DYNAMIC FRACTURE BEHAVIOR OF COMPOSITES

S. Ravi[1*], N.G.R. Iyengar[1], N.N. Kishore[1] and A. Shukla[2]

[1] Indian Institute of Technology, Kanpur 208 016, India
[2] University of Rhode Island, Kingston, RI 02881, USA
[*] Presently at RIAM, Kyushu University, Kasuga 816-8580, Japan

ABSTRACT

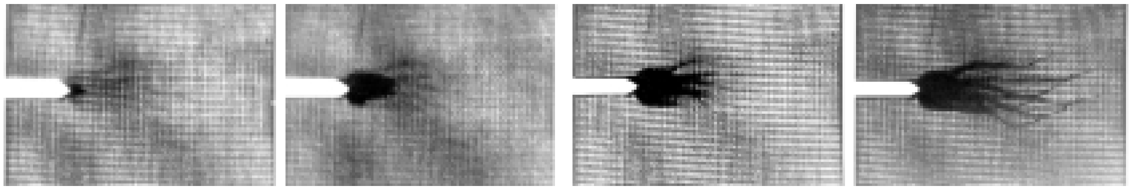
Dynamic fracture behavior of glass-polyester composites subjected to dynamic loads has been studied. The aim is to study the effect of reinforcement type, fiber volume fraction, initial notch orientation and fiber orientation. Cranz-Schardin type multi-spark high speed recording system has been used to record the initiation and propagation history at a pre-determined short intervals of time. It has been observed that the damage grows normal to the loading direction irrespective of the type of reinforcement, initial notch orientation and fiber orientation. The damage propagates at higher velocity than in the unreinforced polyester matrix. Further, for a given energy input, the damage area reduces with increase in fiber volume fraction.

KEY WORDS

Dynamic fracture, stress waves, high speed recording, damage zone, glass-polyester composite.

INTRODUCTION

The fracture behavior of composite materials under various loads is of significant practical importance in terms of its service performance. It is known that the fracture process in composites precedes with the formation of a zone, often referred to as *damage zone*, ahead of the crack tip. The damage zone consists of many micromechanisms like fiber fracture, matrix cracks, interface failure etc. Further, as the damage propagates, these failure modes may interact with each other resulting in a complex fracture process. Shukla and Khanna [1, 2] have investigated the effect of fiber-matrix interface on dynamic crack growth and associated fracture energy in a brittle matrix material reinforced with discrete fibers. The results indicate that the fiber reinforcement reduces fracture energy available at the crack tip as calculated from the instantaneous stress intensity factor and results in small crack jump distance. Agarwal et al. [3] used Cranz-Schardin camera to study the dynamic damage growth in glass/polyester composites. Their results show that the dynamic damage in composite, propagates with a slightly lower velocity than the crack propagation velocity in a polyester resin. In the present study, we attempt to study the fracture behavior in glass-polyester composites having reinforcements in the form of cloth and chopped strand mat loaded with stress waves.



97.5 μsec 114.0 μsec 127.5 μsec 205.5 μsec

Figure 1: Damage growth pattern in glass/polyester composite MSEN ($V_f = 5.3$ % and 0° notch)

EXPERIMENTAL PROCEDURE

Material

Optically transparent glass/polyester composite plates have been fabricated in the laboratory from sheet grade polyester resin(Parikh Chemicals, Kanpur 208016, INDIA) and glass fibers in the form of cloth (balanced weave) and chopped strand mat (Harsh-Deep Industries, Ahmedabad 380023, INDIA). The refractive index of the polyester resin is modified to match with that of the glass fibers by adding 5% di-butyl pthalate and 2% di-vinyl benzene. The resin mixture has been cured using 1% MEKP and 0.03% cobalt octate at room temperature for $24\,h$ and post cured at $80°C$ for $8\,h$. The plate thus fabricated with 33% fiber volume fraction shows a transmission ratio of 69.5%.

Testing

Dynamic damage growth in fiber composites have been studied using modified single edge notched (MSEN) specimens containing an initial notch length of 0.25 times the width. The specimen is mounted on the optical bench of Cranz-Schardin high speed camera. Dynamic loads are produced by the simultaneous detonation of two explosive charges on both side-shoulders of the specimen. For the present study, 50 mg and 25 mg of PETN explosive charge with lead azide as explosion initiator have been used respectively for cloth and mat composites. Detonation generates compressive waves which get reflected as tensile waves from the free end. The end shape of the MSEN has been selected in such a way that the reflected tensile waves propagate as a planar wave front. It has been established [4] that a plane fronted loading tensile wave can be achieved with the specimen configuration considered for the present analysis. The planar wave loads the notch and initiates the damage.

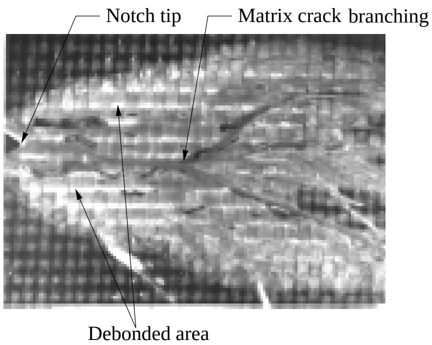
Damage Zone Measurements

The detonation simultaneously sends signal to the high speed camera to start recording twenty pictures of damage initiation and propagation history at 5 μsec interval. Image processing tool, IDRISI has been used to obtain the useful informations, like the damage area etc., from the recorded images.

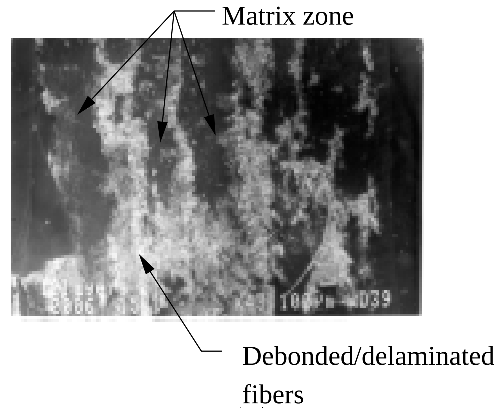
RESULT AND DISCUSSION

Damage in Woven Fabric Composites

The damage pattern and the propagation history in woven fabric (cloth) composite specimen having $V_f = 5.3$ % with $\theta = 0$ ° are shown in Figure 1. The dark area ahead of the machined notch are the 3 dimensional damage occurred as the notch is loaded with the stress waves. Similar images have been obtained for all the cases considered. From these images, it is observed that the damage propagates perpendicular to the loading direction and parallel to the notch plane. In homogeneous materials, single crack propagates with possible crack branching under appropriate loading conditions, while in composites, a damage zone is formed ahead of the notch and this damage zone propagates. Further, it is observed that for a given energy, the damage zone size reduces as the fiber volume fraction increases.



(a)



(b)

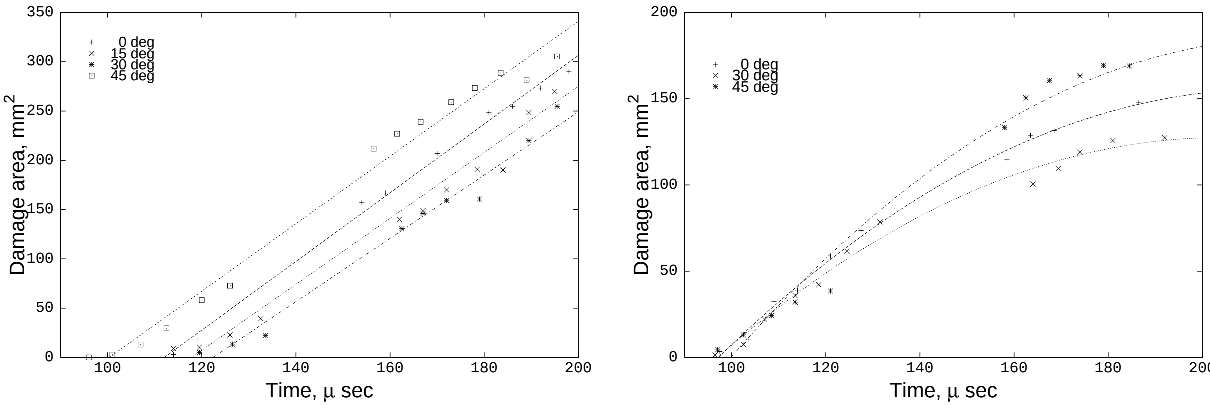
Figure 2: Microscopic picture showing (a) debonded area and matrix crack with branching in MSEN specimen having $V_f = 2.4$ % and $0°$ notch (b) delaminated and debonded fibers as bright spots in MSEN specimens having $V_f = 33.0$ % and $0°$ notch

Table 1: Damage propagation velocity and rate of growth of damage in glass/polyester composites

Volume fraction %	Notch orientation deg	Velocity (m/s)		Rate of growth (m^2/sec)	
		Initial	Final	Initial	Final
Woven fiber cloth composite					
2.4	0	460	260	3.49	–
	15	400	210	3.35	–
	30	420	320	3.21	–
	45	470	150	3.42	–
5.3	0	490	0	2.50	0.45
	30	380	0	2.22	0.13
	45	450	0	2.92	0.98
Chopped strand mat composite					
10.0	0	500	0	–	–
	15	250	0	–	–

Another important feature observed in specimens with low fiber volume fractions is the damage zone splitting, analogous to the crack branching in homogeneous materials. For low fiber volume fractions, the mechanisms involved in the formation of damage zone are, the matrix cracking, fiber-matrix interface debonding and branching in matrix region (Figure 2a). On the other hand, the mechanisms involved in high fiber volume fraction are matrix cracking, fiber-matrix interface debonding and delamination (Figure 2b).

Table 1 gives the damage velocity for different specimens studied. It is observed that the initial velocity is approximately same for both $V_f = 2.4$ % and 5.3 %. But during the end of the observation period, the damage slows down in single layer composites ($V_f = 2.4$ %), while it gets arrested in two layer composites ($V_f = 5.3$ %). Further investigations revealed that the damage traveled to the entire width of the specimen in single layer composite which is not seen in other specimens. This lowering and arrest may be due to the unloading of the damage zone as the trailing part of the stress wave passes over and due to the increased resistance due to rise in fiber volume fraction.



(a) (b)

Figure 3: Propagation of damage zone during the observation period (a) single layer ($V_f = 2.4\%$) and (b) two layer ($V_f = 5.3\%$) composites

Figures 3a and b show the variation of damage area with respect to time for the composites specimens studied. Table 1 also presents the damage growth rate calculated from the above figures. From the figures and table, it is seen that for single layer composites, irrespective of the initial notch orientation, the damage zone grows at a constant rate. On the other hand, the damage has to overcome the resistance by the increased fiber and so the damage zone grows at a slower rate during the end of the observation period in two layer composite specimens.

Damage in Chopped Strand Mat Composites

Figures 4 and 5 shows damage sequences in short fiber composites with $V_f = 10\%$ and $0°$ notch. It is noted that the overall damage is perpendicular to the loading direction as observed in woven cloth composite specimens. In mat composites, the damage zone is formed due to multi-directional micro-cracks in the matrix, at the interface and due to fiber fracture. The damage zone initiates at the crack tip and grow perpendicular to the loading direction in a narrow band. Damage zone splitting, as seen in woven fabric composites, is not observed in mat composites. However, *secondary damage*, away from the notch tip and independent of main damage, has been noted. Some time this secondary damage is from the corner of the 'V' notch (Figure5). The energy absorbing mechanisms in mat composites are the matrix cracks and interface debonding at the ends of the short fibers. As the stress waves passes over, the dynamic load increases, which leads to an increase in the stress intensity around the notch. This raise in stress level leads to the concentration of stresses at the ends of the fibers, ultimately leading to the initiation of the debonding.

Table 1 also gives the the velocity of damage in chopped strand composites. It is observed that the initial propagation velocities are in the range of $250 - 500$ m/sec. These damage velocities are higher than the crack velocity of 240 m/sec for glass-polyester composite model [3]. It is observed that in all the damage propagation velocity reduces and gets arrested. This reduction in velocity is analogous to the reduction in crack velocity with decrease in stress intensity factor in Homalite-100.

It may be pointed out here that the above definition of damage propagation velocity may provide a method for analyzing the results of dynamic fracture experiments on composite materials. However, the difference between this damage propagation velocity and the crack velocity in homogeneous materials should be recognized and properly accounted for in developing the analysis procedures and interpreting results. Actual damage in composites consists of numerous 3D micro damages in the form of fiber–matrix interface debonding, fiber, matrix cracks, etc., which is quite different from through-the-thickness cracks. On the other hand, the Cranz-Schardin camera records the 2D

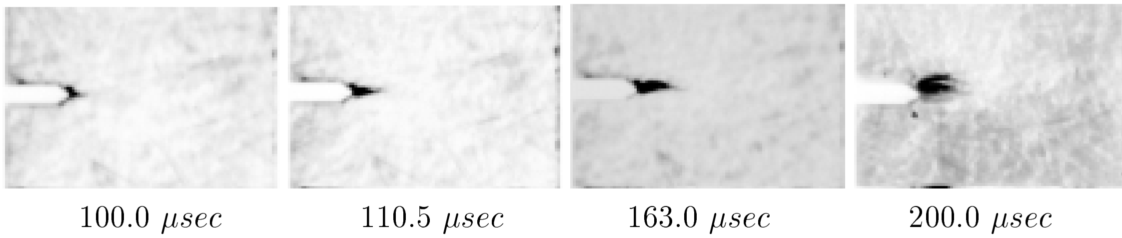


Figure 4: Damage sequence in random mat composites, $V_f = 10\%$, $0°$ notch, 25 mg PETN charge

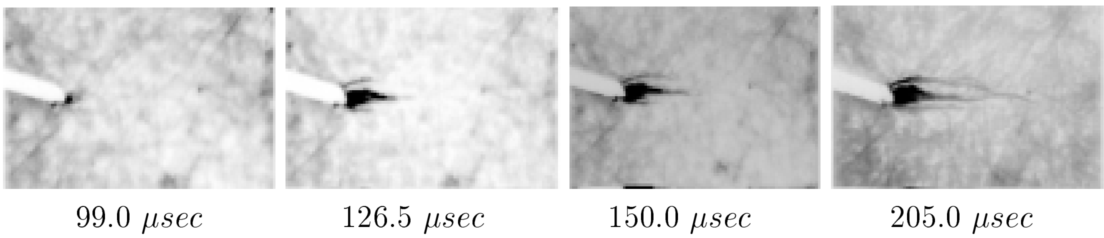


Figure 5: Damage sequence in random mat composites, $V_f = 10\%$, $15°$ notch, 25 mg PETN charge

projection of the 3D damages. Establishing the relationship between the shadow areas and the 3D fracture surface area is quite challenging and requires further work.

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