



AN EXPERIMENTAL STUDY OF LOW VELOCITY IMPACT RESPONSE FOR COMPOSITE LAMINATED PLATES

Ceyla AKIN¹, Mehmet ŞENEL²

¹Dumlupınar University, The Institute of Science and Technology, Department of Mechanical Engineering, 43270 Kutahya

²Dumlupınar University, Engineering Faculty, Department of Mechanical Engineering, 43270 Kutahya, msenel@dpu.edu.tr

Geliş Tarihi: 28.08.2009

Kabul Tarihi: 25.02.2010

ABSTRACT

This paper deals with the response of E-glass/epoxy laminated plates subjected to low velocity impact loading. Impact tests were performed using a specially designed vertical drop-weight testing machine. The samples used for this study were 8 plies symmetric laminated composites. These composites were characterized by three different stacking sequences, $[0/90]_{2s}$, $[-30/30]_{2s}$, $[-45/45]_{2s}$, and they were compared with each other. Specimens were impacted at constant weight and different impact energies. Damage processes examined step by step from initiation of damage to final perforation. The studies were carried out on plate dimension of 140mm x140mm with both four and two opposite sides clamped. Impact loads were applied at the center of each plate.

Effect of different clamped cases, stacking sequences and impact energies were investigated on the composite structures.

Key Words: *Low velocity impact; E-glass/epoxy; laminated composite materials*

TABAKALI KOMPOZİT PLAKLARIN DÜŞÜK HIZLI DARBE ETKİSİNİN DENEYSEL ÇALIŞMASI

ÖZET

Bu çalışma düşük hızlı darbe yükü etkisi altında E-cam elyaf/epoxy tabakalı plakların tepkisinin incelenmesi ile ilgilidir. Darbe testleri, özel olarak tasarlanmış düşey ağırlık düşürme test cihazı kullanılarak yapılmıştır. Bu çalışmada 8 kat simetrik olarak tabakalanmış kompozitler kullanılmıştır. Bu kompozitler, $[0/90]_{2s}$, $[-30/30]_{2s}$, $[-45/45]_{2s}$ olarak üç farklı şekilde istiflenmiştir ve sonuçları birbirleri ile karşılaştırılmıştır. Hasar oluşumları numunede batmadan başlayarak tam delinme durumuna kadar kademeli olarak incelenmiştir. Çalışmalar 140mmx140mm'lik kare plakların iki ve dört taraflı ankastre bağlantı durumlarında yapılmıştır. Darbe yükleri plak ortalarına uygulanmıştır.

Anahtar Kelimeler: *Düşük hızlı darbe, E-cam fiber/epoxy, tabakalı kompozit malzemeler.*

1. INTRODUCTION

Composites are materials of choice for light-weight structures due to their excellent weight/strength and weight/stiffness properties. Composite structures may be subjected to low-velocity impacts. Under the dynamic loading of the material, these unseen damages can become larger and even cause the loss of the material. Because of this, on a layered composite build, foreseeing the damage caused by the impact is very important on design and usage.

The configuration and the dimensions of the composite structures have been chosen as parameters to define the size and general appearance of the structure. Komorowski, et al. [1] have studied compression dominated fatigue of 18-ply AS4/3501-6 and IM6/5245C graphite/epoxy laminates with two different stacking sequences of $[\pm 45/0/90/0/\pm 45]_s$ and $[90/(0/45)_2/(0/-45)_2]_s$. To investigate the effect of stacking sequence, Ratwani and Kan

[2] have conducted experiments on notched 16-ply AS4/3501-6 graphite/epoxy laminates and concluded that the failure mode in composites changed with the change in stacking due to the stress redistribution within the laminate. Stinchcomb, et al. [3] also have indicated that the mode and extent of damage in multidirectional laminates were governed by the stress states in the constituent plies and their relationships to the respective strengths. The dimensions and boundary conditions of the laminate are important, because they determine its flexural stiffness, for a given material whose thickness and stacking sequence are fixed [4–6].

In the past few years, considerable amount of studies have been conducted in the area of impact damage resistance of composite laminates. A detailed reviewed of the impact mechanics and dynamics of composite structures have been made by Abrate [7-9]. Thanomslip and Hogg [10] have investigated penetration impact resistance of hybrid composites. They have considered various thermoplastic fibers with different resin system. They have concluded that plastic deformation in the thermoplastic fibers was the key factor in the improvement in energy absorption of the hybrid composites. The low energy impact characteristics of four different E-glass fibers reinforced thermoplastic and thermosetting matrix composites have been studied by Sadasivam and Mallick [11]. Naik et al.[12] have investigated impact behavior and post impact compressive characteristics of glass carbon hybrid composites with alternative stacking sequences. They have concluded that hybrid composites are fewer notches sensitive as compared to only carbon or only glass composites. Aslan et al. [13-14] have done a numerical and experimental analysis to investigate the effects of the impactor velocity. They have concluded that the peak force in an impact event increases with the thickness of composite as the contact time decreases.

The aim of the present work is to investigate impact response of the cross-ply and angle-ply glass/epoxy laminate plates. Here, two different clamped cases, three type of stacking sequences and different impact energies are considered. The behaviors are presented forms of the curves of contact force-displacement, contact force-time, absorbed energy-time, velocity-time etc. and images of damages specimens.

2. FABRICATION OF COMPOSITE PLATES

The composite material used for this study was manufactured from unidirectional E-glass continuous fibers and epoxy resin. The fiber volume fraction and the nominal thickness of the composite was approximately %55 and 2 mm respectively. E-glass/epoxy composite plates with 8 plies were manufactured at Izoreel Firm by using hand lay-up technique. For matrix material, the epoxy CY225 resin and hardener HY225 was used. The curing process was carried out at 120 °C during 3 h under a pressure of 0.25 MPa. Then, the composite was cooled to room temperature. The specimens were cut to required dimensions of 140mmx 140mm from the manufactured composite plates.

3. EXPERIMENTAL TEST APPARATUS

Impact tests were performed using a specially designed vertical drop-weight testing machine. The test machine consists of five main components (Figure 1): a L-Shaped base steel plate, a drop weight tower, an elevator, a control unit, and a brake system.



Figure 1. Drop-weight test machine: 1) L-shaped base steel plate, 2) drop weight tower, 3) elevator, 4) control unit, 5) brake system.

L-shape plate

L-shape plate consists of 50mm thick mild steel plate. It is bolted to the floor. Four grips and two hydraulic pistons are mounted on the base plate. Two grips mounted hydraulic pistons are moveable and others are fixed. Test specimens are hold with these grips. The pistons are capable of applying in-plane loading in two independent perpendicular axes on specimens (Figure 2).

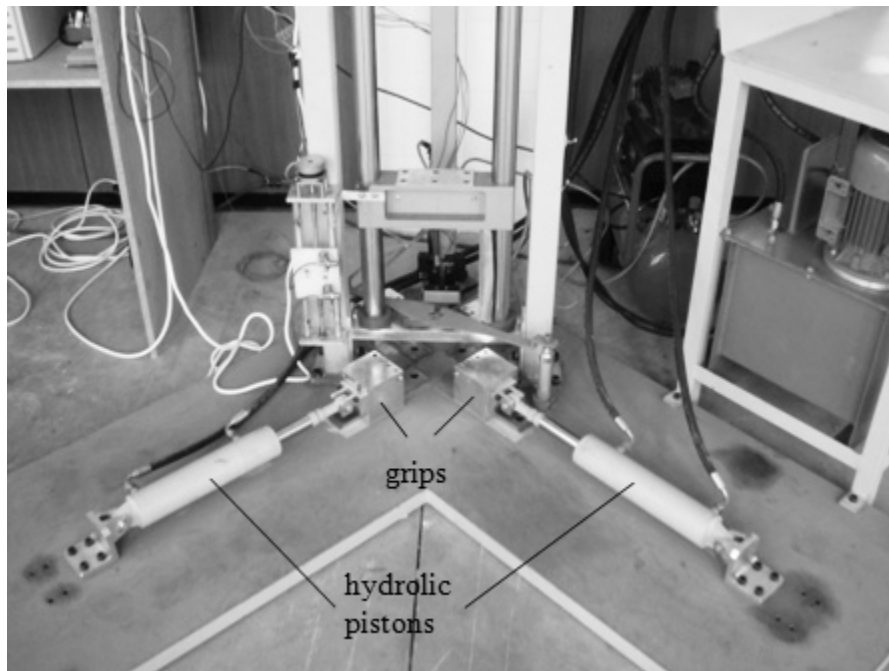


Figure 2. Pistons and grips

Drop-weight tower

The drop weight tower consists of two rectangular steel bar and two steel rods which are 5 m high (Figure 1). Besides, two components assemble with bearings on the rods. These components are electromagnet and drop weight which has a force sensor and an impactor (Figure 3). Electromagnet catch drop weight and elevate it to appropriate drop height.

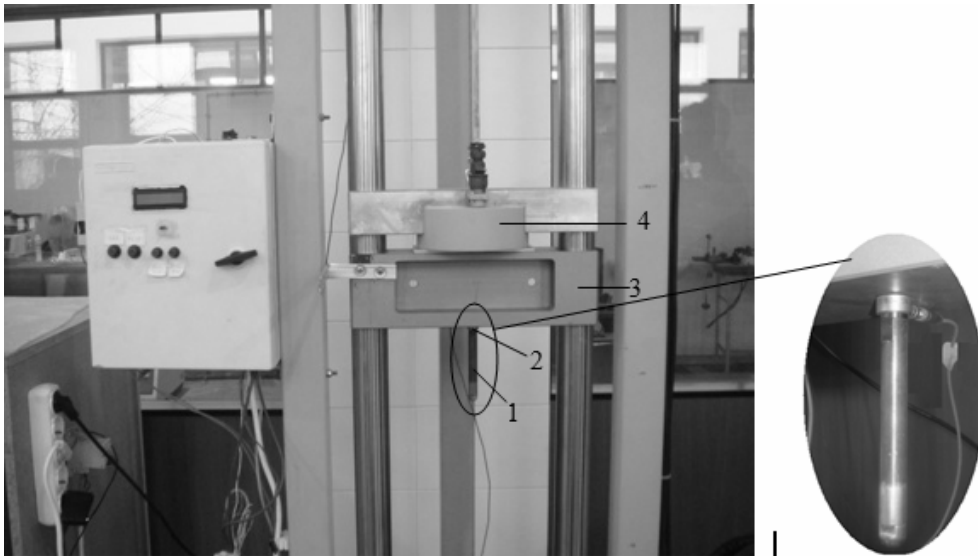


Figure 3. Drop weight tower components: 1) Impactor, 2) Force sensor, 3) Drop weight, 4) Electromagnet

Elevator and control unit

Elevator system has a motor, cables and an electrical magnet. The motor is located on the weight tower. It elevates the electromagnet with a steel cable up to appropriate height. Control unit manages elevator system, hydraulic system for grips and electromagnet (Figure 1).

Brake system

This system prevents multiple impacts on sample. If the impactor rebounds after the impact, the brake system turns on and catches impactor immediately. Two optic sensors, a flag, weight holder, two pneumatic pistons, a solenoid valve and a compressor are used in the system (Figure 4).

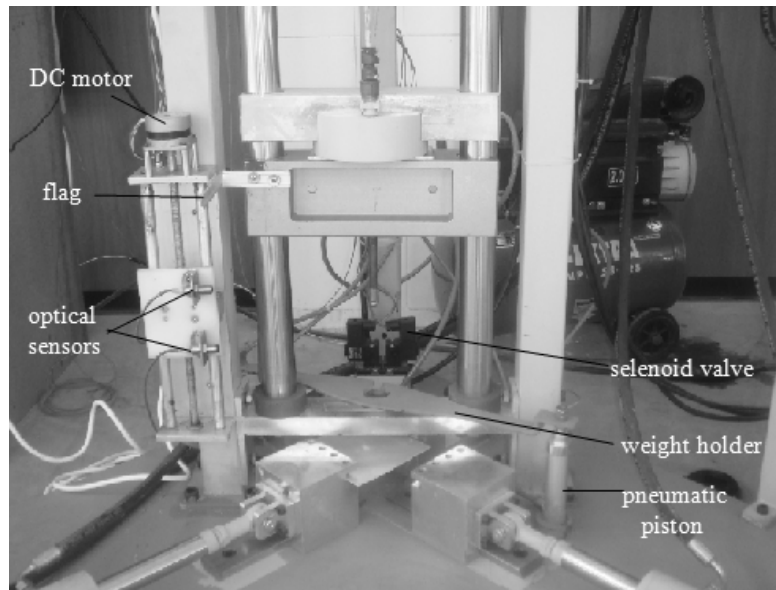


Figure 4. Brake system

4. EXPERIMENTAL PROCEDURE

The tests were performed by a drop weight testing system. The composite panels tested in this work were based on a glass fibre reinforced epoxy. The dimensions of the panels were 140mm by 140mm and their average thickness was 2.1mm. The samples used on this study were 8 plies symmetric laminated composites and were characterized by three different stacking sequences, $[0/90]_{2s}$, $[-30/30]_{2s}$, $[-45/45]_{2s}$, and they were compared with each other. For each test, we used three samples in same cases. Specimens were impacted at constant weight, different impact energies and two different clamped cases (Figure 5).

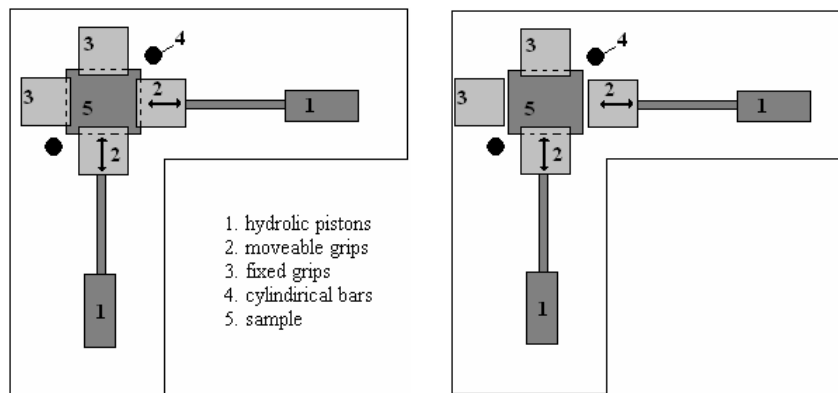


Figure 5. Two different clamp cases; a) two-side clamp, b) four-side clamp

The impactor, which was perfectly rigid, had a 12mm diameter hemispherical tup nose. It was located to bottom of the drop weight. Force sensor was mounted between impactor and drop weight (Figure 6). It was calibrated prior to testing. Total mass of impactor used was 3.1 kg.

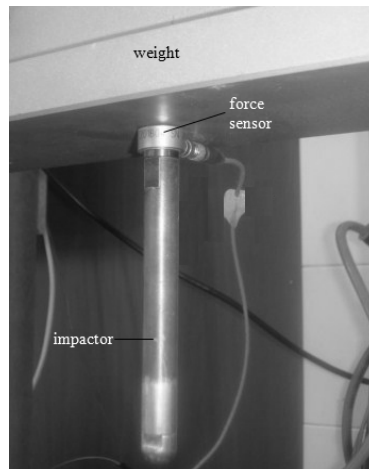


Figure 6. Force Sensor

Firstly, the specimen was located in the grips as the impactor orients to the center of sample. To calibrate of brake system, the impactor was touched surface of sample and so, two optical sensors was calibrated. After, the impactor was lifted with electromagnet to appropriate drop height. At the same time, LabView, which is data logger program, was started in the computer. Then, electromagnet was closed and impactor crashed to the sample. Data took from the force sensor was sent to the computer. A program written in LabView calculated and plotted force-time curve. Other curves were calculated by these data.

5. EXPERIMENTAL RESULTS

Each of the following graphics is obtained from various impact energies. Experiments start from minimal damage to perforation of the sample. Three different experiments were performed at the same impact energy and the same conditions because there may be loose connection, defected samples or errors in sensors. As result, total of 27 experiments were conducted. In this work effect of time and deflection parameters such as sample clamp, impact force, displacement, impact velocity and were observed energy on composite materials. Before analyzing the experimental results, perforation and penetration should be defined. In general, the energy of which impactor makes contacts with the sample is defined as penetration threshold. Perforation threshold on the other hand, can be defined as the energy of which impactor reaches the other side of the sample. In ideal case, however, penetration occurs when hemisphere end of the impactor completely goes into sample. To satisfy the conditions, the ratio of impactor radius to sample thickness should be less than one. In our work, since the ratio is larger than one (radius of impactor is 6mm and sample thickness is 2mm), it is difficult to identify the penetration threshold. In the experiments, when impactor hits the sample, it is already close to reaching the other side of the sample. For this reason, the penetration threshold is not considered.

Contact force can also be defined as the response force of samples against the impactor. Contact forces are measured by force sensor and recorded. From the recorded data valuable informations such as velocity, deflection observed energy can be calculated by using Newton's second law, kinematics formulas. Force-time graphics are shown in figures 7a, 8a and 9a. The figures also show that the maximum force increases with increasing impact energy. In the experiments the measured maximum force is about 4.5 kN of which sample is penetrated. Sharp falls in the energy curves in figures 7a, 8a and 9a happens because fibers of the bottom of the samples bend on cracks causing loose contact between sample and impactor. At the energy level sample is completely perforated.

The graphics of the contact force-deflection obtained under various impact energies can be consider as response of composite materials to impact loads. Figures 7b, 8b and 9b shows force-deflection curves for damaged samples. As seen from the figures, there are two types of curves defined close and open. The relationship between load and deflection was obtained at 14.17J and 22.02J energy levels. In figures 7b, 8b and 9b, they are shown as closed curves. For the closed curves, the impactor hits the sample and rebound. In these cases, there

may be small matrix fractures in samples. In the open curves, on the other hand, the load-deflection curve is parallel to deflection axis. The parallelism of the curves indicates that sample is completely perforated and there is a friction force between the impactor and the sample. Because of the perforation, the fibers are cracked and sample strength is reduced.

Experimental results for velocity-time relationships are given in figures 7c, 8c and 9c. in these figures, the velocity at the time zero is the impactor velocity at which the impactor hits the sample. Figures 7c, 8c and 9c show that, unperforated samples, energy levels of 14.17J and 20.02J values, velocity decreases after touching the sample and finally after a certain time goes to zero. Maximum deflection occurs when velocity is zero. For the energy levels 14.17J and 20.02J velocity curves decreases and takes negative values. These negative values represent velocity of the impactor of the rebound.

For the perforated samples, the velocity of the impactor decrease by time and since there is no rebound velocity goes to zero and remain. In figure 8c, for sample [-30/30] at energy level 29.43J, velocity seems take negative values. However, as the sample is perforated, it is expected to have positive velocities. It is assumed that this situation occurs due to sensor errors.

Impact energy time curves are given in figures 7d, 8d and 9d, which show that impact energy increases by time. When we analyze unperforated samples at 14.17J and 20.02J energy levels, impact energy-time curves a little bit and remain constant. At these curves, the highest tip of the curve shows maximum impact energy and the end of the curve shows the absorbed energy. The energy differences between maximum impact energy and absorbed energy are used for rebound of the impactor. For perforated samples, the energy difference is used for friction between impactor and sample. For this reason, in the case of perforation these curves increase without any reduction and finally saturates. In addition, figures 7b, 8b and 9b indicate that, the area under the load-deflection curve gives observed energy. The observed energy can also be defined as the energy transferred from impactor to the composite material after the impact.

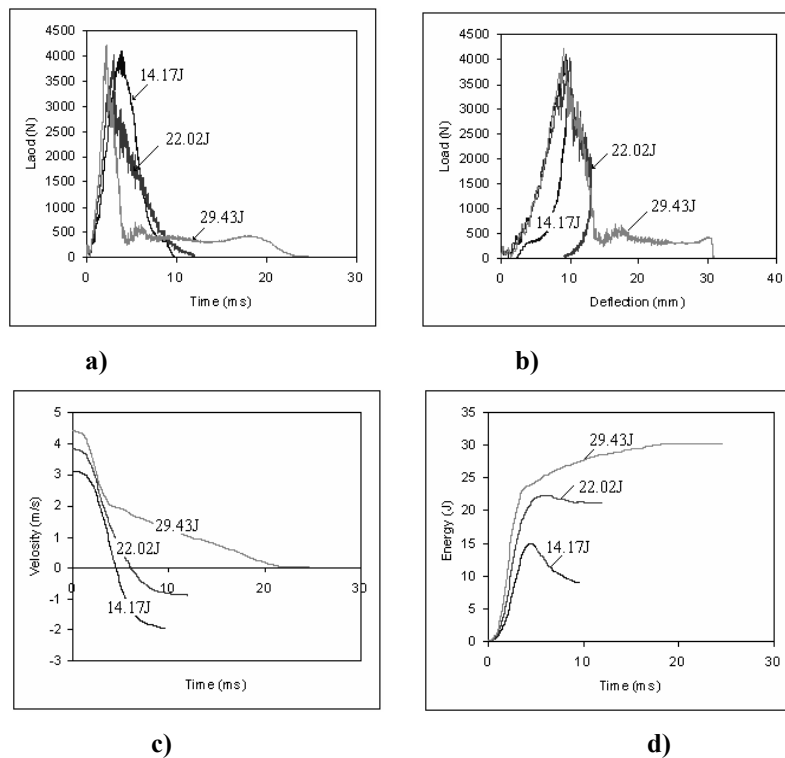


Figure 7. a) Load-time, b) Load-deflection, c) velocity-time and d) energy-time curves for impact energy of 14.17J, 22.02J and 29.43J in $[0/90]_{2s}$

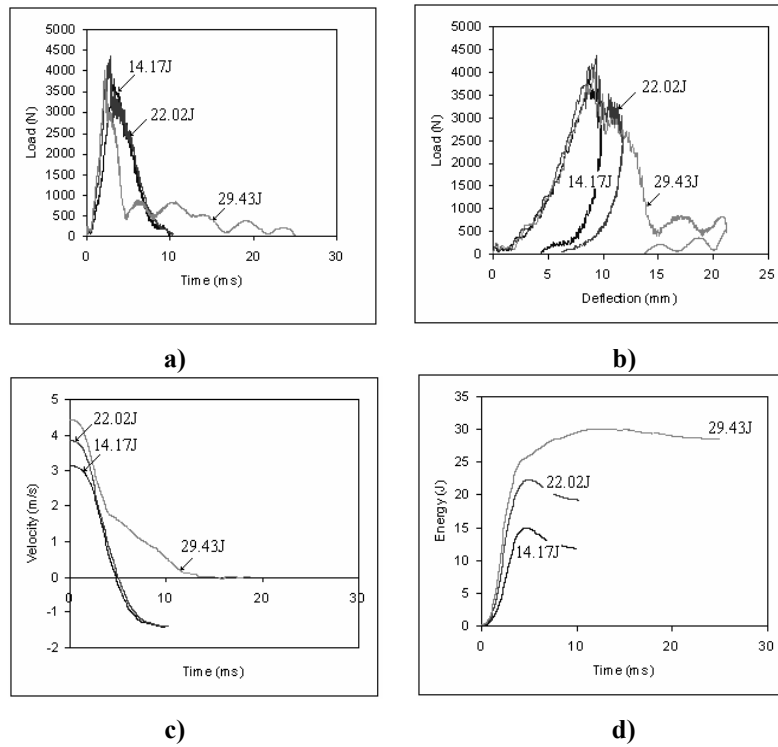


Figure 8. a) Load-time, b) Load-deflection, c) velocity-time and d) energy-time curves for impact energy of 14.17J, 22.02J and 29.43J in $[-30/30]_{2s}$

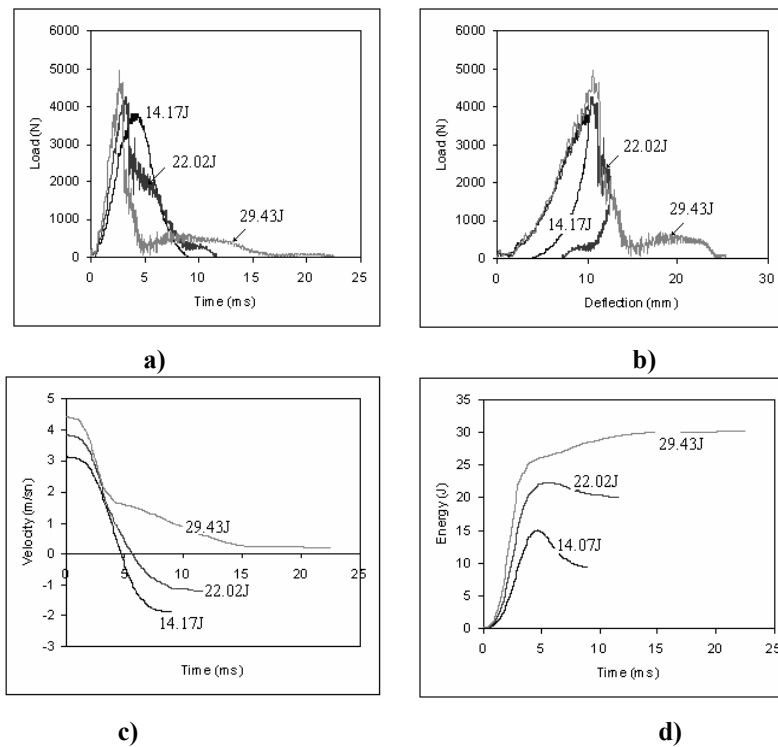


Figure 9. a) Load-time, b) Load-deflection, c) velocity-time and d) energy-time curves for impact energy of 14.17J, 22.02J and 29.43J in $[-45/45]_{2s}$.

For the second part of the experiment, $[0/90]_{2s}$, $[-30/30]_{2s}$ and $[-45/45]_{2s}$ laminated composite plates were clamped from the both sides and used with its and then tested for various energy levels, such as 14.7J, 22.02J, 29.43J. Experiments were conducted for having minimal damage on the samples to 29.43J.

In the first part of the experiments, samples are clamped from the four sides to have more stable structure. As it is expected, these stable structures provided more logical experimental results. In the second part of the experiments, samples are clamped from the two sides. However, this structure possesses elastic behavior and is less stable. This behavior can be seen from figures 10, 11 and 12. While we obtain full perforation at 29.43J for four side clamped samples, upon 29.43J was need (51.50J) for two-side clamped samples. The differences of impact energy in the both experiments results from the way that samples are clamped. Two-side clamped samples exhibit elastic behavior.

Load-time curves given in figures 10a, 11a and 12a are similar to those in figures 7a, 8a and 9a. In this case the maximum load increases. For full perforation, the necessary load is increased because of the connection of samples. Similarly, load-deflection curves given in figures 10b, 11b and a2b, shows that load and deflection are increased.

An interesting result was obtained for velocity-time graphics given in figures 10c, 11c and 12c. In this case, negative velocities were measured for perforated samples. When the impactor perforates the sample, the sample and the impactor moves together because the connection of the samples gives the system certain elasticity. Negative velocity corresponds to the movement of the sample and the impactor together opposed to impact direction.

Figures 10d, 11d and 12d show that the difference between impact energy and absorbed energy is larger than that of the first part of the example. Since the elastic behavior of the system in the second part of the experiments, the impactor rebound and has large displacement (compared to first part of the experiment). For the same reason, velocities in the region increases as shown in figures 10c, 11c and 12c. As an example, velocities in negative region in figures 7c, 8c, and 9c are between -1 and -1.5m/s while they are between -3.5 and -4.5m/s in figures 10c, 11c and 12c.

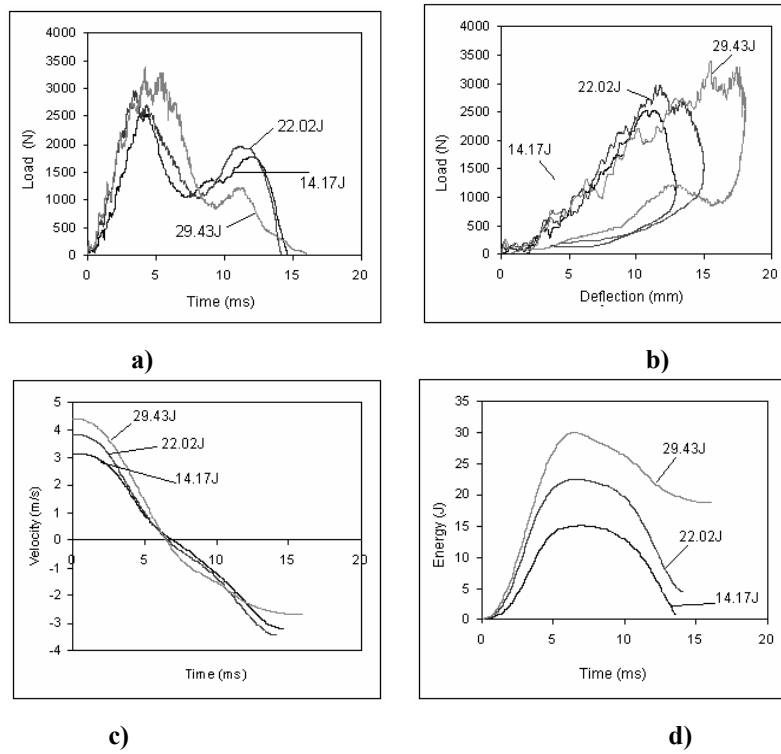


Figure 10. a) Load-time, b) Load-deflection, c) velocity-time and d) energy-time curves for impact energy of 14.7J, 22.02J and 29.43J in $[0/90]_{2s}$

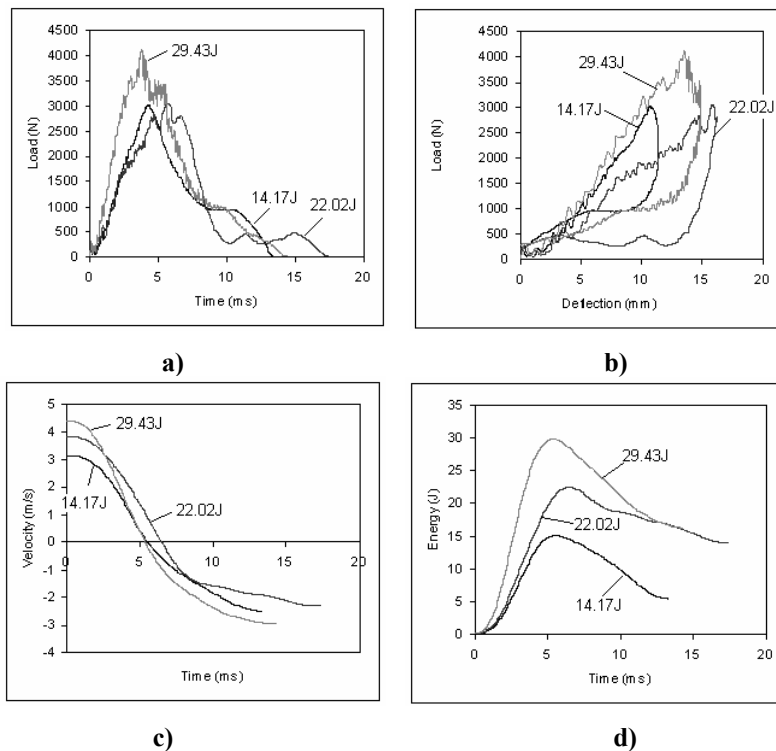


Figure 11. a) Load-time, b) Load-deflection, c) velocity-time and d) energy-time curves for impact energy of 14.7J, 22.02J and 29.43J in $[-30/30]_{2s}$.

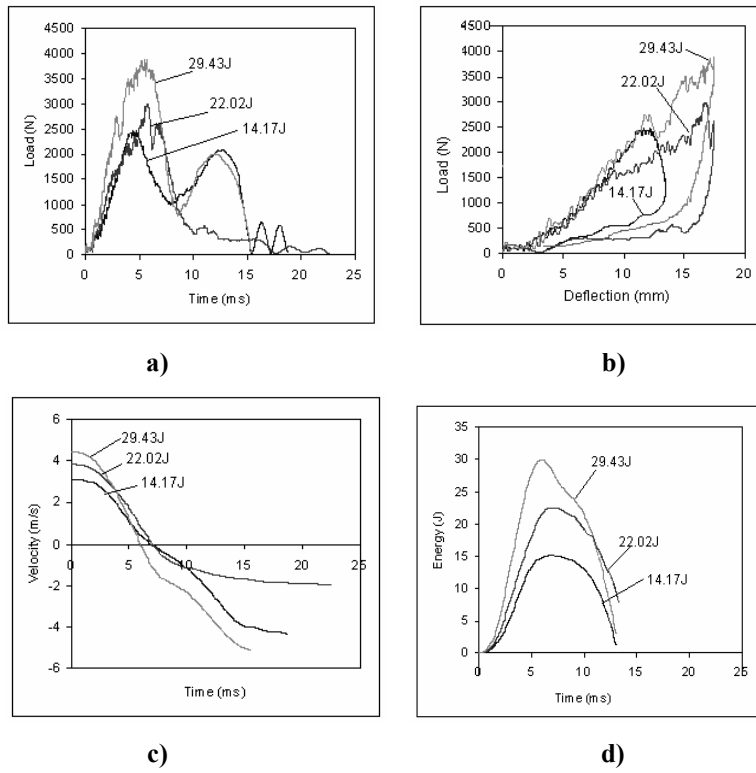


Figure 12. a) Load-time, b) Load-deflection, c) velocity-time and d) energy-time curves for impact energy of 14.7J, 22.02J and 29.43J in $[-45/45]_{2s}$.

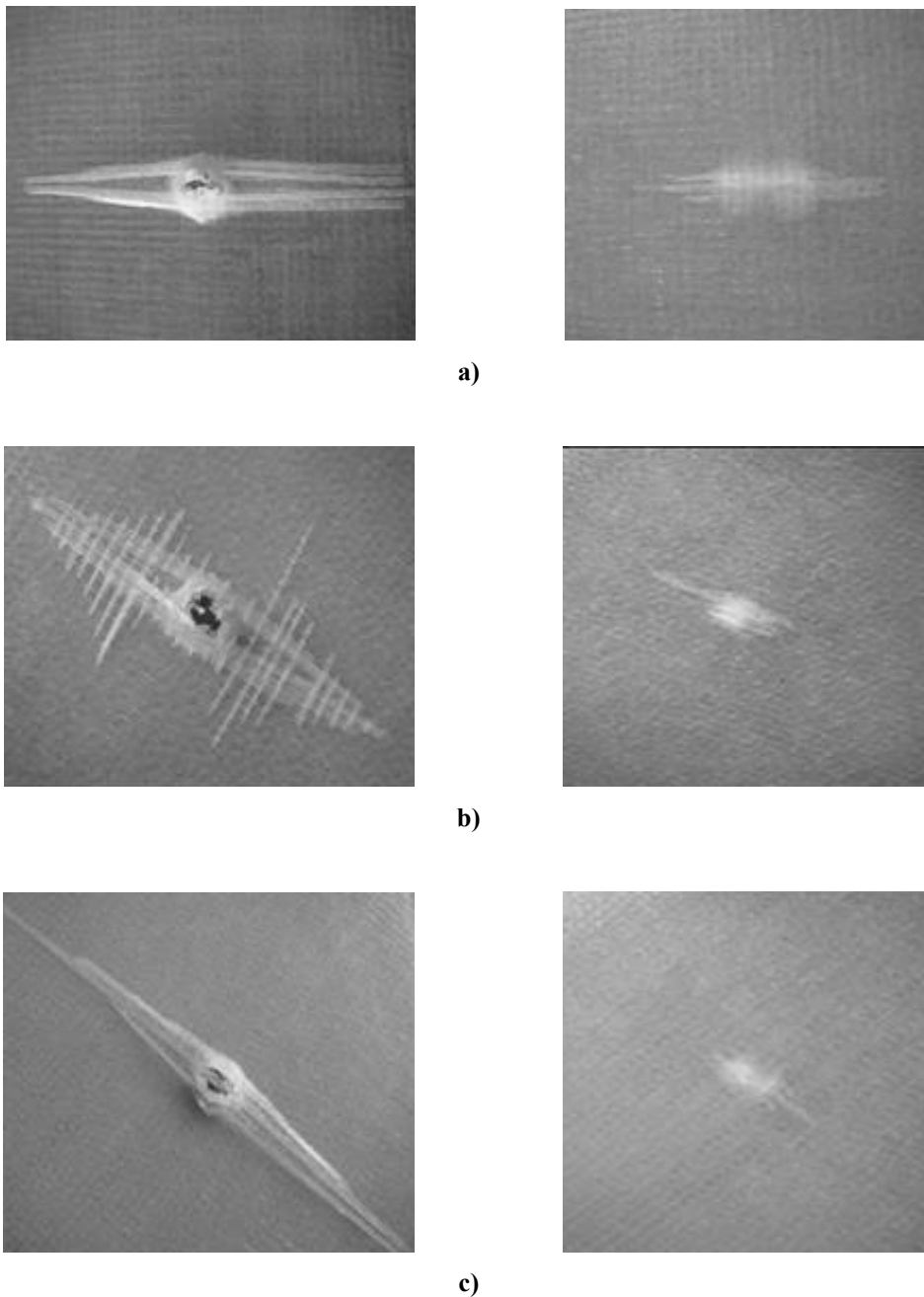


Figure 13. Damages in bottom surface for clamped in four sides (left) and in two sides (right) samples for 29.43J: a) $[0/90]_{2s}$, b) $[-30/30]_{2s}$, c) $[-45/45]_{2s}$

Pictures on the left side of the figure 13 shows the surface of the four side clamped composite material while pictures on the right side of the figure represent damages on the two side clamped material. The pictures reveals that, at the same energy levels, while there is full perforation for four side clamped case, only partial penetration occurs for two-side clamped material. This indicates that observed energy is much larger in four side clamped case. Damages at the bottom of the samples are observed in fiber directions. It is also observed that for the four sides clamped situation, damage distribution is much larger at the same energy level compared to that of the two side clamped case.

6. CONCLUSIONS

This work presents an impact response of the cross-ply and angle-ply glass/epoxy laminate plates. Here, two different clamped cases, three type stacking sequences and different impact energies are considered in order to investigate behavior of composite structures.

Our experiments show that clamping the material at its four sides makes more stable structure compared to two side clamping. There is more damage distribution at the bottom of the samples in four side clamping case. While observed energy is reduced, more energy is needed to perforate the sample in two side clamping. An interesting behavior is observed when sample is fully perforated in two side clamping case; both impactor and sample move together in impact direction.

It is also concluded from our experiments that the fiber orientation angle has little effect on impact experiments. One considerable effect is that, damages at the bottom of the composite material on fiber direction are observed in full perforation. It is our intention that the experiments on different ways of clamping samples will guide the future works on the determination of damages on preload samples.

ACKNOWLEDGEMENTS

This research is supported by The Scientific and Technological Research Council of Turkey (TUBITAK).

REFERENCES

- [1] J.P. Komorowski, D. Lefebvre, C. Roy, and C. Randon, "Stacking Sequence Effects and Delamination Growth in Graphite/Epoxy Laminates Under Compression-Dominated Fatigue Loading," *Composite Materials Fatigue and Fracture, Fifth Volume, ASTM STP1230*, R.H. Martin, ed. American Society for Testing and Materials, Philadelphia, PA, pp. 249-267, (1995).
- [2] M.M. Ratwani, and H.P. Kan, "Effect of Stacking Sequence on Damage Propagation and Failure Modes in Composite Laminate," *Damage in Composite Materials, ASTM STP 775*, K.L. Reifsnider, ed. ASTM, pp. 211-228, (1982).
- [3] W.W. Stinchcomb, K.L. Reifsnider, P. Yeung, and J. Masters, "Effect of Ply Constraint on Fatigue Damage Development in Composite Material Laminates," *Fatigue of Fibrous Composite Materials, ASTM STP 723*, pp. 64-84, (1981).
- [4] P. Robinson Davies GAO. Impactor mass and specimen geometry effects in low velocity impact on laminated composites. *Int J Impact Eng*;12(2):189–207 (1992).
- [5] D. Liu, BB. Raju Dang X. Size effects on impact response of composite laminates. *Int J Impact Eng*;21(10):837–54 (1998).
- [6] WJ. Cantwell, Geometrical effects in the low velocity impact response of GFRP. *Compos Sci Technol*; 67(9):1900–8 (2007).
- [7] S. Abrate, Impact on Laminated Composite Materials, *Applied Mechanics Review*, Vol. 44, No.4, pp. 155-190, (1991).
- [8] S. Abrate, Impact on Laminated Composites: Recent Advences, *Applied Mechanics Review*, Vol. 47, No 11, pp. 517-554, (1994).
- [9] S. Abrate, Modeling of Impacts on Composite Structures, *Composite Structures*, Vol. 51, pp. 129-138, (2001).
- [10] C. Thanomslip, PJ. Hogg, Penetration Impact Resistance of Hybrid Composites Based on Commingled Yarn Fabrics, *Comp. Sci. Thecnol. Vol. 63*, pp 467-82, (2003).

- [11] B. Sadasivam, PK. Mallick, Impact Damage Resistance of Random Fiber Reinforced Automotive Composites, *J. Theroplast. Compos. Mater.* Vol. 15, pp 181-91, (2002).
- [12] NK. Naik, R. Ramasimha, H. Arya, SV. Prabhu, ShamaRAo N. Impact Response and Damage Tolerance Characteristics of Glass-Carbon/Epoxy Hybrid Composite Plates, *Composite Part B*, 32:565-74, (2001).
- [13] Z. Aslan, R. Karakuzu, O. Sayman, Dynamic Characteristics of Laminated Woven E-glass/Epoxy composite plates subjected to low velocity heavy mass impact, *J. Compos Mater* 36(21): 241-42, (2002).
- [14] Z. Aslan, R. Karakuzu, B. Okutan, The Response of Laminated Composite Plates Under Low Velocity Impact Loading. *Compos Struct*, 59:119-27, (2003).