3D Fabric/Polyurethane Foam Composites Containing Various Fabrics: Property Evaluations

Chen-Hung Huang, Yi-Jun Pan, Yu-Chun Chuang, Zheng-Ian Lin, Ching-Wen Lou and Jia-Horng Lin

ABSTRACT

In this study, different combinations of non-woven fabric, glass fiber fabrics, and carbon fiber woven fabrics are needle punched, and are then laminated with 3D fabrics. These materials are impregnated in a two-package PU blowing agent in order to form 3D fabric/PU foam composites. Bursting strength test, compression test, dart drop test, and sound absorption test are used to evaluate the effect of the skin fabrics on the properties of 3D/PU foam composites. The test results suggest that the skin fabrics containing nonwoven fabrics and carbon fiber woven fabrics have an optimal bursting strength of 4320.9 N. The skin fabrics that are composed of nonwoven fabrics and glass fiber woven fabrics have an optimal compressive strength of 15 MPa. The drop-weight impact test results indicate that skin fabric containing nonwoven fabrics and glass fiber woven fabrics have a residual stress of 540.8 N, moreover, this skin fabric also attain an optimal sound absorption coefficient of 0.9. Therefore, having composite fabrics as the skin layer is conducive for the mechanical properties and sound absorption coefficient of PU foam materials. In addition, the proposed 3D/PU foam composites can be mechanically reinforced, and the disadvantages of their constituent 3D fabrics can also be improved. The skin composite fabrics are adjustable for possible clinical applications, and provide the 3D/PU foam composites with diversity of applications, such as building materials and protective materials.

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INTRODUCTION

In recent years, people have been actively looking for methods that improve mechanical properties of composites materials. Some research indicates that the reinforcement along the parallel direction of 2D fabric composite materials is favorable for their tensile strength, toughness, ductility, and energy absorption. In terms of application, when 2D fabrics are used to reinforce composites, the laminates of composites should be designed with a lay-up structure. However, this structure is subjected to have de-lamination and is easily damaged by a shearing force [1-4].

The advancement of modern textile techniques provides the fabric structural design with great flexibility. 3D fabrics are developed in order to improve the drawbacks of 2D fabrics. 3D fabrics can stabilize fabrics with the yarns, which strengthens the mechanical properties along three-dimensional directions, and overcomes the disadvantages of 2D fabrics in terms of delamination and low shear strength. There are many methods for the production of 3D fabrics, including knitting, weaving, and braiding. The most powerful reinforcement is producing 3D fabrics by using Raschel knit. This method provides the fabric with an open structure that allows for an even penetration of the reinforcing materials. Raschel knits are composed of the third yarns that can combine two independent 2D fabrics along the direction of the thickness, and eventually constructs a 3D fabric. The connecting yarns are called pile yarns. 3D fabrics are used for practical purposes, as in reinforced cement composites [5, 6].

Polyurethane (PU) foam materials are a reaction result of isocyanate, polyols based, and water. Based on mechanical strengths, PU foams can be divided into rigid foams and soft foams. Rigid foams are primarily applied in the architecture, aviation, and shipbuilding fields, while soft foams are used as cushioning materials and in transportation equipment. Therefore, with a selection of reactant and proper manufacturing, PU foam materials can fulfill diverse requirements for different applications [7].

This study combines nonwoven fabric, fiberglass fabric, and carbon fiber woven fabric. These materials are impregnated in a two-package PU blowing agent in order to foam in the interior of 3D fabrics, in order to form PU-foam based composite. A bursting strength test, a compression test, a drop-weight impact test, and a sound absorption test are used to evaluate the effects of different skin layers on the properties of the 3D fabric/PU foam composites.

EXPERIMENTAL

Materials

PET monofilament yarns (J and V Monofilament and Fiber Inc., Taiwan, R.O.C.) have a 0.3-mm diameter. High strength PET yarns (Universal Textile, Taiwan, R.O.C.) have a specification of 500 D/96 F. Recycled Kevlar selvage (Formosa Taffeta Co. Ltd) have a length of 40~65 mm. Fire-retardant PET fibers (Far Eastern New Century, Taiwan, R.O.C.) has a 6 D fineness and a 64-mm length, and the LOI is 39. Glass fiber (GF) woven fabrics (Jinsor-Tech Industrial Corp., Taiwan, R.O.C.) have a warp density of 27 ends/inch and weft density of 18 picks/inch. The carbon
fiber (CF) woven fabrics are also purchased from Jinsor-Tech Industrial Corp., Taiwan, R.O.C. Polyurethane (PU) blowing agent (Chung Hsing Chemical, Taiwan, R.O.C.) have a specific gravity of 1.12-1.15 g/m³ and a viscosity of 900±100 CPS/25 °C. The accelerator (Chung Hsing Chemical, Taiwan, R.O.C.) has a specific gravity of 1.23-1.24 g/m³ and a viscosity of 200±50 CPS/25 °C.

**Preparation of 3D Fabric**

A double-needle-bed warp knitting machine (Dah Heer Industrial, Taiwan, ROC) is used to fabricate six bars of warp yarns into warp knitting spacer fabrics (i.e., 3D fabrics). With 500 D/96 F PET multi-filaments, the first/second layers and the fifth/sixth layers are made into the top and bottom layers. The top and bottom layers are then bound with 0.3-mm monofilaments, and form the 3D fabrics.

**Preparation of Skin**

6 D fire-retardant PET fibers and Kevlar fibers are blended with a weight ratio of 80:20, followed by being processed with nonwoven manufacturing involving opening, mixing and blowing, combing stitching, and needle punching, in order to form PET/Kevlar nonwoven fabrics. The PET/Kevlar nonwoven fabrics and GF woven fabrics or CF woven fabrics are needle punched to for the skin of the PU foam materials.

**Preparation of 3D Fabric/PU Foam Composites**

The two-package PU foam involves there being blowing agent and accelerator, both of which are blended at a 1:1 ratio and are then stirred at 300 rpm. The PU foam mixture is poured into a 350 mm × 320 mm × 100 mm mold where 3D fabric and the skin are poised. After an emulsion for twenty seconds, a cure time for PU foam for 100 seconds, and a storage in room temperature for two hours. Samples are denoted as composites A, B, C, and D, according to their components as indicated in Table 1.

<table>
<thead>
<tr>
<th>Composite Types</th>
<th>3D Fabric</th>
<th>PU Foam</th>
<th>PET/Kevlar Nonwoven Fabrics</th>
<th>GF Woven Fabrics</th>
<th>CF Woven Fabrics</th>
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**TESTS**

**Bursting Strength**

This test is performed by incorporating an Instron 5566 (Instron, US), as specified in ASTM D1883. Samples have a size of 150 mm × 150 mm × 10 mm, and a total of five samples from each specification are tested. The applied bursting test rate is 100 mm/min.
Compressive Strength

An Instron 5566 (Instron, US) is used to measure the compressive strength, as specified in ASTM D1621. Samples have a size of 10 cm × 10 cm × 1 cm, and a total of five samples from each specification are tested. The applied test rate is 2.5 mm/min.

Drop-Weight Impact Test

The drop-weight impact tester (KN-001, Kuang Neng Machine Factory Co., Ltd., Taiwan, R.O.C.) is used to measure the impact strength, as specified in ASTM D2794. Samples have a size of 100 mm × 100 mm × 10 mm, and a total of five samples from each specification are used for this test. The height where the hemispherical head falls is 80 mm, and the weight of the head is 6.5 kg.

Sound Absorption Test

Samples are tested for sound absorption in a frequency range of 125-4000 Hz by using a double-microphone impedance tube (ARTC, TW), as specified in ASTM E1050-07. Samples are cylindrical and have a diameter of 38mm. After the test, the curve chart where the sound coefficients and their corresponding frequency are indicated will be produced.

RESULTS AND DISCUSSION

Bursting Strength

The bursting strength of various 3D fabric/PU foam composites is indicated in Figure 1. When the 3D/PU foam composites contain nonwoven fabric and CF woven fabric as skin, composite D has a higher bursting strength. This is ascribed to the nonwoven fabrics from the skin, which effectively reinforces the bursting strength and thus the composite have a higher bursting strength. During the bursting strength test, the externally applied force is primarily taken by the skin and then the core. In addition, the skin of composite D consists of PET/Kevlar nonwoven fabric, 3D fabrics, and PU foam materials. PET/Kevlar nonwoven fabrics are easily damaged, as they are characterized by having entangled fibers as a result of needle punching.

![Figure 1. Bursting strength of various 3D fabric/PU foam composites.](image-url)
Compressive Strength

Figure 2 indicates the compressive strength of the various 3D fabric/PU foam composites, and composite D has the optimal compressive strength. The compressive increases as a result of the greater hardness of the PU foam, which means rigid PU foam can withstand a high level of compressive strength. Moreover, composite C has a lower compressive strength than composite D. During the foam reaction, glass fibers would absorb some foaming mixture, which in turn changes the foaming density, and thus the compressive strength of composite C is lower.

![Figure 2](image)

**Figure 2.** Compressive strength of various 3D fabric/PU foam composites.

Drop-weight Impact Strength

The drop-weight impact strength of various 3D fabric/PU foam composites is indicated in Figure 3. The constant foam density has a significant influence on the residual stress of composite C. This result is due to glass fibers that provide a cushioning effect to the composite C, which decreases the impact manners exerted on the composite. In addition, when 3D fabric/PU foam composites are exerted with an impact, the impact energy is transmitted from the skin and then to the core. The cells that constitute the core deform as a result of energy transmission, and they are then fractured in order to dissipate the residual energy when the damage energy reaches their limits. As a result, 3D fabric/PU foam composites can absorb the impact energy via the energy transmission in their skin as well as the porous structure of the PU foam material [8].

![Figure 3](image)

**Figure 3.** Drop-weight impact strength of various 3D fabric/PU foam composites.
Sound Absorption

Figure 4 shows the sound absorption of the various 3D fabric/PU foam composites, and composites C and D both have a sound absorption coefficient of 0.9, which indicates their sound absorption. The foam materials have a smooth surface, which is dis-advantageous to sound absorption. The incorporation of nonwoven fabrics provides the PU foam material with a rough surface, which increases its sound absorption property. In addition, when the incident sound waves reach the surface of nonwoven fabrics, they are thus not reflected, but absorbed by the interior of nonwoven fabrics through their porous structure. When sound waves are transmitted to the inter PU foam, the constituent pores of the PU foam then cause the resonance with the sound waves, which causes the second sound absorption [9, 10].

CONCLUSIONS

This study examines the influences of different compositions of 3D fabric/PU foam composites. When the foaming density is constant, composite D containing CF woven fabrics has the optimal bursting strength of 4320.9 N. When being tested with a compressive strength test, the composite D also yields the optimal compressive strength of 15 MPa. According to the drop-weight impact strength test, the composite C that contains GF woven fabrics have the optimal residual stress of 540.8 N. Finally, both composites C and D can yield a sound absorption coefficient of 0.9. The 3D fabric/PU foam composites are expected to be used as construction and decoration materials.

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