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# Blast response of cladding sandwich panels with tubular cores

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ABSTRACT

This paper reports on the response of cladding sandwich panels with tubular cores to uniform blast load. The core of the cladding sandwich panels consisted of empty or foam-filled thin-walled circular tubes (38 mm in diameter) made from either aluminium 6063-T6 or mild steel riveted laterally between the skin plates at varying spacing arrangements. The tubular cores were arranged to provide four different types of panels. The front plate skin of the panel, exposed to the blast load, was made from DOMEX 700 Steel while the back plate skin was made from mild steel. Three types of polymeric cellular foams, namely self-raising polyurethane, expanded polystyrene and cross-linked polyethylene, were used to fill the circular tubes. The "uniform" blast load was achieved by detonating varying charge masses of explosive (ranging from 6 g to 50 g) with a prescribed load diameter of 40 mm at a stand-off distance of 200 mm down a square tube. Energy was dissipated mostly through the plastic deformation of the tubular cores. The foam added extra energy absorbing capacity. The results showed an increase in average deflection with an increase in charge mass/impulse for the different types of panels. The cladding panels with the least interaction between the tubular cores were observed to have the highest energy absorption capabilities for a given charge mass.



## 1. Introduction

With the ever-increasing terrorist threats and possibilities of accidental explosions there has been a growing drive to develop better blast barriers. Smith [1] presented a review on the performance on blast walls for structural protection against the damaging effects of high explosive threats. Blast barriers using different materials such as metals [2–6], concrete [7–9], soil [10–12], and water [13–16] have all been developed and used. However many of these thick armour systems, used to mitigate blast loads, are often heavy and significantly affect the payload of the structure. In the design of structures for blast protection, lightweight sandwich type cladding structures with cores that absorb large amount of plastic energy with minimal weight penalty are often used. The choice of the core for these cladding sandwich panels has significant influence of the performance of the structure. The cores are typically made from cellular materials such as wood, foam derived from different materials and tubular structures. Because of its high energy absorption capabilities tubular structures are commonly used.

The sandwich paradigms can be divided into two main categories: (1) sandwich panels and (2) sacrificial cladding. In a sandwich panel the back-face can deform. The performance of such sandwich panels is generally defined by the maximum back-face deformation for a given load. A sacrificial cladding structure, on the other hand, is a type of sandwich panel that is fixed or retrofitted to an existing structure. In this configuration, the back-face of the panel is assumed to be rigid. The panel is generally designed to deform in such a way that the front face distributes the load evenly across the core that is responsible for absorbing the impact energies while transmitting minimal/controlled forces to the main structure. A sacrificial cladding structure in the form of an efficient energy absorber should also be light in weight with ease of installation.

One of the advantages of sandwich panels is the ability to be tailored, subject to ease of manufacturing, cost and weight, to allow for potentially better performance than monolithic plates. Zhu and Lu [17] and Yuen et al. [18] presented overviews on the response of sandwich structures made from different materials to impact and blast loading. Xue and Hutchinson [19] compared the performance of three different core geometries of metal sandwich plates to that of solid plates of the same material and same mass. These studies have indicated that advanced sandwich structures can potentially have significant advantages over monolithic plates in absorbing the blast energy whether in air or underwater.

Considering the energy absorbing capabilities and characteristics, several authors have carried out research with a view to using tubular structures in cladding structures. Because of the high stiffness, tubular structures are typically used in sacrificial cladding panels and not in sandwich panels. To maximize energy absorption the tubular structures can be arranged either in the lateral (single or multi layers) or

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in the axial direction to deform a large volume of material plastically. Yuen and Nurick [20] presented a current state of the art on the use of tubular structures as cores for sandwich panels.

There have been numerous studies characterising the behaviour of single or multi-layers circular and quadrangular thin-walled tubes subjected to a lateral load [21–30] with regards to energy absorption. In some studies, tubular shells were axially stacked to form the core of cladding panels. Palanivelu et al. [31,32] suggested the use of readily available metal beverage cans that are environmentally friendly and non-corrosive as “greener” sacrificial claddings to protect against blast loads. Theobald and Nurick [33,34] reported on the response of sandwich cladding panels with thin-walled square tubes as the core material to blast loads.

A few studies on the response of sandwich panels consisting of laterally stacked tubular structures as core have also been presented. Palanivelu et al. [31,32] suggested the use of recyclable metal beverage cans stacked in the lateral direction as core for sacrificial cladding but presented no results of the performance of “such” cladding structure. Chen and Hao [35,36] presented experimental and numerical studies on the use of multi-arch shells as core of a double layered panel representing a blast resistance door panel. Single-layered flat steel panels were used as control structure to compare the efficiency of the double-layered multi-arch panel. The results showed that the multi-arch panel with specific configuration performed better as protective structures against uniform impulsive loadings. Xia et al. [37] recently reported on the response of sandwich panels with tubular core to blast loads. When subjected to close-in explosion, it was reported that the front face appeared to mitigate the shock wave through plastic deformation with insignificant deformation of the tubular core. Under contact explosive load, the tubular core collapsed locally while the front face tore.

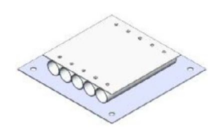
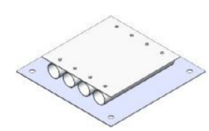
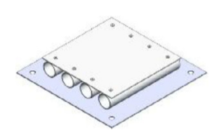
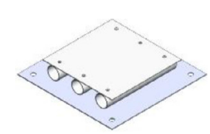
This paper, in some ways, extends the study carried out by Xia et al. [37] and presents the results of a study on the response of cladding sandwich panels with tubular cores to uniform blast load. In this study, the panels are cladding structures that are smaller in size, as are the loads. The blast load range studied by Xia et al. [37] was obtained by detonating masses of TNT explosives ranging from 0.5 kg to 10 kg. In this study, the amount of explosives used ranged between 6 g to 50 g of PE4. Panels with different number of tubular structures (empty or foam-filled) and spacing were tested with a view to characterise their blast mitigating capabilities and energy absorption characteristics.

## 2. Experiments

### 2.1. Specimen

The cladding panels, as shown in Fig. 1, consisted of thin-walled circular tubes (outer diameter 38 mm) made from either aluminium 6063-T6 (AL) or mild steel (MS) riveted laterally between the skin plates at varying spacing arrangements to provide four different types of panels listed in Table 1. Aluminium and mild steel tubes were chosen as cores because of their availability in similar sizes and cost. Both materials are also commonly used in the manufacturing industries. In this application it was assumed that the manufacturing process i.e. extrusion for the aluminium tubes and possibly seam welding and its orientation for steel tubes had insignificant effect on energy absorption. The top skin exposed to the blast load was made from 2 mm thick DOMEX 700 Steel while the back face skin was made from 2 mm thick mild steel with an area of 300 mm x 300 mm. The area of the top skin is 220 mm x 220 mm. The tubes were firstly glued between the top and bottom plates before being secured by means of 4 mm rivets. The rivets were used as a means to hold the tubular cores in the panels and assumed to have insignificant contribution towards the blast mitigation of the structures. Additional series of experiments were also conducted whereby the tubes were filled with polymeric cellular foams; namely self-raising polyurethane (PU), expanded polystyrene (PS) and cross-linked polyethylene (PE). The polyurethane foam was prepared by mixing polyurethane liquid with a synthetic resin in equal proportions to provide a foam with a nominal density of 200 kg/m$^3$.

**Table 1**
Types of cladding panels.

| Arrangement | Description | Illustration |
|---|---|---|
| 1 | Core consists of 5 touching tubes (gap 0 mm) |  |
| 2 | Core consists of 4 tubes with a gap of 10 mm between neighbouring tube |  |
| 3 | Core consists of 4 tubes with a gap of 20 mm between neighbouring tube |  |
| 4 | Core consists of 3 tubes with a gap of 38 mm between neighbouring tube |  |

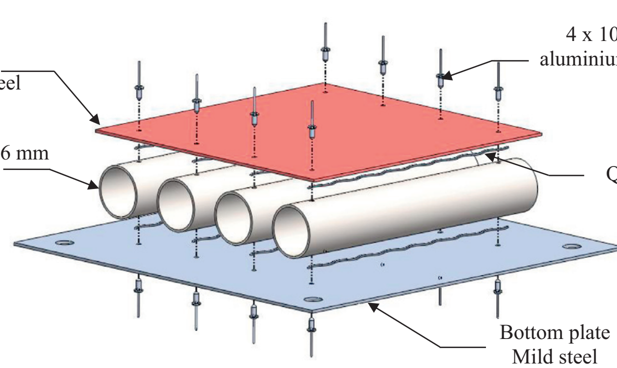



**Fig. 1.** Schematic detailing the basic construction of the sandwich panel (4 tubes).