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Effect of Loading Rate on the Open Hole Compression Strength of Quasi-Isotropic Carbon/Epoxy Laminates

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LIST OF ACRONYMS

ATL	automated tape laying
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
OHC	open hole compression
QI	quasi-isotropic
w/d ratio	width/depth ratio

TECHNICAL MEMORANDUM

EFFECT OF LOADING RATE ON THE OPEN HOLE COMPRESSION STRENGTH OF QUASI-ISOTROPIC CARBON/EPOXY LAMINATES

1. INTRODUCTION

The "building block" approach is typically thought to be the methodology to design a structure made of composite materials. The first tests suggested to be performed are at the coupon level at the bottom of the "building block" pyramid, which then goes up to testing a few element level tests and eventually ending at the tip of the pyramid with a full-scale component test.[1] Unnotched tension and compression, and "notched" (open hole and/or impact damage) tension and compression are typically called for at the start of a program involving composite materials that the authors have worked on.

In a previous paper, the question was raised as to why un-notched tests are performed.[2] Therefore, notched compression testing was the test of choice for this paper as it better represents a realistic design value. In addition, the test specimens are easier to manufacture and test since the failure is being forced at the notch.[2]

The inspiration behind this test program developed when the authors performed "interrupted testing" on open hole compression (OHC) specimens where some specimens failed while being held at a given load below the average breaking load (creep rupture failure) before they could be unloaded and removed from the fixture. This raised questions as to the validity of allowables data determined by standard OHC test methods (such as ASTM D6484 which specifies a loading rate of 0.05 in/min).

The effects of testing rate on carbon/epoxy laminates are sparse in the open literature. Kawai, et. al.[3] examined the loading rate dependency of off-axis compression strength at a high temperature (212°F) and found that laminates with fiber dominated strengths showed slightly higher strength values when tested at 1 mm/min versus when tested at 0.01 mm/min. This higher strength at higher loading rates was more noticeable as the matrix began to dominate the failure load.

Ou et. al.[4] showed that tensile strength of carbon fiber fabric laminates tested in the warp fiber direction showed a small increase in tensile strength with increasing loading rate.

Wang et.al.[5] showed that the tensile strength of carbon/epoxy laminates was not affected by loading rates between 1 and 5 mm/min but the compression strength did increase when the test speed was increased from 2 mm/min to 6 mm/min.

No data on test speed regarding notched laminates could be found in the open literature so the data presented in this study would be the first to the authors' knowledge.

The aim of this study was to develop a baseline average strength and "B-basis" allowables for OHC testing of QI carbon/epoxy laminates tested at the standard rate of 0.05 in/min and then at a much slower rate of 0.0005 in/min, and a faster rate of 10 in/min, and compare values.

In addition, some creep rupture tests were performed by holding the specimens at stress levels below the average failure stress of the 0.0005 in/min specimens and recording the time for these specimens to fail while being held at the lower stress level.

2. EXPERIMENTAL DETAILS

2.1 Materials for Test Specimens

The carbon/epoxy material used to manufacture the laminates in this study was IM7/8552. A large flat panel was manufactured via Automated Tape Laying (ATL) at NASA's Marshall Space Flight Center (MSFC). The laminate was cured in an autoclave with a pressure of 40 psi and a temperature of 350°F. The flat panel made for use in this study was 36 inches by 36 inches in size. The layup sequence for the laminate was 16-ply [+45/0/-45/90]2S quasi-isotropic. Specimens were cut from this panel with the loading direction in the 0° fiber direction. The specimens were one inch wide and three inches tall. A 0.125-inch hole was drilled in the center of the specimen and then reamed to a final diameter of 0.13 inch giving a w/d ratio of 7.7. (The standard ASTM D6484 test was not used since that test calls for a much larger specimen and material was limited). Figure 1 shows a cross section of a typical specimen and the laminate appears to be of good quality and the hole edges showed little to no delamination.

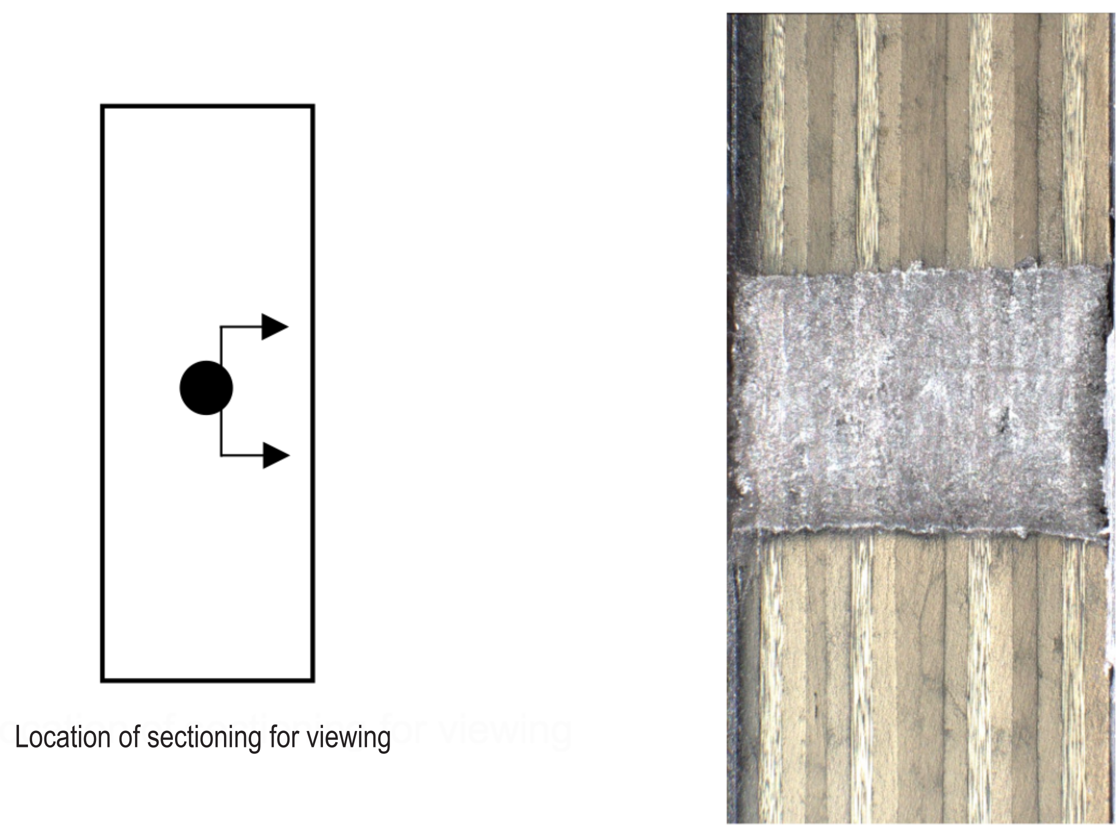

Figure 1. Cross-sectional photomicrograph of typical specimen used in this study.

2.2 Open Hole Compression (OHC) Strength

A "Northrop" OHC fixture was used to determine the OHC strength of the specimens and is shown in figure 2. Results of the OHC tests are shown in table 1 and illustrate that the specimens tested at the slow loading rate had a lower average OHC strength (and B-Basis allowable) than the specimens tested at the standard 0.05 in/min loading rate. The specimens tested at the highest loading rate had a slightly higher average OHC strength (and B-Basis allowable) than the specimens tested at the standard 0.05 in/min loading rate.

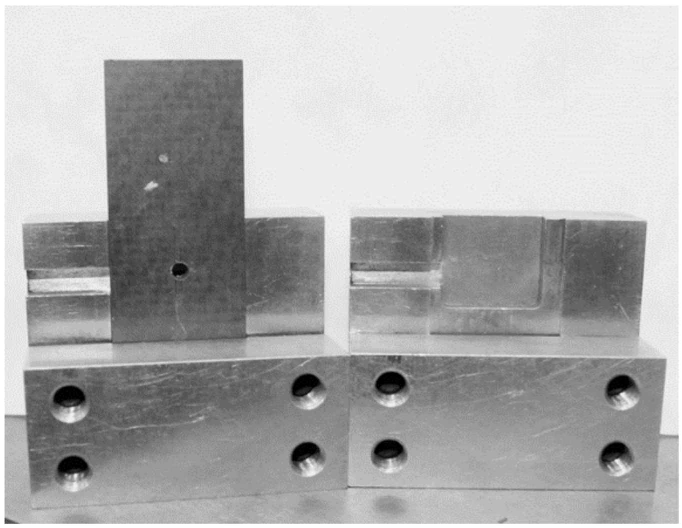

Figure 2. OHC fixture used in this study.

Table 1. Summary of OHC Results from this study.

Test Speed (OHC Strength Results in ksi)		
0.0005 in/min	0.05 in/min	10 in/min
50.2	51.4	54.6
48.6	53.4	55.8
48.9	53.1	56.7
51.1	51.5	53.0
50.9	54.2	55.2
50.8	52.7	54.0
48.3	53.4	57.9
49.1	51.6	56.6
48.6	52.5	55.7
49.6	54.2	57.9
49.4	53.2	55.4
Average = 49.6±1.0	Average = 52.8±1.0	Average = 55.7±1.5
B-Basis = 47.3	B-Basis = 50.6	B-Basis = 52.2

Despite coming from the same panel, these three groups of specimens all have different OHC strength values, even when considering any standard deviation overlap. A k-Sample Anderson-Darling test indicated that these three data groups were not from the same population. The average strength value at the lowest loading rate is only 94% that of the average strength value found using the conventional loading rate of 0.05 in/min. Six specimens were loaded at or below the average strength value found at the slowest loading rate (49.6 ksi) and held at that value until failure. The log of time to failure in seconds versus percentage of average failing stress at 0.05 in/min is plotted for each specimen in figure 3.

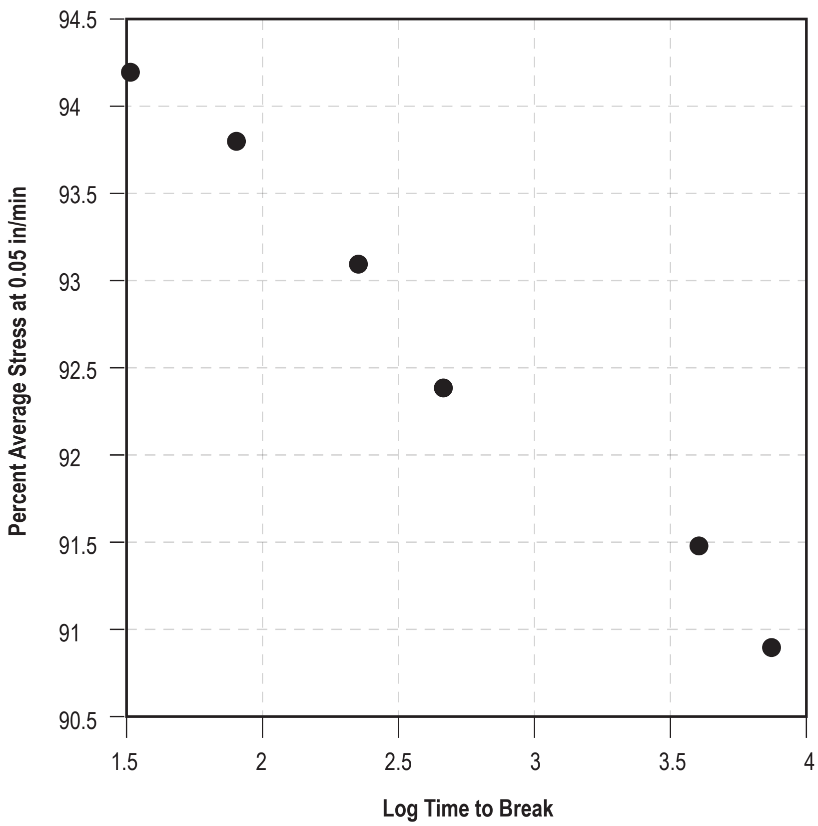

Figure 3. Log of time to failure of specimens held under a constant stress. Stress values given as a percentage of the average failing stress of the 0.05 in/min loading rate specimens.

3. CONCLUSIONS

The measured strength of laminates in coupon tests were found, (for OHC testing in this particular study), to be different depending on the test speed which raises the question as to what test speed to use when developing allowables for the "building block" approach often suggested for composite structures. Should lower allowables be used for structures that will see long term static loads and larger ones for structures that will fail under a high dynamic load? If the methodology of developing allowables presented in Nettles et al.[2] are used, then this becomes a moot point as the allowable used will be more conservative than the value obtained at the slowest test rate.

4. DECLARATION OF CONFLICTING INTERESTS

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