INTRODUCTION

The response of composite laminates under impact loads is an important step to establish relationships between damage and material properties and current problem in structural design. Composites are already in use where they are susceptible to the impact of foreign objects. The increasing use of layered composites in light weight, high strength structure has led to a corresponding increasing in effort to analyze the damage behavior of such material [1-15]. In most of these studies, the composite is molded as a periodically layered body, with the constituent layers composed of homogeneous, linearly elastic material. In spite of the extensive use of fibrous composites, there is a widespread feeling that current applications still fall far short of the ultimate potential of such material. Consequently, as a practical matter the determination of both the stiffness and the ultimate load of a composite require an understanding of the mechanics of damage accumulation [1-5]. Experimental observations can be helpful in making the problem amenable to analytical study [6-9].

Two major types of matrix controlled failure exist in composites; delamination and matrix cracking [9]. Delamination is in the form of interlaminar separation as a result of the out-of-plane stresses induced in the laminate. Matrix cracking occurs in the plies along the fiber direction due to the load transverse to the fibers. Hearakovich [10] obtained the unnotched strength for graphite/epoxy laminates with 0,90,45,-45 degree orientation. He used linear elastic finite element stress analysis. He found that when 45 or -45 plies were interspersed among 0 and 90 plies the mismatch between the coefficient of mutual influence is reduced, which leads to the reduction of interlaminar shear stress. This increases the resistance to the initiation of delamination and thereby increases the unnotched strength. When 0 or 90 plies are placed outside, the interface moment reduces. He concluded that the 45 and -45 plies should be dispersed and the interface moment be minimized. The interlaminar stresses about their magnitude and sign can be accurately calculated using analytical models [8]. The magnitude and distribution of the interlaminar stress components depend on the type of laminate, stacking sequence, properties of the constituent materials and type of loading [11].

In the present work an investigation of impact compression experiments on glass/epoxy unidirectional lamina and laminated composite plate is discussed. For high rate of loading Split Hopkinson pressure Bar was used. The influence of fiber orientation and stacking sequence on the composite compression strength are discussed .

MATERIALS

The tested composite material used in this work are constructed from a continuous glass fiber and epoxy (M10). On the basis of the geometrical lay up, the composite materials used are classified into two types labeled A and B . Type A represents the unidirectional material ,while the type B refers to the laminated structure. Composite material of type A is considered the basic building for the materials of type B. The fiber volume fraction of type A was found to be 52.5 % and lies between 49% and 53% for type B. Test specimens were cut and prepared using diamond-impregnated tool and the ends were ground and flat and parallel. Specimens of type A were selected such the fiber orientation of specimens made an angle of 0 , 45 and 90 degree with the loading axis.

Laminated structure of type B had 16 identical layers with a nominal thickness of about 10 mm but of different stacking sequence, and denoted as follows.

Plate 1 : $\{ 0,0,45,45,-45,-45,90,90\}_s$

Plate 2 : $\{ 0,45,90,0,90,0,-45,0\}_s$

Plate 3 : $\{ 0,0,45,0,0,-45,90,90\}_s$

The tested specimens were cut and prepared with axis parallel and normal to the fiber direction of the first layer of each laminate plate.

EXPERIMENTAL PROCEDURE

In the compression version of the Split Hopkinson Pressure Bar, the specimen is sandwiched between two elastic loading bars, as shown in Fig. 1 , which is subjected to impact load using an elastic striking bar. The incident, reflected and transmitted stress waves are determined from strain gauges attached to these loading bars. The overall apparatus consists of the mechanical system, the measurement system and the data acquisition and analysis system. The incident pulse (ε_I) represents the amount of impact energy. The reflected pulse (ε_R) indicates the strain rate and strain in the tested specimen, while the transmitted pulse (ε_T) indicates the specimen stress. A typical pulse record is shown in Fig. 2. Experimental dynamic data were analyzed and recoded in the form of stress-strain curves. A brief description of the Split Hopkinson Pressure Bar apparatus used are presented elsewhere [12-14]. In the static range, some of composite specimens of type A and B have also been tested. A universal testing machine was used in the range of compressive cross-head speed from 8 to 10 mm/min. Results were recorded in the form of load-displacement curve at room temperature.

RESULTS AND DISCUSSION

At low and high rate of loading, experiments were achieved to relate the ultimate compressive stress and the compressive strain rate. The tested composite material has been characterized by the ultimate stress level reached during the deformation and the corresponding value of the strain rate. The influence of fiber orientation on the composite strength has been revealed by testing the specimen of type A. While, the laminated structures, type B, reveals the influence of stacking sequence on the composite strength.

Influence of Fiber Orientation

Figure 3 shows the influence of impact compressive velocity (strain rate) as well as the fiber orientation on the ultimate compressive stress.It is observed that the ultimate compressive load is influenced by the fiber orientations. The total deformation at failure is greatest at fiber orientation of 45 degree. From quasi-static tests, for tested fiber orientation the compressive stresses and strains are drawn versus the one of the dynamic values as shown in Fig. 4.

The results for 0 and 90 degree's fiber orientations are in agreement with Daniel's results[14], regardless of the type of fiber used. In spite of the different specimen geometry of Kumar[13] and the testing condition of Harding[15]. Kumar tested different orientations at only two strain rates, while Harding tested 0 and 45 fiber orientations at three values of strain rates. The present results and the previous investigations reveal that the fiber orientation has a large effect on the composite strength. It is found also that the fiber orientation degree has the smallest effect on strain rate sensitivity of the composite strength.

Influence of Stacking Sequence

The impact load was directed parallel to the fiber direction of the first layer of each laminate plate. The fiber volume fraction of each laminate plate are 52.3 %, 53.5% and 52.5 %,respectively. Figure 5 shows typical stress-strain of tested laminate plates at different impact speeds. The degree of non- linearity depends on the presence of 45 plies in the plate as well as the deformation rate. Figure 6 shows the ultimate compressive stresses versus the corresponding strain rates. Straight lines can be fitted using least square methods. It is observed that the slope, strain rate sensitivity parameter, is not affected by stacking sequence. While, the stacking sequence affects directly on the strength level. The higher strain of 45 plies gives a post failure strength that is the strength of laminate after the failure of 0 plies. It is observed that the laminate plate 1 with 45 plies stacked together had higher post failure strength. The laminates 2 and 3 has lower post failure strength. This is because the 45 plies are dispersed among 0 and 90 plies that have already failed[10].

The strength for different stacking sequence ,from the quasi-static tests, are also shown in Fig. 6. The laminate plate 3 has the highest failure strength while plate 1 has the lowest value. This can be explained the influence of the distribution of the 45 plies in the laminate plates.

Failure Surface

A typical impact fracture surfaces of unidirectional and cross-ply laminate plates are shown in Fig.7 . The specimen surfaces have many longitudinal splits, and splaying of fibers occurred. For quasi-static tests and at low impact energy tests, the fracture surface is associated with fiber debonding . This was correlated during testing with the point on the stress strain curve for which the composite maximum loaded was attained. However, at high impact energy , complete separation and fragmentation of the specimen were observed. The amounts of longitudinal splits were observed to vary from one specimen to another , depending on the impact energy and also on the fiber matrix interface condition. The fracture surfaces of the unidirectional composite specimens are in agreement with the results obtained by Kumar [13] .

For quasi-static and impact tests the fracture surfaces of 45 degree fiber orientations are predominated by the matrix shear. In general, failure takes place due to debonding of fibers and matrix and most of the separation occurs at the interfaces without any shearing in the fibers. At high impact rate of loading, the tested laminate specimens were fragmented. While, at quasi-static and low impact compression tests the fracture surfaces were observed. The fracture modes are mainly the matrix cracking and delamination as well as splaying of the fibers. For the plates 2 and 3 , failure occurred due to delamination only without any matrix cracking this is due to dispersing of the 45 plies among the 0 and 90 plies. Referred to the delamination failure mode, the tested specimens could be defined as a brittle specimen. The maximum permissible compressive plate deformation seems to be constrained by the longitudinal deformation of 0 ply. The minimum failure deformation in a continuous lamina is found in the longitudinal direction .

CONCLUSIONS

The following concluding remarks can be summarized as follows:

1- At low rate of loading, the ultimate compressive stress is not influenced as the corresponding values that vary linearly at high rate of loading.

2- The load orientation concerning the fiber direction has agreat effect on the strain rate sensitivity parameter. While , 45 degree fiber orientation has not any effect on the strain rate sensitivity parameter.

3- The highest compressive strength of laminated composite structure could be obtained if the 45 ply has been dispersed between the 0 plies and 90 plies.

4- The composite laminated structure has the same value of the strain rate sensitivity parameter, in spite of the difference of their stacking sequence. It means that the influence of strain rate sensitivity on the 0 plies has not appeared in the tested laminates.

5- For both impact and quasi-static tests, failure modes of composite laminate plates were denoted by the matrix cracking that appears in 45 and 90 plies and the delamination mode with splaying of fibers in 0 plies.

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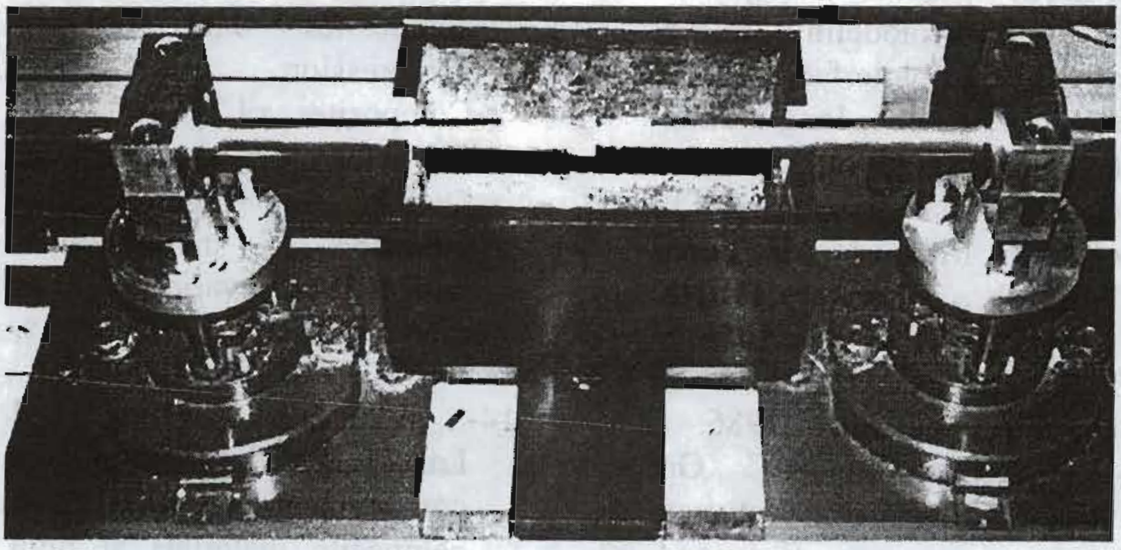


Fig. 1. Specimen position between the incident and transmitted bars.

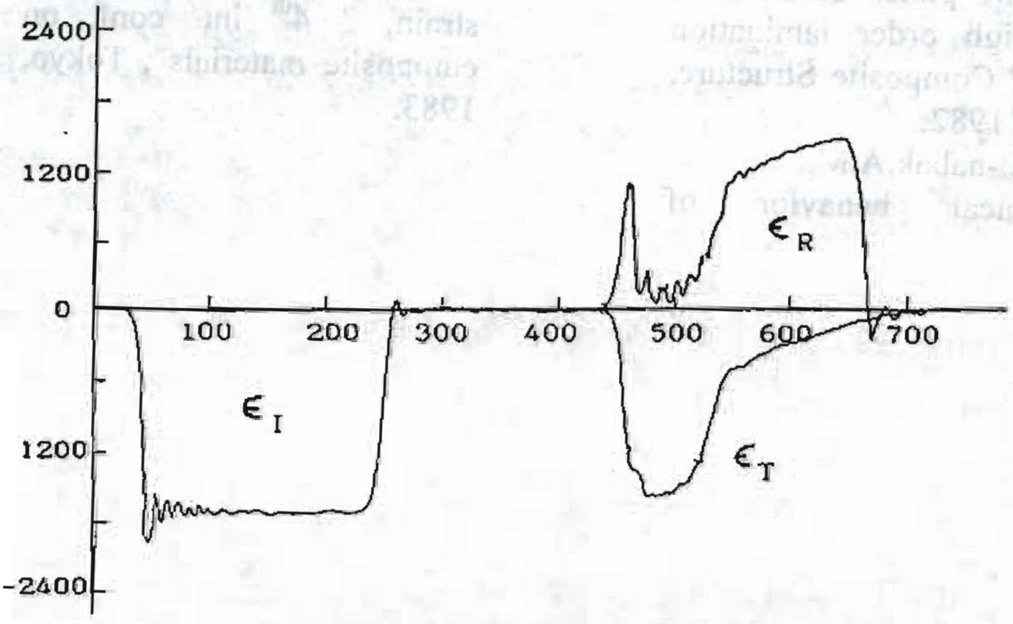


Fig. 2. Typical strain pulse record of unidirectional laminate at impact velocity 14 m/s.

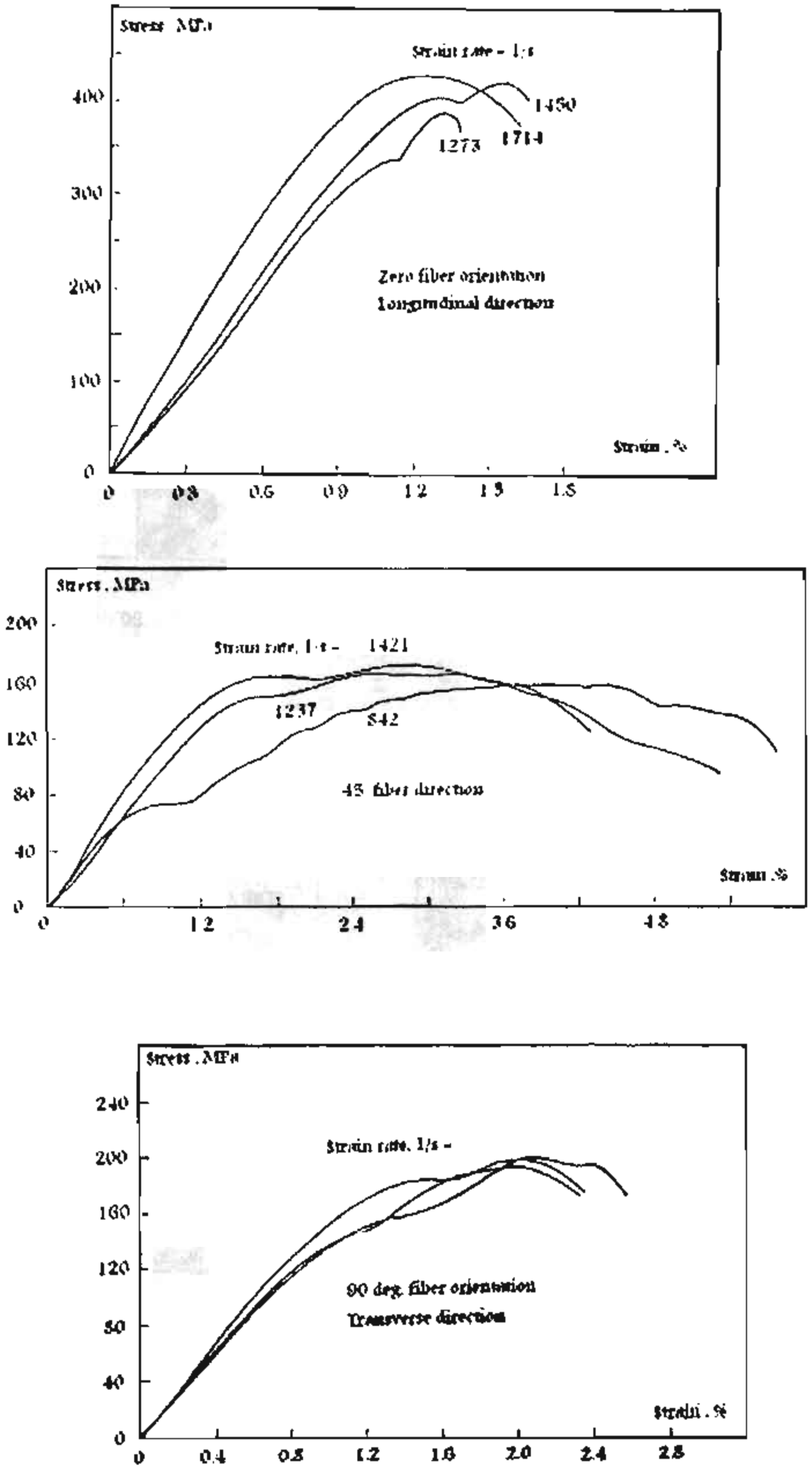
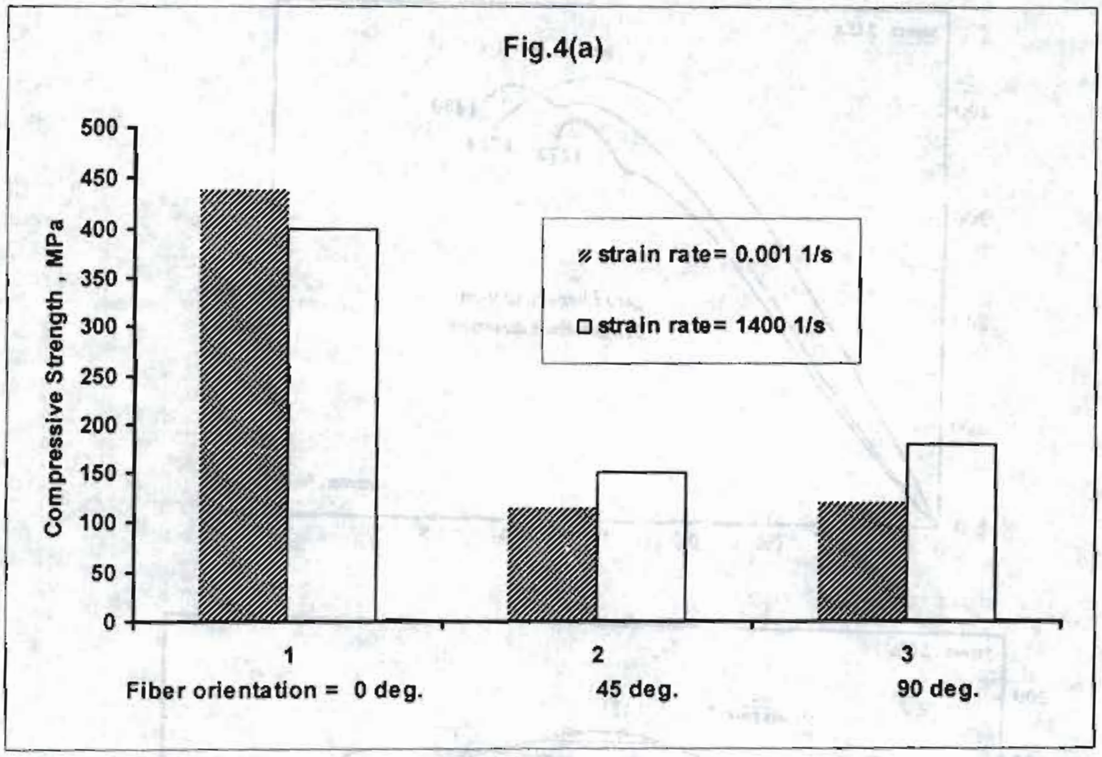


Fig.3. Dynamic stress – strain curves with different fiber orientation



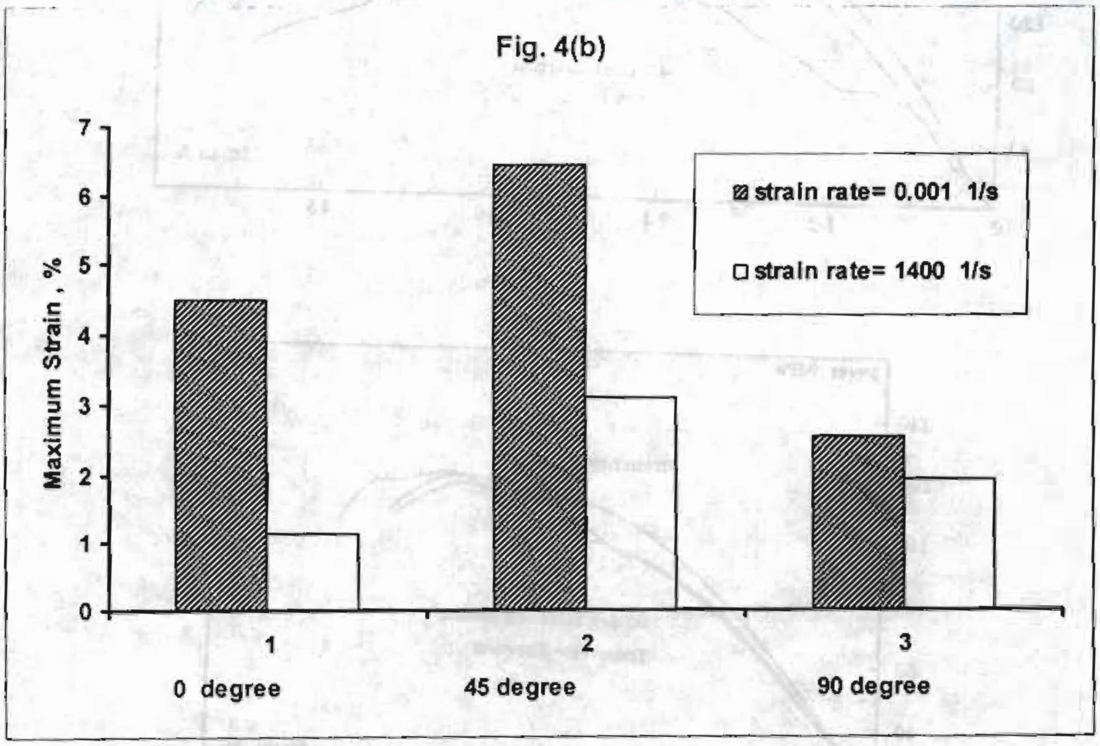


Fig. 4. Influence of fiber orientation at low and high rate of loading on Failure composite strength (a) , and failure strain (b).

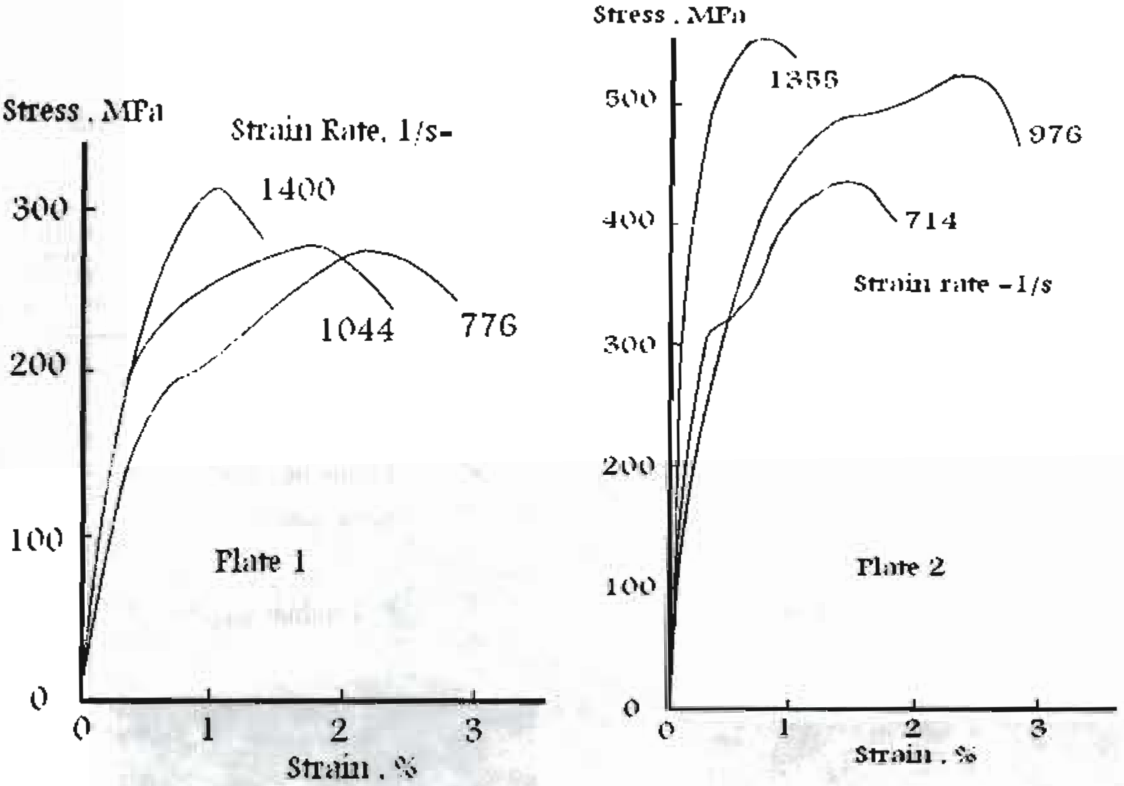


Fig.5. Typical impact stress-strain laminated plates

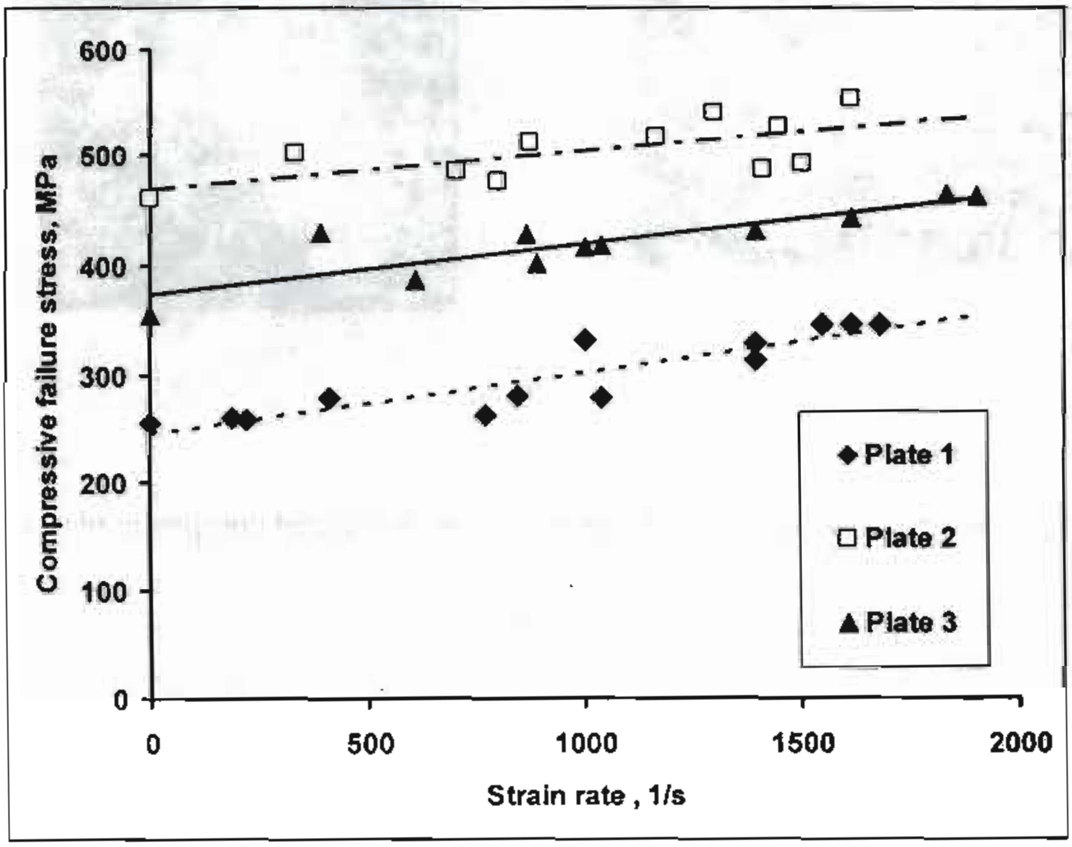
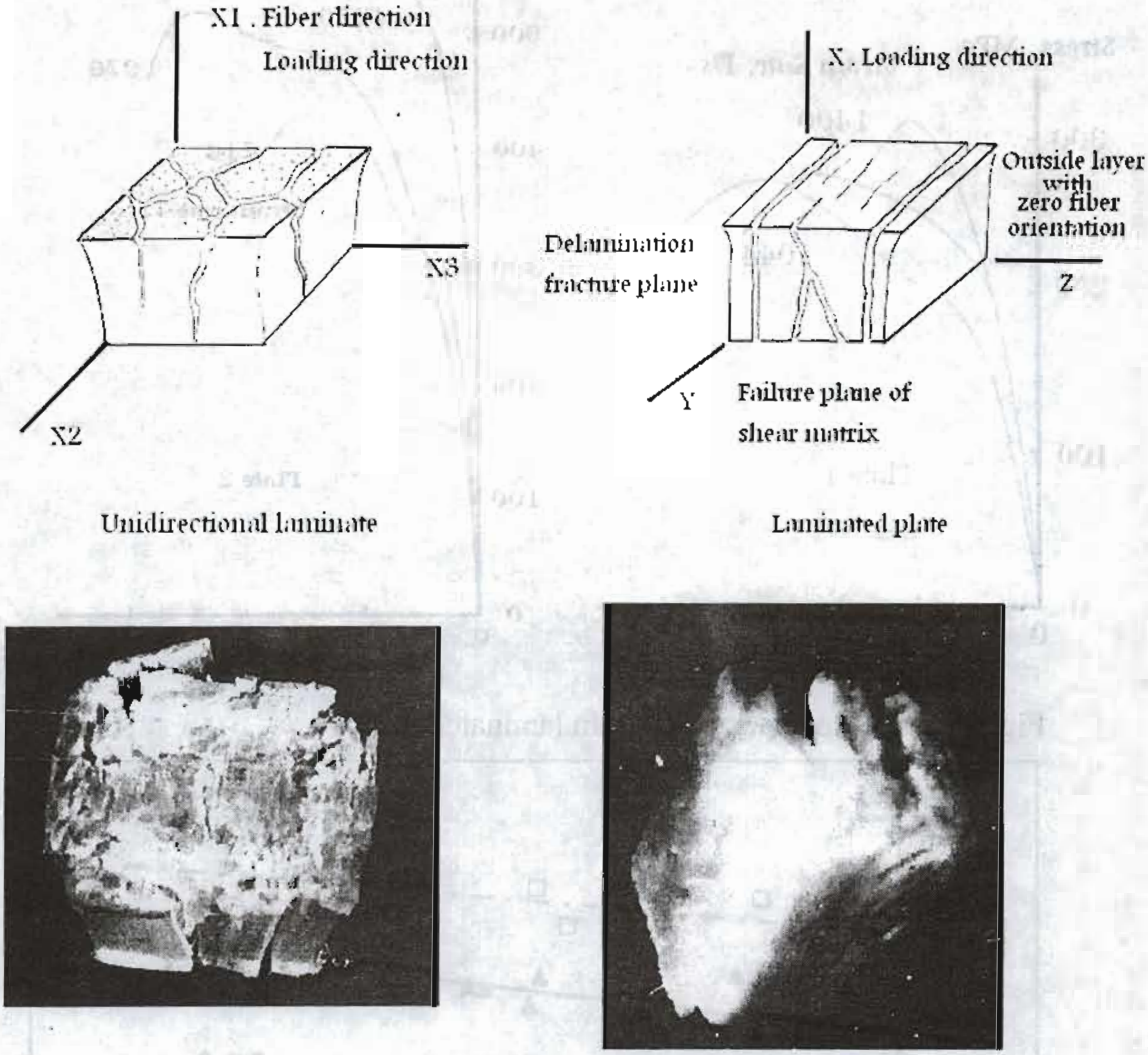


Fig. 6. Influence of stacking sequence on the composite strength at different strain rates.



Unidirectional laminate

Laminated plate

Fig. 7. Fracture surfaces of unidirectional and laminated composite plates