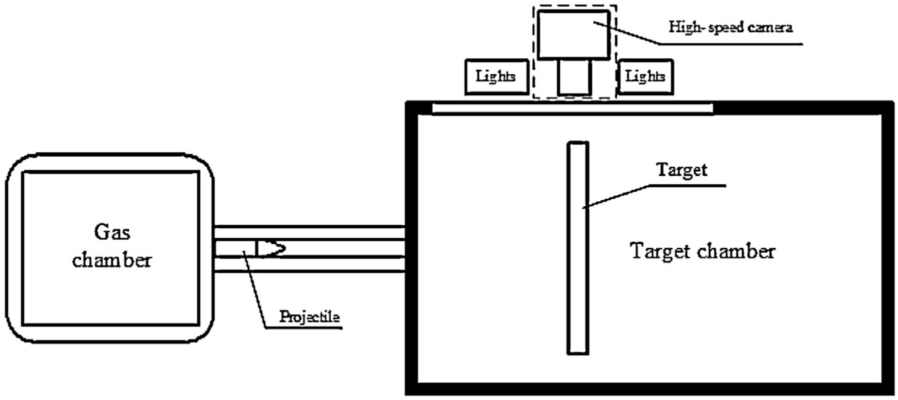

Fig. 1. Schematic of the impact test system.

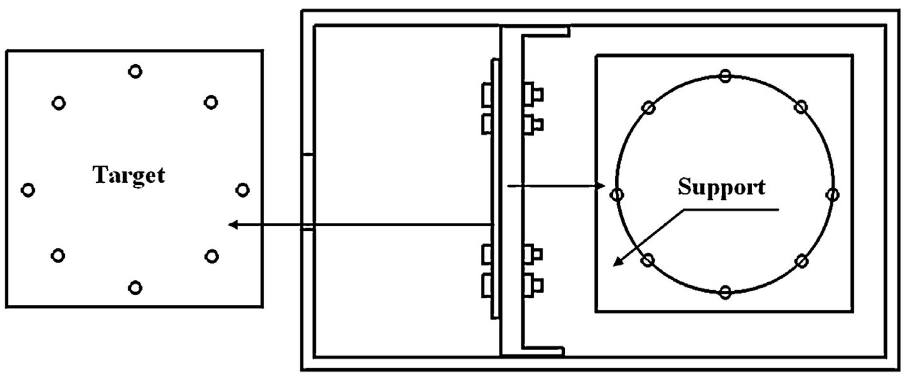

Fig. 2. Target supports.

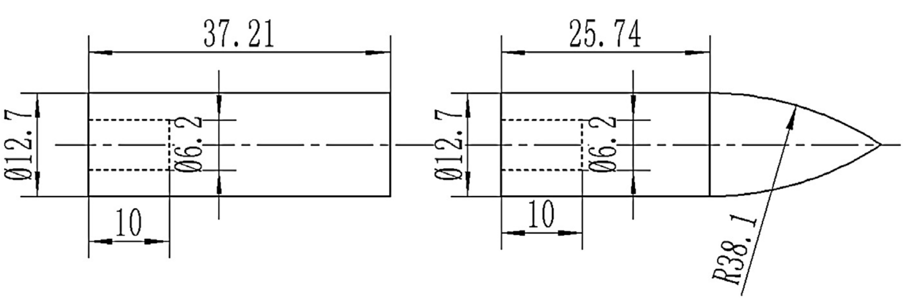

Fig. 3. Geometry and dimensions of the projectiles (unit: mm).

Table 1
Chemical composition (in weight %) of the 38CrSi steel alloy.

Element	C	Si	Mn	Cr	S	P	Ni	Cu
Containing	0.35–0.43	1.00–1.30	0.30–0.60	1.30–1.60	< 0.035	< 0.035	< 0.030	< 0.030

Table 2
Specification of the materials used in this study.

Material	Density (kg/m^3)	Thickness (mm)	Yield strength (MPa)[a]	Failure strain[a]
PC	1200	2	50.3	–
PMMA	1180	2	55.2	0.114
AA2024-T4	2700	2,3,4	301.5	0.175

[a] Average values obtained at the strain rate of 0.0013 s^{-1}.

polyurea coated plates. Their experiment results showed that polyurea will better absorb the shock wave energy when positioned on the side in contact with water.

Researchers have increasing interest in polyethylene. Mohagheghian et al. [8] investigated the projectile nose shape sensitivity of polyethylene-aluminum alloy laminates. They revealed that projectile nose shape greatly influenced the ballistic resistance of the polymer-metal laminated plates. A switch of the failure mode from discing to tensile is caused by a polyethylene placed on the impact face of a thin aluminum alloy substrate for blunt-nosed projectiles, which is of great importance for aluminum plates. Liu [9] reported a new type of