

# In-Plane Shear Response of Laminated Composites at High Strain Rates

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## 1. Introduction

In recent years, composite materials are increasingly replacing conventional metallic materials in airframe structures. Some applications of composite materials involve dynamically loaded components and structures. Hence, there is a need to fully understand the dynamic behavior of composite materials to facilitate the analysis and design of composite structures at high strain rate loadings[1]. Research activity performed in this area has several purposes. First, there is a need to understand the effects of strain rates on the material behavior- strength, stiffness and failure modes, as limited experiments on composite structures under impact loading, have exhibited characteristics that are contrasting relative to that at quasi-static rates. Secondly, there is an increasing demand for numerical modeling of structures subjected to high rate loading, which require reliable dynamic material properties and complete stress-strain curves as a function of strain rate.

## 2. Experiments, Results and Discussion

The in-plane shear responses of two different material systems, Newport NB321/3k70 plain weave carbon/epoxy (PWCF) and Newport NB321/7781 fiberglass/epoxy (SWGF) systems have been investigated. The two materials share the same matrix/resin system but differ in reinforcement material and architecture. The shear responses were characterized using the v-notch rail shear test apparatus [2] illustrated in figure (1). Testing was conducted at nominal stroke rates of 1, 10, 100, 250 and 500 in/sec. The stress-strain behavior and the ultimate shear strength of the two material systems at different test speeds were recorded during the tests and the results are reported.

Laminates with planar dimensions of 48inches  $\times$  12inches and stacking sequence of  $[0]_{12}$  were fabricated and cured in an autoclave cycle at 275°F for 90 min under a pressure of 50 psi. Test specimens with notches were machined to size from the cured laminates per ASTM D7078-05[2]. The final dimensions of rectangular specimen blanks were obtained by coolant lubricated precision milling or grinding. The notches were cut in the specimen blanks using a diamond coated cutting tool. The specimen blanks were appropriately supported during the notching process to reduce the risk of delaminations and matrix cracking. Micro-Measurements [3] EA125TH-120,  $\pm 45^\circ$  strain rosettes were bonded at the center of the gage section to measure the shear strains during the test. The test specimens were mounted in the test fixture and the two halves of the fixture were pulled apart at different speeds. The high rate servo-hydraulic testing machine at National Institute for Aviation Research was used for conducting the tests. The test control was accomplished using MTS [4] multi-purpose testware computer program and the data was recorded using National Instruments[5] PCI-6111 simultaneous sampling data acquisition board. The data was acquired with 12 bit resolution and speeds up to 5MHz. The load, actuator displacement and strain readings were recorded during the tests.

The in-plane shear-stress behavior SWGF specimens are illustrated in figure (2). A drastic change in stress-strain behavior was observed at stroke rates exceeding 10 in/sec. The change in behavior can be attributed to the strain-rate sensitivity of the material. Note that the constant stroke rates do not necessarily translate into constant strain rates due to the dynamic behavior of the test apparatus. Note that the stress-strain diagrams in figure (2a) are truncated at

a maximum strain level of 0.1 radians due to the physical limitation of the strain gages. The specimens were able to carry additional load than those indicated in figure (2a), prior to failure. The strengths of SWGF and PWCF specimens as a function of stroke rate are plotted in figure (2b). The strengths of both material systems were observed to increase by equal amounts with increasing stroke rate. This suggests that the strain rate sensitivity of in-plane shear strength is independent of reinforcement type and architecture.

### 3. Conclusions

The behavior of two composite material systems subjected to in-plane shear loading at different strain rates was investigated experimentally. Both material systems exhibited an increase in strength with increasing stroke rates and the stress-strain behavior was observed to change drastically with increasing stroke rates. The rate sensitivity of the in-plane shear strength was observed to be independent of the reinforcement type and architecture.

- [1] Peijs, T., Smets, E.A.M., Govaert, L.E., "Strain rate and temperature effects on energy absorption of polyethylene fibers and composites," *Applied Composite Materials* 1 1 1994 p 35-54  
 [2] ASTM D7078-05 Standard Test Method for Shear Properties of Composite Materials by V-Notched Rail Shear Method, ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States.  
 [3] Vishay Micro-Measurements, P.P. Box 27777, Raleigh, NC 27611  
 [4] MTS Corporation, Eden Prairie, MN  
 [5] National Instruments Corporation, 11500 N Mopac Expwy Austin, TX 78759-3504

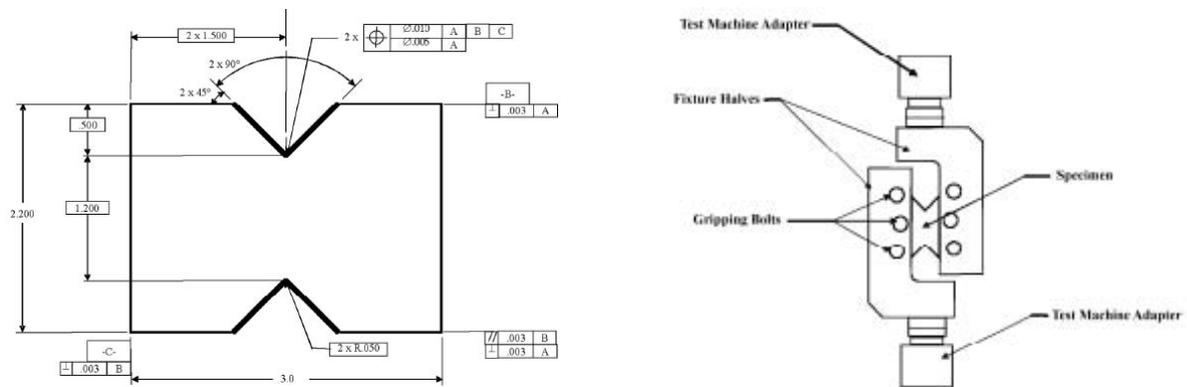


Figure (1): Test specimen geometry and test fixture per ASTM D7078-05[1].

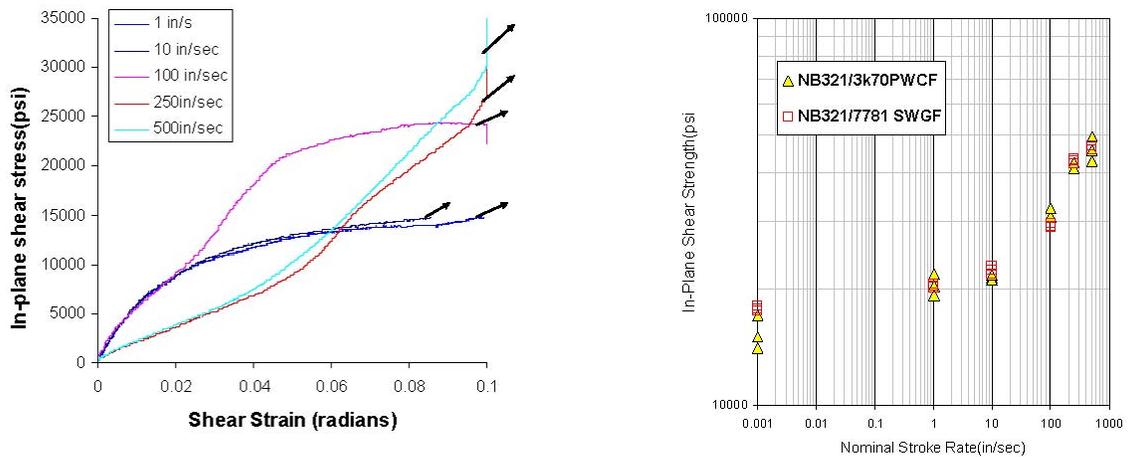


Figure (2): (a) Shear stress vs. shear strain plots for SWGF specimens tested at different stroke rates and (b) in-plane shear strength as a function of stroke rates for SWGF and PWCF materials