(REFEREED RESEARCH)

COMPRESSION AFTER IMPACT OF 3-D INTEGRATED HOLLOW CORE SANDWICH COMPOSITES

3-BOYUTLU BOŞLUKLU YAPIDAKİ SANDVİÇ KOMPOZİTLERİN DARBE SONRASI SIKIŞTIRMASI

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ABSTRACT

This work was designed to investigate the compression after impact of 3-D integrated hollow core sandwich composites. The 3-D integrated hollow core sandwich composites were prepared and tested. The development process of the compressive damage after low-velocity impact was investigated by image observations. The test results indicated that the impact damage considerably affected the compressive resistance of the sandwiched composites. It was found that the compression after impact decreased with the increasing of impact energy. The compressive damage of the composite was mainly controlled by the front face-sheet, and the load caused the bending of the front face-sheet local was nearly equal to the load of the composite compressive damage. The skin cover could not only reduce the impact damage of the composite, but also leave the damage on the surface, which could be detected easily.

Key Words: Composites, Strength, Performance, Low velocity impact, Damage.

ÖZET

Bu çalışma, 3-boyutlu boşluklu yapıdaki sandviç kompozitlerin darbe sonrası sıkıştırma özelliklerinin incelenmesi üzerine tasarlanmıştır. 3-boyutlu boşluklu yapıdaki sandviç kompozitler hazırlanmış ve test edilmiştir. Düşük hızlı darbe sonrası sıkıştırma hasarının oluşturulması işlemi, görüntü gözlemleme yoluyla araştırılmıştır. Test sonuçları, darbe hasarının sandviç kompozitlerin sıkıştırma direncini önemli ölçüde etkilediğini göstermektedir. Darbe enerjisinin artması ile darbe sonrası sıkıştırmanın azaldığı tespit edilmiştir. Kompozitin sıkıştırma hasarı esas olarak ön üst katman tarafından kontrol edilmektedir ve ön üst katman bölgesinin eğilmesine neden olan yük, kompozit sıkıştırma hasarı yüküne hemen hemen eşit olmaktadır. Dış örtü, yalnızca kompozitin darbe hasarını azaltmakla kalmayıp, aynı zamanda hasarın kolaylıkla fark edilebilecek şekilde yüzeyde kalmasını sağlamaktadır.

Anahtar Kelimeler: Kompozitler, mukavemet, performans, düşük hızlı darbe, hasar.

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1. INTRODUCTION

3-D integrated hollow core sandwich composites have been increasingly used in various industries for their excellent properties, such as high strength, high modulus, low weight, fire retardancy, ease of machining and forming. However, the sandwiched composites are sensitive to impact events and easily damageable which would lead to reduction of residual mechanical properties, especially compression after impact of the composite. The damage would limit the composites' applications and sometimes could even cause severe consequences (1-5). Therefore, it is of great importance to study the low velocity impact damage as well as the residual mechanical properties of the composites.

Compared with the laminated structural composites, the studies on the residual mechanical properties of the 3D integrated hollow core sandwich composites after low-velocity impact are still in the primary stage. Cheng et al (6) investigated the post-impact compressive strength of small composite laminate specimens, and proposed a corresponding model. Yan and Zeng (7) studied the influence of impact energy on the compression after impact of the composite laminates. Lin and Xu (8) developed a reduced stiffness inclusion model to predict the compression after impact of composite laminates. Cheng and Wu (9) also studied the impact damage and damage tolerance of the composite laminates, and analyzed the main influencing factors on the compression after impact.

In this paper, various tests were carried out in order to investigate the compressive breakage behavior of the sandwiched composites after low velocity impact. This work would give some insight to the fatigue damage of the 3D integrated hollow core sandwich composites.

2. MATERIALS AND METHODS

2.1 Specimen preparation

The 3-D sandwich composites, as shown in Figure 1, were prepared by a standard hand lay-up technique with a mixture of epoxy resin (WSR618), hardener (polyamide 651), and diluents (propylene oxide tert-butyl ether 660). The mass ratio of the mixture is 100 of epoxy resin, 20 of hardener, and 10 of diluents (2-3).

2.2 Low velocity impact

Low velocity impact was performed using an instrumented impact testing system, which consists of a drop tower equipped with an impactor and a variable cross-head weight arrangement, a high speed data acquisition system (INV306DF), and a load transducer mounted in the impactor. The impactor weight was kept constant at 3.385 kg for all the tests. Impact energy was adjusted by changing the drop height. The specimen support fixed at the bottom of the drop tower facilitated circular clamped condition with a clear span of 76 mm. The falling weight was guided through two smooth columns. The hemispherical impactor end was fitted with an instrumented tup size 12.7 mm in diameter. Transient response of the sample included acceleration, velocity, deflection, load and energy as function of time. A total of 400 data points were collected during the impact event. In the current study, specimen size by 100 mm × 100 mm was used and tested at energy levels ranging from 8 to 10 J.

2.3 Compressive property test

Compressive tests were performed using a material testing machine (WDW-E2000). The environment conditions of the lab were controlled at 23±2°C and 50±10% relative humidity. The loading speed of the testing machine was set at 1.5mm/min in order to observe the damage propagation at any time during loading process. Compressive load was recorded if there was obvious local instability (the visible salient on the surface of the composites) during the tests, and the instability would occur with a big noise. In order to observe the compressive damage, certain number of samples were unloaded as soon as local instability occurred, and the damage of the samples was examined.

The size of compressive samples is shown in Figure 2. The length filled with resin of two terminal of the samples was 20 mm, and the surface covered with aluminum skins was 1 mm in length. The impacted face-sheet was defined as the front face-sheet, and the other face-sheet as the back face-sheet.

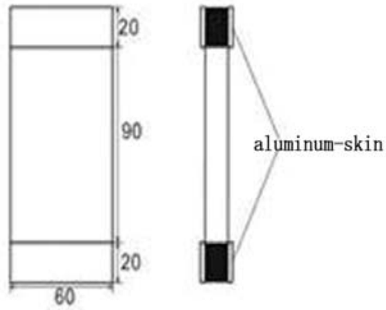


Figure 2. Diagram of sample dimension

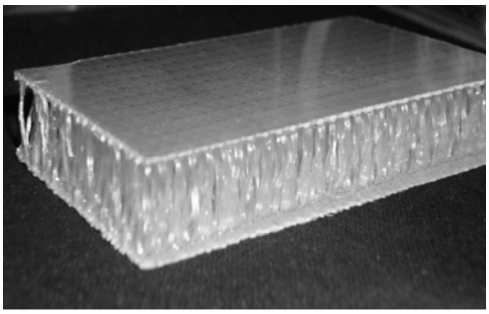
2.4 Damage photographing

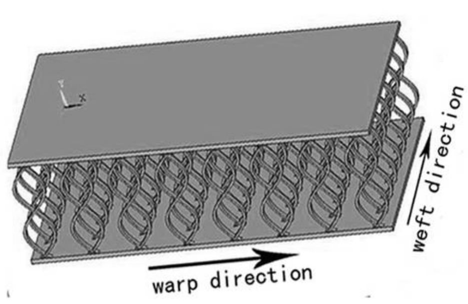
The photographs of the surface damage were taken using a digital camera (Sony DSC-W130) with two 80W light sources. The light passed through the specimen from the bottom. The location and depth of the impact damage were observed on the impact surface of the specimen. The photos were taken for comparison after low velocity impact and compressive tests.

3. RESULTS AND DISCUSSION

3.1 Compression after impact of the sandwiched composites

Three types of 3-D structures were investigated in terms of the impact properties as a function of the z-direction fiber length (5、6 and 7 mm). The compressive resistance of the composite, as shown in Table 1, indicated a dramatic drop after low velocity impact. It can be seen that the average drop was above 18% in warp direction and 24% in weft direction.





(a) (b)

Figure 1. Structure of integrated hollow core sandwich composite:
(a) real diagram of 3D composite, (b) structural diagram of 3D composite

Table 1. Results of compressive tests

Sample	Height of pile/mm	Impact energy/J	Compression before impact/MPa		Compression after impact /MPa	
			warp	weft	warp	weft
1	5	8	3.93	8.19	3.24	6.47
2	6	8	4.22	8.99	3.46	6.83
3	7	6			4.02	7.29
4	7	8	4.73	9.56	3.74	6.98
5	7	10			3.65	6.68
6	7（covered with skins）	8	4.83	9.78	4.18	7.89

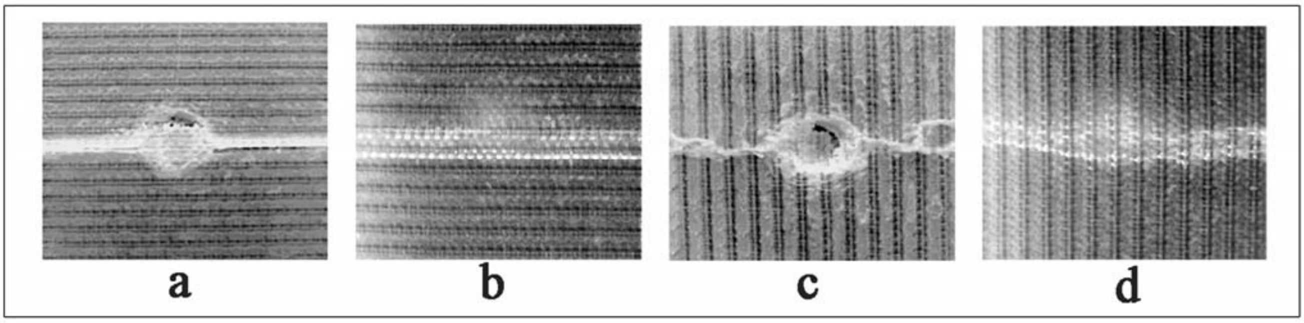


Figure 3. Breakage outline of compression in warp & weft directions: (a) Breakage outline in warp direction (front facesheet) , (b) Breakage outline in warp direction (back facesheet), (c) Breakage outline in weft direction (front facesheet), (d) Breakage outline in weft direction (back facesheet)

The reason can be explained that, on the one hand, the epoxy resin matrix was inherent sensitive to the velocity, and it would become brittle at the high speed load (10). On the other hand, as the core piles of the composites in an “8” construction in the warp direction, they would cause instability when the composites were subjected to the impact damage, leading to the decrease in compressive resistance of the composites.

Figure 3 shows the compressive failure of the sandwiched composites after low velocity impact. The images clearly indicated the compressive breakage was mainly occurred on the front face-sheet, and damage was relatively smaller on the back face-sheet. It was revealed that the residual compressive property of 3-D sandwich composites with low velocity impact damage was mainly controlled by the front face-sheet.

It was also observed that the breakage shapes, as shown in Figure 3, looked quite different in the warp direction and in the weft one. The breakage in the warp direction occurred between the two rows of core piles across the impact point, which seemed like a line on the front face-sheet. It can be explained that the distance between two rows of piles had a certain distance in warp direction, and the face-sheet between the two piles had no support, and easy to break. While the breakage shapes in the weft direction appeared irregular. The reason is that the piles in the weft direction were arranged dense and irregularly and some piles under the punch would squeeze each other when the composites were subjected to impact, resulting in the bigger damage region in weft direction than that in warp direction.

3.2 Influence of impact energy on compression after impact

Figure 4 shows the compression after impact of the sandwiched composites. It clearly reveals that the compression after impact decreased with the increase in impact energy, while the compression kept constant before impacting. For the core height of 7 mm, the compression after impact dropped from 4.02 MPa to 3.65 MPa in warp direction when the impact energy increased from 6 J to 10 J, and the data dropped from 7.29 MPa to 6.68 MPa in weft direction. This can be attributed to the damage degree of the composites caused by the increase in impact energy, leading to the decline in the compression after impact of the composites (2).

The appearance of compressive failure of the sandwiched composites observed by the digital camera is presented in Figure 5. Although the breakage shapes looked different in the warp direction and in the weft one, as presented in Figure 3, the breakage process of the composites is similar in both directions. For the energy of 6 J, cracking of the resin across the central line of the impact point occurred, accompanied with whitening phenomenon near the contact between the core piles and the face-sheet. For the energy of 8 J, the resin across the central line of the impact point cracked completely, and some degree of tearing were observed for the fibers, and the decline of the core piles occurred too. For the energy of 10 J, the resin and fibers across the central line of the impact point were both failed, and the front face-sheet ruptured and the core piles were damage severely.

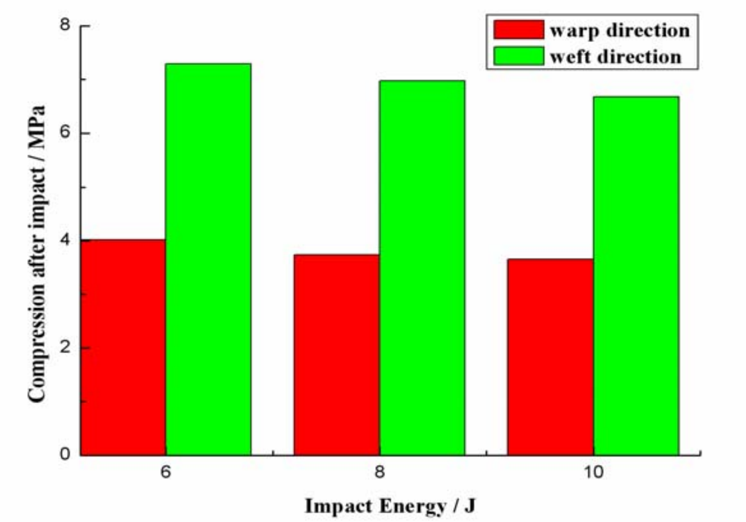


Figure 4. Influence of impact energy on compression after impact

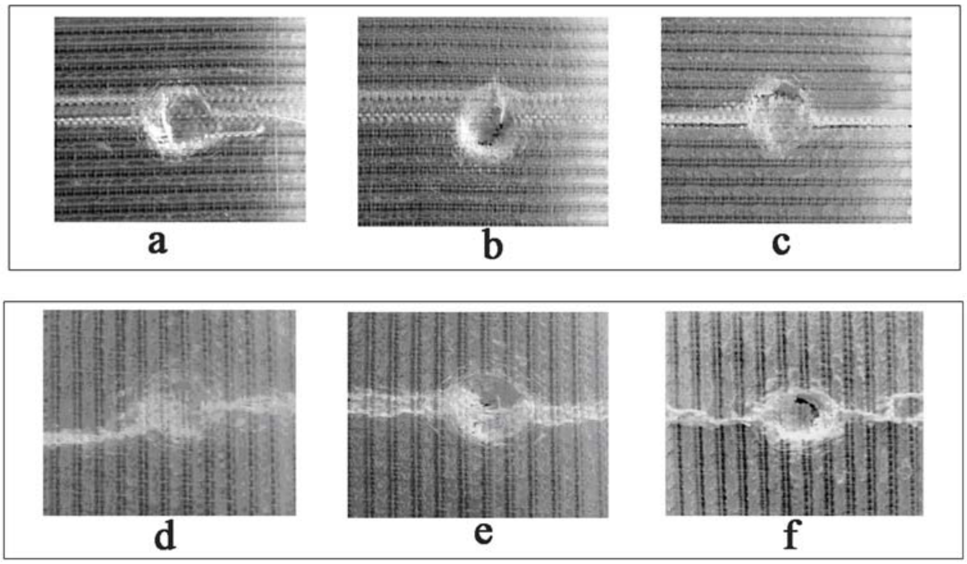


Figure 5. Compressive breakage outline of the composites in different energy:

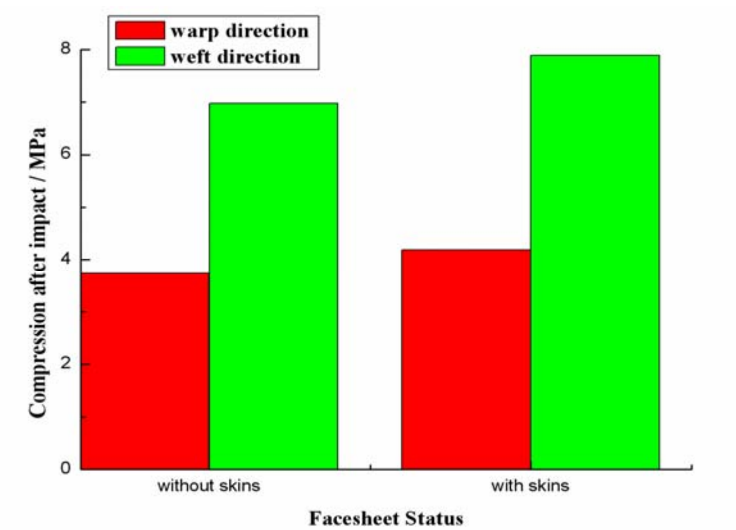


Figure 6. Influence of covered skins on compression after impact

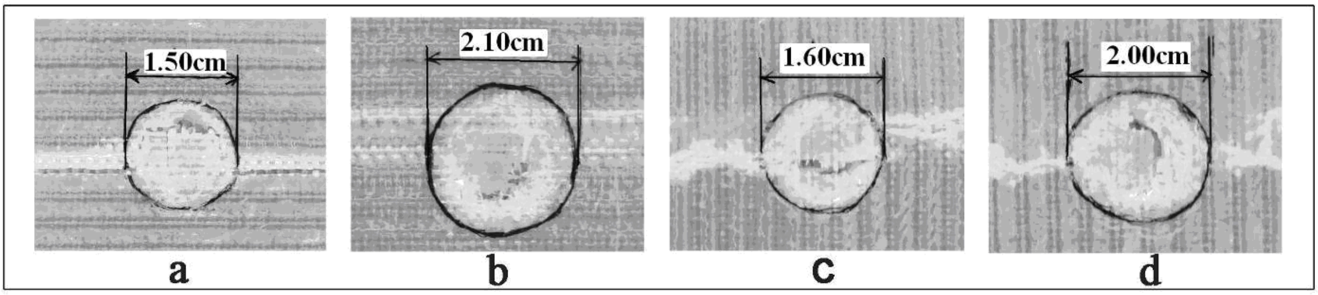


Figure 7. Influence of aluminum skins on compression after impact of the composites: (a) Damage in warp direction (covered no aluminum), (b) Damage in warp direction (covered with aluminum), (c) Damage in weft direction (covered no aluminum), (d) Damage in weft direction (covered with aluminum)

It was observed during the tests that there were five specimens appeared the phenomenon of local instability (invisible surface salient) in the process of the compression, and the loads of the local compressive instability and compressive damage were recorded in the tests. Although the impact energies of these five specimens were different, the relative deviation of the load of local compressive instability and compressive damage was less than 7.1% for these five specimens. It was also found that although the compression was stopped immediately once the specimens displayed visible failure, it was observed that the specimens had reached ultimate failure at that point. The other specimens did not show obvious stage of local instability during the test, but the existence of local instability could be judged by observing the structures of the ultimate failure. It can be concluded based on the testing observations that the local instability was the main damage form of the composites after low velocity impact, and the load of local instability of the laminates could be viewed as the ones of compressive damage (11-12).

a) Breakage outline in warp direction (6J), (b) Breakage outline in warp direction (8J), (c) Breakage outline in warp direction (10J), (d) Breakage outline in weft direction (6J), (e) Breakage outline in weft direction (8J), (f) Breakage outline in weft direction (10J)

3.3 Influence of aluminum skins on compression after impact

Figure 6 shows the results of compression after impact of the composites with and without aluminum skins. The test results indicated that the aluminum skins had less influence on the compressive properties of the sandwiched composites before low velocity impact. However it could improve the compressive resistance of the composites after low velocity impact, as revealed in Figure 6. For the pile height of 7 mm and the impact energy of 8 J, the compression after impact increased from 3.74 MPa to 4.18 MPa in warp direction for the composites covered with aluminum skins, and the data increased from 6.98 MPa to 7.89 MPa in weft direction. The reason is that aluminum skins could absorb the impact energy effectively (2), thus the compressive resistance of the composites could be improved obviously after low velocity impact.

Comparing the appearance of compressive damages, it was found that the damage area of the composites with aluminum skins was obviously expanded, as shown in Figure 7. The damage diameter of the composites covered with aluminum skins was about 2.1cm in warp direction, while 1.5cm for the ones without aluminum skins. In weft direction, the damage diameter of the composites covered with skins was 2.0cm, and 1.6cm for the ones without skins. On the other hand, the compression after impact of the composites covered with aluminum skins was higher than that of the ones without skins, as illustrated in Figure 6. The reason is that the absorption energy of the composites was mainly interacted by plastic deformation of the aluminum skins, and the crackle in the panel and the breakage in the core fibers. The aluminum skins had better toughness, which could absorb the energy effectively, thus the composites covered with aluminum skins had better residual strength.

4. CONCLUSIONS

This study revealed that the behavior of compressive damage was different in warp and weft directions for the 3-D integrated hollow core sandwich composites. The compressive damage was mainly caused by local instability in warp direction, while by pile squeezing damage in weft direction. It was also found that the damage of low velocity impact would severely affect the compressive resistance of the sandwiched composites, and the compression after impact of the composites would decrease with the increase in the impact energy. The aluminum skins had an obvious reinforcement function to the sandwiched composites, which could not only reduce the damage caused by impct, but also increased the residual compressive resistance of the composites with low velocity impact damage.

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