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**DAMAGE ACCUMULATION IN CLOSED CROSS-SECTION,
LAMINATED, COMPOSITE STRUCTURES**

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INTRODUCTION

The need for safe, lightweight, less expensive, and more reliable launch vehicle components is being driven by the competitiveness of the commercial launch market. The United States has lost 2/3 of the commercial launch market to Europe. As low cost Russian and Chinese vehicles become available, the US market share could be reduced even further. This international climate is driving the Single Stage To Orbit (SSTO) program at NASA. The goal of the SSTO program is to radically reduce the cost of safe, routine transportation to and from space with a totally reusable launch vehicle designed for low-cost aircraft-like operations. Achieving this goal will require more efficient uses of materials. Composite materials can provide this program with the material and structural efficiencies needed to stay competitive in the international launch market place.

In satellite systems the high specific properties, design flexibility, improved corrosion and wear resistance, increased fatigue life, and low coefficient of thermal expansion that are characteristic of composite materials can all be used to improve the overall satellite performance. Some of the satellites that may be able to take advantage of these performance characteristics are the Tethered Satellite Systems (TOSCIFER, AIRSEDS, TSS2, SEDS1, and SEDS2), AXAF, GRO, and the next generation Hubble Space Telescope. These materials can also be utilized in projects at the NASA/MSFC Space Optics Technology and System Center of Excellence.

The successful implementation of composite materials requires accurate performance characterization. Materials characterization data for composite materials is typically generated using flat coupons of finite width. At the free edge of these coupons the stress state is exacerbated by the presence of stiffness and geometric discontinuities. The exacerbated stress state has been shown to dominate the damage accumulation in these materials and to have a profound affect on the material constants. Space structures typically have closed cross-sections, absent of free edges. As a result, composite material characterization data generated using finite width flat specimens does not accurately reflect the performance of the composite materials used in a closed cross-section structural configuration.

Several investigators have recognized the need to develop characterization techniques for composite materials in closed cross-sectioned structures [1-3]. In these investigations test methods were developed and cylindrical specimens were evaluated. The behavior of the cylindrical specimens were observed to depart from behavior typical of flat coupons. However, no attempts were made to identify and monitor the progression of damage in these cylindrical specimens during loading. The identification and monitoring of damage is fundamental to the characterization of composite materials in closed cross-section configurations. In the study reported here, a closed cross-sectioned test method was developed to monitor damage progression in 2 in. diameter cylindrical specimens and 1.5 in. finite width flat coupons subjected to quasi-static, tensile, loading conditions. Damage in these specimen configurations was monitored using pulse echo ultrasonic, acoustic emission, and X-ray techniques.

In the remainder of this report the specimen configuration and test method are describes, the non-destructive evaluation techniques are summarized, and the preliminary results discussed. Because the efforts being reported on here are part of a larger characterization study, the larger

characterization study will also be described. This report will conclude with a summary of the progress made on this study.

CLOSED CROSS-SECTION SPECIMEN AND FIXTURE DESCRIPTION

The investigation into the characterization of closed cross-sectioned composite material structures utilizes both flat, finite width, coupons and cylindrical specimens as seen in Figure 1. Two laminate stacking sequences are used in the fabrication of these specimens, $[\pm 45/90/0]$, and $[\pm 45/0/90]$. These laminate stacking sequences are chosen because they isolate the effects of the Mode I and II interlaminar damage initiation and propagation mechanisms during static and fatigue loading [4].

The finite width specimens were manufactured using 0.005 in thick AS4/3501-6 prepreg tape and a standard cure cycle. The end tab material is a Spalding G-10 fiber glass sheet that is attached to the coupon using Newport NB102 film adhesive. The Tube specimens were manufactured using 0.01 in AS4/3501-6 towprepreg tape supplied by Fiberite Corporation and a standard cure cycle. The end-tab material is Fiberite MXB 7701/7781 glass/epoxy cloth that is co-cured with the cylindrical specimens.

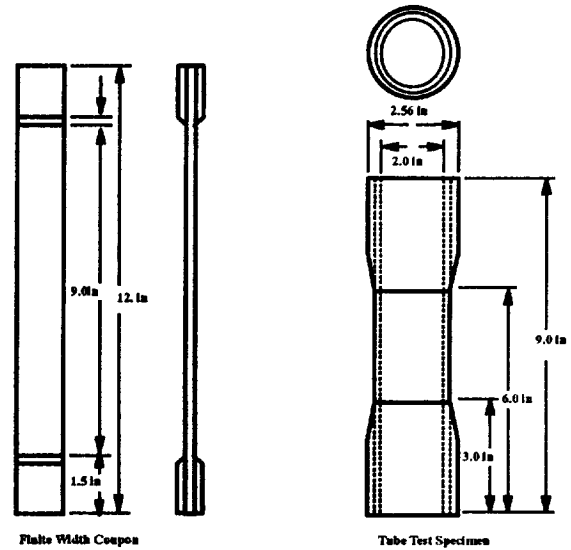


Figure 1: Test specimen configurations used in damage investigation.

Tube testing has yet to be standardized or widely accepted in the composites community, therefore, a test fixture to test the tube was designed and fabricated for this testing program at Union College. The test fixture is seen in Figure 2 attached to the 100 Kip load frame at the NASA Marshall Space Flight Center. The fixture uses mechanical jaws inside the housing, seen enclosing the test specimen in Figure 2, to grip the specimen. Both the top and bottom housings have 4 independent, concentric, grip sections that are hand tightened by threaded studs to a torque of 100 ft-lbs. To prevent the tubes from being crushed by this loading, an expanding collet insert is placed in the top and bottom of the tube end tab region to support the inner wall of the tube.

TEST MATRIX AND DAMAGE MONITORING TECHNIQUES

The evaluation in this study focuses on the accumulation of damage under quasi static tensile loading conditions. Both tube and finite width coupons were utilized in order to make a comparison between the damage accumulation characteristics in these two structural geometries. Damage was monitored using a gated pulse echo ultrasonic, acoustic emission, and x-ray techniques.

Five finite width coupons for each of the laminate geometries were tested in this study. The coupons were loaded to 70% , 90%, and 100% of their ultimate strength. At each of these load level the specimen was removed from the test fixture and impregnated with a dye penetrant and x-rayed. These x-rays were used to monitor the damage accumulation. Data generated as a result of these experiments compared favorably with previous studies [5,6]

The test matrix for the tubes is much more extensive than the finite width specimens because of the scant amount of data on damage progression in composite tubes. Twenty four tubes were tested in each of the previously described laminate configurations. Four tubes of each type were loaded to 60%, 70%, 80%, 90%, 95%, and 100% of the ultimate strength of the tubes. Prior to the testing each tube, an ultrasonically inspection was made in order to identify flaws in the tubes that were not related to the loading. The tubes were also ultrasonically inspected after each of the

load levels in order to determine if this technique could be used to monitor damage progression. The acoustic emission sensor pictured in Figure 2 was attached to one specimen at each of the load levels to monitor the acoustic signature of the damage progression. After the tubes reached their designated load level, the tubes were cut axially into two halves, impregnated with a dye penetrant, and x-rayed. This technique allowed the coupon and tube damage progression data to be directly compared. This technique also aided in the interruption of the ultrasonic and acoustic emission data.

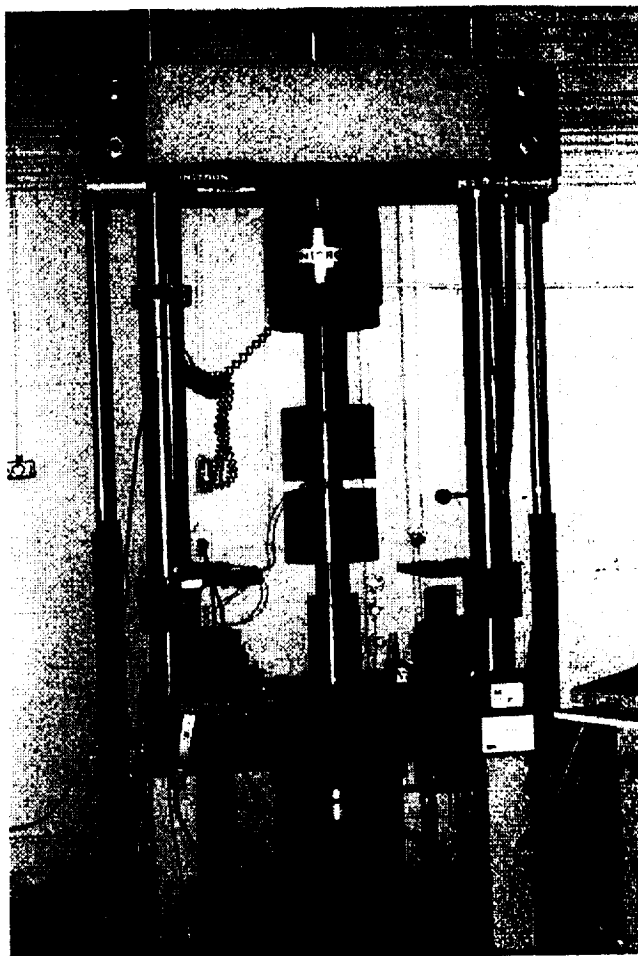


Figure 2: Load frame and test fixture used in the evaluation of the 2 in diameter composite tube specimens.

PRELIMINARY RESULTS

The ten week term for this project barely provided enough time to perform all of the designated testing and inspection described above. Thus, reflection on the data generated has yet to commence. However, some preliminary results do look interesting.

Radiographic images of the damage progression in the flat coupons show several damage types that proceed failure of the coupon. The damage includes transverse cracks in the 90°

layers, splitting in the 45° layers, and interlaminar delamination between layers. The radiographic images of the tube only indicate the presence of transverse cracking in the 90° layers. This was expected since interlaminar delamination is typically a free edge phenomenon. The constraint of the cylindrical geometry could be constraining the 45° layer from straining in a fashion that would lead to transverse cracking.

The only other preliminary data comes from direct observation. Both the flat coupon and tube specimens were very audible during testing. Both specimen geometries exhibited a unique set of sounds that appear to be related to fiber failure, bundle failure, and matrix cracking. The observations of these sounds were recorded during the testing. It is hoped that the inspection techniques used will help to positively identify the source of these sounds.

SUMMARY AND FUTURE WORK

The work performed this summer is the initial phase of a much larger composite materials characterization effort. To maximize the efficiency of composite materials, it is necessary to characterize the progression of damage during the life of the material in a given structure. The onset of damage can be a result of static and fatigue loads, impact events, thermal loading, etc. The anisotropic and heterogeneous nature of the material complicates the analysis.

6. Bucinell, R.B., Wang, A.S.D., "Delamination crack growth in fatigue loaded laminated composite materials," Proceedings of the 23rd Annual Meeting of the Society of Engineering Science, Buffalo, NY, (1986)

