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REPEATED IMPACT RESPONSE OF SANDWICH COMPOSITES

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Abstract: Due to high mechanical properties like high strength, and light weight, fiber-reinforced/core have been commonly utilized in structural sandwich composites that are used in many diverse engineering areas like complex aircraft and automobile parts, wind turbine blades, cage systems also and so on. In this study, Vacuum assisted resin infusion molding (VARIM) was used to manufacture two types of synthetic sandwich composites by using 80 °C for duration of 8 hours. Stacking sequences of sandwich composites were [0º/90º/0º/PVC foam 10 mm /0º/90º/0º] and {0º/90º/PVC foam 5 mm /0º/0º/PVC foam 5mm /90º/0º}with constant thickness. The experimental investigation on two types of synthetic sandwich composites by using repeated impact for different impact energy from 5 to 20 J at room temperature was compared. Specimens prepared with dimension 100 mm square were subjected to low velocity impact (LVI). The results are obtained show that the sandwich composites with multi core are stiffer than the normal sandwich composites.

Keywords: *repeated impact, two-core, glass fiber, low velocity, PVC foam, sandwich composites.*

أستجابة الساندوج للأحمال المتكررة

الخلاصة: بالنظر للخواص الميكانيكية العالية التي تتميز بها المواد المركبة مثل القوة وخفة الوزن يتم استخدام ألياف التقوية واللب في تركيب الساندوج والذي يستعمل في الكثير من المجالات الهندسية المتنوعة مثل السفن الفضائية، قطع غيار السيارات، ريش توربينات الرياح لأنتاج الطاقة الكهربائة الخ. تم تصنيع العينات بأستخدام طريقة تغلغل الراتنج بالضغط عند درجة حرارة 80 سيليزي ولمدة 8 ساعات. ترتيب الالياف واللب للساندوج كانت [0°/90°/0°/ اللب 10ملم/0°/90°/0°] للساندوج الاعتيادي, [0°/90°/ اللب 5 ملم/0°/0°/ اللب 5 ملم/90°/0°] للساندوج ذو اللب المزدوج مع تثبيت السُمك لكلا النوعين. أجريت هذه التجربة بأستخدام نوعين من العينات وعُرضت الى احمال متكررة مختلفة من 5 الى 20 جول عند درجة حرارة الغرفة وتم مقارنة التنائج. أبعاد العينات المعدة 100 ملم مربع والتي عُرضت الى حمل السرعة المنخفضة. وتشير النتائج ان التصميم الجديد من الساندوج المركب ذو اللب المزدوج أقوى من الساندوج الاعتيادي .

1. Introduction

1.1. General background

In the last decade, fiber-reinforced and core have been commonly used in order to product traditional sandwich composite which consists of different core thickness or material between two layers, however in this paper, he used sandwich composite with two-core, internal sheet and two layers.

Due to superior specific properties of sandwich composites like light weight, high stiffness, high strength, excellent thermal insulation, and high bending stiffness, the

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sandwich composite has used in various areas such as aircraft, marine industries and automotive etc. The purpose of study is an experimental investigation in effect the core number on repeated Impact response for sandwich composites.

1.2. *Review*

Core and face sheet material and their thicknesses play mainly role in structural design of sandwich composites. Icten [1] used single and repeated impact test of woven E-glass/epoxy composite in order to investigate in effect the temperature on the impact response. He found that composite was subjected to repeated impact at -50°C larger than that at room temperature. Effect thickness on the repeated impact response of composite plates was performed by Atas et al [2]. The authors depicted perforation case occurs completely by repeated impact energy on the samples by using different energy levels.

Alshamary et al [3] have investigated experimentally of low velocity impact behavior for three types of sandwich composites by using drop weight impact machine; they found that by increasing the number of core the contact force values decreases.

Icten [4] studied repeated impact response of glass and epoxy laminates, the author used two types of specimen. Impact tests were conducted at room temperature and -40°C. The specimens were subjected to impact loading at -40°C have higher peak force values than specimens were impacted at room temperature, however the absorbed energy lower than that subjected to impact loading at room temperature.

Authors in [5] have examined the low velocity impact behavior to two types of cores which were deferent in material and thickness, Caprino et al compared the results of absorbed energy, perforation energy, and maximum contact force. They found that the core is affective on the material response of sandwich composite.

Drop-weight impact loading machine was used to obtain on repeated impact by Baucom et al [6]. Prepared specimens of sandwich consist of a plain-woven laminate, orthogonally woven monolith, and a warp-knit, the results indicate that specimens with orthogonally woven monolith greater opposition penetration threshold.

Effect thermal ageing was studied by Atas et al [7] they used single impact and repeated impact test to calculate damage resistance of composites. Arikan and Sayman [8] manufactured two types specimens composites by using E-glass fiber as reinforcing while polypropylene and epoxy as a matrix material, and they used single and repeated impacts test. They found that the composite is affected by type of resin.

1.3. Numerical Studies Review

Li and sun [9] studied effect of repeated impact loading on structures of steel. Impact damage and low velocity impact properties in the sandwich composites were studied by Karahan et al [10]. They used four types of core thicknesses between the face sheets. Impact damage and compressive strength were analyzed and they also found energy, absorbed energy to load and time to load. Daniel et al [11] manufactured composite laminates by using Woven carbon/epoxy and woven glass/vinyl ester with different

PVC foams densities in order to investigate in tolerance of damage and they found that damage cannot be visible but its effects on the mechanical properties of the structure. Experimental and numerical study by Gordon et al [12] investigated that the damage areas are classified to three types; the firstly hardly visible impact damage, secondly visible impact damage and thirdly apparently visible impact damage.

2. Manufacturing of samples

2.1. *Material Description*

Synthetic sandwich composites were manufactured by using E-glass fabrics (0, 90) direction as reinforcing material however PVC foam (5/5mm, 10mm) thicknesses as a core material were chosen. Epoxy resin and hardener were used as a matrix material and the ratio of the resin and hardener was 3/1. The typical properties of E-glass and core are given in Tables 1 and 2, respectively.

Table 1 Mechanical properties of E-glass (from the manufacturer's data sheet).

	Ex	Ey	Xt	Xc	Yt	Yc	S	G12	V12
Unit	Mpa	Mpa	Mpa	Mpa	Mpa	Mpa	Mpa	Mpa	
E-Glass	28600	10760	653	301	62	100	56	7390	0.26

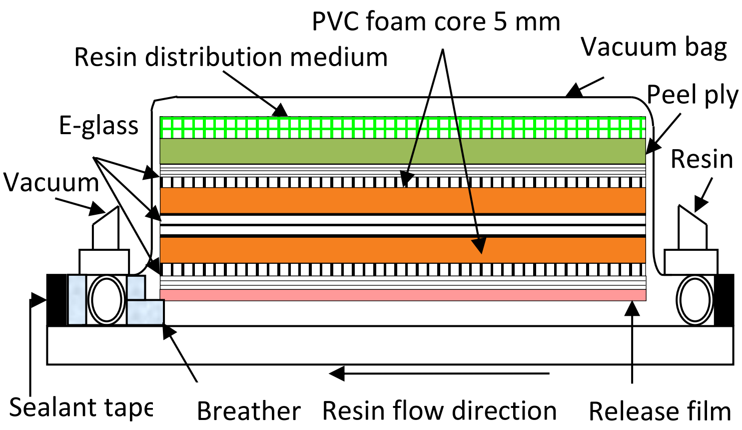
Table 2 Mechanical properties of C.71.55 PVC foam core (typical properties for AIREX,) (Metyx, nd)).

	Density	Compressive modulus	Compressive strength	Shear modulus	Shear strength
Unit	Kg/m^3	MPa	MPa	MPa	MPa
C.71.55 PVC	60	70	0.95	21.5	0.93

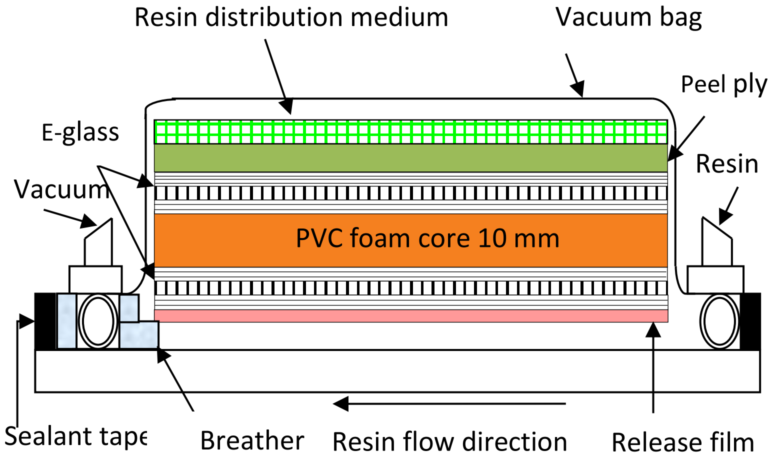
2.2. Fabrication of Sandwich composites

E-glass fabrics and PVC foam core were used in order to obtain two types of stacking sequences (Synthetic sandwich composites), {0º/90º/0º/ 10 mm PVC foam /0º/90º/0º} and {0º/90º/5 mm PVC foam/0º/0º/5 mm PVC foam/90º/0º}. Vacuum assisted resin infusion molding (VARIM) was used to manufacture the samples at 80 °C during 8 hours under a pressure of 250 kPa, and then the temperature is decreased gradually to room temperature Fig 1. Samples prepared with dimension 100 mm square subjected to low velocity impact (LVI).

The first design of sandwich composites were manufactured by using 10 mm core thickness while the second design of sandwich composites were manufactured by using two cores with 5 mm thicknesses each other. Specimens are depicted in Fig 2.



a



b

Figure. 1 Explains the Schematic drawing of components of VARIM process for (a) sandwich composites with multi core (b) Normal sandwich composites

Figure 2. Prepared specimens of sandwich composites (a) with multi core (b) normal

2.3. Testing Machine

Repeated impact tests were performed by using drop-weigh machine (Fractovis Plus impact machine) as shown in Fig 3. Prepared specimens of sandwich were subjected to different impact energies by using hemispherical impactor nose steel 12.7 mm diameters, the specimens were based on inner diameter 76 mm at the machine during the impact tests. Impactor falling height is increased in order to obtain on impact energy from 5 to 20J at room temperature with constant mass 5 kg. The maximum energy and velocity for the drop-weigh machine is 1800 J and 24 m/s, respectively. Every test was repeated three times for each type of sandwich composite and impact energy. Force, time, velocity, deflection, and absorbed energy values were recorded by using data acquisition system (DAS), which gives 16000 data for each test.

Figure 3 Fractovis Plus impact machine with data acquisition system (DAS)

3. Results and Discussion

Effect repeated impact of Synthetic sandwich composites was studied in this paper, experimentally. Two types of Synthetic sandwich composites consist of six layers with various PVC foam core configurations. Prepared specimens of each arrangement were subjected to impact energy 5, 7.5, 10, 15 and 20J until perforation case occurs. Number of repeated impacts (Nr) for sandwich composites with multi core higher than normal sandwich composites until 15J impact energy however at 20J numbers of repeated impacts (Nr) for two types of sandwich composites are similar because perforation threshold happens at high impact loading in general as can be seen from the Fig 4. Percentage of repeated impact-impact energy curve is given in the Fig 5. The percentage increases by increasing impact loading until 10J, then the percentage decrease by increasing impact loading because the impactor penetrates in specimen by using higher impact loading. The percentage of repeated impact between normal sandwich composites and sandwich composites with multi core was calculated by

$$\% (N_I) = \frac{Nr_L - Nr_H}{Nr_L} * 100 \qquad (1)$$

Where NrL, and NrH represent low repeated impacts number (number of repeated impacts for normal sandwich composites and high repeated impacts number (number of repeated impacts sandwich composites with multi core), respectively.

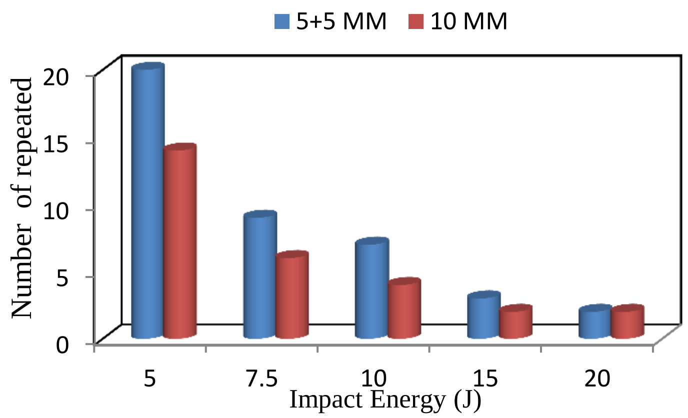


Figure 4. Number of repeated impacts (Nr) with impact energy diagram of sandwich composites

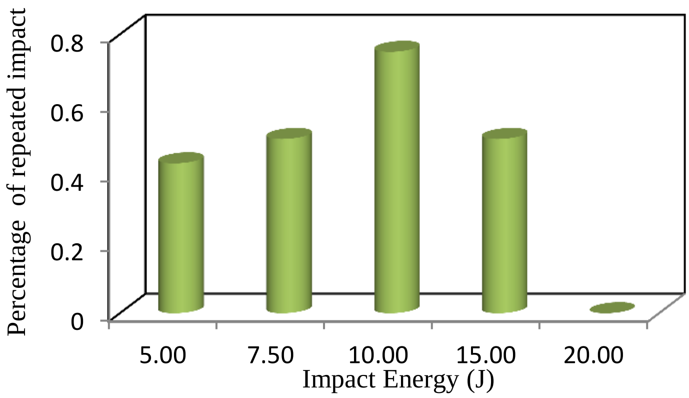


Figure 5. Percentage of repeated impact number with impact energy

3.1. Contact force-deflection response

Contact force-deflection curves explain damage of specimens subjected to impact loading. There are two types of curves, open curve and closed curve. The open curve represents perforation threshold while closed curve contains ascending segment and descending segment as shown in Fig 6. The ascending segment slopes are called impact bending stiffness however descending segment slopes indicate to rebounding threshold after impact the sample. It can be observed from Fig. 7 by using 10J repeated impact energy the bending stiffness increase by increasing number of repeated impact of sandwich composites, the first impact number depicts rebounding threshold at two types of Synthetic sandwich composites. Perforation threshold occurs at fourth repeated impact loading of normal sandwich composites whilst occurs at seventh repeated impact number of sandwich composites with multi core. It is also found that peak force values of sandwich composites with multi core higher than peak force values of normal sandwich composites because the compressing of the PVC foam core during repeated impact loading at fourth impact. On the contrary, deflection values decrease by increasing repeated impact energy of sandwich composites with multi core but deflection values increase by increasing repeated impact energy of normal sandwich composites. Penetration represents 50 % of peak force according to soliman et al [13]. The results show that Penetration energy is needed in order to penetrate the Impocter in specimen for sandwich composites with multi core is nearly 31% greater than of normal sandwich composites after comparing the results for peak force values.

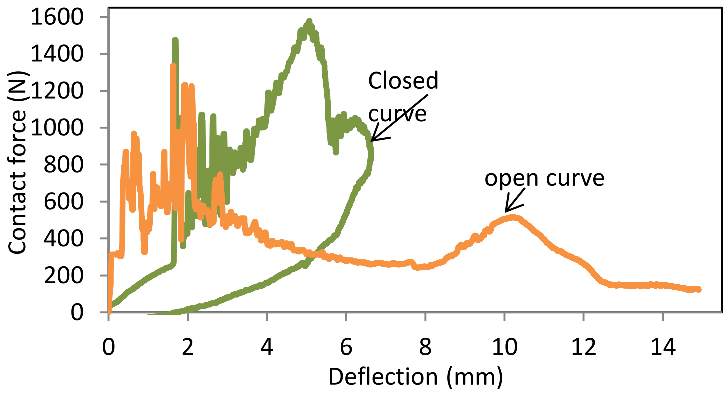
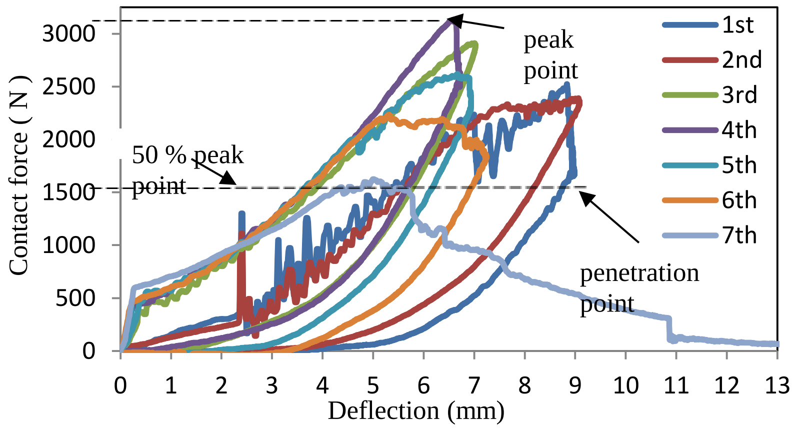
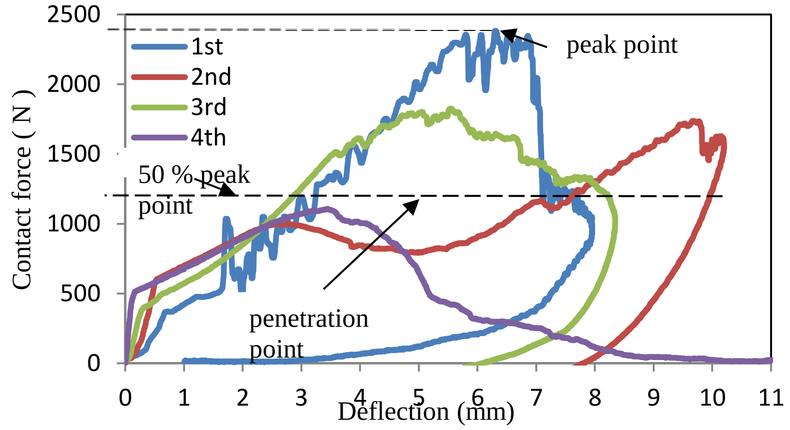


Figure 6. Types of curves



(a)



(b)

Figure 7. Contact force-deflection curves of sandwich composites (a) with multi core (b) with traditional

3.2. *Velocity-time response*

Impactor height was increased to obtain on different impact loading at room temperature with constant mass 5 kg, fig. 8 clearly shows velocity with time curves, and prepared specimens were subjected to impact loading from 5 to 20J. The positive values of velocity indicate to impactor lowdown motion before impact the specimen however the negative values indicate to rebounding threshold which explain impactor upward motion after impact the specimen. Perforation threshold occurs at normal sandwich composites speedier than sandwich composites with multi core because sandwich composites with multi core are more stiffness. Rebound point represents velocity of impactor approaching to zero which decrease with time by using repeated impact test for sandwich composites with multi core while increase at normal sandwich composites.

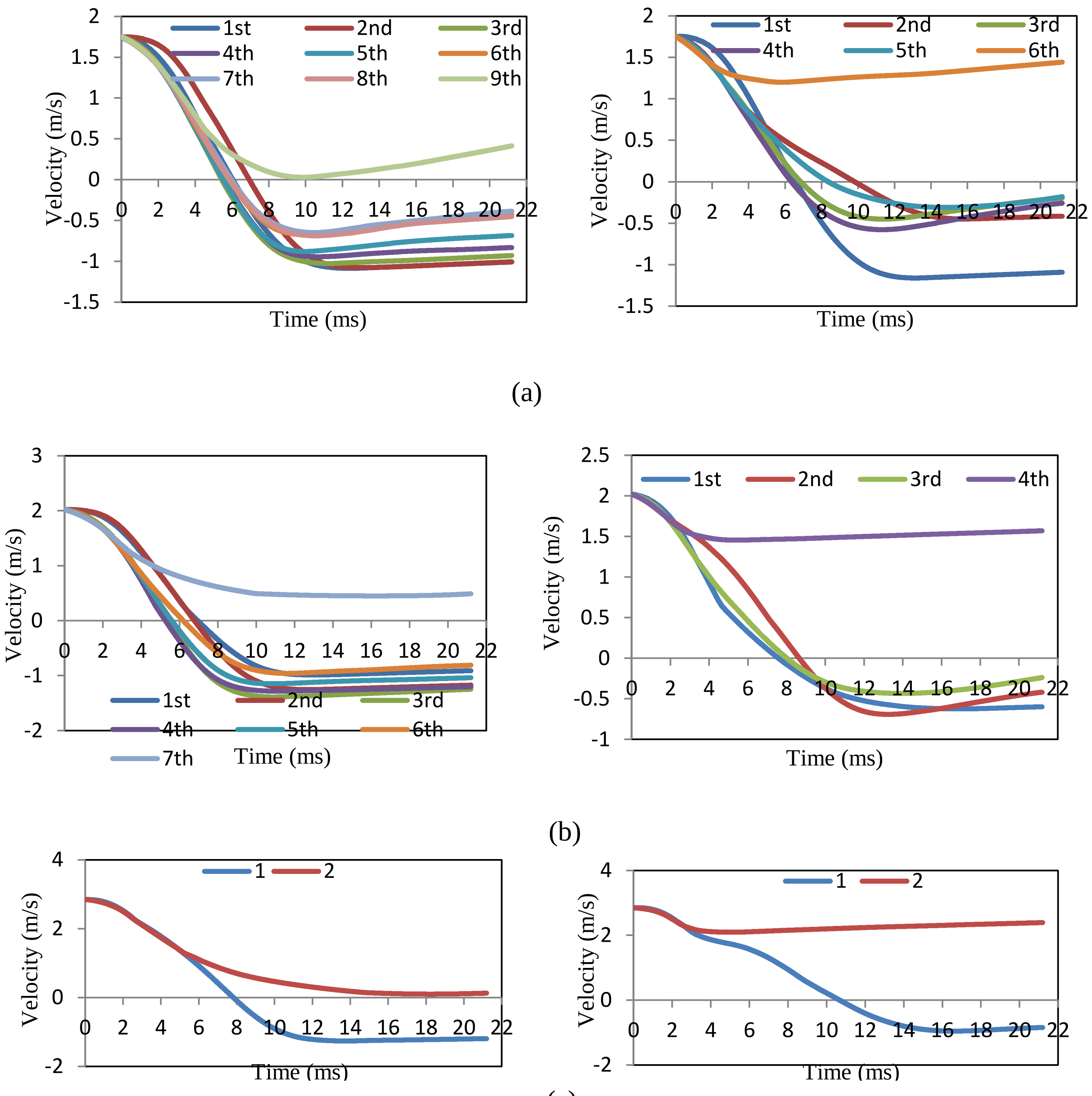


Figure 8. velocity-time responses for various impacts loading on sandwich composites with multi core and traditional sandwich composites impacted at (a) 7.5J, (b) 10J and (c) 20J

3.1 .The Damage response

The significance of arrangment core on the damage size is observed in fig. 9 the damage size increases by increasing impact loading number which occurs at top layer, core and bottom layer, respectively. The incipient damage is shown in matrix at top layer which occurs as delamination while there is no damage on bottom layers by using 5J as shown in Fig. 9a, which is called rebounding threshold and by increasing the impact loading number the delamination area increases and fiber breakage occurs on top layers and the delamination is noted in the bottom layers as given in the Fig. 9b, which is called penetration threshold because the inpactor penetrates top layer and stops in the specimen after impact the bottom layer. Moreover, the damage mechanism progresses in the top and bottom layers as matrix cracks, delamination and fiber breakage which is named perforation threshold as seen in the Fig. 9c because the specimens cannot able to resist expansion for the impact loading number.

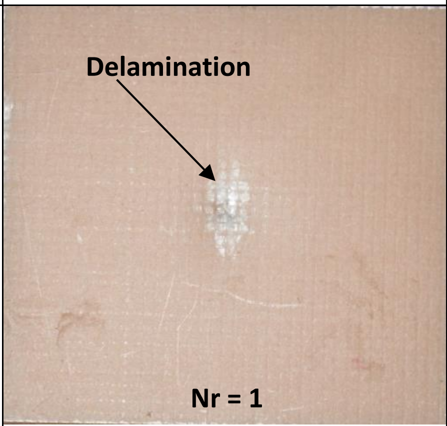
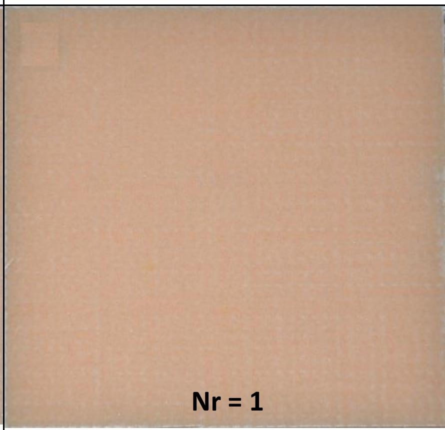
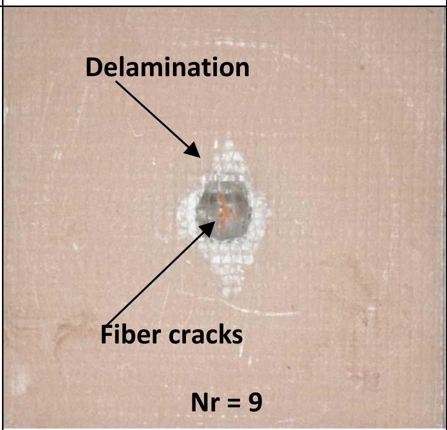
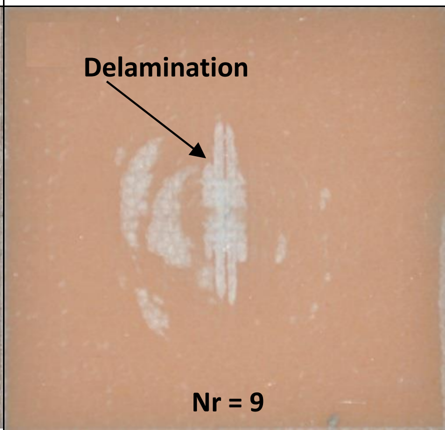
damage modes	**Top**	**Bottom**	
Rebounding threshold			a
Penetration threshold			b

Figure 9. Damage modes of normal sandwich composites impacted at 5J

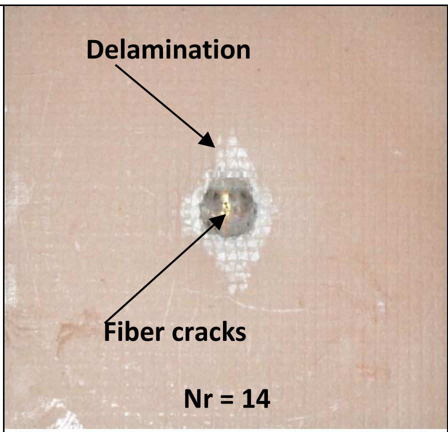
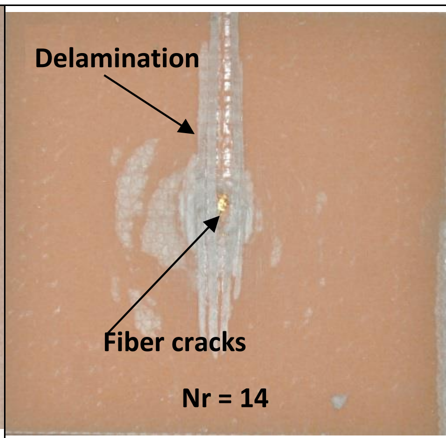
Perforation threshold			c

Figure 9.Continued

By visual inspections of specimens, the damage size is affected by arrangement core of specimens, as given in the Fig. 10 the damage is noted at top layer as delamination however there is no damage on bottom layers by using 5J as shown in Fig. 10a and by increasing impact loading number to 12 (Nr) the matrix crack and fiber breakage occur at top surface while delamination is smaller than the others which are subjected to repeated impact test by using 5J for normal sandwich composites as shown in Fig. 10b.

The matrix crack, delamination and fiber breakage were occurred by increasing impact loading number to 20 (Nr), impact loading number for sandwich composites with multi core bigger than impact loading number for normal sandwich composites which is meaning that sandwich composites with multi core are stiffness in order to find internal sheet between tow-core in sandwich composites. The full perforation threshold occurs in all specimens as shown in Fig. 10c.

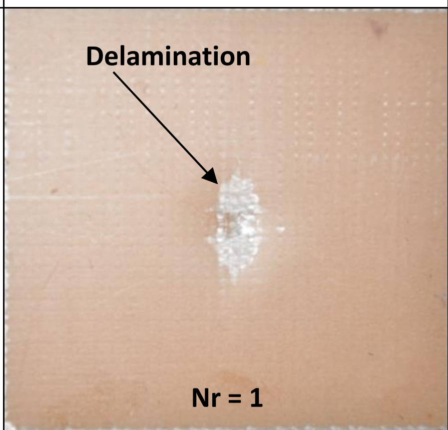
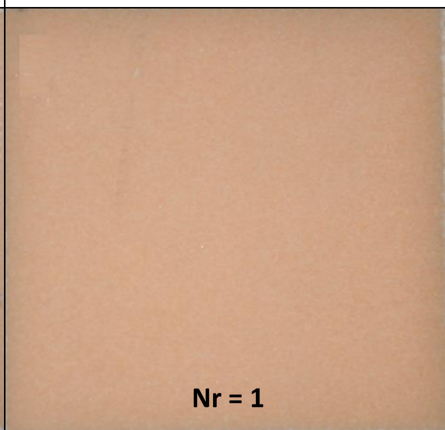
damage modes	**Top**	**Bottom**	
Rebounding threshold			a

Figure 10. Damage modes of sandwich composites with multi coreimpacted at 5J

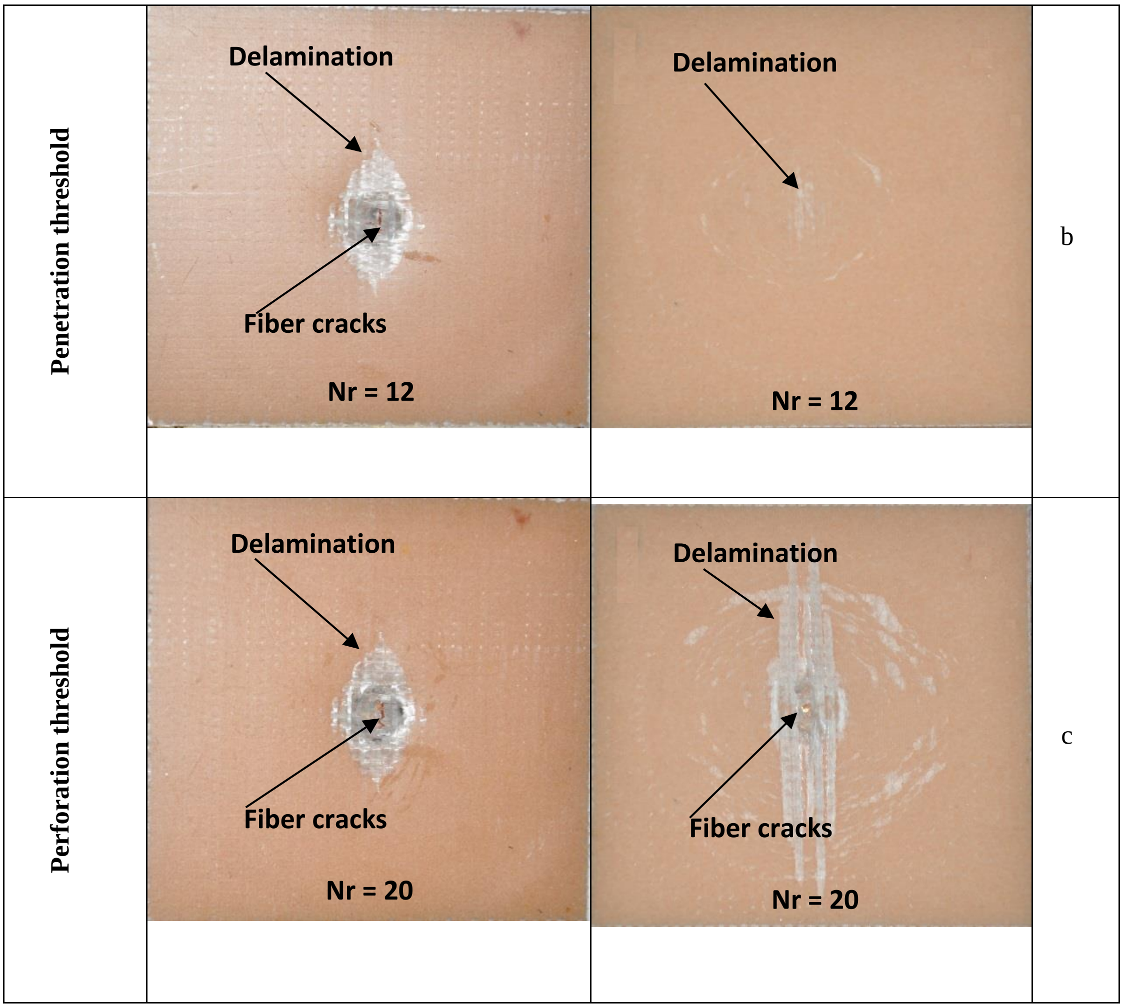


Figure 10. Continued

Fig. 11 shows top and bottom layers for normal sandwich composites; Samples prepared subjected to repeated impact loading by using 15 J, there are visible damages at top and bottom layres.

Penetration threshold occurs in top layer after first impact loading number while full perforation threshold occurs after second impact loading number at comparison with Fig. 12 which represents sandwich composites with multi core, there are three damage modes are happened.

Also, there are no incipient damages like a delamination at bottom layres after first impact loading number. The delamination area increases by increasing impact energy while decreases by increasing number of layers (thickness) according to Karakuzu et al [14] so the delamination at bottom layers for normal sandwich composites smaller than the other which are subjected to repeated impact test by using 15J as shown in Fig. 11 – 12.

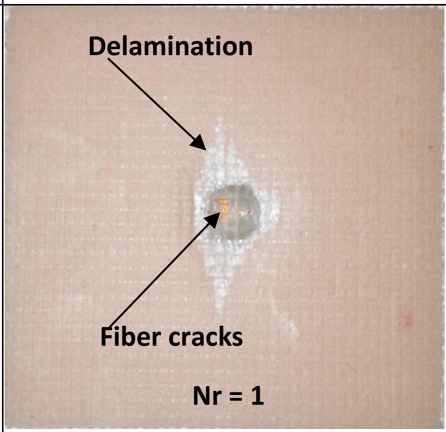
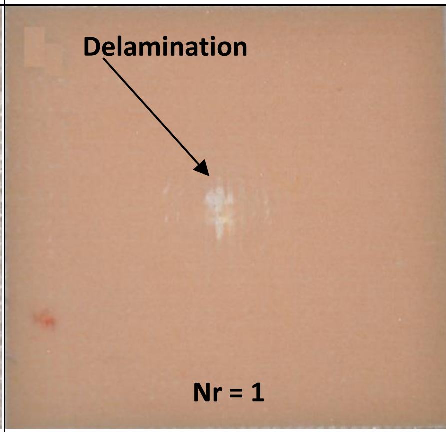
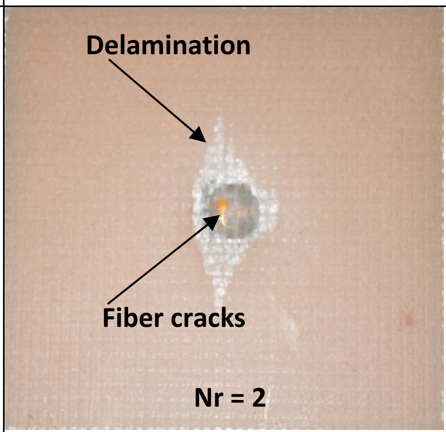
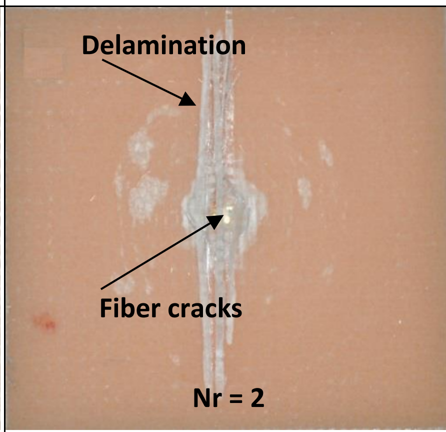
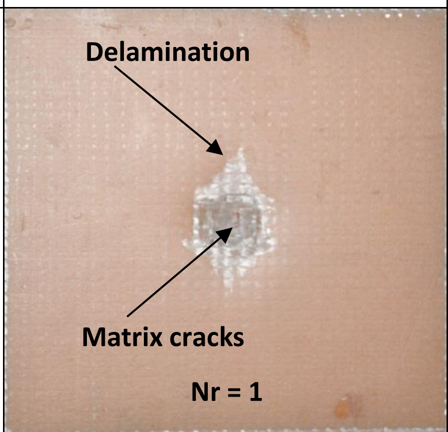
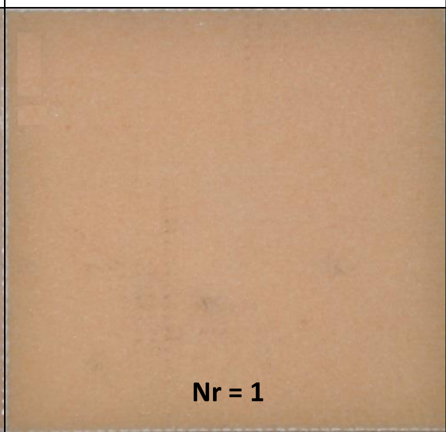
damage modes	Top	Bottom	
Penetration threshold			a
Perforation threshold			b

Figure 11. Damage modes of traditional sandwich composites impacted at 15J

damage modes	Top	Bottom	
Rebounding threshold			a

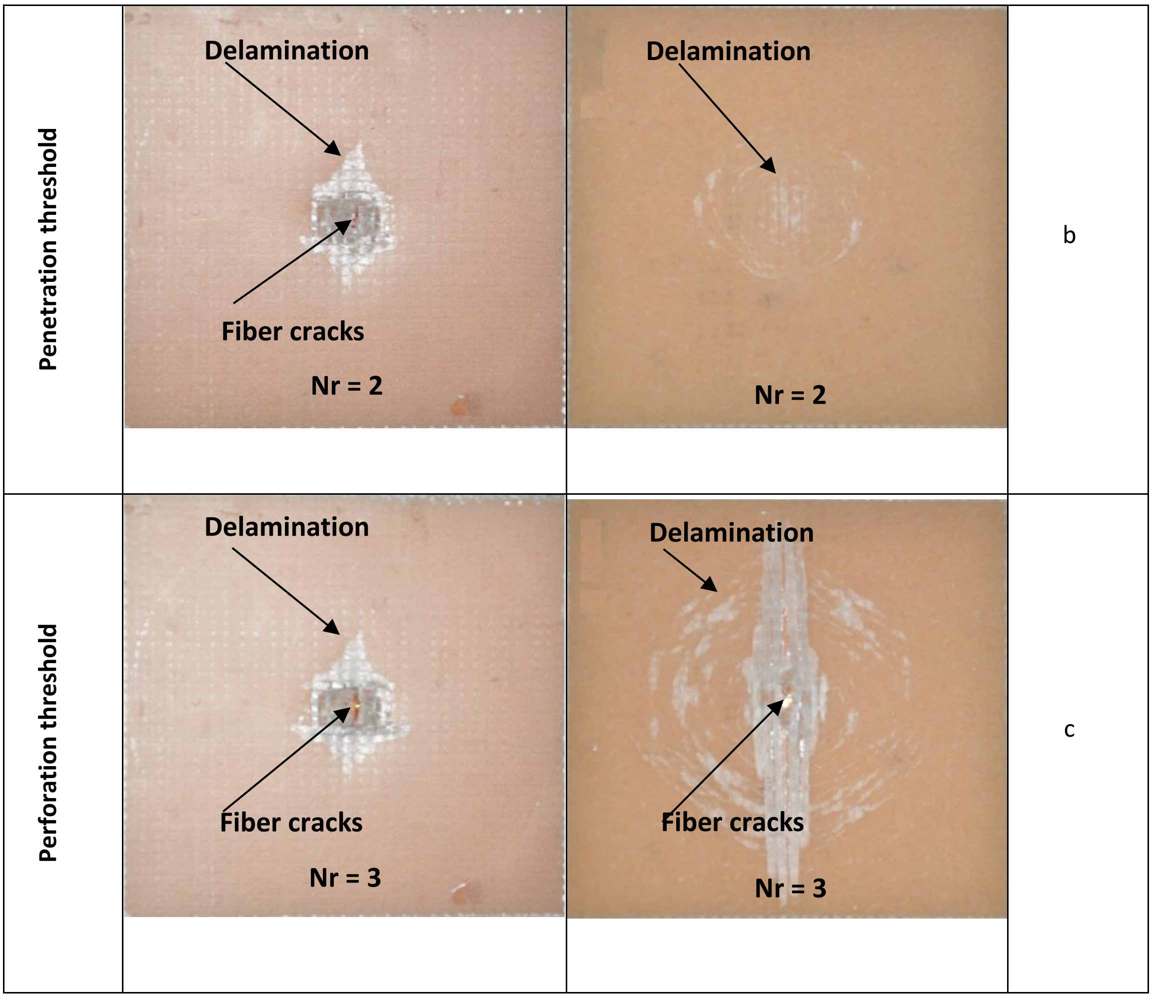


Figure 12. Damage modes of sandwich composites with multi core impacted at 15J

4. Conclusions

In this study, effect repeated Impact on two types of synthetic sandwich composites was carried out experimentally by using same impact energy from 5 to 20 J at room temperature. All the specimens were used in this paper have been manufactured in the composite research laboratory of Mechanical Engineering Department in Dokuz Eylul University/Izmir/turkey. The obtained results show that:

- Number of repeated impacts (Nr) for sandwich composites with multi core higher than normal sandwich composites at low impact energy values. On the other hand, the sandwich composites with multi core are stiffer than the normal sandwich composites.
- It is also found that two types of synthetic sandwich composites are same by using high impact energy values (20J) to full perforation.
- Sandwich composites are affected by arrangement core, layer, and internal sheet. Two types of Synthetic sandwich composites consist of six layers with various configurations, Number of repeated impacts (Nr) for new design at 5, 7.5, 10 and 15J are approximately 34%, 50%, 75% and 50% higher than of normal design, respectively by comparing the results as shown in the fig. 5.

- Penetration limit for new design of sandwich composites with multi core higher than penetration limit of normal sandwich composites which explains that the new design is more stiffness and absorbed energy of normal sandwich composites.
- It is noted that time increases by increasing number of repeated impacts of normal sandwich composites however decreases of sandwich composites with multi core.

5. Acknowledgement

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