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Volkan Arikan, Onur Sayman

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Comparative Study on Repeated Impact Response of E-Glass Fiber Reinforced Polypropylene & Epoxy Matrix Composites

Volkan ARIKAN[1] and Onur SAYMAN[2]

[1] Department of Mechanical Engineering, Dokuz Eylul University, Izmir, Turkey

[2] Department of Mechanical Engineering, Gediz University, Izmir, Turkey

*volkan.arikan@deu.edu.tr

Abstract

In this study, E-glass fiber reinforced composites have been manufactured with two types of resin, polypropylene and epoxy (Thermoplastic and Thermoset) and they have been subjected to the low velocity single and repeated impacts and effect of resin type on the impact response of composites are investigated. Impact energies were chosen as 20 J, 50 J, 80 J and 110 J for single impact tests while 50 J was chosen for repeated impact tests. Comparisons between the results of 110 joule single and 50 joule repeated impacted specimens were performed. As a result of the study it is concluded that the resin type is a crucial parameter for the repeated impact response of the composites.

Keywords:

A. Glass fibers; B. Impact behavior; D. Mechanical testing E. Thermosetting resin; E. Thermoplastic resin.

Introduction

Requirements have changed with technological developments. Sometimes, traditional materials are insufficient to meet these requirements. Especially, in marine applications, wind turbine blades and space craft, it is desired to have light weight in addition to high strength. Having high strength and low density properties, fiber reinforced composites have been widely used in many engineering applications including military, marine industries and aerospace engineering. However, these materials are exposed to different loads and harsh conditions. In example, accidental impact (in transporting etc.), runway debris, wave impact and tool drop at maintenance. These kinds of loadings may result in some kind of damages such as delamination, fiber breakage and matrix cracking.

There has been many studies reported about transverse impact loading but these works commonly focused on the effect of composite plate's thickness, orientation impactor type or fiber type and also some environmental conditions [1-5]. Zhang et al. [6] researched the effect of voids on the residual tensile strength after impact and they found that, with the same impact energy, the dent depth increased with increasing void contents. Likewise, repeating impacts could cause void formation in the composite structure and this formation decreases the residual strength of the composites. In thermoplastic matrix composites, void formation, which occurs from impact loading, could less than thermoset composites. De morais et al.[7] conducted a study on the effect of the laminate thickness on the resistance of carbon, glass and aramid fabric composites to repeated low energy impacts and they obtained results for the different fiber reinforced composites which were correlated with the characteristics of the used fibers and fabrics. Atas et al. [8] investigated repeated impact response of woven E-glass/epoxy composites with various thicknesses. Duc et al. [9] studied damping capability of thermoset and thermoplastic composites reinforced with flax fiber fabric and compared the effects of matrix on damping properties. They used epoxy, polypropylene and polyactide as matrix material. They found best damping properties in flax fiber reinforced semi-crystalline polyactide. Lu et al. [10] studied the synergistic effect of self-assembled CNF and boron nitride (BN) nanopaper on the electro-activated shape memory effect. They finally introduced BN to improve the thermal conductivity and large dissimilarity of the nanocomposite for enhanced heat transfer and electric-activated shape recovery. Erkendirci and Haque [11] compared the penetration resistance behavior of glass/polyethylene composites with the baseline glass/epoxy composites and they showed that the force–displacement behavior of HDPE composites differs from the baseline SC15 epoxy composites. Shyr and Pan [12] studied impact resistance and damage characteristics of different composite laminates and they used different fabrics, thickness and impact energy levels as parameters. Fotouh et al. [13] performed cylic loading tests on the naturalfiber–reinforced thermoplastic composites and they were developed a model which predicts the fatigue behavior of these composites. Vieille et al. [14] studied the impact behavior of woven ply carbon fiber reinforced thermoplastic and thermosetting composites comparatively. They found that epoxy laminates experienced larger delamination than thermoplastic laminates and thermoplastic laminates showed better impact performances. Richardson and Wisheart [15] proposed a review of low velocity impact response of composite materials. They defined major impact –induced damage modes (matrix damage, delamination, fiber failure and penetration). Finally they proposed toughened resins or thermoplastics can reduce matrix dominated damage and they showed that post impact performance is related to the major damage.

In this study, E-glass fiber reinforced composites have been manufactured with two types of resin, polypropylene and epoxy (Thermoplastic and Thermoset) and they have been subjected to the low velocity single and repeated impacts and effect of resin type on the impact response of composites are investigated.

Material and Methods

This study focused on the effect of resin type on the impact response of composite plates therefore it's important to choose proper (impact resistant) reinforcement material. E-glass and carbon fibers are the most common form of reinforcing fiber used in polymer matrix composites. However carbon fiber reinforced composites are delicate to impact loadings. In this point of view E-glass fiber chosen for reinforcement and resin type impact behaviors are examined. Composite plates with thermoset matrix were produced by using vacuum infusion method. Composite plates with thermoplastic matrix, however, were produced by hot press method with using prepreg fabrics. Both plates were manufactured in $[0/90]_{10s}$ orientation with using 300 gr/m^2 areal density of E-glass fiber. Epoxy and its hardener were used for thermoset, polypropylene was used for the thermoplastic resin. Mechanical properties of both composites are given in table 1. Specimens were cut from these produced plates by using a water refrigerated diamond blade to the dimensions of

100 x 100 mm. Impact tests were performed by using Cheast Fractovis Plus drop weight test machine. The total mass of the stainless steel 12.7 mm hemispherical nosed impactor was 5 kg. 110 joule single impact tests and 50 joule repeated impact tests were made with same impactor. Composite plates thickness were approximately 5 mm and every specimen fixed by pneumatic fixture with 76.2 mm hole diameter. Each impact energy were tested with five separate specimens for thermoplastic and thermoset composites and time – contact force data were collected from top side of the specimen by DAS 16000 data acquisition system and converted to velocity, deflection and absorbed energy data. Low velocity impact test machine is shown in figure 1. Comparisons between the results of 110 joule single and 50 joule repeated impacted specimens were performed. Repeated impact test continued until the perforation occurred.

Results and Discussion

Force-deflection curves gives information about the impact test and the specimen. There are three basic types of impact test result case; rebounding, penetration and perforation. A closed force-deflection curve means impact tests resulted as rebounding and open curve means impact test resulted as either penetration or perforation case. Similarly absorbed energy can be determined from the covered area under the force-deflection curve.

First three impact tests were applied with 20, 50 and 80 joule impact energy. No perforation or penetration for both thermoplastic and thermoset composites were observed. When the impact energy was increased to 110 joule, both thermoplastic and thermoset composites perforated. The amount of energy absorbed by thermoset and thermoplastic composites were found to be 102 and 106 joules respectively. Although peak contact force differs sharply between two types of composites, both composite plates absorbed nearly the same impact energy. Polypropylene resin based composite plates deflected much more than the epoxy matrix composite thus thermoplastic composite make up the difference. As seen in figure 2. fiber failure begins at 2 kN for both composites and the maximum contact force for the thermoset and thermoplastic composites were measured as 16 kN and 8.9 kN respectively. Through thickness failure occurred at 16 kN and between 6-7.5 mm deflection for thermoset composite, however for the thermoplastic composite through thickness failure occurred at 8 kN contact force and between 8-15 mm deflection. At 8 kN contact force (through thickness failure point for thermoplastic composite), deflection measured 3.5 mm and 8.1 mm for thermoset and thermoplastic composites respectively. The slope of the ascending section of force-deflection curve is named as the impact bending stiffness [8]. Thermoplastic and thermoset matrix bending stiffness are found as 940 N/mm and 2225 N/mm respectively. Depending on the stiffness of the matrix material, the contact force differs between both composites nearly in half, though they both have absorbed approximately the same energy. Deformation ability of the thermoplastic matrix takes up the absorbed energy level at same degree. Damaged specimens after 110 joule impact tests are shown in figure 3.

Repeated impact tests were applied with 50 joule impact energy. 50 joule energy impact life of thermoset and thermoplastic composites were found as 4 and 18 impact steps respectively. Stresses which caused by bending were responsible for the delamination. After each impact, delamination occurs and advances, so the composite becomes more deformable. Deformability makes the absorbed energy higher. Thermoset matrix has a vitreous structure and repeating impacts easily damaged the laminates in every step. In the repeating impact tests of thermoset composites there weren’t any cracks due to impact fatigue, only the laminates damaged step by step and the void contents between laminates increased. It is known that increasing void contents decreases the impact resistance [6]. It took four step to failure for thermoset composites but in thermoplastic composites the matrix absorbed the impact energy and fibers transmitted stress to the whole body and impact fatigue occurred. Repeated impact contact force-deflection diagrams for both composites are shown in figures 4 and 5. Additionally, repeated impact performance of thermoplastic composite shown in video 1. After tenth impact step, material became more deformable and over delaminated so all of the impact energy absorbed. In this video it can be easily seen that zero velocity moment of the impactor.

In figures 6 and 7, absorbed energy and contact force change is shown step by step for thermoset and thermoplastic composites comparatively. As seen in figure 6, the contact force decreases dramatically by repeating impacts for thermoset composites because of the fiber failure and delamination, on the other side, for the thermoplastic composite, contact force increases in first three impacts and then decreases slowly until final failure occurs. Strain hardening of the thermoplastic resin made the composite tougher and in the first three impacts contact force increases and then decreases slowly. The absorbed energy level increased for both composites, especially for the thermoset composite this increase was very sharp, besides rising of the delamination.

Figure 8. shows the variation of the peak energy that had been reached at every impact step for both composite types. As seen in the figure, peak energy for thermoset composites had sharp decrease after each impact, however, thermoplastic composite has the peak energy nearly the same in each impact step. This difference results from the fact that there hadn’t been any matrix cracking in thermoplastic composite and every repeating impact reached nearly the same energy level until final failure.

In figure 9. section views of the specimens are shown. As seen in the figure thermoset composite had a local deformation only in a small area and damage propagated through the thickness. But the damage in thermoplastic composite nearly involved the entire body. Only the fiber breakage is seen in the local area but delamination and matrix deformation occurs on entire body. This was the main reason why thermoplastic composite’s impact life was longer than the thermoset one.

Conclusion

- Perforating impact energies are nearly the same for both thermoplastic and thermoset matrix composites.
- Maximum contact force of the thermoplastic matrix composite is nearly the half of the thermoset one, but the low bending stiffness and the deformable structure of the matrix, takes the absorbed energy levels same degree.

- Deformability caused by delamination which occurs as a result of impact, increases the absorbed energy. Delaminated composite design in structures can increase the impact response of the composites.
- Vitreous structure of the thermoset matrix causes fiber damage under early deformation and fibers do not transmit the stress through the body and damage propagates through the impact direction.
- Thermoplastic matrix composites are suitable to repeated impact conditions like wave impact.

This work shows that the resin type is a very important parameter for the impact response of the composite. With its deformation ability, low density and damage propagating properties, using the thermoplastic resin in some applications may provide better results.

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	E_1 (GPa)	V_{12}	G_{12} (GPa)	X_T (MPa)
Thermoset	19.2	0,18	3.1	370
Thermoplastic	13,4	0,23	2.6	245*

* Represents tensile strength at yield.

Table 1. Mechanical properties of thermoset and thermoplastic composites.

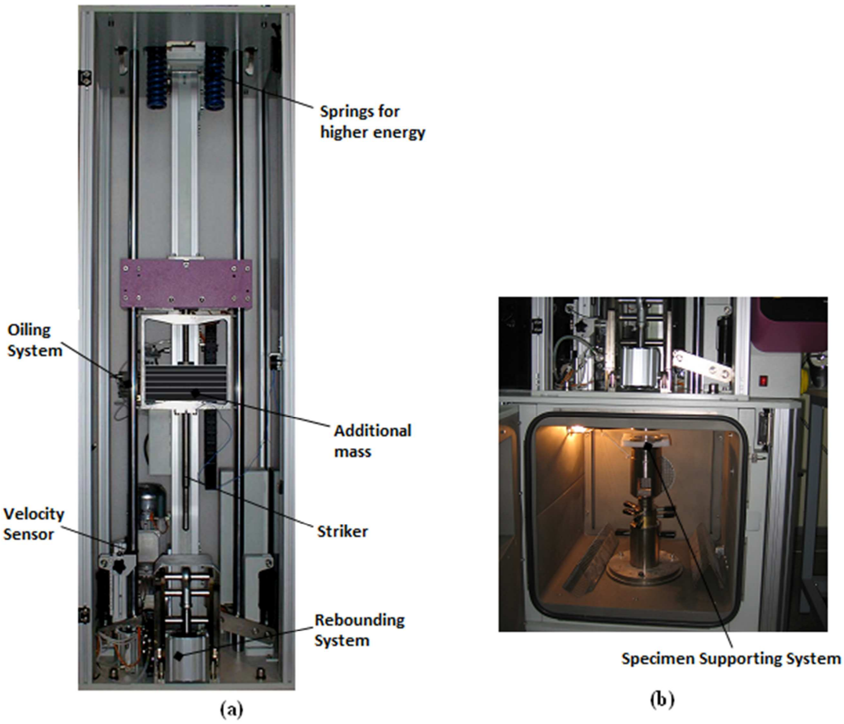

Figure 1. Fractovis Plus drop weight test machine

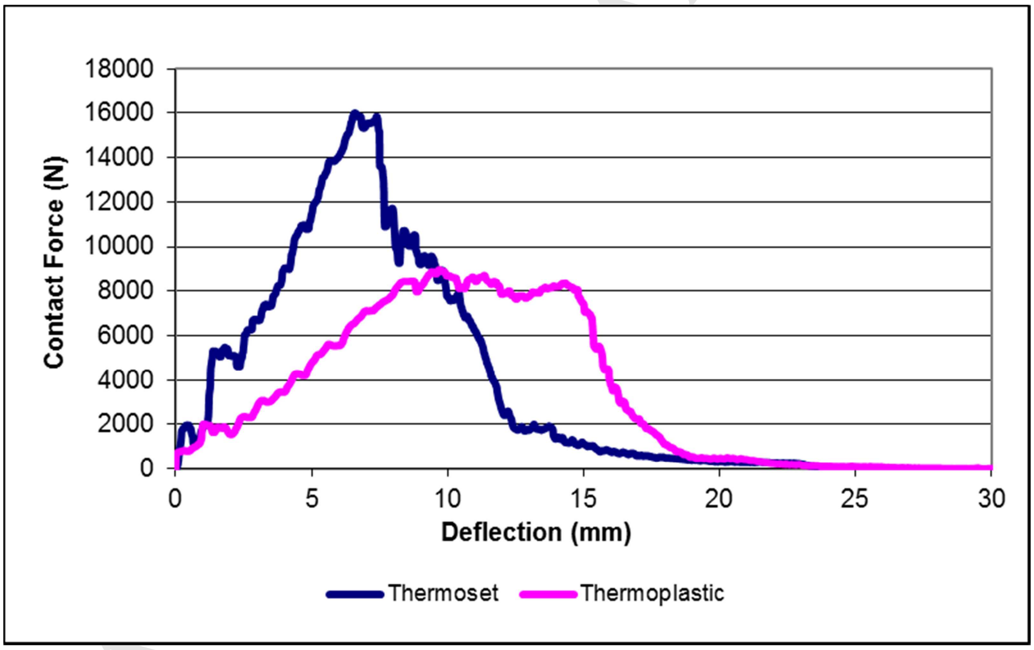

Figure 2. Contact force/Deflection diagram for 110 joule impact energy.

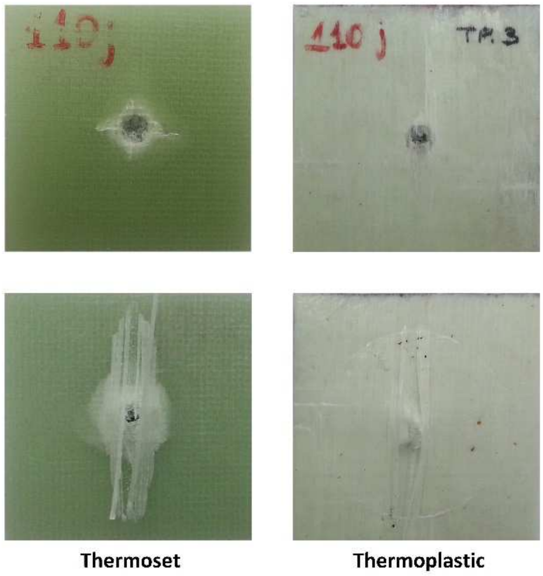

Figure 3. Deformation of the specimens after 110 J impact tests.

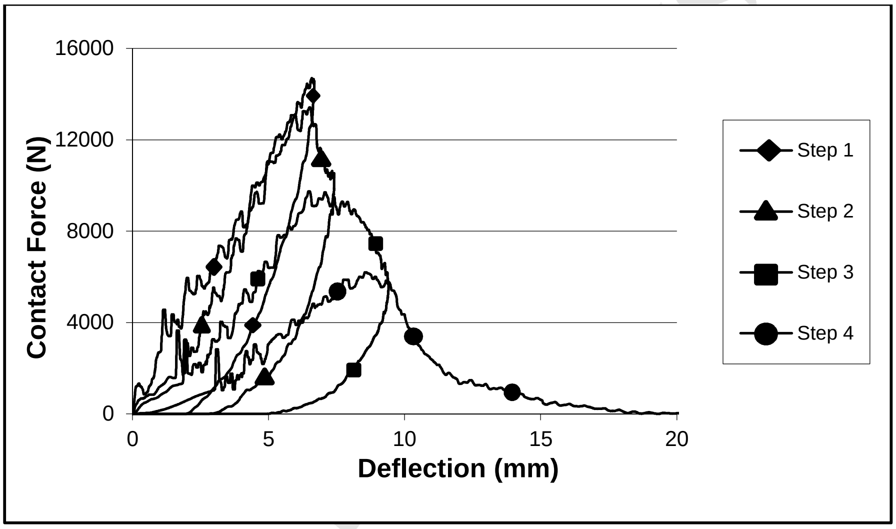

Figure 4. Contact force- deflection diagrams of thermoset composite (50 J Repeated)

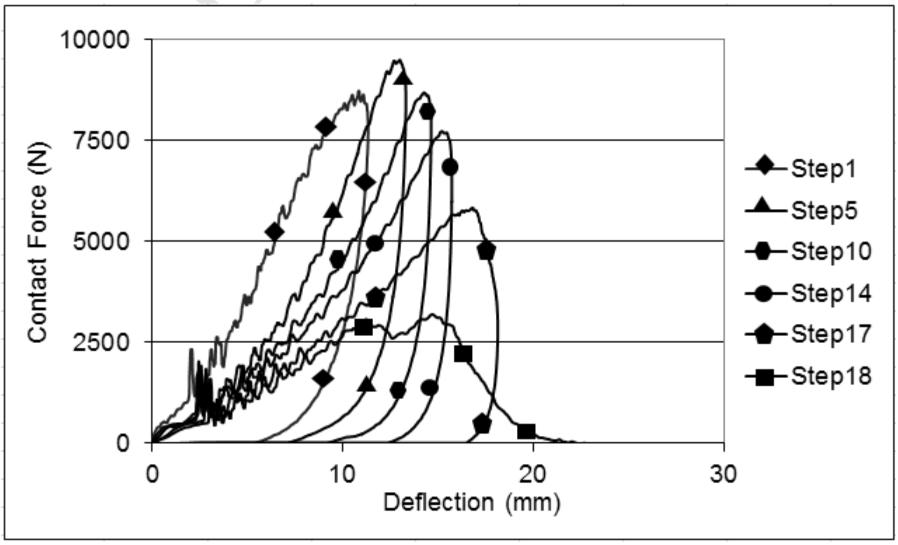

Figure 5. Contact force- deflection diagrams of thermoplastic composite (50 J Repeated)

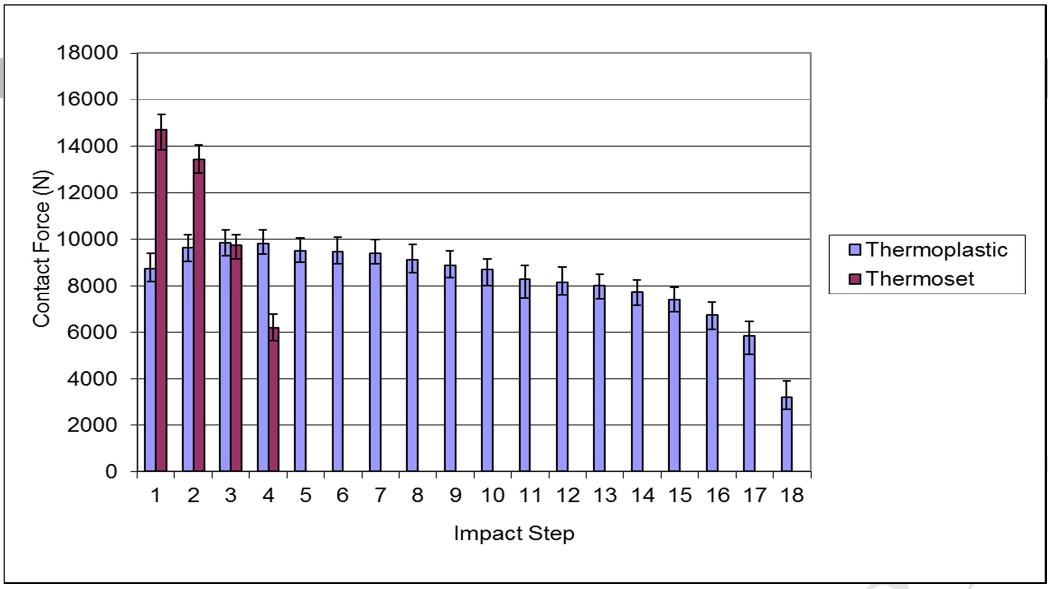

Figure 6. Variation of contact force by impact step

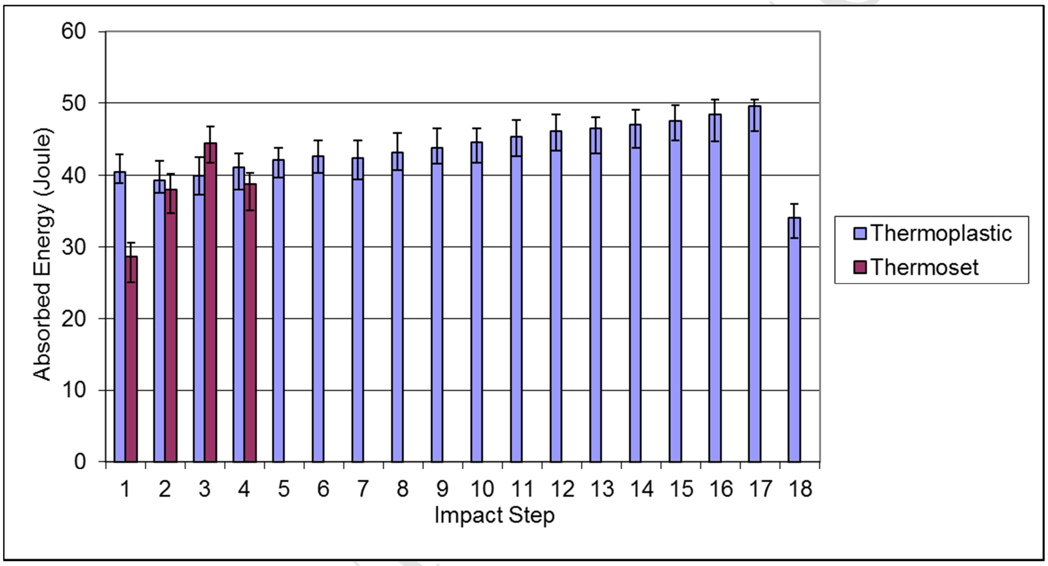

Figure 7. Variation of absorbed energy by impact step

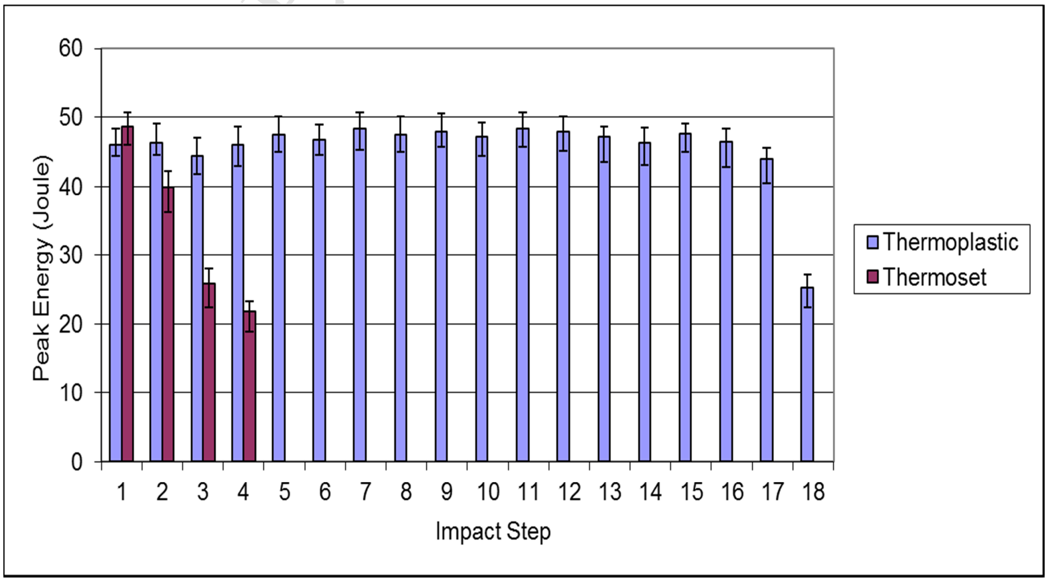

Figure 8. Variation of the peak energy by impact step

Figure 9. Section view of the specimens after 50 joule repeated impact tests.