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Effect of core topology on projectile penetration in hybrid aluminum/alumina sandwich structures[☆]

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ABSTRACT

A series of hybrid sandwich structures were fabricated by shrink-fitting precision-ground prisms of alumina (CoorsTek grade AD 995) with triangular, trapezoidal or rectangular cross-sections into the voids of extruded sandwich panels made from Al 6061-T6. The panels were subjected to impact tests using hard steel spheres over the velocity range 570–1800 m s^{-1}. A combination of X-ray tomography, high-speed video imaging and cross sectioning of impacted samples was used to investigate the penetration mechanisms. We find that the ballistic performance of these structures, characterized by the ballistic limit and the exit velocity of impact ejecta beyond this limit, is significantly improved when triangular prisms are replaced by trapezoidal prisms, provided the base width of the prism exceeds about three times the projectile diameter. Additional performance improvements are obtained when the trapezoidal prisms are replaced by rectangular prisms, albeit at the expense of an increase in the lateral extent of damage. The variations in impact response are found to arise from: (i) the effect of prism size and shape on the degree of confinement of the ceramic by the metallic webs, (ii) the core web structure, which influences the fracture conoid angle in the transverse plane, and (iii) the spacing of web-face nodes on the back face, which governs the deflection and fracture of the back-face sheet.

1. Introduction

Metallic sandwich panels have been extensively explored for impulsive load mitigation. Benefits of sandwich construction for edge-clamped panels subjected to normal impulse arise mainly from the superior bending resistance of sandwich panels relative to monolithic plates of equivalent areal density [1,2]. Additional benefits are obtained from fluid-structure interactions when the impulse is created by explosions in water [3–6] and to a lesser extent in air [7–10] or by soil impact [11–14]. Recent studies [15,16] on extruded 6061-T6 aluminum sandwich panels with a strong triangular corrugated core [17] have shown reductions in panel deflection relative to equivalent monolithic plates under high-intensity soil loading (until the intervention of panel fracture).

In targeted applications, such panels could also be exposed to high-velocity ballistic threats. A previous study on the extruded aluminum sandwich panels revealed that the ballistic resistance of these panels for zero-obliquity impact by high-strength spherical projectiles is similar to that of a solid plate of the same alloy with a thickness approximately that of the two face sheets [18,19]. At the ballistic limit, penetration occurs by shear-off of the impacted face sheet, followed by tensile fracture of the core webs and shear-off of the rear face sheet, and is accompanied by minimal deformation of the projectile. The same study went on to explore the effect of triangular alumina prisms inserted into the core channels upon the mechanisms of penetration. Some of the insights gleaned from that study provided the impetus for the present study, as described below.

Since the early work of Wilkins [20], many studies have explored the damage mechanisms in ceramic tiles on supporting metallic back-plates [21–23]. Impact by a projectile leads to

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deformation, and sometimes fragmentation of the projectile if the stress induced in the projectile exceeds its dynamic strength (Fig. 1). It also causes some plasticity and extensive microcracking within the ceramic directly beneath the impact site [24–26]. Stress waves launched from beneath the impactor travel across, and are reflected at the rear surface of the tile, creating tensile hoop stresses which initiate radial cracks whose density increases with reduction in the bending resistance of the tile/support system. These begin to grow toward the impacted surface of the tile and at some stage in this process are intersected by cone cracks that define a fracture conoid that, for alumina, intersects the surface normal at an angle that depends upon the projectile shape/material and geometry of the target, but is typically about 65° [27–30]. The material within the fracture conoid is then accelerated toward the back-plate, causing the plate to undergo bending and stretching [31]. The ballistic limit is reached when either the back-plate is unable to sustain the stretching strains resulting from the loads applied by the fracture conoid footprint, or the loading conditions are sufficient to cause shear-out around the periphery of the conoid base. While the fracture conoid characteristic of ceramics results in a large loading footprint on the back-plate and hence a reduced pressure for a fixed impact momentum, a second subsequent impact near the first is likely to experience less resistance to penetration (Fig. 1c).

The insertion of ballistic-grade alumina prisms into the triangular voids of the extruded aluminum corrugated-core sandwich panel has been shown (unsurprisingly) to have a dramatic effect upon the ballistic impact process [19]. In that system, front face penetration occurs by ductile hole enlargement. Upon subsequent impact with the ceramic insert, the projectile is severely deformed and fractured, and the impacted insert suffers severe comminution and cone cracking, with some cracks

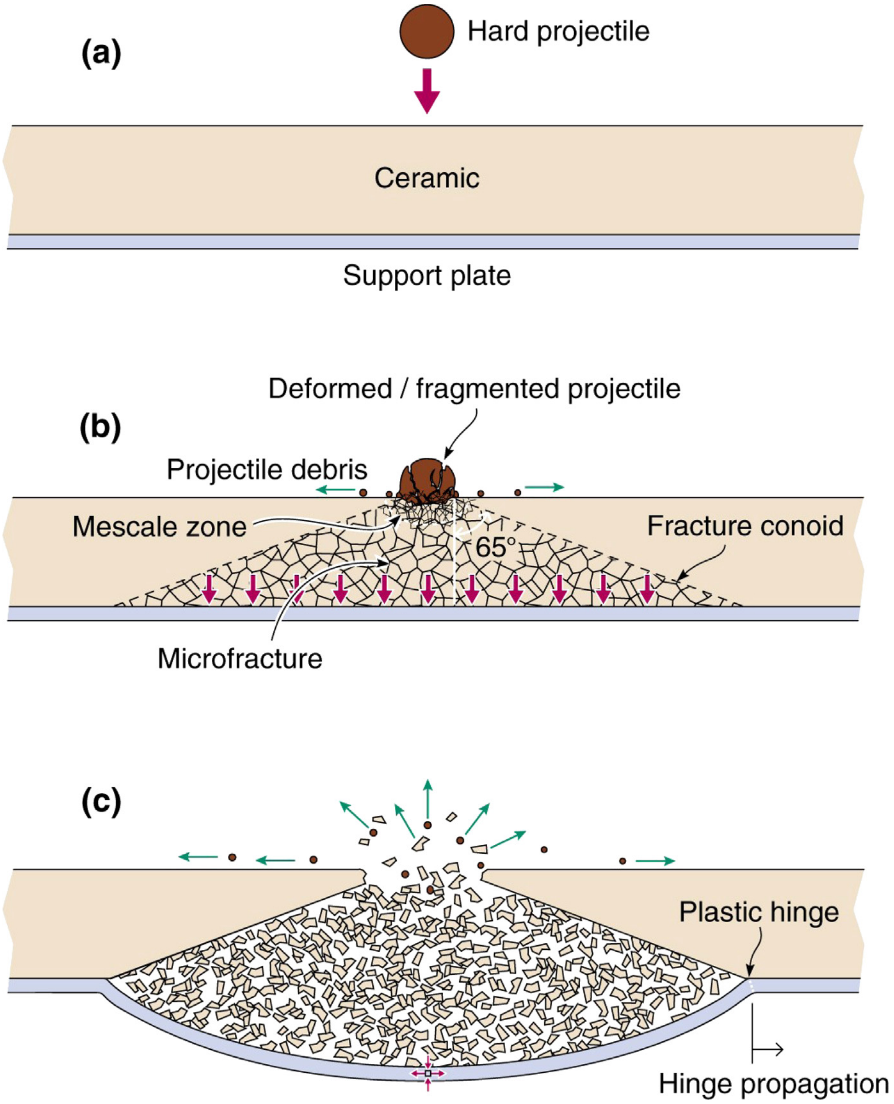

Fig. 1. A schematic illustration of the penetration mechanisms of a supported ceramic impacted by a hard metal sphere at zero obliquity. A second impact whose fracture conoid intersects the first more easily penetrates the composite panel.