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13. ABSTRACT *(Maximum 200 words)*

Mechanical Engineering department of Southern University, Baton Rouge received a grant in the amount of $93,250.00 from United States Air Force for the purchase of an impact testing equipment and accessories. This was in response to a purposal for the project titled, "Enhancing DoD Related Research Through Acquisition of Impact Testing Equipment". The total amount shown above was used to purchase and install an Instron - Dynatup Impact Testing Equipment and accessories. This a model 8250HV Drop Impact Test Instrument with Pneumatic Assist which is used in impact tests and research involving composite materials and other engineering materials. While two research projects have already been completed on this equipment, many more are current or pending. The undergraduate student research assistants who completed their works will be presenting their results at the March meeting of the American Society of Engineering Educatiors. These projects would not have been completed without the provision of these equipment. Two faculty members, two research fellows, and three undergraduate students were trained on the use and operation of this important equipment and thus have acquired very valuable professional mechanical skill thereby enhancing their technical ability and professional development. The hands-on

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training the undergraduate students received has build up their confidence in their ability, and the realization that they can make it at graduate school. Since the receipt of this grant, two additional projects that derive an important part of their objectives from research works to be completed on the impact testing equipment have been funded. The projects are (1) "Minority Undergraduate Research Experience" (MURE) program funded for $500,000 for 3 years, and NASA-funded " Research and Education experiences for Minority Undergraduates in Composite Materials funded for $200,000/year for two years. The availability of the purchased equipment made the funding of the above grants possible. It has greatly enhanced the technological infrastructure of the institution thus situating the department and college to competitively bid for many research projects especially those DoD is interested in. Furthermore and very significantly, it has augmented Southern University's ability to immensely contribute towards the engineering and science educational goals for minorities in Louisiana state, and the United States.

FINAL REPORT ON

DURIP-97 ENHANCEMENT OF DOD RELATED RESEARCH THROUGH ACQUISITION OF IMPACT TESTING EQUIPMENT.

Grant No. F49620-97-1-0134

Submitted to

United States Air Force Office of Scientific Research (AFOSR/NL)
110 Duncan Avenue Room B115
Bolling AFB DC 20332-8050

by

Samuel Ibekwe, Ph.D. – Project Director/Principal Investigator

Mechanical Engineering Department
Southern University
Baton Rouge, Louisiana 70813

February 1998

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23. TERMS AND CONDITIONS
The "Air Force Office of Scientific Research (AFMC) Grant Terms and Conditions," dated January 1995, and the Grantee's Technical Proposal, identified in Block 19, are hereby incorporated by reference.

The recipient is not required to countersign this grant; however, the recipient agrees to the conditions specified in this award unless notice of disagreement is furnished to the contracting officer within 15 calendar days after the date of the contracting officer's signature. In case of disagreement, the recipient shall not incur any costs for research unless and until such disagreement is resolved.

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		Marcia E. Rodrigues	
NAME AND TITLE OF SIGNER	DATE SIGNED	NAME OF CONTRACTING OFFICER	DATE SIGNED
		MARCIA E. RODRIGUES	2/13/97

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SUMMARY

Mechanical Engineering department at Southern University, Baton Rouge received a grant in the amount of $93,250.00 from United States Air Force for the purchase of an impact testing equipment and accessories. This was in response to a proposal for the project titled, "Enhancing DoD Related Research Through Acquisition of Impact Testing Equipment". The total amount shown above was used to purchase and install an Instron – Dynatup Impact Testing Equipment and accessories. This a model 8250HV Drop Impact Test Instrument with Pneumatic Assist which is used in impact tests and research involving composite materials and other engineering materials.

While two research projects have already been completed on this equipment, many more are current or pending. The undergraduate student research assistants who completed their works will be presenting their results at the March meeting of the American Society of Engineering Educators. These projects would not have been completed without the provision of these equipment. Two faculty members, two research fellows, and three undergraduate students were trained on the use and operation of this important equipment and thus have acquired very valuable professional mechanical skill thereby enhancing their technical ability and professional development. The hands-on training the undergraduate students received has built up their confidence in their ability, and the realization that they can make it at graduate school.

Since the receipt of this grant, two additional projects that derive an important part of their objectives from research works to be completed on the impact testing equipment have been funded. The projects are (1) "Minority Undergraduate Research Experience" (MURE) program funded for $500,000 for 3 years, and NASA-funded "Research and Education Experiences for Minority Undergraduates in Composite Materials funded for $200,000/year for two years. The availability of the purchased equipment made the funding of the above grants possible. It has greatly enhanced the technological infrastructure of the institution thus situating the department and college to competitively bid for many research projects especially those DoD is interested in. Furthermore and very significantly, it has augmented Southern University's ability to immensely contribute towards the engineering and science educational goals for minorities in Louisiana state, and the United States.

FINAL PROJECT REPORT

1. Accomplishments in Meeting Stated Goals and Objectives of the Project.

The goals and objectives of this project have been fulfilled as explained below. The main goal was to acquire an impact testing equipment and accessories that is computer interfaced for the purpose of utilization in an on-going funded research, future faculty research and education of our students. The formal procedure of going through the bids and inviting different vendors to submit bids on the specified equipment was followed. Eventually mechanical engineering department, Southern University Baton Rouge acquired Instron – Dynatup Impact Testing equipment consisting of the following:

- Model 8250HV Drop Impact Test Instrument with Pneumatic Assist. Equipment has a velocity range of 2.0 to 44 ft/sec (0.61 to 13.41 m/s) and an energy range of 0.5 to 620 ft.-lbs. (0.6J to 840J). Also included are
    - ✓ Powerful electric hoist motor
    - ✓ Electric motor braking mechanism
    - ✓ Safety enclosure with electric interlocks
    - ✓ Adjustable crosshead locator
    - ✓ Remote hand-held pendant for crosshead control
    - ✓ Color coded weights (3 sets)
    - ✓ Color coded shock absorbers (3 sets)
    - ✓ Standard table raising work area to 24 inches
- Pneumatic Rebound Brake
- Support Pedestal for Model 8250 Impact Test Machines
- Model 8250 Environmental chamber with a temperature range of –50°C to 175°C (-60°F to 350°F).
- Model PNF 3.0 Pneumatic clamping fixture (high) temperature version
- Model 8682 NASA ST-1 Fixture
- Two TUP Package 505 lb to 20 klb (2.25 kN to 89.0kN)
- Model 8496-1 General Purpose Tup
- TUP INSERT, ½" diameter for testing to ASTM 3763, NASA ST-1, ASTM D-244 (Method C) penetration specs.

- TUP INSERT, 5/8" diameter hemispherical tup for penetration testing.

- Model 930-I MS Windows Data Acquisition System including the following:
  - ✓ Model 930-I Software Package
  - ✓ High speed data acquisition and memory boards
  - ✓ Model 930-I Signal conditioning unit
  - ✓ Velocity measuring and triggering unit
  - ✓ INMAC Surge protector
  - ✓ Pentium PC hardware with these capabilities
  - ✓ 1 MHz data sampling
  - ✓ 100 kHz frequency response
  - ✓ 2 channel support
  - ✓ Database and SPC capabilities
  - ✓ 17" Color Monitor
  - ✓ 3.0 GB HDD
  - ✓ Installed Sound Card and Speakers
  - ✓ Ethernet Card
  - ✓ 200 MHz CPU
  - ✓ 32 MB RAM
  - ✓ Windows '95

- One Day START-UP.
  One Day Installation and Start-Up Training for Dynatup System

- TUP INSERTS
  1" diameter hemispherical tup
  2" diameter hemispherical tup

Complete installation of the above equipment and accessories was completed on Wednesday, January 14, 1998 by Mr. David Smith of Instron company. Figures 1 through 5 respectively show the installed equipment. The institution provided the requisite infrastructure as well as space and technical support towards the successful installation.

In the short time since the installation of the acquired equipment and accessories, 2 research projects have been completed on it resulting in publication of papers to be presented by undergraduate research student assistants at the ASEE conference slated for March 24 – 26 at New Orleans, Louisiana. The titles of the papers included in the Appendix are (1) "Determination of Damage Tolerance of GFRP Composites Due to Low Velocity Impact" by Angela Collins, Don Scott, and

Samuel Ibekwe, and (2) "Post-Impact Evaluation of Laminated and Textile Composites" by Simeon Orji, Samuel Ibekwe, and Su-Seng Pang. Specimens tested are shown in figure 6. Due credit was given to Air Force Office of Scientific Research for the provision of the equipment as shown highlighted in the copies of the papers. Also one doctoral student, Mr. Sharif Razi in Materials Engineering department conducted part of his research dissertation work on the equipment by testing impact strength of a new wood-based composite material.

The principal investigator is utilizing the equipment to continue research work on "Determination of Damage Tolerance of Composite Materials Due to Low Velocity Impact" funded by the Louisiana State Board of Regents. Also three undergraduate students namely Mr. Jamal Knight, Mr. Brad Nicholas, and Mr. Solomon Abdi are working on a sponsored project titled "Influence of High temperature on Low Velocity Impact of Composite Materials". Several research proposals are planned on the use of this acquired important research tool.

2. Accomplishment in Enhancing the Quality of Mechanical Engineering Department Performing DoD related Research.

The research capability of mechanical engineering department was greatly enhanced by the acquisition of this research equipment. One project – "Determination of Damage Tolerance of Composites Due to Low Velocity Impact" funded for $113,666.00 for 3 years is being executed as a result of the availability of the equipment. Two other projects were attracted and funded because of the strong influence and availability of the impact testing equipment. They are:

"Minority Undergraduate Research Education" (MURE) program funded for $500,000 for 3 years, and

"Research and Education Experiences for Minority Undergraduates in Composite Materials" funded for $200,000/year for two years.

The results of these scientific investigations are often published in scientific journals and proceedings of different scientific societies. These papers in addition to disseminating scientific results and discoveries also serve to the name of the institution to the limelight. Hence the image will be enhanced positioning it to attract brighter students and acclaimed scholars.

The funding of this project has given the principal investigator and his colleagues the impetus to seek other grants to improve the College's research and educational infrastructure.

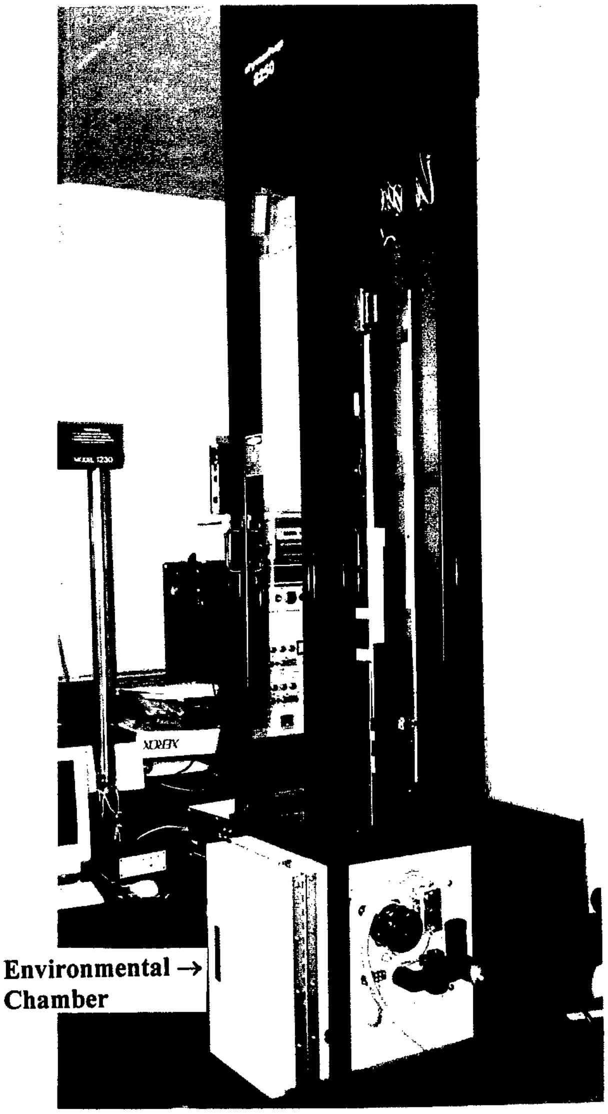

Figure 1. Impact Testing equipment with attached environmental chamber.

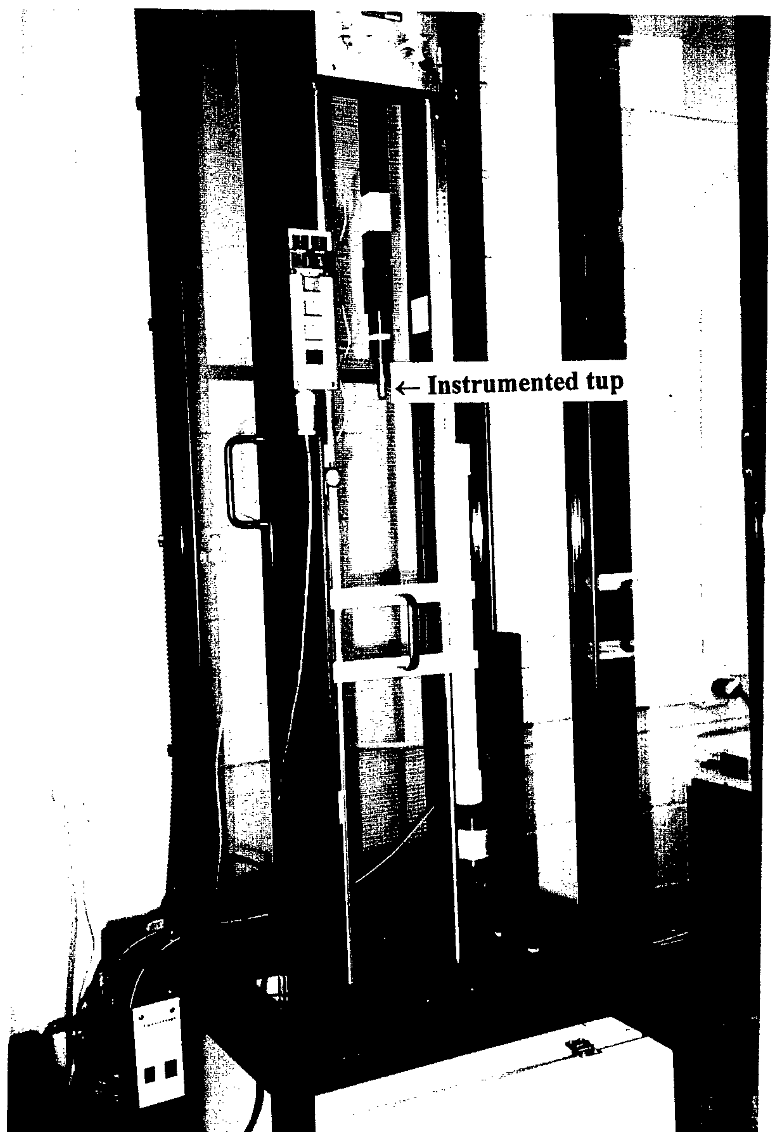

Figure 2. Impact Testing equipment showing instrumented tup.

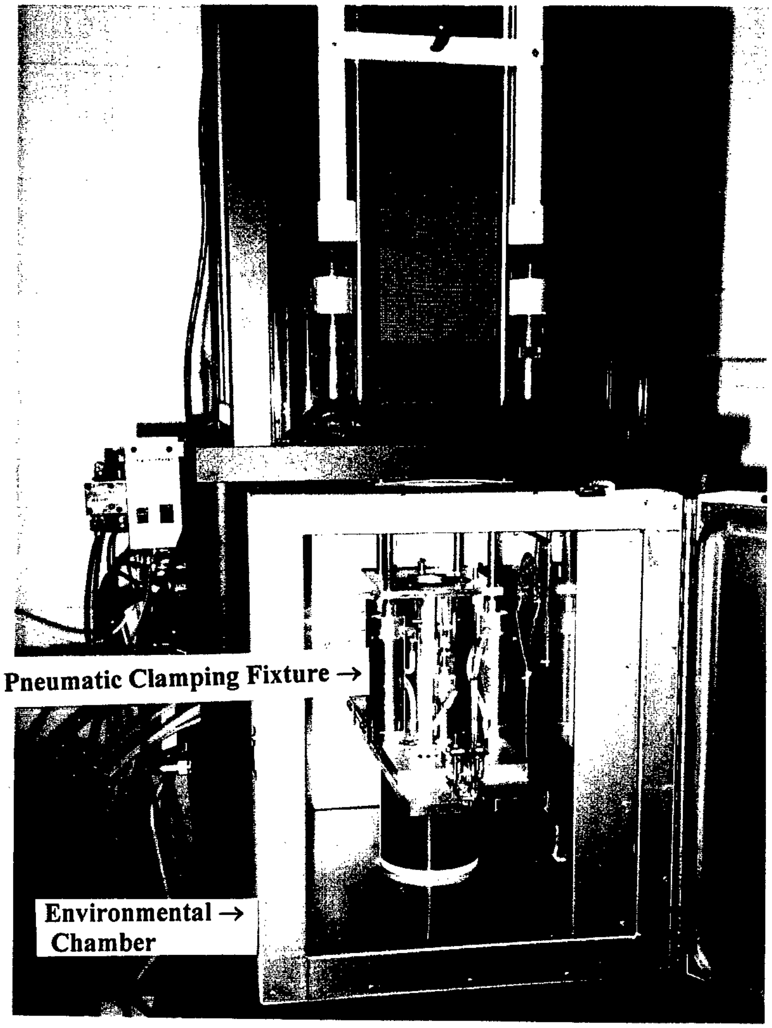

Figure 3. Pneumatic Clamping Fixture shown mounted inside the environmental chamber

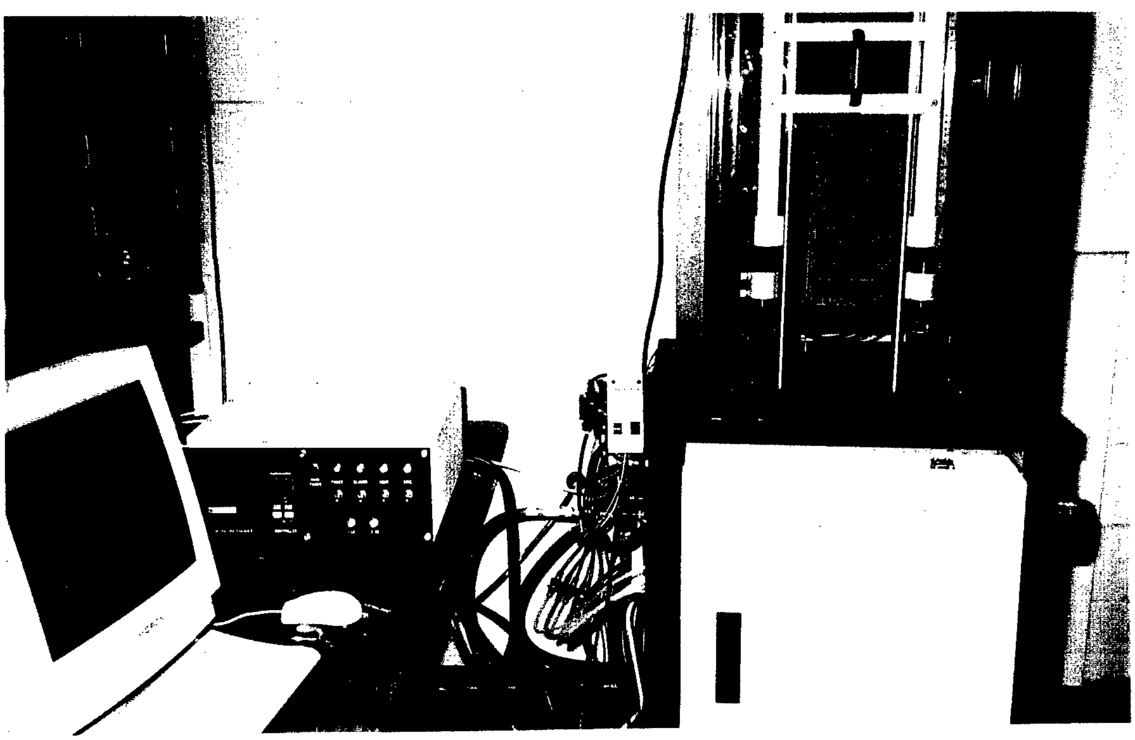

Figure 4. Connected Personal Computer and Data Acquisition system to Impact Testing equipment.

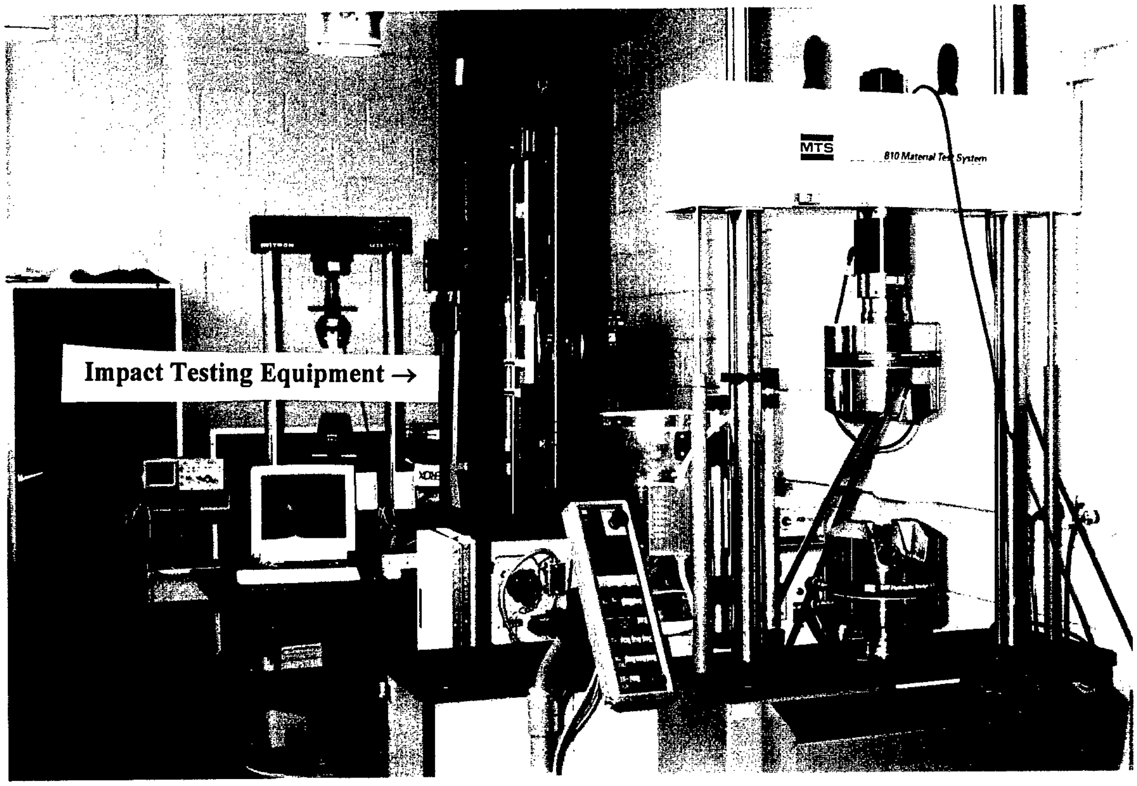

Figure 5. Impact Testing Equipment located amongst other research equipment.

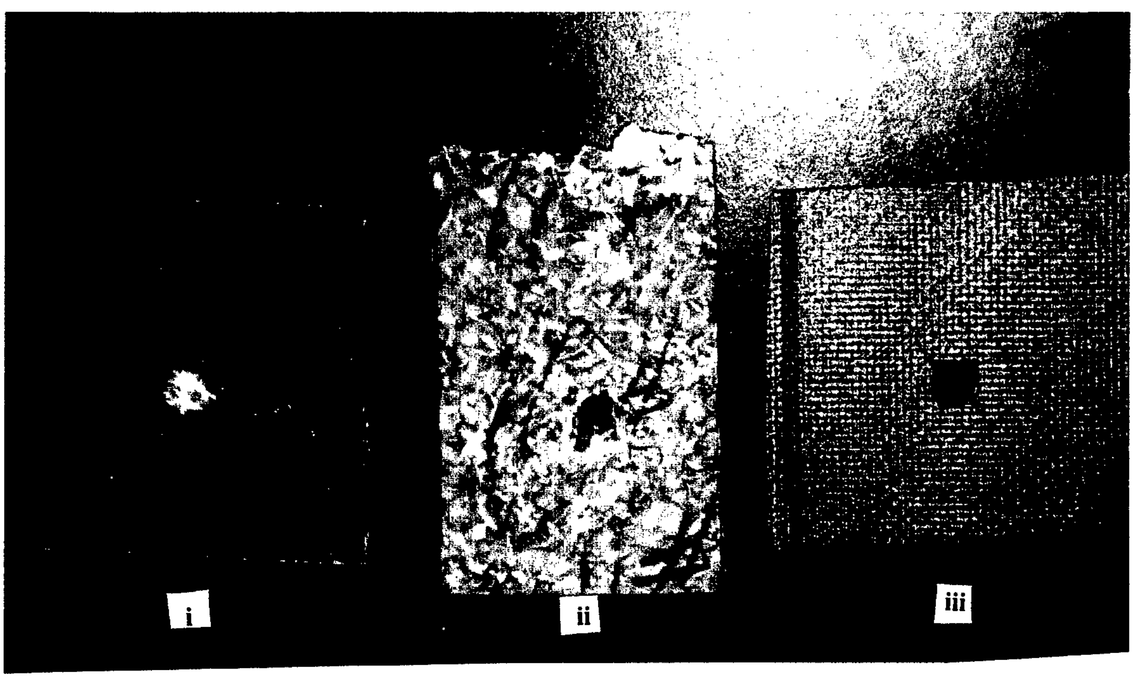

Figure 6. Some of tested specimen samples on the equipment.

(i) Glass Fiber Reinforced Polymer Composite
(ii) Wood-based Composite material
(iii) Graphite-Epoxy Composite Material

APPRECIATION

The Principal Investigators, and Mechanical Engineering Department, Southern University Baton Rouge wishes to express their profound gratitude and indebtedness to

United States Air Force Office of Scientific Research AFOSR/NL

For supporting the enhancement of engineering research through the award of the grant F49620-97-1-0134.

APPENDIX

Determination of Damage Tolerance of GFRP Composites Due to Low Velocity Impact

Angela Collins[1], Don Scott[2], and Samuel Ibekwe[3]
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Southern University
Baton Rouge, Louisiana
[2]Chemical Engineering Department
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Baton Rouge, Louisiana

Abstract

An experimental investigation was conducted to determine the damage tolerance of laminated E-glass reinforced composite materials (GFRP) due to low velocity impact that ranged from 4.28 ft/s through 13.07 ft/s, using instrumented impact testing. Properties compared include total energy, maximum load, deflection at maximum load, and energy to maximum load. Plots of energy and load versus time were also used to evaluate how the specimen reacted over time to the different impacts. The greatest damage was sustained by the balanced [0/90] poly vinylester GFRP. It had the lowest maximum load and energy to maximum load in addition to the highest total absorbed energy and deflection to maximum load. Damage was essentially due to matrix cracking and axial splitting across the width of the specimen. Poly vinylester GFRP chopped-mat had a greater maximum load than polyester GFRP reinforced with the same fibers. The other properties which include energy to maximum load, total absorbed energy and deflection to maximum load for the most part proved that poly vinylester matrix GFRP is a better composite than polyester matrix GFRP.

Introduction

Composite materials made with high performance polymers reinforced with different fibers are constantly gaining the acceptance of the engineering industry. This is mainly due to the material properties and relevant performance characteristics, which include high strength-to-weight ratios, tailorable properties, longer life, inherent damping, and redundant load path. However, impact loading which could inflict insidious damage has been identified as a threat to the widespread use of composites in circumstances where this is possible. An example is the damage that can occur as a result of low velocity impact, which may take the form of dropping of a tool on surface panels leading to these damages: delamination, fiber breakage, matrix cracking, and fiber debonding. These damages are of extreme importance because apart from a high possibility of its occurrence, the resulting flaw that could propagate through the material may not be visible on the surface to the naked eye. As a result, several researchers are actively working in this area in an effort to define this phenomena and characterize the material behavior. Chang and Sirkis [1] investigated low velocity impact of optical fiber embedded laminated graphite epoxy. They used optical microscopy and scanning electron microscopy to investigate the micro-crack distribution in the vicinity of optical fibers embedded in laminated graphite/epoxy plates subjected to low velocity impact, while Chu [3] investigated the damage containment and residual strength of 2 graphite epoxy systems T300/5208 and AS/3501-6. In addition, Chang et al [2] studied the damage mechanisms and mechanics of laminated composites due to low velocity impact with a line-nose impactor while Portanova [6] evaluated the impact response of textile composites. Furthermore, Hong [4], and Liu [5] concluded that the delamination area of Kevlar/epoxy, graphite/epoxy and glass/epoxy composite laminates is proportional to the change in impact energy.

This study focuses on the comparison of the dynamic response of three types of GFRP materials. This effort is to determine the effect of the matrix as well as the type of fiber on impact response of these composite materials.

Materials and Test Procedures

Material Description

The three types of materials tested in this study are (i) polyester matrix reinforced with chopped mat E-glass fibers, and (ii) poly vinylester reinforced also with chopped E-glass. Each contained five (5) layers of 1-oz mat. The third material is a poly vinylester reinforced with balanced [0/90] E-glass fibers.

Each material was cut into 4-inch by 4-inch specimen sizes. The chopped mat laminates had a thickness of 0.25 inches. Polyester GFRP is more translucent than the darker poly vinyl ester GFRP. This characteristic will prove to be a benefit in visualizing the perceived region of damage.

Experimental Procedure

Falling weight impact tests were performed using a tower instrumented impact machine. The main components of the impact tester are the pneumatic clamping fixture and the instrument impactor.

The pneumatic fixture consists of two 6 in. square blocks, made of corrosion resistant stainless steel, each 0.75 in. thick and having a central 4 in. × 4 in. cutout in which the specimen to be tested is usually placed. This 4 in. x 4 in. specimen is clamped down during the test by the fixture leaving a 3-in diameter area of the clamped material available for impact. A clamping force of 160 lb was used to hold the properly aligned specimen so that the falling tup will strike it at the center. The instrumented impactor consists primarily of a falling weight (cross head - total hammer weight of 7.463lb) with a ½ in.-diameter hemispherical tup. Rebound brakes which are activated on the first impact were used to ensure that the specimen was impacted only once. The impactor used here was basically gravity driven, hence different heights were utilized to attain corresponding velocities and impact energies. Usually a dry run (without the specimen) of the set-up was done at the onset in order to determine the velocity at different heights.

Data was recorded via a data-acquisition board connected to a personal computer. Photographs were taken afterwards in order to visually document the extent of damage.

Results and Conclusions

Using the instrumented impact test machine, 24 samples were impacted at various velocities to compare the end condition of the samples. Three sets of specimen samples were impacted at these four (4) different velocities: 4.28 ft/s, 7.04 ft/sec, 10.02 ft/sec, and lastly 13.07 ft/sec. The data recorded and compared were energy to maximum load, the maximum load, the total energy absorbed, and the deflection to the maximum load. The energy to maximum load is the energy absorbed by the specimen up to the point of maximum load, while the maximum load is the highest point on the load-time curve. Frequently the point of maximum load corresponds to the onset of material damage or complete failure. The deflection to the maximum load is the distance the impactor traveled from the point of impact to the point of maximum load.

Two comparisons were made for this investigation. Averages of the critical values obtained during the test are listed in Table 1 below. In addition, load and energy-time curves can be found in the Figs. 1-3.

Impact Velocity/Material				
4.28 ft/s	**Energy to Max Load [ft-lb]**	**Max Load [lb]**	**Total Energy [ft-lb]**	**Deflection to Max Load [in]**
Polyester	2.16	584	0.99	0.09
Poly vinylester-chopped mat	2.16	626	0.64	0.08
Poly vinylester—[0/90]	1.55	252	1.6	0.14
7.04 ft/s				
Polyester	5.84	831	1.92	0.17
Poly vinylester-chopped mat	5.7	978	1.44	0.15
Poly vinylester—[0/90]	4.51	371	5.94	0.28
10.02 ft/s				
Polyester	10.51	1180	5.38	0.23
Poly vinylester-chopped mat	8.94	1240	5.49	0.18
Poly vinylester—[0/90]	4.99	363	8.14	0.29
13.07 ft/s				
Polyester	14.15	1417	13.34	0.23
Poly vinylester-chopped mat	17.55	1461	11.55	0.24
Poly vinylester—[0/90]	7.53	538	13.87	0.31

Table 1. Table of Results.

First, the polyester GFRP and the poly vinylester GFRP chopped mat samples were tested and the results compared. Figures 1 and 2 show plots of load and energy versus time for poly vinyl ester GFRP and polyester GFRP respectively at velocities of 7.04 ft/s. Additional plots were generated but the behaviors were basically the same. It can be see from table 1, and Figures 1 and 2 that poly vinylester GFRP had a greater maximum load then polyester GFRP. Therefore, it required a greater load to damage poly vinyl ester composite material than the polyester composite. This implies that the former was more damage-resistant that the later. This is apparent from the visible damage area shown in Figures 4 and 5 respectively.

Numerical values from Table 1 show that the energy to maximum load was relatively the same at velocities at or below 7.04 ft/s but differed as the velocity increased for the two chopped-mat materials. At 10.02 ft/s the energy to maximum load for polyester was greater than the value for poly vinylester GFRP. However, when the velocity was increased to 13.02 ft/s the results were completely different. This behavior could be statistical in nature. Also Table 1 shows that the total absorbed energy for polyester chopped-mat GFRP was greater than poly vinylester chopped mat at all velocities except at 10.02 ft/s. It is possible that there was an anomaly in the conduct of the tests in this velocity range especially since the polyester material absorbed more energy which is corroborated by a larger damage area. In addition, the deflection to maximum load values for both materials were almost identical. The greatest difference 0.05 inches occurred at 10.02 ft/s.

Secondly, the poly vinylester chopped mat , and the balanced [0/90] poly vinylester GFRP's samples were then tested and the results compared. There were obvious differences in the behavior of the samples. The chopped mat sample was 0.25 inches in thickness, while the balanced [0/90] sample was 0.125 inches. This difference was computed into the instrument impact machine and accounted for in results. However, this disparity could be one of the major reasons why the materials responded differently to impact

Figures 2 and 3 show plots of load and energy versus time for both materials respectively at velocities of 7.04 ft/s. It can be seen from these figures, as well as from Table 1 that poly vinylester chopped mat had a greater maximum load than balanced [0/90] poly vinylester. Therefore, the poly vinylester GFRP mat sustained a greater load to material damage than balanced [0/90] poly vinylester. Damage in the latter specimen was extensive and resulted in axial splitting of the material at all velocities. The damage on the surface of impact progressed from fiber breakage to matrix cracking as shown in Figures 6 and 7 respectively. Some delamination could be observed in the material also. However the brittle matrix cracking was the dominant catastrophic failure mode. Damage in the chopped mat composite was confined to a small area very close to the impact point. Mode of failure was basically by fiber breakage and some delamination. The opposite side of surface of impact had a lot of fiber debonding. Energy to maximum load was greater for the chopped- mat poly vinylester GFRP than for the balanced [0/90] poly vinylester which is understandable since the later required less energy to initiate the damage that occurred.. The differences ranged from 0.61 ft-lb at 4.28 ft/s to 10.02ft-lb at 13.07 ft/s. The total energy absorbed by the materials is however 67% more for the balanced [0/90] poly vinylester than for poly vinylester chopped-mat. This total energy was used to extend the damage in the former while the later bounced off a lot more of the energy. The deflection to maximum load values for balanced [0/90] poly vinylester were greater than those for poly vinylester chopped-mat GFRP. Results from Table 1 show that the average difference between the two composites is 0.0925 inches.

It can therefore be concluded from the critical values shown in Table 1. that poly vinylester chopped mat GFRP is more damage-resistant and therefore behaved better under impact loading than the balanced [0/90] poly vinylester GFRP. This project is continuing and the following tests will assist in further characterizing the behavior of the materials: Damage assessment tests - C- scans will be conducted on the samples to determine the measure of areas of damage. Though it may not account for all the damage, it will however allow for comparisons of the damaged materials. Post-impact compressive and tensile tests - These will assist in evaluating and assessing the post-impact residual mechanical strength.

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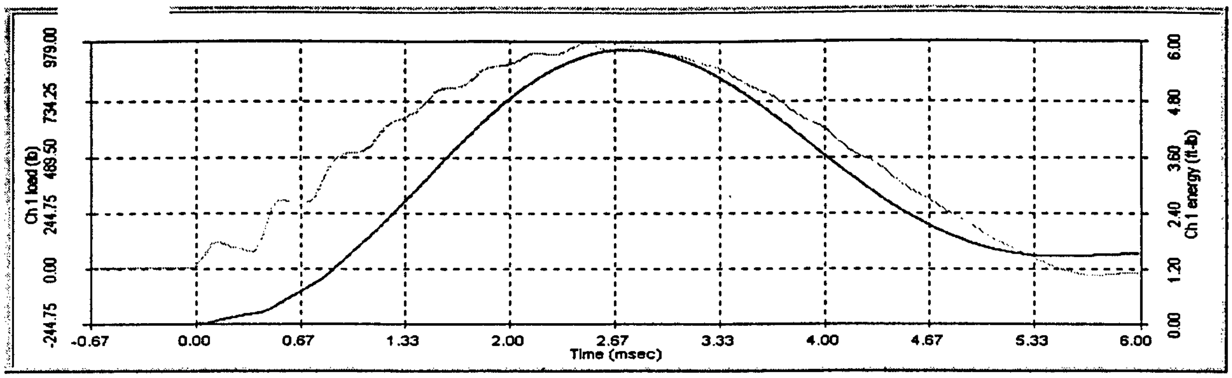

Figure 1. Plot of Load and Energy versus Time for Poly Vinylester chopped-mat GFRP @ 7.02 ft/s

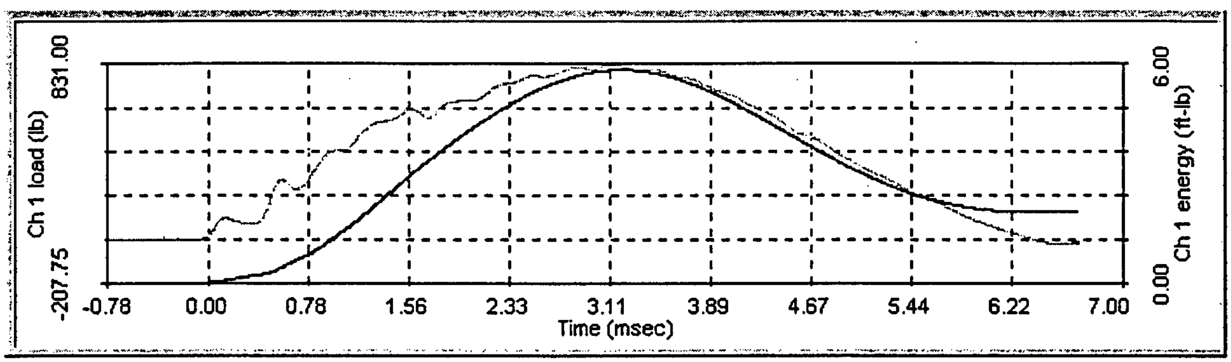

Figure 2. Plot of Load and Energy versus Time for Polyester chopped-mat GFRP @7.02 ft/s

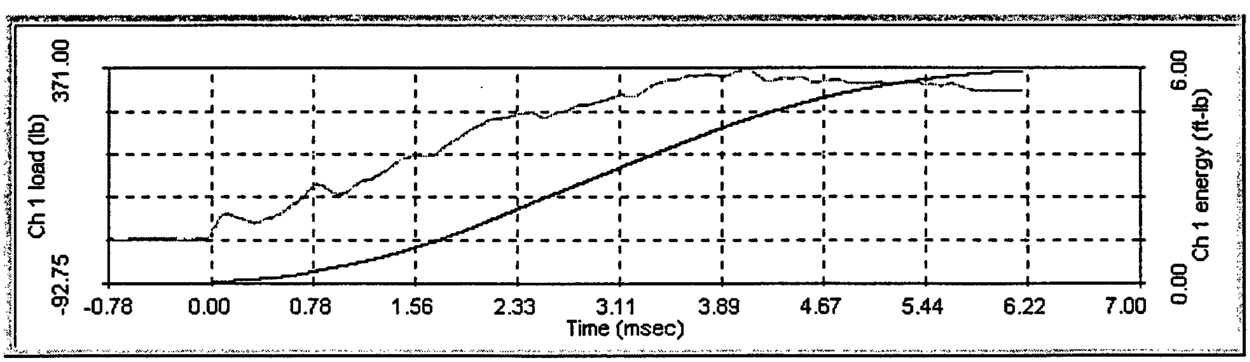

Figure 3. Plot of Load and Energy versus Time for Balanced [0/90] Poly vinylester GFRP @7.02 ft/s

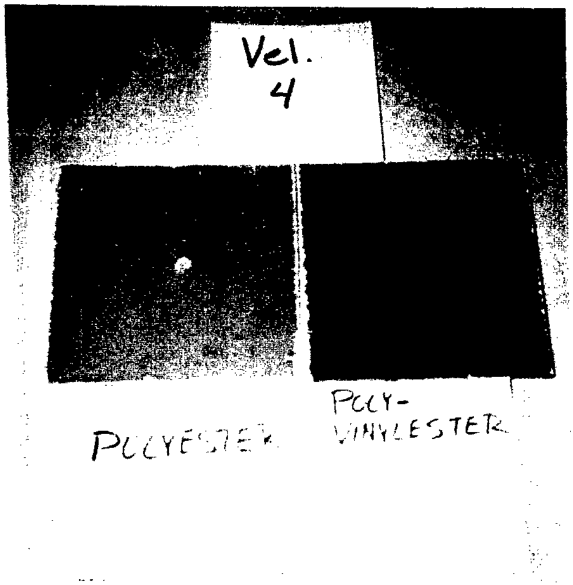

Figure 4. Comparison of Damage zone of Polyester and Poly vinylester chopped-mat GFRP composite materials after impact at 4.28 ft/s

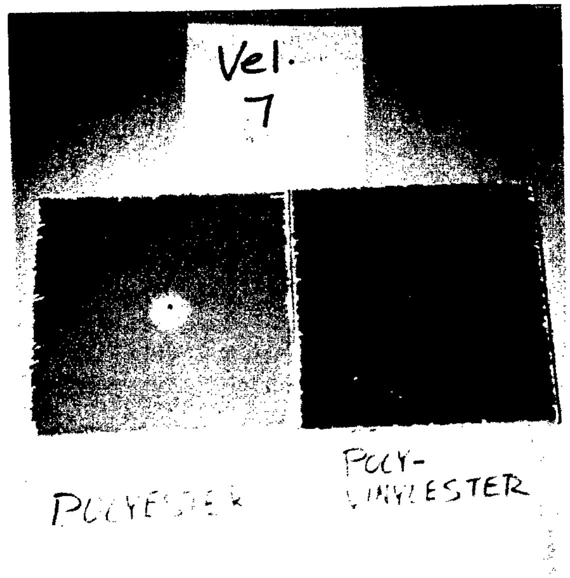

Figure 5. Comparison of Damage zone of Polyester and Poly vinylester chopped-mat GFRP composite materials after impact at 7.04 ft/s

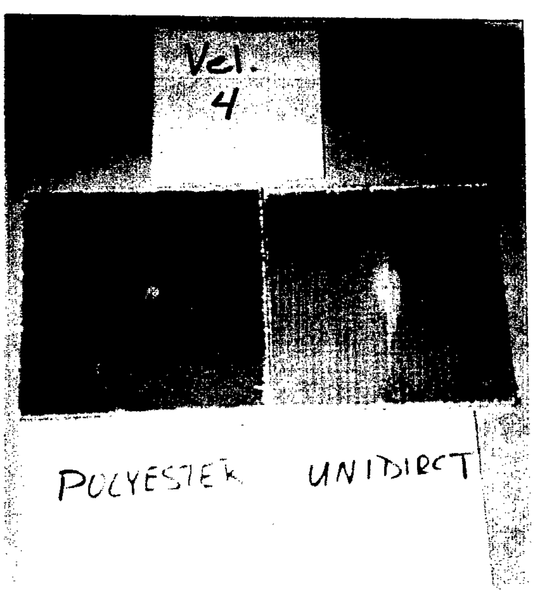

Figure 6. Comparison of Damage zone of Poly vinyl ester chopped-mat, and balanced [0/90] GFRP composite materials after impact at 4.28 ft/s

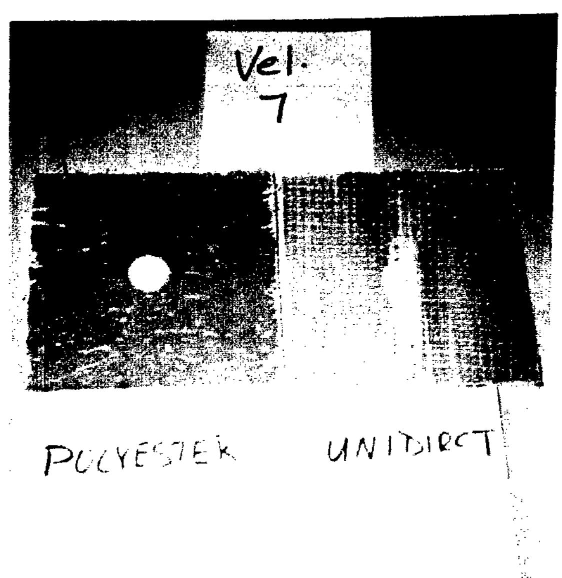

Figure 7. Comparison of Damage zone of Poly vinyl ester chopped-mat, and balanced [0/90] GFRP composite materials after impact at 7.04 ft/s

Post-Impact Evaluation of Laminated and Textile Composites

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Abstract

An instrumented drop weight tester was employed to perform impact tests on graphite-epoxy materials fabricated by Resin Transfer Method (RTM) and Autoclave-cure methods. Composite specimens were subjected to impact velocities ranging from 4.0 to 10 ft/s which translates to impact energies of 1.99 to 11.68 ft-lb.

Damage resistance, maximum load, energy to maximum load and deflection to maximum load among other properties formed the basis of post-impact comparisons between both composites. Test data and graphs generated showed that the autoclave-cured laminate composite possessed a higher damage resistance than the RTM fabricated textile graphite-epoxy composite. The latter however was more energy absorbent than the autoclave-cured material at different levels of impact energy.

Introduction

Advanced composites are gradually taking over the place of aluminum, steel and titanium as structural components in aerospace applications for reasons of specific strength and specific stiffness. During the past decade, significant progress has been made in developing advanced composites that have high strength, high modulus and low mass. Some of the techniques developed for the production of advanced composites are Autoclave-curing, and Resin Transfer Molding (RTM) methods. Furthermore, there has been a growing interest in the use of textile architecture for advanced composite structures because of their reputation for improved interlaminar properties, impact resistance [1], dimensional stability and promising ease of manufacture by the RTM technique.

Studies done in this area [1-5] have shown that many properties of composites may be considerably degraded by low velocity impacts that rarely show visible damage. This therefore threatens the unhindered use of composites. Impact induced damage on composites have been identified as delamination, matrix cracking, fiber breakage and fiber debonding. Impact damage tolerance of composites is an essential property that is pertinent to the proper utilization of this material. Srinivasan *et al.* and Portanova [2-3] evaluated the impact damage resistance and residual compressive strength of various composite systems and compared the effect of the impact force on impact damage tolerance. Hyung *et al.* [5] noted in their studies that interlaminar shear stresses/strength and inplane tensile stress/strength are the dominant factors causing the critical matrix cracks which they believe is the initial failure mode of impact damage. In Nettle's [7] investigation on the residual tensile strength of composites, he showed that the tensile strength decreased with increase in the impact energy. Certain techniques have been utilized to determine the extent of damage. Sirkis *et al.* [1] used nondestructive evaluation techniques to investigate the development of low velocity impact induced delamination in composites laminates with a single optical fiber embedded at the laminate mid-plane. Woo *et al.* [4] used global/local methodology combined with special macro elements instead of conventional finite element method in the analysis of textile composites.

The goal of the present study is to evaluate and compare impact properties of textile composites fabricated by Resin Transfer Molding and Autoclave-cure methods. Impact damage resistance, maximum load and energy to maximum load will be investigated. The standard test employed is the drop weight test which readily lends itself to instrumentation through its data acquisition and analysis system to capture among many other things the load / energy - time profiles. An assessment of the damage area visual to the naked eye will be made here.

Materials and Test Procedures

Material Description

The two composite materials selected for evaluation were Autoclave-cured laminate and Resin Transfer Molded graphite-epoxy. Both materials were fabricated at the Materials Laboratory of North Carolina A. & T. State University. The table below shows details of textile composite panels as reported by Ibekwe *et al.* [9]

	Autoclave-Cured Laminate	*RTM Graphite-Epoxy*
No. of Plies	14 ply	14 ply
Orientation	0/90, 7s	0/90, 7s
Material	T300 3K Carbon Epoxy	T300 3K Carbon 3M PR-500 Epoxy
Length (in)	20	12
Width (in)	7	12
Fiber Volume Fraction (%)	61.63	56.99
Average Thickness (in)	0.098	0.1

Table 1. Material details of composites tested

The autoclave-cured panel is a symmetric cross ply laminate material HMF 5-322D, 34C Plain weave Fiberite while the RTM graphite-epoxy molded panel has PR-500 Epoxy as its resin/matrix and graphite fabric W 5-322 as the reinforcing fiber. The average thickness for the autoclave-cured panel and the RTM graphite-epoxy panel were 0.098 in and 0.1 in respectively.

Specimens with dimensions 4.00 in. × 4.00 in. were then cut from the two composites plates. To ensure flat and perpendicular faces all edges of the specimens cut were ground.

Experimental Procedures

Instrumented drop weight tester shown in Figure 2 that consisted primarily of a falling weight with a 0.5 in.-diameter hemispherical tup was employed in this study. The equipment incorporated pneumatic rebound brakes, which ensured that the specimens were impacted just once. A total cross head hammer weight of 7.463lb was used in this study. The height of this weight from the point of impact on the specimen determines the velocity of the test according to the formula $v^2 = 2gh$, where v is the velocity, g is the acceleration due to gravity and h is the height of impact.

Attached to the cross head of the instrumented impact tester is a flag which functions in conjunction with the velocity detector. During impact, as the cross head descends via the guide bars, the flag intercepts the velocity detector just before impact. The resulting signal from the velocity detector triggers the rebound brakes electronically, making the pistons rise from the stop block shocks preventing a second impact. Also, the velocity detector output permitted precise measurement of the impact velocities. Velocity tests were therefore run prior to an impact test to ascertain a height for a particular velocity.

Even though Verpoest *et al.* [8] had earlier proposed that the outcome of the impact test did not depend exclusively on the use of clamping force, all specimen materials tested in this study were however rigidly clamped on all the edges by a pneumatic fixture. The pneumatic fixture shown in Figure 1 consists of a pair of 6 in. square blocks, made of corrosion resistant stainless steel, each 0.75 in. thick and having a central 4 in. × 4 in. cutout in which the specimen to be tested is usually placed. After clamping pneumatically between blocks, a

3-in. diameter circle of the specimen was subjected to impact. A clamping force of 160 lb. was used. The specimen was properly aligned so that it was impacted at the center.

Different values of incident impact energy on the specimens were obtained by varying the drop height of the cross head. Four different drop heights were employed for each set of the specimen which translated to impact velocities of 4.16, 6.21, 8.12 and 10.03 ft/s. Raw impact data was recorded and analyzed with the high speed data acquisition system and computer program connected to the impact tester.

All the impacted specimens were then photographed in slides to preserve a visual record of the damage.

Results and Discussion

Certain critical values were known from data obtained during the course of the tests. They include: impact energy, maximum load, energy to maximum load, total absorbed energy and deflection to maximum load. Load - deflection, load - time, load - energy and maximum load - impact energy profiles were also generated. The table below reflects average critical values obtained during the impact test.

	Impact Velocity (ft/s)	*Impact Energy (ft-lb)*	*Maximum Load (lb.)*	*Energy to maximum Load (ft-lb)*	*Deflection to Maximum Load (in.)*
	4.16	2.01	332.27	1. 36	0. 1
RTM Graphite	6.21	4.47	396.16	1. 71	0. 1
Epoxy	8.12	7.65	421.71	7. 45	0. 32
	10.03	11.68	445.62	7. 92	0. 32
Autoclave-	4.16	1.99	457	1. 68	0. 09
cured	6.21	4.42	507. 21	1. 77	0. 09
Laminate	8.12	7.64	508. 23	4. 21	0. 17
	10.03	11.64	449. 54	3. 85	0. 16

Table 2. Table of results

Figures 3a and 3b depict a typical load - deflection curve for RTM Graphite Epoxy and Autoclave-cured laminate specimens subjected to same impact energy and velocity of 7.65 ft-lb and 8.12 ft/s respectively. The highest point on the curve is a critical point called the *maximum load*, which corresponds to the onset of material damage or complete failure. The x-coordinate of this point corresponds to the *deflection to maximum load*, which is the distance the impactor travels from the point of impact on the specimen to the point of maximum load. This implies that a more damage resistant material will have a higher peak, in other words, the value of the maximum load is a function of the damage resistance of a material. The repeated loading cycles shown in these figures are due to hysteresis, which results from loss of energy when specimens are impacted. As seen from the Figures 3a, 3b. and the numerical values in Table 2 above, the autoclave-cured laminate displayed a more damage resistant property than RTM graphite epoxy.

Figures 4a and 4b show plots of load and energy as functions of time for both composite specimens under similar impactor parameters. The highest point on the load- time plot also represents the maximum load. The energy value corresponding to the same x (time) - coordinate as the maximum load on the energy-time plot is the *energy to maximum load*, which is the energy absorbed by the specimen up to the point of maximum load. The plots show RTM graphite epoxy specimens absorb more energy than the autoclave-cured laminate specimens with every increase in impact energy.

Area calculations of damage incurred by the specimen were made by measuring areas on the specimen that showed visual signs of impact-induced damage. Although it is not an accurate method as it discounts damage areas within the specimen, it gives approximate values for comparison. Figure 5 shows that the RTM specimens incur greater damage than Autoclave-cure specimens subjected to the same impact energy. The slope of the plot for each material increases with impact, which implies that the extent of damage increase with impact energy.

A plot of maximum load against impact energy shown in Figure 6 indicates that although each material exhibits a different level of load and deflection for every impact, for both materials, load and deflection tend to remain constant with increase in impact energy.

Visual inspection of the impacted specimens shows that there exists a certain impact energy value below which no visible impact-induced damage is seen unless viewed under an optical microscope. However, above this critical impact energy value, impact-induced delamination and fiber breakage are evident.

Acknowledgements

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Appendix

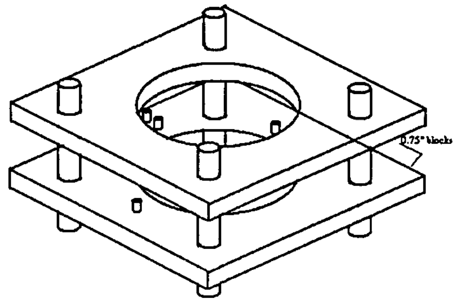

Fig 1. Pneumatic Clamp

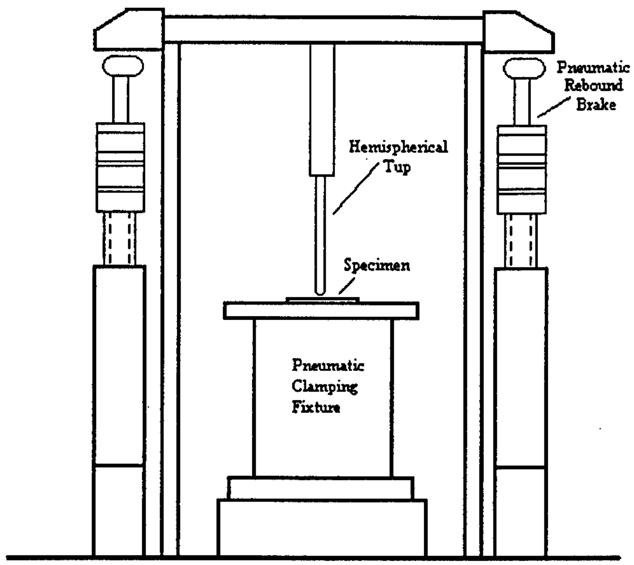

Fig 2. Schematic diagram of drop weight tester

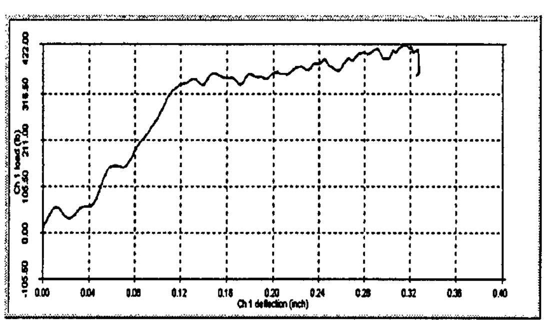

Figure 3a. RTM composite

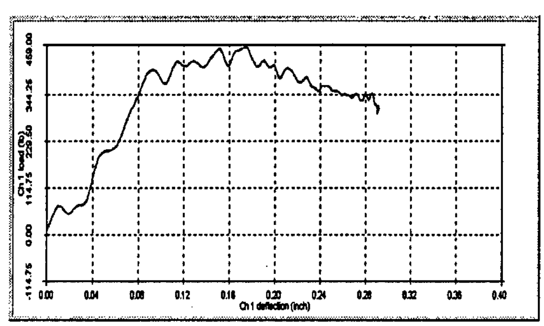

Figure 3b. Autoclave-cured composite

Figures 3. Load-deflection curve for RTM and Autoclave-cured composites at v=8.12 ft/s, Impact energy = 7.68 ft-lb.

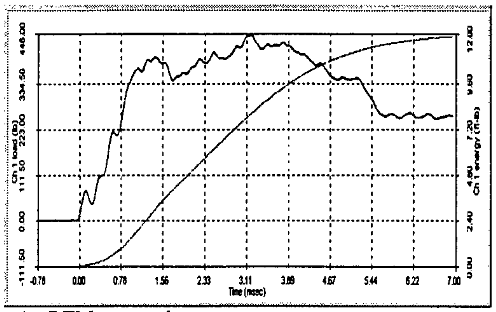

Figure 4a. RTM composite

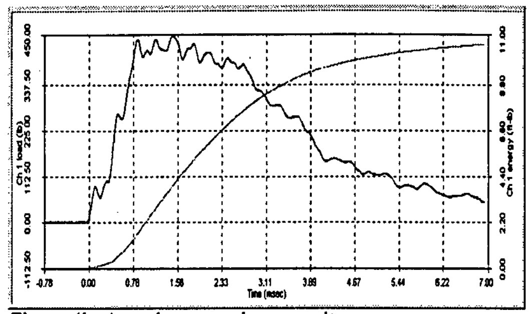

Figure 4b. Autoclave-cured composite

Figure 4. Load and energy versus time for RTM and Autoclave-cured composite at v=10.03, Impact energy = 11.66 ft-lb.

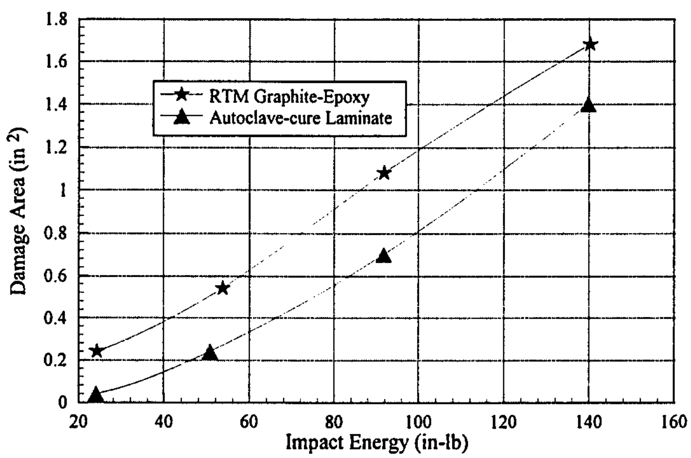

Figure 5. Damage area versus Impact energy.

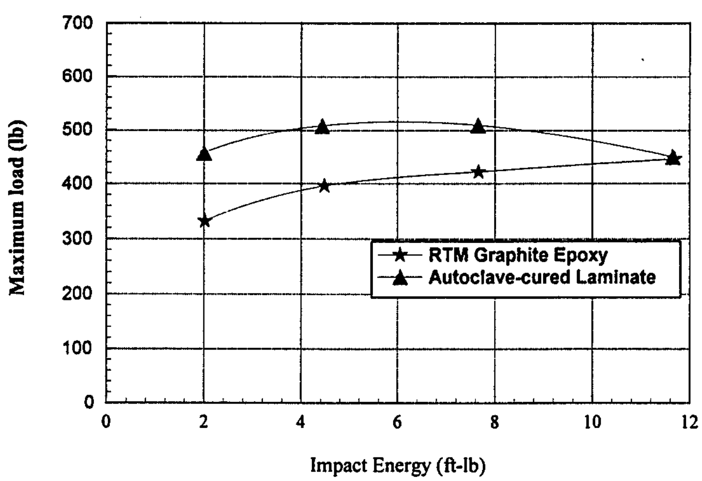

Figure 6. Maximum load versus Impact Energy.