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Failure in three-dimensional woven composites subjected to quasi-static and dynamic indentation

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14. ABSTRACT
Angle-interlock 3D woven composite specimens were tested under quasi- static and dynamic loads using a Hopkinson pressure bar to determine the effect of loading rate on damage evolution. The equilibrium condition in the composite specimen under dynamic loads was verified using FE analysis of the experiment. A high speed camera was used to capture delamination initiation and propagation during the experiments. The apparent inter-laminar shear strength and the bending stiffness increased with rate of loading. The damage propagated at a

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a. REPORT	b. ABSTRACT	c. THIS PAGE			Bhavani Sankar
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Report Title

Failure in three-dimensional woven composites subjected to quasi-static and dynamic indentation

ABSTRACT

Angle-interlock 3D woven composite specimens were tested under quasi- static and dynamic loads using a Hopkinson pressure bar to determine the effect of loading rate on damage evolution. The equilibrium condition in the composite specimen under dynamic loads was verified using FE analysis of the experiment. A high speed camera was used to capture delamination initiation and propagation during the experiments. The apparent inter-laminar shear strength and the bending stiffness increased with rate of loading. The damage propagated at a steady rate during quasi-static loading. The high rate of energy input during dynamic loading resulted in a rapid propagation of damage and a subsequent loss of stiffness in the composite. Delamination initiation and propagation in plain woven laminates and 3D orthogonal woven composites during short beam shear tests were analyzed using FEA. Two kinds of 3D woven composites, bound with single and double z-yarns, were considered. The FE models were guided by experimental observations from SBS tests on the same materials. . A series of mechanisms including creation and evolution of matrix cracks and delaminations were modeled discretely. The force-displacement curves obtained from the simulations were compared with experimental results. 3D woven composites with double yarns showed better damage tolerance.

Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Received		Paper
08/22/2013	8.00	Bhavani Sankar, Min Song. Translaminar Reinforcements in Fiber Composites, Journal of Aerospace Sciences and Technologies, (02 2013): 1. doi:
08/22/2013	11.00	T. R. Walter, G. Subhash, B. V. Sankar, M. C. Song, C. F. Yen. A Novel Method for Dynamic Short-Beam Shear Testing of 3D Woven Composites, Experimental Mechanics, (08 2012): 0. doi: 10.1007/s11340-012-9659-4

TOTAL: **2**

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

Received	Paper

TOTAL:

Number of Papers published in non peer-reviewed journals:

(c) Presentations

Number of Presentations: 0.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

(d) Manuscripts

Received		Paper
08/20/2012	5.00	. A novel method for dynamic short-beam shear testing of 3D woven composites, Experimental Mechanics (07 2012)
08/22/2013	9.00	Min Song, Bhavani Sankar, Ghatu Subhahs, Chian Yen. Finite element analysis of delamination in woven composites under quasi-static indentation , CMC: Computers, Materials & Continua ( )
08/22/2013	10.00	Timothy Walter, Bhavani Sankar, Prabhakar Rao, Ghatu Subhash, Chian Yen. Analysis of failure modes in three-dimensional woven composites subjected to quasi-static indentation, Journal of Composite Materials (07 2013)

TOTAL: **3**

Number of Manuscripts:

Books

Received	Paper

TOTAL:

Patents Submitted

Patents Awarded

Awards

Dr. Ghatu Subhash was awarded the Teacher-Scholar of the Year Award

Dr. Ghatu Subhash received the UF Research Foundation Professor Award

Graduate Students

NAME	PERCENT_SUPPORTED	Discipline
Min Song	0.23	
Timothy Walters	0.36	
Abir Bhattacharyya	0.02	
FTE Equivalent:	**0.61**	
Total Number:	**3**	

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
M.P. Rao	0.40
FTE Equivalent:	**0.40**
Total Number:	**1**

Names of Faculty Supported

NAME	PERCENT_SUPPORTED	National Academy Member
Bhavani Sankar	0.05	
Ghatu Subhash	0.02	
FTE Equivalent:	**0.07**	
Total Number:	**2**	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED	Discipline
John Pittary	0.09	
FTE Equivalent:	**0.09**	
Total Number:	**1**	

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: 1.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:...... 1.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:...... 1.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):...... 1.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense 0.00

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields:...... 1.00

Names of Personnel receiving masters degrees

NAME
Total Number:

Names of personnel receiving PHDs

NAME	
Timothy Walter	
Min Song	
Total Number:	**2**

Names of other research staff

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

Recent years have shown an increase in the use of structural composites in many industries. This increase is a response to the need for lightweight high strength materials to reduce weight and increase performance. Many structures are often subjected to impact loading events. Due to the susceptibility to delamination damage caused by such impacts the characterization of delamination damage in laminated composites becomes critical to creating safe designs. 3D woven composites are one method in reducing or mitigating delamination damage. In this study several 3D woven composites were tested at a variety of loading rates to gains insight into the effect of weaving architecture on the delamination resistance and damage tolerance of a woven composite. Preliminary impact tests were performed to examine the damage mechanisms during high velocity and low velocity impact of a 3D woven composite. Tests are performed using the short beam shear test. This test method was used to examine several designs of composites through monotonic and cyclical static testing. A new method for performing dynamic short beam shear tests was developed and results will be presented detailing the effect of loading rate on the performance of these materials. This test method was modified to perform blunt impact tests on small test coupons. Beam specimens were cut from these coupons which include the damaged region and bend tests were performed on these specimens to determine the effect of damage by examining the residual stiffness of the samples. The results from these tests show unanimous agreement that 3D woven composites have lower damage resistance but higher damage tolerance when compared to traditional 2D woven composites.

The effects of translaminar reinforcements (TLR) and hybridization on impact damage resistance and damage tolerance of laminated composites were analyzed. The TLR increase the apparent fracture toughness of composite laminates and contribute to improved impact properties. Analytical and computational methods were used to investigate the damage of laminated composites with special focus on delamination. A non-dimensional analytical model for mode I delamination of z-pinned composites was developed and verified using finite element (FE) analysis. The analytical and FE models were compared with experimental results to evaluate the adequacy of the model in describing the role of translaminar reinforcements. The influence of the TLR on the apparent fracture toughness and bridging length was quantitatively investigated through parametric studies. The maximum allowable bridging force before inherent failure of the material was suggested as well. A 3D woven composite was chosen to study the effect of z-yarns on impact damage. A detailed analysis was performed to understand the limitations of quasi-static analysis in low-velocity impact studies. The static equilibrium and shear stress evolution in a beam made of orthotropic material subjected to quasi-static and impact loadings under various impact speeds were compared. The maximum impact velocity for which static analyses are adequate was determined. Short beam shear (SBS) test specimens of plain woven laminated composite and 3D woven composites were analyzed for the purpose of evaluating the effect of z-yarns on delamination. The FE model, that considered both intralaminar and interlaminar fracture, predicted damage patterns (transverse cracks and delaminations) observed in the tests. The z-yarns in the composites increase damage tolerance by interrupting crack propagation. Finally, the advantage of hybridization of laminate composites was evaluated using the FE models. Some hybrid composites reduce the maximum interlaminar shear stress in beam-type specimens, and therefore enhance the damage resistance of composite laminates.

Technology Transfer