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Low Velocity Impact Behaviour of Carbon/XPS Sandwich Composites

Karbon/XPS Sandviç Kompozitlerin Düşük Hızdaki Darbelere Karşı Davranışı

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Araştırma Makalesi / Research Article

LOW VELOCITY IMPACT BEHAVIOUR OF CARBON/XPS SANDWICH COMPOSITES

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ABSTRACT: This work presents drop-weight impact properties of carbon fabric/extruded-polystyrene (XPS) sandwich composites reinforced with different ratios of carbon nanotubes (CNT). Sandwich composites were infused with epoxy resin containing 0.5% and 1% CNT during the manufacturing. The sandwich composites were impacted with 10J, 30J and 50J energies to compare their impact resistance and energy absorption properties. Impact test results showed that sandwich composites with CNT had higher energy absorption and deformation values with lower maximum loads compared to neat sandwich composite at 10J impact energy. However, neat sandwich composites had both higher energy absorption and maximum load than sandwich composites with CNT's due to more severe impact damages and higher dent depths at 50J.

Key words: Sandwich composites, carbon nanotubes, impact resistance, carbon fabrics.

KARBON/XPS SANDVİÇ KOMPOZİTLERİN DÜŞÜK HIZDAKİ DARBELERE KARŞI DAVRANIŞI

ÖZET: Bu çalışma, farklı oranlarda karbon nanotüp (CNT) ile güçlendirilmiş karbon kumaş/ekstrüde-polistiren (XPS) sandviç kompozitlerin düşük ağırlıklı darbe dayanımı özelliklerini sunmaktadır. Sandviç kompozitler, üretim sırasında %0,5 ve % 1 CNT içeren epoksi reçinesi ile infüzyon edilmiştir. Sandviç kompozitler 10J, 30J ve 50J enerjilere maruz kalarak darbe dayanımları ve enerji absorpsiyonları karşılaştırılmıştır. Darbe testi sonuçlarına göre CNT'li sandviç kompozitler 10J darbe enerjisinde, CNT içermeyen sandviç kompozitlere göre daha fazla enerji absorpsiyonu ve deformasyon değerlerine sahipken daha düşük maksimum yük değerleri göstermiştir. Ancak, 50J darbe enerjisinde CNT içermeyen sandviç kompozitler daha fazla darbe hasarı ve darbe derinliğine sahip olmalarından dolayı, CNT içeren sandviç kompozitlere göre daha yüksek enerji absorpsiyonun ve maksimum yük değerleri göstermiştir.

Anahtar Kelimeler: Sandviç kompozitler, karbon nanotüpler, darbe dayanımı, karbon kumaşlar.

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1. INTRODUCTION

Fibre reinforced sandwich composite laminates are commonly used in aerospace, automotive, military and marine applications due to their lightweight and specific strength [1]. They are consisted of high strength fabric face materials and lightweight but thick core materials. Foams are one of the most preferred materials to be used for the core part of the sandwich structures due to their low costs [2, 3]. Although sandwich composites have advantages over metallic structures, their low impact tolerance, easy delamination, and poor damage tolerance behaviours are the main drawback [4]. Low velocity impact damage can be introduced as a result of events such as dropping of tools during maintenance or due to impact of hailstones.

One of the methods to improve impact damage-tolerance of composite laminates or sandwich composites is making the through-thickness reinforcement using stitching, tufting or Z-pinning methods [5-7]. However, it requires additional tooling and manufacturing process which increases the cost of the composite laminates. Kaya and Selver [8]observed that using carbon or glass composite Z-pins enhanced impact resistance of glass or carbon face sandwich composites. Santhanakrishnan et al. [9] studied impact response of glass face/foam core sandwich composites after applying a novel stitching technique. Their results showed that sandwich composites with stitching had more load carrying capacity than the unstitched composites. Henao et al. [10] analysed energy absorption capacities of sandwich composites made from glass and carbon faces with polyurethane foam core. Sandwich preforms were tufted with E-glass threads through various tufting densities.

Modifying the resin system is one of the other methods for improving energy absorption and enhancing impact resistance the composite laminates using nanoparticles [11, 12]. Among them, carbon nanotubes (CNT) offer to enhance poor out-of-plane mechanical performance of fibre reinforced composites [13, 14]. Soliman et al. [15] investigated impact performance of carbon woven fabric composites containing 0.5%, 1.0%, and 1.5% multi-walled carbon nanotubes (MWCNTs). They observed that MWCNTs enhanced the impact response and reduced the impact induced areas of composites with higher energy absorption. Kostopoulos et al. [16] observed an increase in impact and damage tolerance of carbon fibre reinforced composites laminates after using 0.5% per weight MWCNTs in epoxy matrix.

To date, only a limited number of studies have investigated the effect of CNTs on flexural properties or fracture toughness of sandwich composites [17, 18]. However, much less is known about how CNT affects impact resistance of sandwich composites. Thus, this study investigates low velocity impact properties of carbon face/extruded-polystyrene (XPS) foam core sandwich composites containing various ratios (0.5% and 1%) of carbon nanotubes (CNT). The sandwich composites were subjected to 10J, 30J and 50J impact energies with drop-weight impact tester.

2. EXPERIMENTAL

2.1. Manufacturing of Sandwich Composites

Sandwich composites were manufactured by using extruded polystyrene (XPS) foam as core material and twill carbon (245 g/m^2) woven fabric as face material. Carbon woven fabrics were placed with $[0°/90°]_3$ configurations over and under the XPS core to create the sandwich preforms. Commercial functionalized Multi Walled Carbon Nano Tubes (MWCNT) (Purity >96%, outside diameter: 8-18nm) were supplied from Nanografi, Turkey. MWCNT and Hexion MGS L160 epoxy resin suspension was mixed with a mechanical stirrer at various speeds and times such as 500 rpm (10 min), 1000 rpm (30 min), 1500 rpm (15 min), and 2000 rpm (15 min) to create a homogeneous dispersion. Then, the suspension was subjected to an ultrasonic bath sonicator for 15 minutes at the room temperature to avoid CNT agglomerations. After the mixing process, Hexion MGS H160 hardener was added with hardener-CNT-epoxy weight ratio of 35:100. Then, sandwich preforms were infused with those epoxy resin systems containing 0.5% and 1.0% carbon nanotubes (CNT) by a VARTM method as presented in Figure 1. Curing was done at 50°C for 1 hour. Table 1 presents sandwich composites containing CNT's.

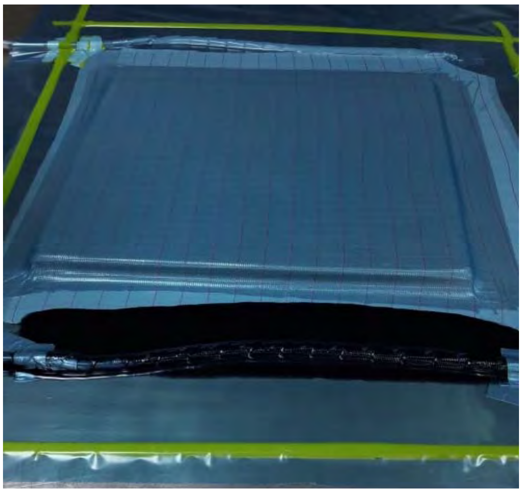

Figure 1. Infusion of sandwich composite with CNT/epoxy mixture.

Table 1. CNT reinforced sandwich composites.

Sample codes	Face material	Core material	CNT weight ratio In epoxy (%)
C	Carbon fabric	XPS	-
C05	Carbon fabric	XPS	0.5
C1	Carbon fabric	XPS	1.0

2.2. Test Methods

Three different energy levels (10J, 30J and 50J) were used to compare the impact properties of sandwich composites with and without CNT's using ASTM D7136 standard method through CEAST 9350 drop weight impact tester. The impactor mass and diameter of the steel striker is 4.9 kg and 12.7 mm, respectively. The size of the test specimens is 100 mm x 100 mm.

The density of sandwich composites was measured by a density-meter (Precisa®, XP205) as following ASTM D792-13 standard using. The density and thickness of sandwich composites were presented in Table 2. The density of sandwich composites was slightly decreased by addition of CNTs. The dent depth of sandwich composites was measured using a digital depth gauge.

Table 2. Properties of sandwich composites.

Sample	Thickness (mm)	Density (g/cm^3)
XPS	17.80 (±0.05)	0.033 (±0.001)
C	18.90 (±0.15)	0.350 (±0.014)
C05	18.30 (±0.20)	0.332 (±0.025)
C1	18.90 (±0.30)	0.312 (±0.056)

3. RESULTS AND DISCUSSIONS

Figure 2 presents test results of 10 J impacted sandwich composites with (C05, C1) and without (C) carbon nanotubes. It can be seen from Figure 2(a) that the addition of CNT decreased maximum impact forces of sandwich composites. This might be due to agglomeration of CNT during mixture and infusion of sandwich composites. However, higher energy absorption can be observed from Figure 2(b) after using CNT's. It seems possible that sandwich composites become more ductile after addition of CNT, and the CNT added sandwich composites absorbed more energy than that of pristine composites as shown in Figure 2(c) with due to higher deformation. None of the samples were perforated or penetrated at 10J impact energy as given in Figure 3. The rebounding of the impactor can be also predicted from Figure 2c, since there are close force-deformation curves for all sandwich samples.

Energy-time plots indicate that there are two energy points (I and II) as shown in Figure 2(b). The highest point is the impact energy (peak energy) point and the lowest one is the total (absorbed) energy point. The difference between those two energies is the excessive energy which kept in the impactor and helped for rebounding during the impact test. The software automatically calculated absorbed energy by using equation (1).

$$E_A = \frac{1}{2} m(v_i^2 - v_r^2) \qquad (1)$$

Where E_A, absorbed energy (J); m, mass of the impactor (kg); v_i, impact velocity (m/s); v_r, rebounding velocity (m/s).

Impactor mass was always constant and velocity values changed the final absorbed energy values. For example; absorbed energy was about 4.2 J for 10 J impacted C sample whereas impact velocity and rebounding velocity were 2.015 m/s and 1.53 m/s respectively with 4.9 kg constant mass.

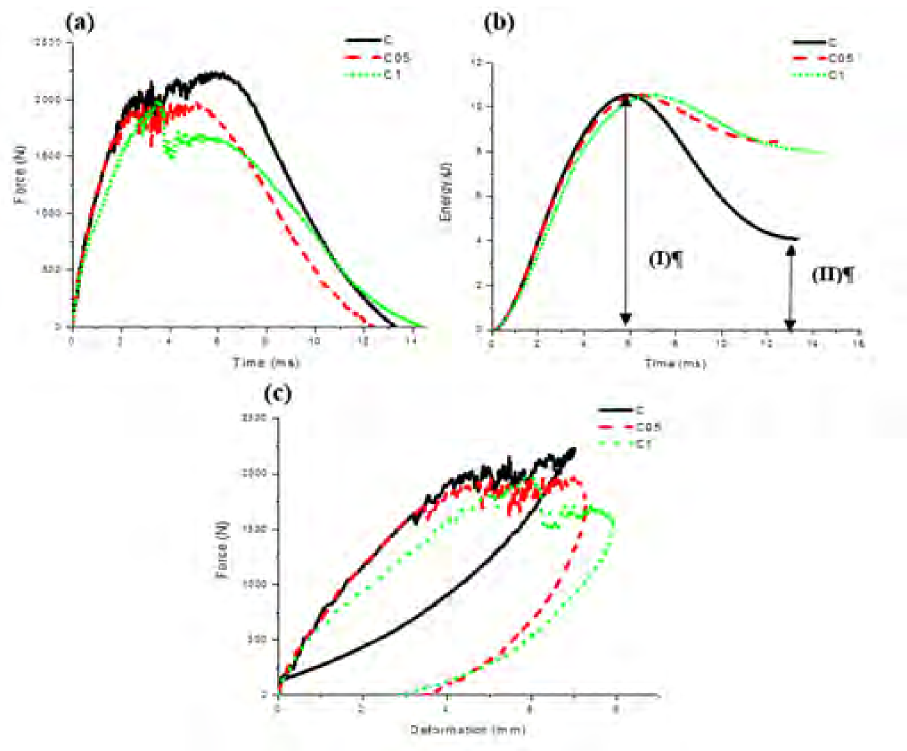

Figure 2. Force-time (a), energy-time (b), and (c) force-deformation history of sandwich composites at 10J impact energy.

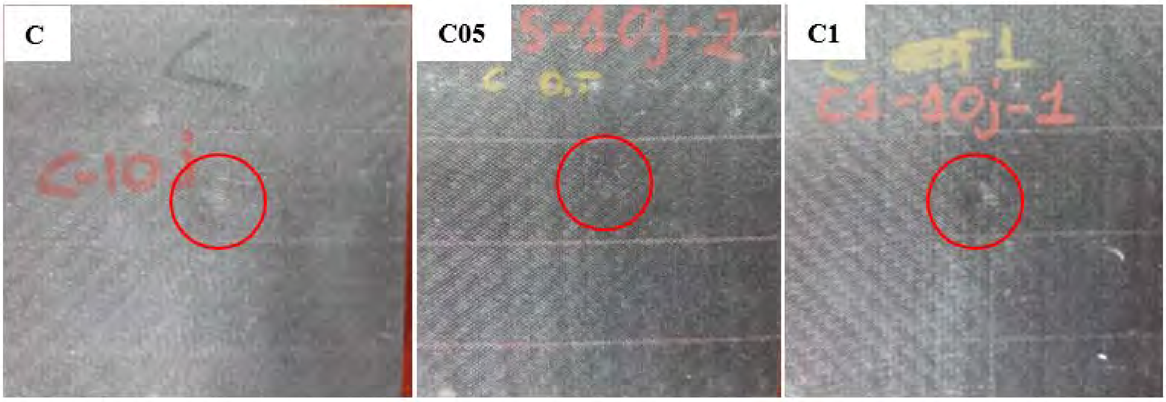

Figure 3. Photos of 10J impacted sandwich composites.

Figure 4 shows the results of 30J impacted composites. Figure 4(a) presents that there are two peak force points (I and II) occurred during the test. This is due the top face part of the sandwich composite was completely perforated, and the back face part of the sandwich composite was met with impactor. Similar behaviour can be also seen for the Figure 4(b) as force-deformation plots. However, C and C05 sandwich composites exhibited closed curves at their second peaks (II) due to not reaching the back face as also observed in Figure 2(c). This indicates that the impactor fully penetrated to the top faces of the sandwich composites, but it could not pass through back face part of the sandwich composites.

Table 3 also presents the top and back-face penetration summary of sandwich composites. It can be seen that only C1 sandwich composite had both full penetrations at top and back faces. Figure 4(a) presents that the addition of CNT decreased maximum impact forces of sandwich composites in terms of first peak points. However, C1 and C composites showed very similar impact force values when the impactor met with back-face of the sandwich composites, which is second peak point. Figure 4(b) indicates that C and C05 sandwich composites had very similar permanent deflection values due to not fully penetration.

For energy absorption behaviours, C1 sandwich composites had higher energy absorption than that of C05 sandwich composites which is due to fact that C1 sandwich composites had higher impact damages due to back face fracture, and most of the impact energies were absorbed by the damages such as fibre/matrix delaminations and fibre breakages.

Figure 5 shows test results of 50J impacted sandwich composites. All the samples were perforated/penetrated at 50 J impact energy level. Figure 5(a) presents that there are two peak points (I and II) occurred during the test again as 30J. The impactor reached to back-face part of composite as shown in Figure 6. It is clear that the peak-II is higher than peak-I for all sandwich composites. It seems that the back face of the sandwich composites can carry more impact forces than the top face of the sandwich composites, resulting in slightly higher peak-II values as shown in Figure 5a.

Table 3. Dent depth of sandwich composite after 10 and 50J impact energy.

Impact energy (J)	Sample	Top face depth (mm)	Back face penetration (mm)
10	C	0.78 (±0.12)	-
	C05	0.21 (±0.04)	-
	C1	0.65 (±0.10)	-
30	C	Full-penetration	1.13 (±0.35)
	C05	Full-penetration	2.26 (±0.35)
	C1	Full-penetration	Full-penetration
50	C	Full-penetration	Full-penetration
	C05	Full-penetration	Full-penetration
	C1	Full-penetration	Full-penetration

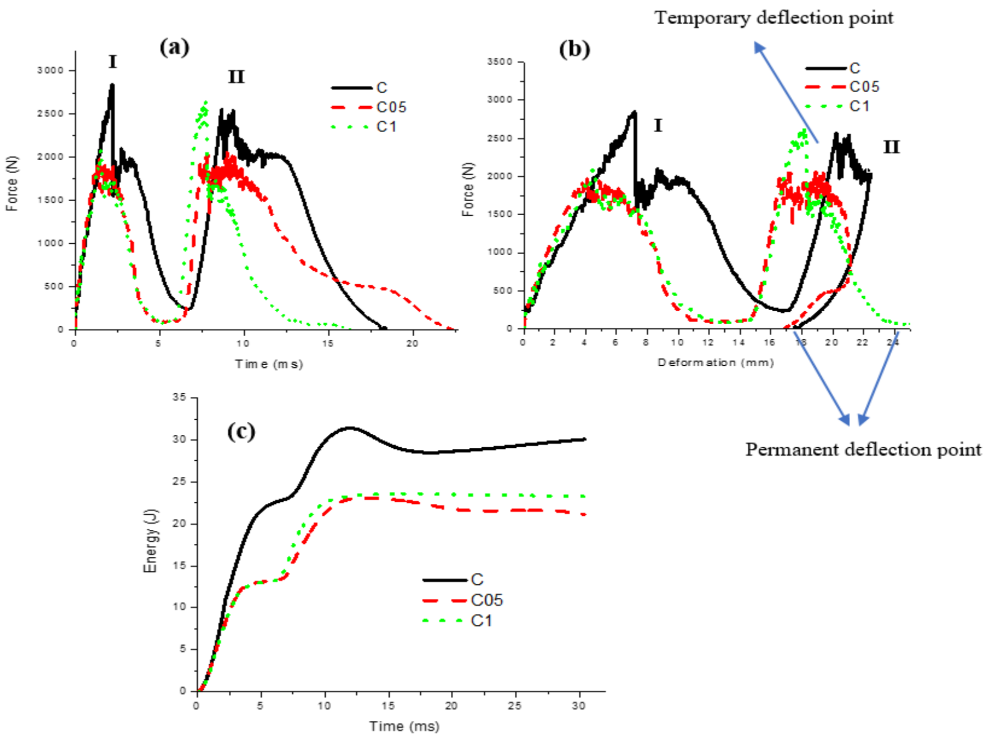

Figure 4. Force-time (a), energy-time (b), and (c) force-deformation history of sandwich composites at 30J impact energy.

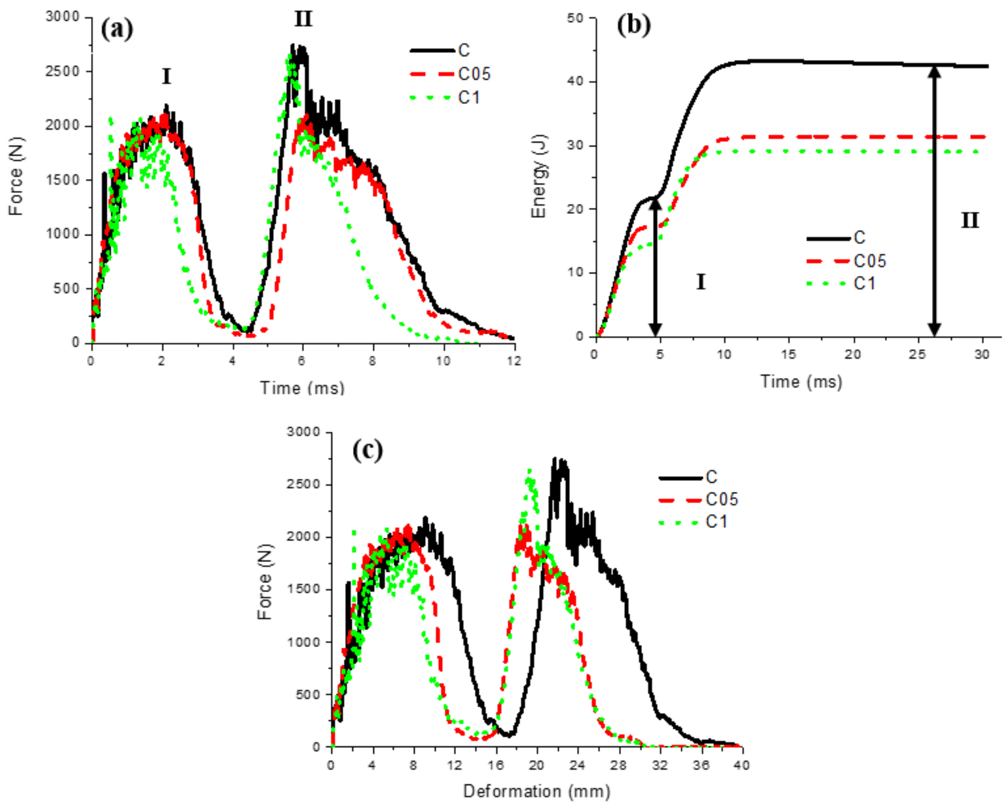

Figure 5. Force-time (a), energy-time (b), and (c) force-deformation history of sandwich composites at 50J impact energy.

Comparing sandwich composites with and without CNT's, they had similar Peak-II values at 50J while the neat sandwich had higher peak-II values compared to CNT added sandwich composites as also seen at 10J. It can be also seen that addition of 1% CNT led to higher back force values compared to 0.5%.

Figure 5(b) exhibits that there are two energy absorption points which are due to top (I) and back (II) face impact penetrations. However, top and back face parts of composites absorbed similar energy absorption. For example, C sandwich composites absorbed about 21J and 43J impact energies for top and back face, respectively according to Figure 5c. The energy absorption is 17J and 31J for C05 and 14J and 29J for C1 sandwich composites. It seems that energy absorption of top face of C05 composite is slightly higher than its back face. This is probably due to top face of carbon fabrics has higher fibre breakages than the back face (Fig.6), since impact energy can be absorbed by fibre fracture in addition to delamination and matrix cracks. It is clear that addition of CNT decreased energy absorption of sandwich composites whilst the 1% CNT loading had the lowest energy absorption peaks. This is probably due to neat sandwich composites showed more severe damages during 50J impact energy in Figure 6, and C sandwich composite absorbed most of its energy by failure mechanism such as fibre breakages, matrix cracks and delamination. Figure 5(c) indicates that the neat sandwich composite had higher deformation values compared to C05 and C1 sandwich composites. This is again due to creating more severe damages at neat composites with higher back face penetration depth as in shown Table 3.

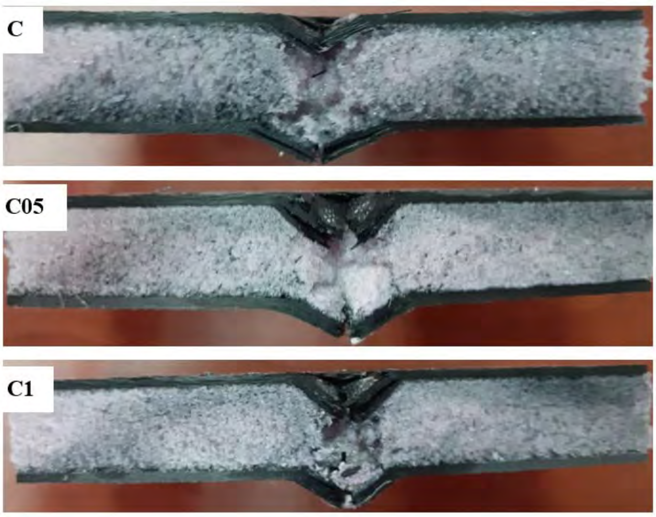

Figure 6. Cross-section images of 50J impacted sandwich composites

4. CONCLUSIONS

Carbon/XPS sandwich composites containing CNT were successfully manufactured using vacuum infusion method. For lower impact energy (10J), the addition of CNT increased energy absorption and maximum deformation of sandwich composites. On the other hand, maximum impact force values were decreased with increasing of CNT loading due to agglomeration of CNT during mixture and infusion of sandwich composites. Two peak force points occurred during the test for 30J and 50J impact energy levels due the top-face part of the sandwich composite was completely perforated, and the impactor reached to back-face part of the composite. The neat sandwich composite had higher impact force and energy absorption values compared sandwich composites with CNT's for high impact energy (50J). It was seen that there were more severe damages and higher dent depth for the neat composites at 50J impact energy. The sandwich composites with CNT absorbed more energy than that of pristine composites at all energy levels due to more severe damages.

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