Impact Behavior of Glass–Epoxy Composites Containing Foam Material

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ABSTRACT: The comparative performance under repeated low mass pendulum impacts of glass–epoxy (G–E) composites, without and with the inclusion in the form of individual flexible foam sheet layer of either two numbers or three numbers at predetermined positions in the lay-up, is reported. Employing square cross-section test coupons, the orientation of the test specimen was changed with respect to the impact direction such that, in one case, the G–E part and the foam layers constituting the system was lying along the direction of impact in an edgewise manner; in the second case, the change was achieved by turning the specimen by 90° i.e., perpendicular (flatwise). The number of impacts causing specimen failure was noted in all the cases. While foam-free samples sustained a greater number of hits in the first set of experiments, foam-bearing ones performed better in the flatwise configuration. To interpret these observations, light macroscopic examination was conducted on the impacted samples. A correlation could be established between the macroscopic features and the impact results. © 1998 John Wiley & Sons, Inc. J Appl Polym Sci **67:** 1565–1571, 1998

Key words: glass-epoxy; impact; foam; macroscopic features

INTRODUCTION

Laminated epoxy-based composites have found several applications in the aircraft and aerospace industries. Many attempts have been made to broaden their usage, including the use of fillers[1–5] and core materials.[6,7] While considerable attention has been paid to the study involving inclusion of various materials into the matrices,[8–11] there is a greater interest evinced by researchers into the systems containing elastomeric additions.[3–5] Literature on reinforced thermosets containing rubber and another material in the matrix is also available.[12]

Among core structures, the composites fabricated from rigid foam material have found considerable development[6,7] for use in both civil and military aircrafts. These rigid cores, having thin skin of a stiff reinforcement, have better strength and stiffness properties[6,7] coupled with the advantage derived from weight considerations. Many structures like honeycomb, rohacell, etc., have been used for the core region.

Though from the engineering point of view, the composites made from the nonrigid variety look less attractive, it would still be interesting to investigate the response to impact of laminated reinforced thermoset polymer systems where the flexible material is inserted at regions both including and excluding the core region, as the literature available on the same is scanty.[13]

For characterizing impacts, drop-weight[14–17] and pendulum-type tests, generally involving the commercially available models, are made use of,

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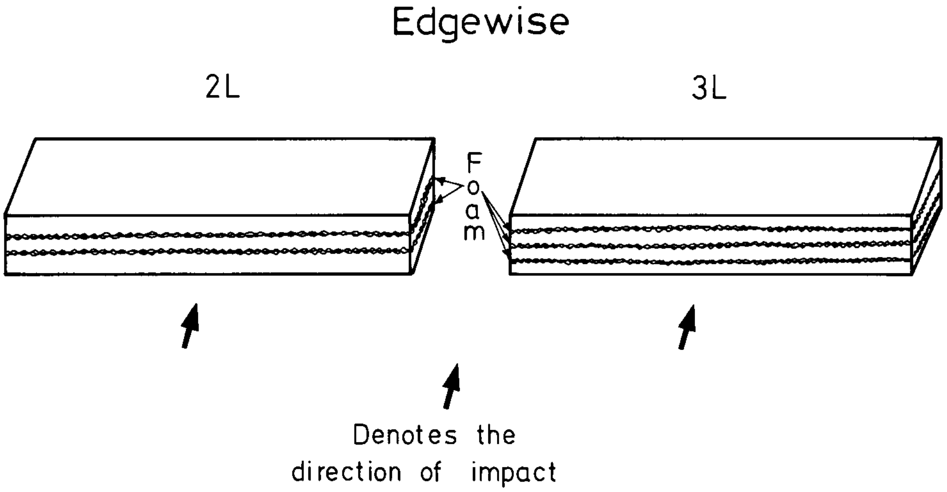

Figure 1 Schematic showing the edgewise loading arrangement for 2 L- and 3 L-type specimens.

although in some cases use of other fixture or alteration of existing commercial units[18–20] are cited in the literature. However, if instead of resorting to a single impact test,[21] the interest lies in repeated impacts causing an impact fatigue of the sample,[22,23] the drop-weight method seems to be preferred. However, for the available (Dynatup model GRC 8250) instrumented impact tester with acquired accessories, samples of a square 150 × 150 mm cross section is used.[24] Impacts are done with the tup of mass of about 2.5 kg and the diameter of 12 mm striking the top face of the clamped specimen from an adjustable height. However, as regards the evaluation of the impact with the tup striking the edge, a proper data acquisition is difficult due to factors like sample size vis-à-vis the tup dimensions, positioning and gripping of the sample, etc. Hence, although impact fatigue of a varying level of impact energy is possible by suitably selecting the mass and drop height of the tup, repositioning the sample to receive impacts on the side other than the flat face, in order to have a comprehensive view, seems not to be feasible, especially when thicknesses of the laminates made and used are small. As regards the case of pendulum strikes, the commercial model (Tinius Olsen universal impact tester with a hammer and integral anvil design) has a mass for the hammer around 27.22 kg. The fatigue-type tests presently contemplated, namely involving low mass, is not viable; further, for the Charpy mode of testing with notches, the samples could fail in single or a few hits, depending on the geometry of the sample and other test conditions. In one study, although a comparatively low mass (14.3 g) was used, the velocity used[25] was in the range of 20 to 100 m/s.

The above factors prompted the revival of an earlier model Hounsfield plastics impact machine for impact fatigue experiments where facilities existed for the mass of the tup to be far less than a pound and the strike velocity to be low. It was considered that an academic exercise of the present nature would bridge the gap that exists in this area in the composite literature field. However, the simplicity of the operation of the unit and absence of any gadgetry that goes with the modern instrumented impact machines precludes the gathering of those currently consolidated and referred to data such as energies absorbed, peak load, information on the aspect of time, slope of the curves, etc., thereby limiting the tests to preliminary findings, more of a qualitative nature, where the performance of foam-bearing ones is compared with the foam-free samples.

EXPERIMENTAL

Materials and Processes

The plain and the foam-bearing laminates were fabricated by the hand lay-up process. For the plain glass–epoxy (G–E) laminate, epoxy compatible E glass woven fabric was laid over a well-ground steel plate over which a release coating/film had been given.[13] On every glass fabric layer, a room temperature curing epoxy resin (supplied

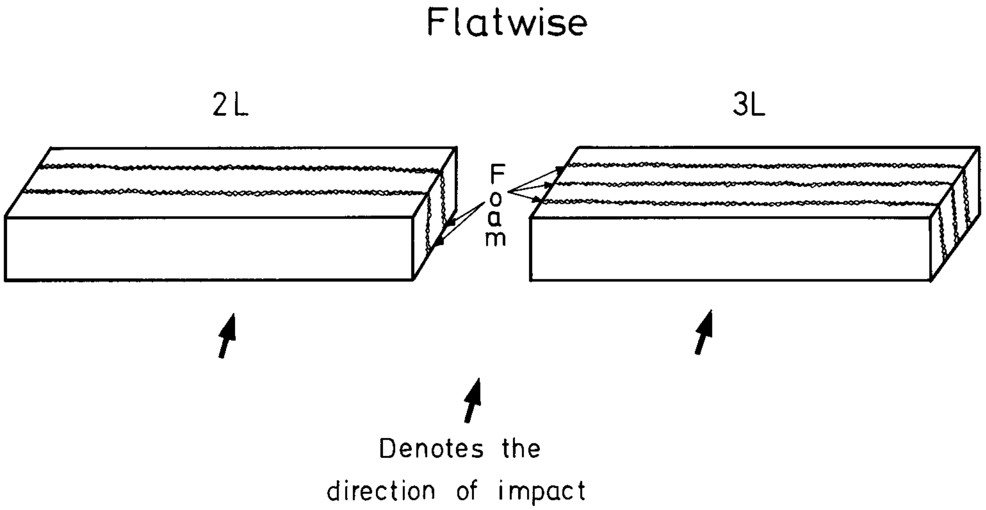

Figure 2 Schematic illustration depicting the flatwise mounting for 2 L and 3 L specimens.

by Hindustan Ciba Geigy, Bombay) mix was prepared and spread. A surface mat layer encompasses the lay-up sequence. Spacers were used for getting the required thicknesses. The uncured material was then pressed in a hydraulic press and allowed to completely cure at ambient temperature. During pressing operations, the excess resin was allowed to squeeze out.

The production of the foam-containing samples also had a similar lay-up and curing procedure, except as the layers of glass fabric were being laid to build up the material, at each of the positions corresponding to locations represented by $\frac{1}{4}$, $\frac{1}{2}$, and $\frac{3}{4}$ of the total thickness, a sheet layer of 6 mm thickness foam, having a coating of a commercial adhesive applied on both the surfaces, was inserted. The cured laminates were designated as 3 L type.

In another case at $\frac{1}{4}$ and $\frac{3}{4}$ thickness, a sheet layer, each of 9 mm thickness, of another flexible foam was inserted, which also had the commercial adhesive applied on them prior to placement in the lay-up. The laminates thus made were classified as 2 L variety. In this way, the total thickness inserted prior to compression and curing schedule was ensured to be nearly the same in both the foam varieties (i.e., 2 L and 3 L).

Impact Set-up

For experiments involving the impacts, a tup impacting low-mass pendulum-type Hounsfield plastics impact machine (model No. P 224) was used.

Specimen Mounting

Noting the thickness of the cured laminate and employing a diamond tipped cutter, samples were cut such that 5 cm long test coupons of a square cross section and a good surface finish could be obtained.

The unnotched test samples were placed on the flat extended arm support of the machine in the ungripped fashion with the face containing the ends of the layers of glass, cured epoxy, and foam materials receiving the impacts in one type of loading (Fig. 1). The terminology, namely, edgewise loading,[26] was adopted for this arrangement. When the square cross-sectioned specimen was turned by 90°, the impacts were received on the face that contains the G–E outer layer. This configuration, schematically shown in Figure 2, was categorized as a flatwise loading arrangement.[26] The precise position of placing the test coupon on the flat arm was marked so that the position during the second and subsequent hits can be made identical for achieving consistency in repeated impact conditions.

The impacts were done repeatedly with a $\frac{1}{4}$-lb mass pendulum tup impactor. The unit is provided with tups of lower and higher masses. Irrespective of the mass of the tup employed, the long suspended mass descends from its raised position by a height corresponding to about a foot before striking the test coupon. The lower end of this striker has a circular mass, which contains a sort of a radial cut (slit) traversing from the periphery to the center point of the mass (tup). Contact with the flat sample is made at this central region of

Table I Ratio of Number of Impacts for Various Samples in Two Modes of Loading

	Impact Loading	
Sample Type	Edgewise	Flatwise
Plain	1	1
2 L	1	1.75
3 L	0.5	1.5

the tup. The experiment consisted of repeating this operation of taking the swinging arm with the tup to a raised position, where it is held by a latch device supplied with the unit, repositioning the (displaced) sample at the same point using the reference markers on the sample, and striking the test coupon again with the same low mass (in the present case, as stated earlier, $\frac{1}{4}$ lb). This way, the impact test runs were continued, and the experiment was generally stopped following the failure of the test coupon. Specifically for visual and macroscopic noting, select samples were withdrawn from the setup either sometime during the impact experiments or prior to a possible final impact. Between four to six samples were tested using this approach.

Macroscopic and Microscopic Studies

A metallurgical microscope made by Neophot was employed to examine the macroscopic failure features. Later, typical features were photographed using a mounted camera with suitable lighting arrangements.

For scanning electron microscopic (SEM) studies, the sectioned pieces of the laminate were coated with a conducting layer[10] using a sputtering unit and examined in a JEOL SEM.

RESULTS AND DISCUSSION

Impact Data

From Table I, it is obvious that on introduction of foam materials, whether of two or three separate layers, the ratio of the number of impacts sustained by the laminate prior to failure generally records a change, irrespective of the loading configuration employed. The data of plain G–E samples are used as reference value for expressing the ratio of number of hits to failure shown in the tabulation (Table I).

For the edgewise-loading configuration, the plain variety sustains a greater number of impacts compared to the foam-containing three-layer samples. Between the two samples that contain foam, the one having the foam layer at two locations in the lay-up (2 L) withstand a greater number of hits prior to failure (Table I). As regards the data on flatwise loading configuration, the number of hits necessary to cause specimen failure is the least for the plain sample, while there is better performance by both 2 L and 3 L samples (Table I). The observations in this mounting are thus different from edgewise mounting.

Macroscopic Observations

In order to explain these responses to impact, the macroscopic features of the plain and the two varieties of foam-bearing impacted samples were looked into.

Edgewise Impacted Features

Figure 3 shows the features in the plain sample. The irregular appearance of the edge delineating the fracture is obvious from an examination of the photograph. The photographs also highlight the fiber pull-out feature.

The edgewise impacted 2 L samples reveal (Fig. 4) a zigzag path for the propagation of the crack (delineated by bright patches). Although both photographs in Figure 4 reveal an irregular path for the crack progression, the shift that occurs in the brightened white regions is distinct in

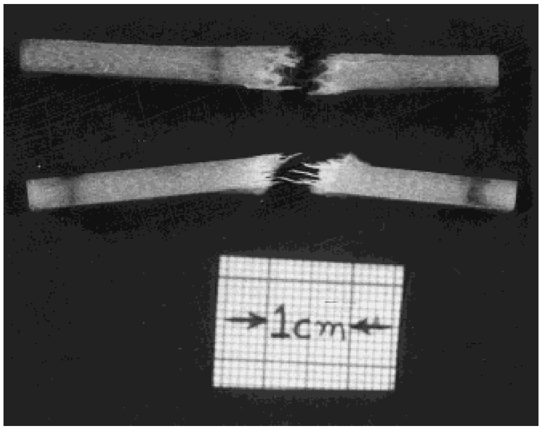

Figure 3 The plain sample depicting the irregular fracture features.

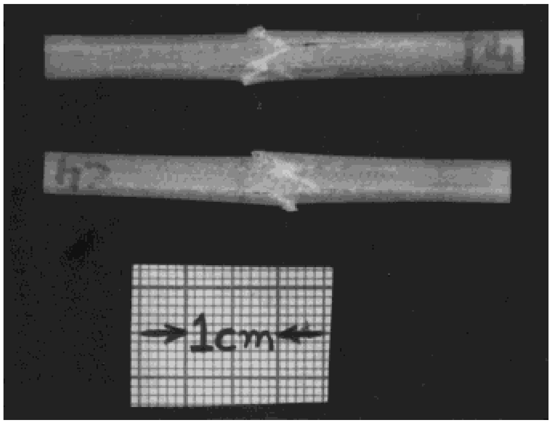

Figure 4 The zigzag crack path shown by two samples of 2 L variety.

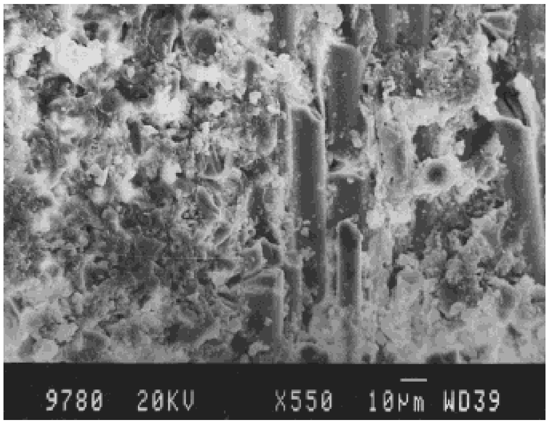

Figure 6 Scanning micrograph showing resin spread on the glass fibers.

the lower sample, emphasizing the influence of foam in the progress of the crack front. Also, a thin separation is noticed at the interface of the G–E and the upper of the two foam layers (top sample).

The results obtained with 3 L samples (Fig. 5), when impact tested edgewise, again show the zigzag appearance for the spread of the crack and a more visible interface separation compared to the 2 L variety. In addition, they show a wider separated region, sort of accommodating the intrusion (partly) into one half of the sample by the counter part resembling a butting in situation.

To account for these observations on the plain and the two foam-containing, edgewise-loaded samples, the features seen on the foam-free sample are considered first. For this sample, the scanning macrographs reveal a good spread of resin on the glass reinforcement (Fig. 6), indicating that the adhesion between the glass and epoxy is good and suggesting that the occurrence of interfacial separation at the zone of reinforcement and matrix is less likely, although through the light macroscopy procedure adopted presently, an event of this nature cannot be monitored.

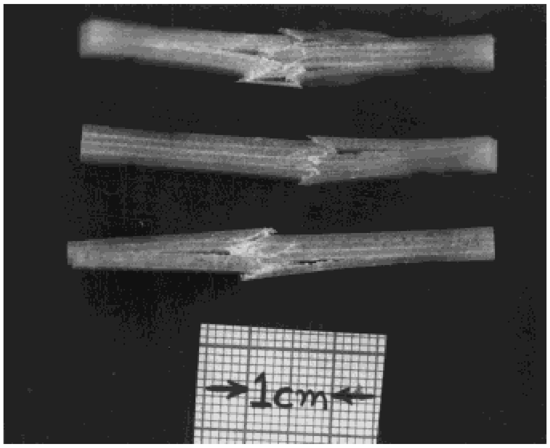

Figure 5 Edgewise impacted 3 L-variety samples showing features on three different test coupons.

In the foam-bearing sample, on the other hand, there is an additional interface, coming by in the form of the region between the foam layer and G–E, whose area is greater the more layers that are introduced into the laminate. The adhesion between these inserted foam and G–E constituent being less strong,[13] the process of interface separation and the spread of the debonded regions is favored as hits are persisted with the low mass tup. Further, in this edgewise loading, as hits are along this weak plane of G–E/foam interface, it is easier for the cracks originating at the impacted end to reach the other nonimpacted side, a factor that is made a lot easier with the square cross-section samples used in this experiment in contrast to the larger width-to-thickness ratio bearing (rectangular) samples used in an earlier study,[13] requiring traversing of the larger width by the originating crack to reach the farther side. Thus, the presence of such a region of separation, as successive impacts take place, can explain the poorer performance by foam-containing samples for this mounting. The inferior performance of 3 L compared to the 2 L for this mounting can possibly be due to fact that as the separation that occurs at the foam/G–E region is wide enough to accommodate intrusion by the counter half of the sample (Fig. 5), the resistance offered by such bent contoured (3 L) sample decreases, thus lowering its performance.

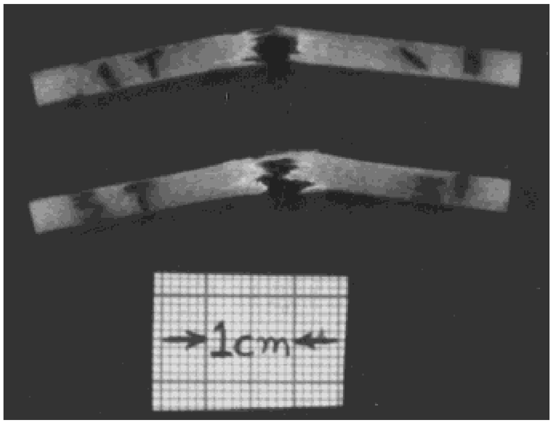

Figure 7 Plain sample showing irregular fracture features.

Figure 9 Two samples of 3 L variety illustrating the interface separation.

Flatwise Impacted Features

The macrographs obtained with the plain sample (Fig. 7) show irregular fracture and fiber pull-out like their counterparts in edgewise loading (Fig. 3). However, for this flat loading condition, the foam-bearing sample reveals an interfacial region separation at two regions (Fig. 8) for the 2 L samples and separation at three regions (one of them being faintly visible) for the 3 L samples (Fig. 9).

To interpret the flatwise loading results, as before, the case involving the plain samples are taken up first. These show irregular crack path and some fiber pull out, which indicate among other things the spread of the crack in the matrix and fiber fracture features like for the ones tested by edgewise loading. The difference, however, comes in the case of foam-containing samples where, besides the type of loading adopted for this case, the interfacial area and the adhesion possible at these areas become important. It may be recalled at this juncture that the specimen is placed on the flat extended arm support in the ungripped position for both mountings. The initiation of cracks at the region near the point of impact and its subsequent propagation to reach the unimpacted end, seen with the other (edgewise) mounting, is conspicuous by its greatly reduced presence for this (flatwise) loading configuration with foam-bearing samples. This path, involving the separation along the interface and starting from the end of the sample, traversing to the mid-regions of the sample, is longer compared to through the cross-section spread seen with all samples for edgewise loading and also in flatwise loading of plain samples. This difference in the process accounts for the larger number of impacts sustained by these foam-bearing samples. Further, the face of the foam layer is perpendicular to the impacting direction, and tearing through the flexible foam is not easily achieved. This also contributes to the enhanced number of impacts witnessed for these samples. It is significant to note that in 2 L samples in Figure 8, the sample at the bottom shows, besides interface separation, a faint whitish line at the center, indicating an attempt for the through-the-section growth of the crack.

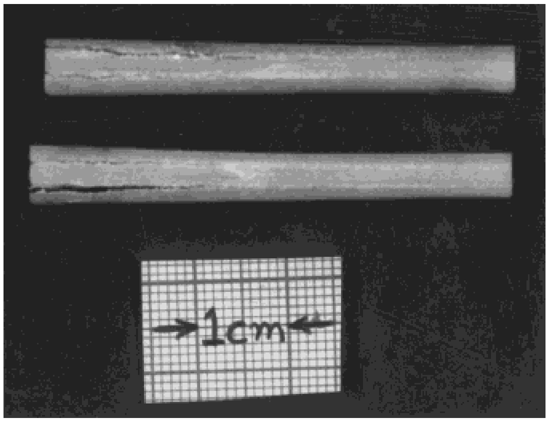

Figure 8 Two samples of 2 L variety showing interface separation.

Summarizing, it is observed that for the edgewise impacts, foam-free samples generally offer a better resistance to repetitive low-mass pendulum tup impacts compared to two or three layers of foam-bearing samples. For the flatwise orientation, the converse is seen. This fact emphasizes the importance of orientation of the sample vis-à-vis the direction of impact and the significance of the interfacial area in the foam-bearing samples.

CONCLUSIONS

The work points to the fact that consequent to the introduction of sheet layer of foam material at different positions of the laminate, the response of the laminate to repetitive low-mass pendulum tup impacts changes. While through the cross section, a zigzag crack propagation trend is noticed for the plain sample on edgewise loading, foam-containing ones show an irregular path for the crack path and some interface separation.

Samples tested in the flatwise loading configuration record a greater ratio of number of hits prior to failure by foam-bearing ones and distinct onset for the interface separation. The plain samples for this loading arrangement show, through the cross section, progress for the crack path and fracture of the test coupons.

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