# Effects of loading speed on the failure behaviour of FRP composites

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**Abstract**

**Purpose** – The objective of the present work is to ascertain the failure modes under different loading speeds along with change in percentage of constituents of FRP composites.

**Design/methodology/approach** – This involves experimental investigation of FRP composites with woven roving fibers and matrix. Different types of composites, i.e. glass: epoxy, glass: polyester and (carbon + glass): epoxy are used in the investigation with change in percentage of constituents. The variability of fiber content of the composite is in the range of 0.55-0.65 weight fractions. The matrix dominated property, like inter laminar shear strength (ILSS) has been studied by three point bend test using INSTRON 1195 material testing machine with increasing five cross head velocities.

**Findings** – The variation of ILSS of laminates of FRP composites is significant for low loading speed and is not so prominent for high speed. The variation of ILSS are observed to be dependent on the type and amount of constituents present in the composites. The laminates with carbon fiber shows higher ILSS than that of glass fiber composites. The laminates with epoxy matrix shows higher ILSS than polyester matrix composites for the same fiber. There is no significant variation of ILSS beyond loading speed 200 mm/min and this can be used for specifications of testing. Matrix resins such as polyester and epoxy are known to be highly rate sensitive. Carbon fiber are relatively rate independent and E-glass fibers are rate sensitive. Woven roving carbon glass fiber reinforced polymer shows small rate dependence and woven roving glass fiber reinforced polymer shows significant rate sensitivity.

**Originality/value** – The findings are based on original experimental investigations in the laboratories of the institute and can be used for characterization of composites.

**Keywords** Composite materials, Shear strength

**Paper type** Research paper

## Introduction

There has been a tremendous advancement in the science and technology of fiber reinforced composites in recent times. The low density, high strength, high stiffness to weight ratio, excellent durability, and design flexibility of fiber reinforced polymers are the primary reasons for their use in many structural components in the aircrafts, automotive, marine and other industries. Fiber-reinforced polymers are now used in application ranging from space craft frames to ladder rails, from aircraft wings to automobile doors, from rocket motor cases to oxygen tanks and from printed circuit boards to tennis rackets. The increasing utilization of polymer composite materials in critical structures necessitates their full characterization. This will bring about the much needed boost in confidence for their application to industrial situations including building industries where high speed load is a concern. Load speed performance can in some way be measured by the energy absorbed or expended to failure of a material. Hence, establishing the effects of failure behavior of materials of different fibers is of paramount importance when designing for load speed. The strength properties of FRP composite materials are based on the content of fiber and matrix material. Glass fiber and carbon fiber based polymeric composites are finding wider and newer applications in different fields. Recently, Beamount (1989) presented an overview of the investigations on failure behavior of composite materials. Daniel and Ishai (1994) presented an excellent review of the previous studies on experimental methods for characterization and testing of composite materials through 1994. Mannini (1997) investigated the thermal buckling of symmetric and anti symmetric cross ply composites laminates. A parametric study for several types of laminates was given for different boundary conditions and changing the values of various parameters such as lay up sequences slenderness ratio and transverse shear moduli. The buckling parameter reduced when the slenderness ratio decreased and increasing the transverse shear modulus would provide a higher thermal buckling. Keusch *et al.* (1998) investigated the influence of the interface of differently sized glass fibers on the mechanical properties of glass fiber epoxy resin composites. The results of micromechanical and macro mechanical tests of unidirectional laminates characterize the fiber/matrix adhesion. Deng *et al.* (1999) conducted a comprehensive experimental study to identify the effects of fiber cross sectional aspect ratio on tensile and flexural properties and the failure modes of glass fiber/epoxy composites by using fibers of three different cross sectional shapes (round, peanut shaped and oval). It was found that, the fibers of peanut and oval cross sectional shapes tend to align with the long axis of the cross section perpendicular to the direction of the applied pressure or in the plane of a composite laminate. As a result, many fibers overlapped each other, having large contact areas which act as a path for longitudinal crack propagation. The longitudinal tensile

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modulus and strength were nearly the same for the three composite systems. The transverse tensile strength and strain to failure results were similar to those for longitudinal tension but the transverse tensile modulus was reduced for composites with fibers of large aspect ratios. Okoli and Smith (2000) performed tensile tests on a glass epoxy laminate at different rates of strain to determine the effects of strain rate in the Poisson's ratio of the material. The findings from the experimental results suggested that Poisson's ratio is not sensitive to strain rate. However, the extent to which fiber content affects the rate sensitivity of Poisson's ratio is yet to be established. Okoli (2001) conducted tensile, shear and three point bend tests on woven glass epoxy laminate at increasing rates of strain to ascertain the relationship between energy to failure and strain rate. The result suggested a linear relationship between expended energy and the log of strain rate in the laminate tested. Silva *et al.* (2001) investigated the effect of the addition of methyl ethyl keytone peroxide (MEKP) and cobalt naphthenate (CoNaph) on the mechanical behavior of epoxy vinyl ester resin (EVER) laminates by using a factorial experimental design in which the MEKP and Naph co contents were vary. The result showed that there is an interaction between the process variables analysed, MEKP and CoNaph contents on the mechanical properties. Okutan (2002) studied the effects of geometric parameters on the failure strength for pin loaded fiberglass reinforced epoxy laminate.

The objective of the present study is to investigate the effect of loading speed on the failure behavior of different types of fiber reinforced composites. The macroscopic property changes of FRP composites can be ascertained by mechanical tests such as three point bend test, which gives an idea about the inter laminar shear strength (ILSS). Three types of composite laminates with woven fiber reinforcement, i.e. glass: epoxy; glass: polyester; and (carbon + glass): epoxy with different weight fractions are fabricated and specimens are tested to failure by three point bend test in five different increasing load speeds on an INSTRON 1195 material testing machine. The test results are analysed to characterize the effects of fiber types and loading speed on failure behavior of FRP composites.

## Experimental work

In the present investigation, three different types of fiber: matrix composites specimens were fabricated. These were:

1 (carbon + glass) : epoxy;
2 glass : epoxy; and
3 glass : polyester.

Each type of preparation of laminates were manufactured of three different type of weight fractions of fiber: matrix, i.e. 55:45, 60:40 and 65:35. Woven roving E-glass and woven roving carbon fibers were cut into required shape and size according to number of specimens required for testing. Each composite laminate consists of 16 plies of fiber as per ASTM (1990) specification. For glass epoxy specimens, three varieties of laminates were prepared i.e.

1 glass : epoxy = 55 : 45;
2 glass : epoxy = 60 : 40; and
3 glass : epoxy = 65 : 35.

The epoxy resins are:

- Araldite LY 556; and
- Hardener HY951.

For preparation of epoxy resin matrix 3 percent Hardeners were used. Similarly three glass – polyester laminates were fabricated i.e.

1 glass : polyester = 55 : 45;
2 glass : polyester = 60 : 40; and
3 glass : polyester = 65 : 35.

For preparation of polyester matrix 1 percent accelerator was added first to the polyester resin. Then 1.5 percent catalyst added to mixture and stirred thoroughly to get polyester matrix. The accelerator and catalyst were used Cobalt Octate 2 percent and MEKP (methyl ethyl ketone peroxide), respectively. Then three types of (carbon + glass) : epoxy hybrid laminates were fabricated, i.e.

1 (carbon + glass) : epoxy = 55 : 45;
2 (carbon + glass) : epoxy = 60 : 40; and
3 (carbon + glass) : epoxy = 65 : 35.

Subsequent plies were placed one upon another with matrix in each layer to obtain sixteen stacking plies. A hand roller was used to distribute resin uniformly, compact plies, and to remove entrapped air. The mold and lay up were covered with a release film to prevent the lay up from bonding to the mold surface. Then the resin impregnated fibers were placed in the mold for curing. The laminates were cured at normal temperature (25°C and 55 percent Relative Humidity) under a pressure of 0.2 MPa for three days. The objective was to ensure good bonding of the resin and reinforcement. After proper curing of the laminates the release films were detached. In (carbon + glass) : epoxy hybrid laminate, there are eight carbon fiber plies and eight glass fiber plies. They were placed alternatively one upon another with matrix in each layer. From the laminates of each is weight fraction of fiber matrix, specimens were cut for three point bend test by brick cutting machine into 45 × 6mm size as per specification. ILSS is a measure of the *in situ* shear strength of the matrix layer between plies. The most commonly used test for ILSS is the short beam under three point bending. The specimens were tested for three point bend test on the INSTRON 1195 material testing machine with different cross head velocities to obtain inter laminar shear strength and to study the effects of loading speed for different types of laminates. The tests were conducted with cross head velocities 2, 20, 100, 200, 500 mm/min with constant span of 34 mm. Then load at yield (max. load) were obtained for each specimens as shown in Tables I to IX. For each type of laminate minimum ten specimens were tested with different cross head velocities. The important procedures were followed during three point bend test as follows. Before testing the thickness and width of the specimens were measured accurately at the midpoint. The test specimen was placed in the test fixture and aligned so that its midpoint was centered and it's long axis was perpendicular to the loading nose. The load was applied to the specimen at a specified cross head speed. Breaking load of the sample was recorded. The same procedure was repeated for all the specimens. The inter laminar shear strength was calculated using the formula, $S = (0.75P_b)/(bd)$ (as per ASTM D 2344-84) where $P_b$, breaking load, kg; $b$, width, mm; $d$, thickness, mm.

## Results and discussion

The details of dimensions of the glass fiber and epoxy matrix test specimens and the yield load under three point bend tests

**Table I** Test results of glass fiber : epoxy = 55:45 specimens

| Sample No. | Width (mm) (*b*) | Thickness (mm) (*d*) | Load at yield (max load) (*N*) ($P_b$) | Inter laminar shear strength (0.75 $P_b/bd$) (MPa) | Average inter laminar shear strength (MPa) | Loading speed (mm/min) |
|---|---|---|---|---|---|---|
| 2 | 5.64 | 4.41 | 1,063 | 32.1 | 30.9 | 2 |
| 3 | 6.14 | 4.49 | 1,089 | 29.6 | | 2 |
| 4 | 6.97 | 4.35 | 1,041 | 25.8 | 27.1 | 20 |
| 5 | 6.18 | 4.68 | 1,092 | 28.3 | | 20 |
| 7 | 6.48 | 4.75 | 734.8 | 17.9 | 17.9 | 100 |
| 8 | 6.73 | 4.71 | 954.9 | 22.6 | 23.4 | 200 |
| 9 | 6.11 | 4.47 | 878.3 | 24.1 | | 200 |
| 12 | 6.16 | 4.65 | 1,088 | 28.5 | 23.3 | 500 |
| 13 | 5.99 | 4.78 | 689.3 | 18.1 | | 500 |

**Table II** Test results of glass fiber : epoxy = 60:40 specimens

| Sample No. | Width (mm) (*b*) | Thickness (mm) (*d*) | Load at yield (max load) (*N*) ($P_b$) | Inter laminar shear strength (0.75 $P_b/bd$) (MPa) | Average inter laminar shear strength (MPa) | Loading speed (mm/min) |
|---|---|---|---|---|---|---|
| 166 | 5.75 | 4.55 | 1,206 | 34.6 | 32.9 | 2 |
| 165 | 6.15 | 5.25 | 1,339 | 31.1 | | 2 |
| 179 | 5.84 | 5.18 | 1,260 | 31.2 | 32.5 | 20 |
| 178 | 5.84 | 5.14 | 1,347 | 33.7 | | 20 |
| 209 | 6.15 | 5.07 | 791 | 19 | 20 | 100 |
| 163 | 7.11 | 5.05 | 1,005 | 21 | | 100 |
| 226 | 6.44 | 5.14 | 1,093 | 24.8 | 23.4 | 200 |
| 175 | 6.24 | 5.20 | 949.8 | 22 | | 200 |
| 159 | 5.27 | 4.97 | 899.7 | 25.7 | 24.7 | 500 |
| 161 | 6.21 | 5.32 | 1,042 | 23.7 | | 500 |

**Table III** Test results of glass fiber : epoxy = 65:35 specimens

| Sample No. | Width (mm) (*b*) | Thickness (mm) (*d*) | Load at yield (max load) (*N*) ($P_b$) | Inter laminar shear strength (0.75 $P_b/bd$) (MPa) | Average inter laminar shear strength (MPa) | Loading speed (mm/min) |
|---|---|---|---|---|---|---|
| 287 | 6.50 | 5.17 | 1,369 | 30.6 | 31.5 | 2 |
| 288 | 6.14 | 4.52 | 1,196 | 32.3 | | 2 |
| 289 | 6.69 | 4.73 | 1,449 | 34.3 | 33.9 | 20 |
| 290 | 5.79 | 5.17 | 1,337 | 33.5 | | 20 |
| 291 | 6.82 | 5.10 | 985 | 21.2 | 24.8 | 100 |
| 292 | 6.50 | 4.55 | 1,118 | 28.4 | | 100 |
| 293 | 6.39 | 4.83 | 837.4 | 20.3 | 23.5 | 200 |
| 294 | 6.86 | 4.71 | 1,144 | 26.6 | | 200 |
| 297 | 6.18 | 4.88 | 1,031 | 25.6 | 27 | 500 |
| 298 | 6.2 | 4.57 | 1,072 | 28.4 | | 500 |

are shown in Tables I-III and the variation of inter laminar shear strength vs loading speed are shown in Figure 1.

The details of dimensions of the glass fiber and polyster matrix test specimens and the yield load under three point bend tests are shown in Tables IV-VI and the variation of inter laminar shear strength vs loading speed are shown in Figure 2.

The details of dimensions of the (carbon + glass) fiber and epoxy matrix test specimens and the yield load under three point bend tests are shown in Tables VII-IX and the variation

**Table IV** Test results of glass fiber : polyester = 55:45 specimens

| Sample No. | Width (mm) ($b$) | Thickness (mm) ($d$) | Load at yield (max load) ($N$) ($P_b$) | Inter laminar shear strength ($0.75\ P_b/bd$) (MPa) | Average inter laminar shear strength (MPa) | Loading speed (mm/min) |
|---|---|---|---|---|---|---|
| 1 | 6.64 | 5.54 | 970.3 | 19.8 | 19.5 | 2 |
| 2 | 6.73 | 5.51 | 949.9 | 19.2 | | 2 |
| 3 | 6.56 | 5.59 | 1,391 | 28.4 | 28.4 | 20 |
| 4 | 6.28 | 5.47 | 1,299 | 28.4 | | 20 |
| 5 | 6.45 | 5.18 | 5,878 | 131.9 | 91.1 | 100 |
| 6 | 6.69 | 5.54 | 2,486 | 50.3 | | 100 |
| 7 | 6.4 | 5.1 | 936.2 | 21.5 | 19.8 | 200 |
| 8 | 6.48 | 5.51 | 956.6 | 20.1 | | 200 |
| 12 | 6.46 | 5.33 | 817.1 | 17.8 | | 200 |
| 9 | 6.58 | 5.52 | 967.8 | 20 | 20.2 | 500 |
| 10 | 6.17 | 5.49 | 881.2 | 19.5 | | 500 |
| 11 | 6.76 | 5.42 | 1,028 | 21 | | 500 |

**Table V** Test results of glass fiber : polyester = 60:40 specimens

| Sample No. | Width (mm) ($b$) | Thickness (mm) ($d$) | Load at yield (max load) ($N$) ($P_b$) | Inter laminar shear strength ($0.75\ P_b/bd$) (MPa) | Average inter laminar shear strength (MPa) | Loading speed (mm/min) |
|---|---|---|---|---|---|---|
| 1 | 6.72 | 4.82 | 998.3 | 23.1 | 24.8 | 2 |
| 2 | 6.46 | 5.16 | 1,172 | 26.4 | | 2 |
| 3 | 6.51 | 5.26 | 1,385 | 30.3 | 29.7 | 20 |
| 4 | 6.56 | 5.23 | 1,329 | 29.1 | | 20 |
| 5 | 6.65 | 4.82 | 1,019 | 23.8 | 21.8 | 100 |
| 6 | 6.58 | 4.92 | 856.2 | 19.8 | | 100 |
| 7 | 6.68 | 5.12 | 992.2 | 21.8 | 22.6 | 200 |
| 8 | 6.64 | 5.04 | 1,007 | 22.6 | | 200 |
| 14 | 6.28 | 5.10 | 999.7 | 23.4 | | 200 |
| 10 | 6.44 | 5.30 | 906.6 | 19.9 | 21.5 | 500 |
| 11 | 6.52 | 5.20 | 1,034 | 22.9 | | 500 |
| 12 | 6.48 | 4.92 | 926.7 | 21.8 | | 500 |

**Table VI** Test results of glass fiber : polyester = 65:35 specimens

| Sample No. | Width (mm) ($b$) | Thickness (mm) ($d$) | Load at yield (max load) ($N$) ($P_b$) | Inter laminar shear strength ($0.75\ P_b/bd$) (MPa) | Average Inter laminar shear strength (MPa) | Loading speed (mm/min) |
|---|---|---|---|---|---|---|
| 1 | 6.48 | 5.04 | 1,080 | 24.8 | 21.4 | 2 |
| 2 | 6.50 | 5.10 | 797.1 | 18 | | 2 |
| 3 | 6.22 | 5.10 | 1,105 | 26.1 | 28.1 | 20 |
| 4 | 6.40 | 5.14 | 1,319 | 30 | | 20 |
| 5 | 6.52 | 5.22 | 912.2 | 20.1 | 21.3 | 100 |
| 6 | 6.54 | 5.02 | 978.5 | 22.4 | | 100 |
| 7 | 6.56 | 5.10 | 880.2 | 19.7 | 20.7 | 200 |
| 8 | 6.50 | 5.11 | 966.7 | 21.8 | | 200 |
| 14 | 6.26 | 5.00 | 865.2 | 20.7 | | 200 |
| 9 | 6.58 | 5.12 | 789.5 | 17.6 | 18.3 | 500 |
| 10 | 6.43 | 4.92 | 825.1 | 19.6 | | 500 |
| 13 | 6.43 | 4.99 | 758.5 | 17.7 | | 500 |

**Table VII** Test results of (carbon + glass) : epoxy = 55:45 specimens

| Sample No. | Width (mm) (*b*) | Thickness (mm) (*d*) | Load at yield (max load) (*N*) ($P_b$) | Inter laminar shear strength (0.75 $P_b/bd$) (MPa) | Average inter laminar shear strength (MPa) | Loading speed (mm/min) |
|---|---|---|---|---|---|---|
| 1 | 6.19 | 6.64 | 2,211 | 40.35 | 37.7 | 2 |
| 2 | 6.58 | 6.83 | 2,105 | 35.13 | | 2 |
| 3 | 6.29 | 5.66 | 1,774 | 37.37 | 39.7 | 20 |
| 4 | 6.26 | 6.22 | 2,178 | 41.95 | | 20 |
| 5 | 6.51 | 5.98 | 1,676 | 32.29 | 31.4 | 100 |
| 6 | 5.86 | 6.37 | 1,519 | 30.52 | | 100 |
| 7 | 6.00 | 5.94 | 1,661 | 34.95 | 33.4 | 200 |
| 8 | 6.32 | 5.64 | 1,509 | 31.75 | | 200 |
| 9 | 6.28 | 6.10 | 1,636 | 32.03 | 32.8 | 500 |
| 10 | 6.23 | 6.79 | 1,898 | 33.65 | | 500 |

**Table VIII** Test results of (carbon + glass) : epoxy = 60:40 specimens

| Sample No. | Width (mm) (*b*) | Thickness (mm) (*d*) | Load at yield (max load) (*N*) ($P_b$) | Inter laminar shear strength (0.75 $P_b/bd$) (MPa) | Average Inter laminar shear strength (MPa) | Loading speed (mm/min) |
|---|---|---|---|---|---|---|
| 1 | 6.19 | 5.98 | 2,130 | 43.16 | 40.7 | 2 |
| 2 | 6.34 | 6.50 | 2,100 | 38.22 | | 2 |
| 3 | 5.85 | 6.25 | 1,935 | 39.69 | 40.6 | 20 |
| 4 | 6.00 | 6.85 | 2,279 | 41.59 | | 20 |
| 5 | 6.36 | 6.50 | 1,585 | 28.76 | 29.8 | 100 |
| 6 | 6.15 | 6.87 | 1,737 | 30.83 | | 100 |
| 7 | 6.21 | 6.97 | 1,701 | 29.47 | 30.4 | 200 |
| 8 | 6.61 | 6.41 | 1,767 | 31.28 | | 200 |
| 9 | 6.31 | 6.39 | 1,666 | 30.99 | 31.2 | 500 |
| 10 | 5.91 | 6.87 | 1,696 | 31.33 | | 500 |

**Table IX** Test results of (carbon + glass) : epoxy = 65:35 specimens

| Sample No. | Width (mm) (*b*) | Thickness (mm) (*d*) | Load at yield (max load) (*N*) ($P_b$) | Inter laminar shear strength (0.75 $P_b/bd$) (MPa) | Average inter laminar shear strength (MPa) | Loading speed (mm/min) |
|---|---|---|---|---|---|---|
| 1 | 6.24 | 5.75 | 1,484 | 31.02 | 34.5 | 2 |
| 2 | 6.06 | 6.34 | 1,949 | 38.04 | | 2 |
| 3 | 6.14 | 6.15 | 2,057 | 40.85 | 39.7 | 20 |
| 4 | 6.18 | 6.07 | 1,925 | 38.48 | | 20 |
| 6 | 5.95 | 6.30 | 1,540 | 30.81 | 27.6 | 100 |
| 13 | 5.55 | 6.32 | 1,141 | 24.4 | | 100 |
| 7 | 6.04 | 5.95 | 1,328 | 27.71 | 27.3 | 200 |
| 8 | 6.71 | 6.27 | 1,509 | 26.9 | | 200 |
| 9 | 6.11 | 6.09 | 1,641 | 33.07 | 31.4 | 500 |
| 10 | 6.49 | 5.69 | 1,459 | 29.63 | | 500 |

**Figure 1** Inter laminar shear strength vs loading speed diagram of glass : epoxy at different weight fractions of fiber matrix composites

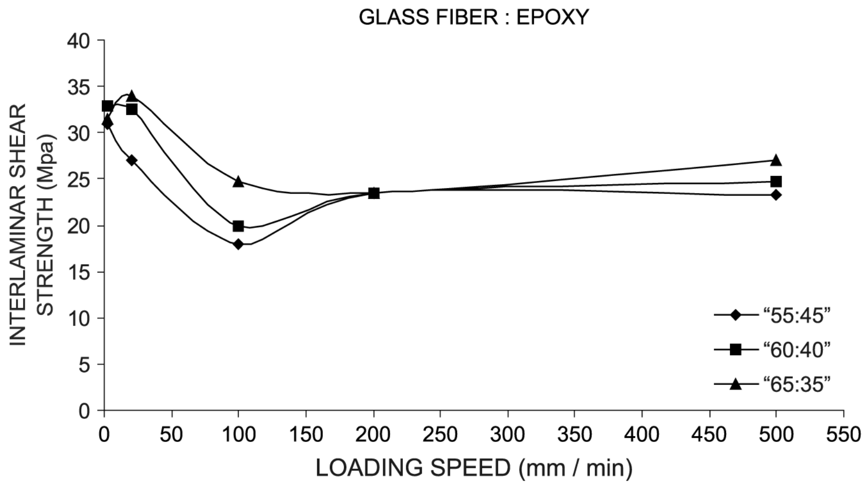
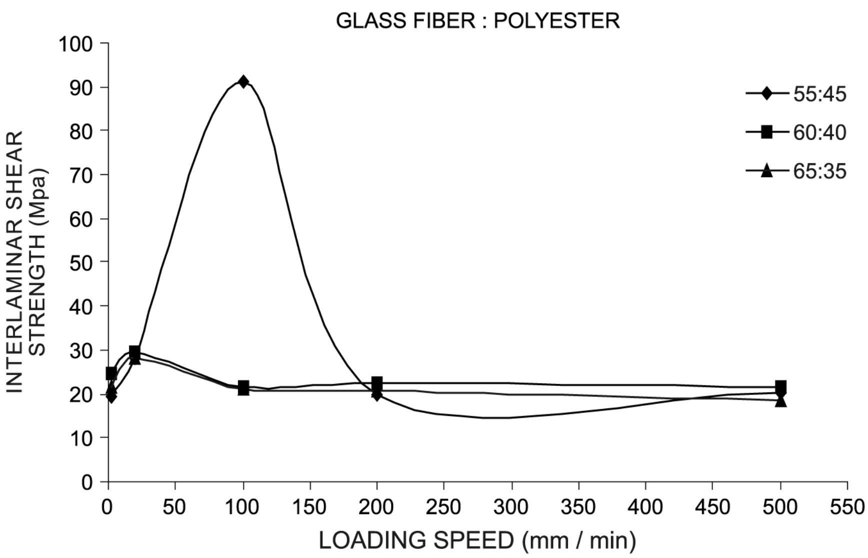



**Figure 2** Inter laminar shear strength vs loading speed diagram of glass : polyester at different weight fractions of fiber matrix composites




of inter laminar shear strength vs loading speed are shown in Figure 3.

The variations of inter laminar shear strength on the weight fractions, loading speed, fiber and matrix types of the FRP composites are discussed below.

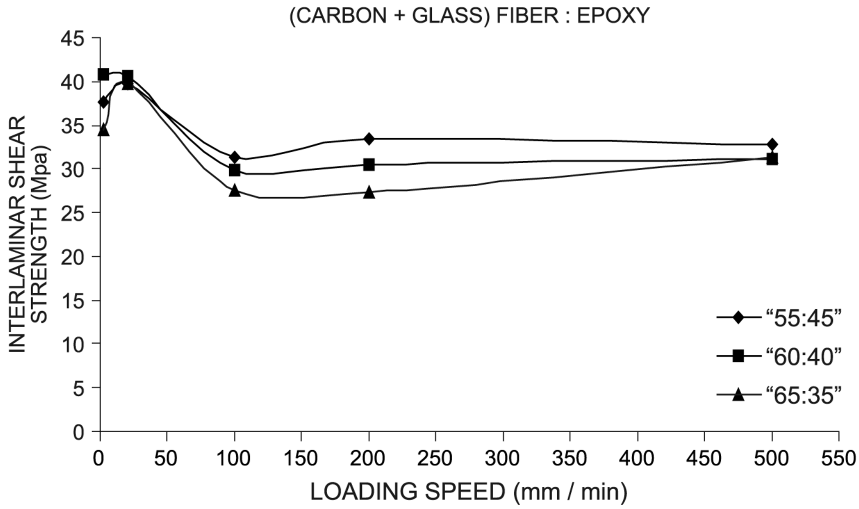
**Effects of weight fractions**

In the weight fraction of fiber-matrix of glass-epoxy, higher fiber percent content gives higher inter laminar shear strength in low loading speed as well as high loading speed than lower fiber percent content of fiber : matrix while in weight fraction of fiber : matrix of (carbon + glass) : epoxy lower fiber percent content gives higher inter laminar shear strength in low loading speed as well as high loading speed than higher fiber percent content of fiber-matrix. In the loading speed of 200 mm/min, the inter laminar shear strength is constant irrespective of weight fraction of fiber matrix of glass : epoxy while in loading speed 20 mm/min, the inter laminar shear strengths are constant irrespective of weight fraction of fiber : matrix of glass : polyester and (carbon + glass) : epoxy specimens. In high loading speed 500 mm/min the inter laminar shear strength is constant for weight – fraction of fiber-matrix of (carbon + glass) : epoxy = 60:40 and (carbon + glass) : epoxy = 65:35 specimens.

**Effects of loading rates**

The inter laminar shear strength is higher at low loading speed and the inter laminar shear strength is lower at high loading speed for a particular weight – fraction of fiber: matrix of glass: epoxy and (carbon + glass): epoxy specimens. In higher loading speed, i.e. 200 mm/min to 500 mm/min optimum fiber: matrix of glass: polyester = 60 : 40 gives the higher inter laminar shear strength while in 100 mm/min loading speed glass: polyester = 55 : 45 gives the maximum inter laminar shear strength. Matrix resins such as polyester and epoxy are known to be highly rate sensitive. In general, the variation of inter laminar shear strengths are found with increasing loading speed. E-glass fibers have been found to be rate sensitive but very little information is available on the rate dependence of the carbon fibers. One should in general

**Figure 3** Inter laminar shear strength vs loading speed diagram of (carbon + glass) : epoxy at different weight fractions of fiber matrix composites




anticipate some rate dependency of composites, although a direct correlation between the rate dependency of the composite and those of the constituent phases, can be difficult or rather complicated. Woven roving glass fiber reinforced polymer (GFRP) show a significant rate sensitivity. The variation of inter laminar shear strengths are found with increasing loading speed. The lack of a significant rate dependency of carbon glass fiber reinforced polymer (CGFRP) likely reflects the lack of rate dependence of the carbon fiber. It is important to note that a change in loading speed can result in a variation of failure modes. A small rate dependence of the strength has been observed with woven reinforcement CGFRP. When subjected to an increasingly higher impact velocity, a laminate behaves like a more rigid beam or plate, less susceptible to bending. This shifts its behavior from that of a flexible beam (very low impact velocity), with failure preferentially initiated from the rear surface, to that of a rigid beam, with damage initiation occurring near the point of contact in the case of much higher impact velocity. At intermediate velocities, one should expect to see complex behavior of mixed fracture modes. This has yet to be verified by a systematic study.

### Effects of different fiber types

The variation of inter laminar shear strengths for epoxy laminates with (carbon + glass) and glass fibers of weight fraction 55:45 are shown in Tables VII and I, respectively. As seen from Tables VII and I, for all loading speed, the ILSS for laminates with (carbon + glass) fiber is higher than glass fiber laminates for same matrix. The variation of Inter laminar shear strength for epoxy laminates with (carbon + glass) and glass fibers of weight fraction 60:40 are shown in Tables VIII and II, respectively. As seen from Tables VIII and II, for all loading speed the ILSS for laminates with (carbon + glass) fiber is higher than glass fiber laminates for same matrix. The variation of inter laminar shear strength for epoxy laminates with (carbon + glass) and glass fibers of weight fraction 65:35 are shown in Tables IX and III, respectively. As seen from Tables IX and III, for all loading speed, the ILSS for laminates with (carbon + glass) fiber is higher than glass fiber laminates for same matrix. So it is concluded that, the laminates with carbon fiber shows higher inter laminar shear strength than that of Glass fiber for same matrix.

### Effects of different matrix types

The variation of ILSS for glass fiber laminates with epoxy and polyester matrix of weight fraction 55:45 are shown in Tables I and IV, respectively. As seen from the Tables I and IV, for all loading speed the ILSS for laminates with epoxy matrix is higher than polyester matrix laminates except for loading speed 20 mm/min and 100 mm/min. There is a general trend of increase of ILSS with epoxy matrix than polyester matrix for same fiber. The variation of Inter Laminar shear strengths for glass fiber laminates with epoxy and polyester matrix of weight fraction 60:40 are shown in Tables II and V, respectively. As seen from the Tables II and V, for all loading speed the ILSS for laminates with epoxy matrix is higher than polyester matrix laminates for same fiber. The variation of ILSS for glass fiber laminates with epoxy and polyester matrix of weight fraction 65:35 are shown in Tables III and VI, respectively. As seen from the Tables III and VI, for all loading speed the ILSS for laminates with epoxy matrix is higher than polyester matrix laminates for same fiber. So it is concluded that the laminates with epoxy matrix shows higher inter laminar shear strengths than polyester matrix for the same fiber.

## Conclusion

The fabrication of samples and subsequent three point bend test is revealed to ascertain the effects of fiber types and loading speed on the failure behavior of FRP composites. The following conclusions were arrived during the present study had its own limitations with regard to limited laboratory facilities available. It may be noted that validity of these can only be assessed to the range of variables covered and the materials used during the investigation.

- In the weight fraction of fiber matrix of glass : epoxy composites, higher fiber content gives higher inter laminar shear strength, in all loading speeds.
- For (carbon + glass) : epoxy composites, lower fiber content gives higher inter laminar shear strength in all loading speeds.

- The variation of Inter laminar shear strengths of laminates of FRP composites significant for low loading speed and is not so prominent for high speed.
- The variations of ILSS are observe to be dependent on the type and amount of constituents present in the composites.
- The composite laminates with carbon fiber shows higher inter laminar shear strength than that of glass fiber.
- The composite laminates with epoxy matrix shows higher inter laminar shear strength than polyester matrix for the same fiber.
- There is no significant variations of inter laminar shear strength beyond loading speed 200 mm/min and this can be used for specifications of testing.
- Matrix resins such as polyester and epoxy are known to be highly rate sensitive.
- E-glass fibers are found to be rate sensitive.
- Carbon fibers are relatively rate independent.
- Woven roving GFRP shows significant rate sensitivity.
- Woven roving CGFRP shows small rate dependence.

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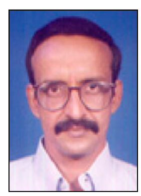

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