DESIGN AND TESTING OF SMALL COMPOSITE SPECIMENS

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NSG-1631

1979-81

Prepared for
Langley Research Center
National Aeronautics and Space Administration
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December 1981

19951228055

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited
--- AD NUMBER: D436204
--- CORPORATE AUTHOR: NORTH CAROLINA AGRICULTURAL AND TECHNICAL STATE
--- UNIV GREENSBORO SCHOOL OF ENGINEERING
--- UNCLASSIFIED TITLE: DESIGN AND TESTING OF SMALL COMPOSITE SPECIMENS.
--- PERSONAL AUTHORS: SHARMA, A. V.
--- REPORT DATE: DEC , 1981
--- PAGINATION: 73P
--- CONTRACT NUMBER: NSG-1631
--- MONITOR ACRONYM: NASA
--- MONITOR SERIES: CR-169059
--- REPORT CLASSIFICATION: UNCLASSIFIED
--- LIMITATIONS (ALPHA): APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.
--- AVAILABILITY: NATIONAL TECHNICAL INFORMATION SERVICE.
--- SPRINGFIELD, VA. 22161. N82-26393.
--- LIMITATION CODES: 1 24

--- END Y FOR NEXT ACCESSION
ACKNOWLEDGMENTS

The financial support provided for this work by the National Aeronautics and Space Administration through a grant NSG-1631 is gratefully acknowledged. The author expresses his sincere appreciation to Mr. Marvin D. Rhodes, Technical Officer, of the Langley Research Center for his assistance in the development of the specimen support fixture and for rendering many valuable suggestions during the course of this investigation.
Design and Testing of Small Composite Specimens

ABSTRACT

An experimental investigation was conducted to study the effect specimen size on the buckling strains of laminates subjected to low velocity projectile impact. The fiber composite selected was T300/5208 graphite/epoxy system. The quasi-isotropic laminates tested had 16 and 32 plies. The results were compared with those of a 48-ply laminate tested elsewhere. Specimens of three different lengths with length to width aspect ratios of 1, 1.5 and 2 were also studied. The results show that (a) the specimen length does not have any significant influence on the buckling strains at failure caused by the projectile impact, (b) the influence of specimen thickness on the strains at failure would decrease as the velocity of the impacting projectile increases.
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LEGEND/ABBREVIATIONS

K.E Kinetic Energy of the impacting projectile, J.

σ Stress, MPa.

σ Maximum Stress (of undamaged specimen), MPa.

ε Strain corresponding to σ.

ε Maximum Strain corresponding to σ.

a Nominal length of specimen, cm.

b Nominal width of specimen, cm.

t Nominal thickness of the specimen, cm.

• Data point corresponding to catastrophic failure.

Ø Data point corresponding to residual strength or strain of specimen surviving the impact.

o Data Point corresponding to preload or prestrain applied to the specimen prior to impact.

i,r,u Subscripts refer to values at impact, residual stage, ultimate or maximum values, respectively.
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INTRODUCTION

The use of high-modulus fiber composites in the design of structural components of aircraft is increasing. One of the problems that need attention in such a design is the effect of low velocity projectile impact on the strength carrying ability of the composite structural components. If the structural components are to be subjected to compressive loads, the analysis of buckling failure modes is also important. The objective of the present work is to show any correlation that may exist between the results obtained from testing large thick panels and small thin panels. Earlier work by Rhodes [1]* addressed some aspects of the buckling strains in thicker composite laminates. Several types of failure modes in the thick compression panels were also identified in this study. With the results of this study in the background, the present study is directed to investigate the advantages, if any, in testing thinner laminates of variable lengths. The specimen stabilization and loading mechanism is similar to that used by Rhodes [1] and is shown in Figure 2.

* Numbers in the square brackets refer to references at end.
SPECIMENS AND EXPERIMENTAL ARRANGEMENT

All the specimens tested were identical with respect to material, orientation, stacking sequence and width with the exception of the thickness and the length. The material selected was graphite/epoxy (T300/5208) system. The orientation and stacking sequence were $(\pm 45,0,90)_{4s}^4$ for the 32-ply A Series laminates and $(\pm 45,0,90)_{2s}^2$ for the 16-ply B Series laminates. Each lamina in the panel had a nominal cured thickness of $140 \times 10^{-6} \text{m} (0.0055 \text{ in.})$. The nominal dimensions of the specimens tested are shown in Table I. A sketch of the specimen indicating the unsupported and the supported dimensions is shown in Figure 1. A general specimen support and stabilization mechanism is shown in Figure 2. This supporting device was used in testing all the specimens. However, the side support bars and channel sections as shown in Figure 2, were of variable lengths to correspond with the respective specimen lengths. The projectile impact at low velocities was accomplished by using an air gun. The projectile is an aluminum sphere 1.27 cm (0.5 in.) in diameter. The projectile firing mechanism was described briefly by Sharma [2].

Static compressive loads were applied to the specimens using the specimen loading and stabilizing device as shown in Figure 2. In this figure, only the bottom support plates are shown. The top support plates (not shown) are similar to the bottom support plates (D & E). The side support bar (A) and the channel (B) were designed to prevent the laminate from column-type failure under compressive loads. The bars, shown
as C (and there were four such bars - two in the bottom and two in the top) serve to prevent the side support mechanism from rotating (or tilting) in compression. The whole device was designed in such a way to accommodate the axial compressive deformation of the specimens. Detailed dimensions of the supporting device were shown in Ref. 3. The compressive loads and the resulting strains were recorded using the standard experimental techniques. The axial strains were measured using four strain gages. Two of these gages were bonded on the front plane and two at the corresponding points on the back plane. Moreover, the gages were located at points on the specimen away from the physical constraints imposed on the specimen by the supporting and loading mechanism. Several undamaged specimens in each of the series were tested to determine the compressive axial strains and the corresponding loads. Some of the specimens were subjected to varying magnitudes of preloads prior to the projectile impact. The magnitude of the preload applied to the specimen was less than the maximum compressive load. Depending on the magnitude of the preload, some specimens failed catastrophically upon impact. Loading was continued on those specimens that survived the impact to determine the residual strength of the impact-damaged specimens. The term "failure threshold" used in subsequent sections is defined as the lowest buckling load which precipitated catastrophic failure in the specimen at a given impact energy. The stress ratio, σ/σ, used in this report is defined as the ratio of the stress in the specimen prior to impact, or the residual strength of the specimen, to the static buckling strength of the virgin specimen.
RESULTS AND ANALYSES

The nominal width of all the specimens was 7.62 cm (3.0 in.). In each of the Series labeled as A and B, specimens of three different lengths with length to width aspect ratios of 1:1, 1.5:1, and 2:1 were tested. The total number of specimens tested in each of the series is shown in tabular form elsewhere in this report.

The numerical data for testing the specimens are given in Tables II through XIII. The normalized values shown in these tables were obtained by dividing the magnitude of the appropriate variable by the corresponding average ultimate values of the undamaged specimens at failure. A few of the abnormal values observed in this process were discarded. These abnormal values were suspected to be the result of either inadvertent misalignment of the loading fixture or by not providing sufficient torque to the bolts that hold the specimen in the loading fixture. It may be remarked that those components of the loading and supporting device that come in contact with the specimen either before loading or during loading were provided with smooth rounded off edges in order to minimize any localized stress concentrations on the specimen.

The numerical data for each of the series of specimens tested is plotted as a function of the kinetic energy of the impacting projectile. The resulting graphs, for example, are shown in Figures 3-6 for the specimens in A 10 Series (aspect ratio 1:1, 32 plies). Based on the limited experimental data, a faired curve through the data points is drawn. This faired curve is designated as a failure threshold curve. The failure threshold curve may be
interpreted to demark the area of graphs shown in this report into
two distinct zones, viz., the failure zone and the survival zone.
Whenever the applied stress (or strain) level is above the failure
threshold, the specimen would fail catastrophically upon impact at
the impact energy level under consideration. From these faired
failure threshold curves, it is possible to develop an approximate
idea with regards to the residual strength of the impact-damaged
laminates subjected to compressive loads. The graphs indicating
the experimental data for the other series of specimens, A 15, A 20,
B 10, B 15, and B 10 are shown in Figures 7-10, 11-14, 15-18, 19-22,
and 23-26, respectively.

The primary objective of this study, as indicated earlier,
is to observe any correlation that may exist in the buckling strains
by testing laminates of various thicknesses and lengths. It was
indicated by Rhodes [1] that width effects beyond a certain minimum
specimen width (for example, width to projectile diameter ratio
greater than 5) appear not to influence the buckling strains.
Consequently, this study is directed towards varying the lengths
and thicknesses of the laminates studied. The variation of strains
at failure as a function of the total projectile impact energy for
all the laminate series tested is shown in Figure 27. The data
base for the curves in Figure 27 is generated from the respective
faired (threshold) curves for each of the series tested. The NASA
data (Ref. 1, Fig. 9, b, 48-ply quasi-isotropic laminate C) that
is used in this report is similarly generated. The data base so
generated is shown in Tables XIV and XV. Since the number of
specimens tested for each series at any one energy level is limited,
the data generated from the faired curves is deemed to be a better representation of the laminate behavior. It may be noted that the magnitude of the impact-energy in the NASA study was at a relatively higher level than the impact energy level used in this study. Further, the number of plies in each of the series and that of NASA are 16 (B Series), 32 (A Series), and 48 (NASA), respectively. For the purpose of comparing the results, the impact-energy needed per ply to cause catastrophic failure at a particular strain level is assumed to be a common denominator for all the laminates. The derived strain data and the corresponding energy per ply for all the laminates are also shown in Tables XIV and XV. These results are plotted as shown in Figure 28.

By studying the series of graphs in Figure 28, a few observations may be made:

1. The laminates of A Series (32 plies) having the length to width aspect ratios of 1:1, 1.5:1, and 2:1 do not seem to have significant variation in their strain values (refer to curves 1, 2, and 3) at any one impact energy/ply level. A similar observation may also be with respect to the 16-ply laminates of B Series (refer to curves 4, 5 and 6). Since the specimen width is essentially a constant for all the laminates (Series A and B), the effect of length on the values of strains at failure for any one Series of laminates appears to be not significant. However, if the behavior of the two Series is observed in the low energy/ply range (less than about 0.05 J/ply), it may be seen that the thicker laminates
(A Series) are exhibiting slightly higher strains than the laminates of the B Series. This may be interpreted to mean that the 'additional' plies in the thicker laminate may be responsible for exhibiting higher stiffness at low impact energy levels. On the other hand, the 48-ply NASA laminate (curve 7, and also see Table XV or Ref. 1) does not exhibit higher failure strains for the controlled (virgin) specimens. Since data is not available, the shape of the curve 7, Fig. 28, between the energy/ply levels of 0 to about 0.09 J/ply is assumed. Some of these small differences in the results may be attributable to the small deviations (specimen supporting devices, effective width to projectile diameter ratios, etc.) that exist in testing the laminates of Series A and B and the NASA's laminates.

2. Between the impact energy/ply range of 0.05 J/ply to about 0.15 J/ply, the magnitude of strains at failure for all the laminates in Series A and B may be observed to be the same. It may be remarked that the strengthening effect of 'additional' plies in the laminates appear to be converging and tend to be asymptotic to the energy axis. It may be noted that all the curves, 1 through 7, appear to be converging to form a common asymptote as the impact energy/ply increases.
CONCLUSIONS AND RECOMMENDATIONS

Based on the results of this investigation, the following conclusions can be drawn:

1. At constant thickness, the length to width aspect ratio of the laminates subjected to low velocity projectile impact does not seem to have any significant effect on the buckling strain values at failure.

2. The laminate thickness appears to have some influence on the failure buckling strains at low impact velocities. As the impact energy per ply increases, all the laminates, regardless of their thickness, show asymptotic buckling strain values at failure.

In order to ascertain the specimen size effects further on the buckling behavior of laminates subjected to low velocity projectile impact, it is recommended that:

1. all the laminates be tested using the same specimen support device and loading mechanism,

2. at least four thicknesses of the same stacking sequence be tested,

3. a large number of specimens per thickness be tested leading to the statistical analyses of the results,

4. the impact energy levels be varied in a systematic way from 0 to about 25 J, and

5. the projectile firing mechanism be improved to develop reliable predetermined energy levels.
REFERENCES


| Series Number | Number of Plies | Nominal Size | | Unsupported Size | |
|---------------|----------------|--------------|-----------------|-----------------|
|               |                | a cm/in     | b cm/in         | a cm/in         | b cm/in         | t cm/in         |
| A1            | 32             | 8.89/3.5    | 7.62/3.0        | 0.448/0.176     | 6.35/2.5        | 6.35/2.5        | 0.448/0.176     |
| A2            |                | 12.07/4.75  |                |                 | 9.53/3.75       |                |                 |
| A3            |                | 15.24/6.0   |                |                 | 12.70/5.0       |                |                 |
| B1            | 16             | 8.89/3.5    |                | 0.224/0.088     | 6.35/2.5        |                | 0.224/0.088     |
| B2            |                | 12.07/4.75  |                |                 | 9.53/3.75       |                |                 |
| B3            |                | 15.24/6.0   |                |                 | 12.70/5.0       |                |                 |
TABLE II. Experimental Data: A10 Series

Material: Graphite/Epoxy, T300/5208
Nominal Size: 3.5" x 3.0" x 0.160"
Orientation: (±45, 0, 90)_{4s} - 32 plies

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<th>( P_1 ) (\text{kips} )</th>
<th>( \epsilon_1 )</th>
<th>( \sigma_1 ) (\text{ksi} )</th>
<th>( P_r ) (\text{kips} )</th>
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TABLE III. Normalized Data: A10 Series

Series: A 10
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Avg. Ult. Stress: 589.475 MPa
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### Table IV. Experimental Data: A 15 Series

**Material:** Graphite/Epoxy, T300/5208  
**Nominal Size:** 4.5" x 3.0" x 0.160"  
**Orientation:** (±45,0,90)₄₅ ± 32 plies

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### TABLE VI. Experimental Data: A 20 Series

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**Orientation:** (±45,0,90)₄₄ - 32 plies

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TABLE X. Experimental Data: B 15 Series

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Orientation: (±45, 0, 90)_{2s} -16 plies

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**Series:** B 20

Avg. Ult. Load: 49.015 kN
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Avg. Ult. Strain: 0.00695
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TABLE XV. Faired Data: Strains, K.E./ply

Series: NASA (Ref. 1)
Size: 5" x 10" and 15" x 10"
Lamina Orientation: (± 45, 0, 90, -40, 0, 90)_{3S}
No. of Plies: 48

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ORIGINAL PAGE IS OF POOR QUALITY
Figure 1. Nominal and Unsupported Specimen Size
FIGURE 2. GENERAL VIEW OF SPECIMEN SUB-OPTING DEVICE

A: SIDE SUPPORT BAR
B: END SUPPORT BAR
C: END SUPPORT BAR
D: SIDE SUPPORT CHANNEL
E: END SUPPORT PLATE
Figure 3. Stress vs. K.E. of Projectile - A 10 Series

Kinetic Energy of Projectile, J
Figure 6. Normalized Strain vs. K.E. of Projectile: A 10 Series
Figure 7. Stress vs. K.E. of Projectile: A 15 Series
Figure 8. Normalized Stress vs. K.E. of Projectile: A 15 Series
Figure 9. Strain vs. K.E. of Projectile: A15 Series

Kinetic Energy of Projectile, J

Strain e
Figure 10. Normalized Strain vs. K.E. of Projectile: A 15 Series
Figure 11. Stress vs. K.E. of Projectile: A 20 Series
Figure 14. Normalized Strain vs. K.E of Projectile: A 20 Series
Figure 16. Normalized Stress vs. K.E of Projectile: B 10 Series

Kinetic Energy of Projectile, J

Stress Ratio, $\sigma$ / $\sigma_0$
Figure 17. Strain vs. K.E of Projectile: S10 Series

Kinetic Energy of Projectile, J

Strain ℓ
Figure 18. Normalized Strain vs. K.E of Projectile: B 10 Series
Figure 19. Stress vs. K.E of Projectile: B 15 Series
Figure 20. Normalized Stress vs. K.E of Projectile: B 15 Series
Figure 22. Normalized Strain vs. K.E of Projectile: B 15 Series
Figure 23. Stress vs. K.E of Projectile: B 20 Series
Figure 24. Normalized Stress vs. K.E of Projectile: B 20 Series
Figure 25. Strain vs. K.E of Projectile: B 20 Series
Figure 26. Normalized Strain vs. K.E of Projectile: B 20 Series
Figure 27. Strain vs. Projectile Energy (values taken from the faired threshold curves).
Curve 1. A 10 Series
2. A 15 Series
3. A 20 Series
4. B 10 Series
5. B 15 Series
6. B 20 Series
7. NASA (Ref. 1)

Figure 28. Strain vs. Projectile Energy/ply