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Experimental investigations of fabric material against projectile impacts

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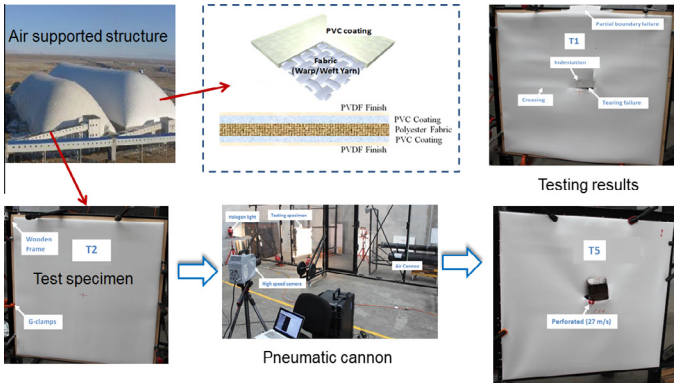
HIGHLIGHTS

- PVC coated polyester fabric material against debris impact was studied.
- Tests were carried out by using a pneumatic cannon testing system.
- The failure and damage modes of specimens were observed and discussed.
- Penetration resistance capacity of fabric against debris impacts was identified.

GRAPHICAL ABSTRACT

The structural response to windborne debris impact of PVC coated fabric material for air supported structure construction is the first study in the literature.



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ABSTRACT

Air supported structures made of PVC coated polyester fabric materials have been used in industrial and commercial building constructions. If they are used in cyclonic regions, the structure envelop might be impacted by windborne debris. The windborne debris might perforate the fabric material, which not only results in total collapse of the structure, flying debris at high speed also imposes threats to people and facilities inside the structure. In this study, the penetration resistant capability of PVC coated polyester fabric material commonly used in air supported structures construction was tested by using a pneumatic cannon system. The impact loading from windborne debris equivalent to a timber projectile of 4 kg mass as specified in the Australian Wind Loading Code (AS/NZS 1170.2:2011) was applied in the test. The failure and damage modes under various projectile impact scenarios were observed and compared. Its capability of resisting projectile impact was assessed. The performances of PVC coated polyester fabric material were examined quantitatively in terms of projectile residual velocity and energy absorption. The effects of various projectile velocity, impact location, fabric pretension and boundary condition on their penetration resistance performance were studied. The testing results will benefit construction designers involved in the fabric material applications in high wind speed area.

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1. Introduction

Air supported structures are becoming popularly used in the seasonal and permanent constructions of warehouse, sports and recreational structures, storage facility, deployable structures for emergency relief, commercial and industrial structures, etc. as shown in Fig. 1. The air inflated structure provides totally enclosed, wide span and large space for various purposes. For example, air supported structure as storage facility for coal and chemical hazardous goods, can effectively seal assorted goods inside structure and reduce pollution and protect the environment. The air supported structure can also be used at mining sites to protect the instruments and property inside. It has advantages of being environmentally sustainable, lightweight, cost-effective, easy to install, quick to construct, rapidly deployable, reusable, thermal insulated and fire proof. It is suitable for various weather conditions, even extreme typhoon event. The cost is estimated around 1/3 of that of conventional construction and energy consumption saving can be over 80% [1]. Therefore, air structure is recognized as a "green" and cost-saving structure. A typical air supported structure system consists of membrane fabric, cables, anchorage, inflation system, lights, doors and HVAC, etc. The analysis and design of air supported structure have been conducted by Bonet et al. [2] and Ando et al. [3].

The membrane fabric material enclosing air supported structures consists of woven fabric, coating and finishing on both sides. The woven fabric can be made from high strength polyester fiber, glass fibers, aramid fiber and polyamide, etc. The mechanical properties of fabric including tensile strength and tearing resistance are determined by the fabric material and the method of weaving. Coating material such as PVC (Poly Vinyl Chloride) is used to enhance the performance and durability of the fabric material. A surface layer of PVDF (Polyvinylidene Fluoride), PTFE (polytetrafluoroethylene) or Acrylic as top finish is applied to further enhance durability of the fabric material. The schematic diagram and composition diagram are shown in Fig. 2. The fabric material has main characteristics of durable, high strength, self-cleaning, anti-corrosion, flame retardant, UV reduction and thermal insulation. The PVC coated polyester fabric, which has been used in membrane structures for more than 30 years, is investigated in this study. The mechanical properties of PVC coated fabric have been studied on the basis of the uniaxial tensile tests, biaxial tensile tests and shear tests, etc. [4–8]. The fabric exhibits high non-linearity.

Air supported structures might be subjected to windborne debris impact. In cyclonic area, cyclone intensity and occurrence increase every year with the climate change. The safety of the air supported structure is a key issue. The post storm investigations found that cyclone generated enormous amount of windborne debris and the windborne debris impact was highlighted as a major cause of damage to building envelope [10]. As shown in Fig. 3, the windborne debris might penetrate through the fabric material which might hurt people or facilities inside. Opening of the fabric results in air leakage which leads to the collapse of the air supported structure. Therefore, it is important to understand the penetration resistance capacity of fabric material, especially when they are used in the regions prone to cyclones. To ensure the safety of air supported structure under severe wind event, the penetration resistance capacity of the fabric envelope to windborne debris impact should satisfy the testing requirements specified in the respective design codes such as the Australian Wind Loading Code (AS/NZS 1170.2:2011) [11]. The impact loading from windborne debris is equivalent to a timber projectile of 4 kg mass with a nominal cross-section of 100 mm × 50 mm impacting end and launching velocity of 0.4 V_R for horizontal trajectories, in which V_R is the regional wind speed. Various structural panels subjected to projectile impacts have been investigated by using pneumatic cannon to simulate the windborne debris impact [12–14].

Numerous experimental, numerical and analytical studies have been carried out to investigate the ballistic performance of various fabrics and composite laminates [15–17]. The factors influencing ballistic performance include the material properties of fabric, configuration of fabric, projectile geometry and velocity, boundary conditions and friction, etc. [18]. Ballistic protection products such as Kelvar® and Twaron® fabric have been used in various impact-related applications such as body protective clothing. Chen et al. [19] experimentally and numerically investigated the ballistic performance of hybrid fabric by using polyethylene woven and unidirectional material. The optimal ratio of woven to unidirectional material was determined for ballistic protection. Kędzierski et al. [20] conducted blunt projectile impact tests on ten high strength fabrics with various architecture including plain woven, unidirectional laminates and multi-axial fabrics. The depth of depression

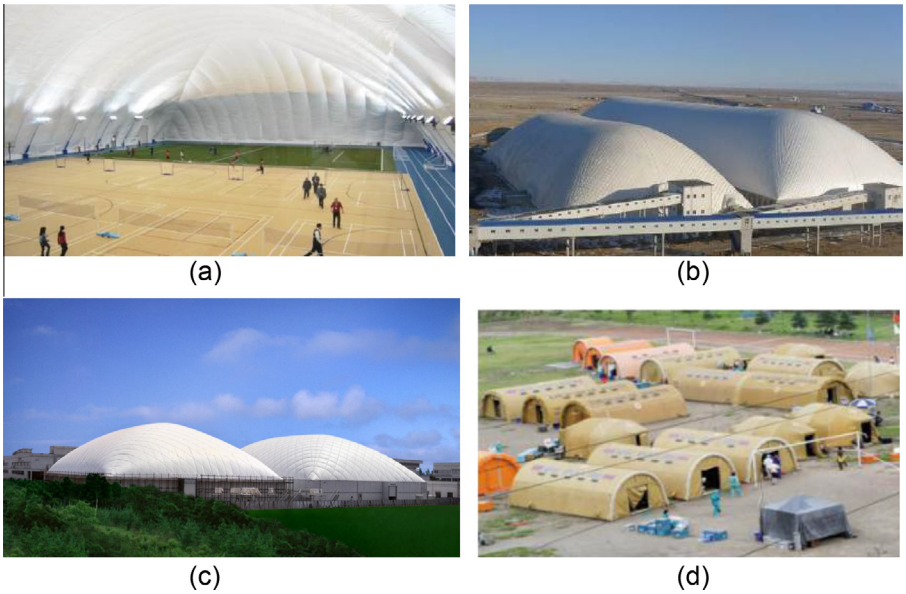

Fig. 1. Examples of air supported structure [1] (a) sports entertainment; (b) coal storage facility; (c) industrial warehouse; (d) deployable structure for emergency relief.