Strategically Tuned Absolutely Resilient Structures (STARS)

ABSTRACT

This paper reports on a new generation of composites fabricated by placing a low modulus, lightweight matrix over multiple layers of a relatively stiff reinforcement. These remarkable concoctions called Strategically Tuned Absolutely Resilient Structures (STARS) are designed to store strain energy in the form of elastic deformation that can be released in a controlled fashion as work or kinetic energy. They are designed to resist reverse loadings created by bending and torsion and can be highly stressed and deformed to store large amounts of elastic strain energy. When the structural response is modified as the service loads are decreased, the stored energy can be released in a controlled fashion to do useful work.

INTRODUCTION

The STARS concept makes it possible to build a structure capable of storing strain energy in the form of elastic deformation that can be released in a controlled fashion as work or kinetic energy [1]. As described below, composite sections made from a new class of Graphite Reinforced Silica/Polymer Matrix Composite (GRSPMC) materials are being designed based on the strength, stiffness, and the position of the component materials in the composite section [2-4]. Their ability to store and release energy depends upon a complex interaction between the shape, modal response, and the forcing function applied to drive the structure.

STAR STRUCTURES

A STAR structure is unique in that the component materials are purposefully stressed and deformed to the largest extent possible to store the maximum amount of strain energy. They are much more complex and versatile than other more simple energy storage devices such as springs.

In general, component materials that have very large differences in stiffness characterize STARS and the composite structure is designed to be absolutely resilient so that it can sustain very large deformations without compromising structural integrity.
Figure 1 illustrates that one method for achieving large deformations is to drive the STAR structure to controlled resonance by using a forcing function having a frequency close to the structure’s natural frequency.

Using adaptive reinforcement can prevent damage. Control elements may be employed to adjust the dynamic response of the STAR structure in real time. The overall design goal is to make STARS absolutely resilient so that strain energy, stored as elastic deformation, can be completely recovered and efficiently converted into useful work or energy.

FIRST GENERATION STARS – STEEL REINFORCED STRUCTURES

Pioneer research involving STARS focused on producing a new generation of thin, lightweight, and structurally efficient panels capable of resisting the dangerous stresses produced by reverse loading [5]. The study showed that a very efficient composite structure could be fabricated by placing a flexible polymer-enhanced cementitious matrix having a relatively low elastic modulus over two layers of a rigid steel wire mesh having a relatively high elastic modulus (see Fig. 2).

The design relied on the large difference in stiffness between the constituents in the composite section to drive the internal stress from the cementitious matrix to the steel reinforcement and materials were placed symmetrically through the thickness to form an "adaptive" section that reacted similarly when bending couples were reversed. The stress transfer was so high that
when the panels were bent, the steel strands broke before the cementitious matrix cracked. The method of photoelasticity was used to illustrate how and why this occurred.

**STRESS TRANSFER – GEOMETRY, STRENGTH, AND STIFFNESS**

Figure 3 shows the isochromatic fringe patterns in four beams made from a plastic called PSM-1, a material manufactured by Measurements Group, Inc.

![Figure 3. Photoelastic fringes in beams.](image)

All four beams shown in the figure have a constant thickness, and each beam is subjected to the same bending moment. The distribution and number of fringes are directly proportional to the stress. The heavy black fringe in each beam represents the neutral axis that passes through the centroid of the section. The stress varies linearly with depth: compression on one side, tension on the other.

The beam situated second from the top is a 2.54 cm (1 in.) deep control standard and represents an unreinforced, homogeneous beam with a cementitious matrix having an elastic modulus equal to that of PSM-1. The maximum stress is 1.50 MPa (218 psi). The top beam is only 1.91 cm (0.75 in.) deep and illustrates that the maximum stress [2.76 MPa (400 psi)] becomes much higher when the depth is smaller.

A 0.64 mm (0.025 in.) thick, 9.5 mm (0.375 in.) wide, steel strip is bonded to the lower surface of the beam situated third from the top. The maximum stress in the plastic is 751 kPa (109 psi), half that found in the control standard. Finally, the bottom beam has steel strips bonded on both the top and bottom faces. The isochromatic fringe pattern in the plastic is barely visible and corresponds to a maximum stress of only 103 kPa (15 psi). This value is over fourteen times less than that in the control standard, clearly indicating that the stress has been driven from the plastic (matrix) to the steel (reinforcement).

**SECOND GENERATION STARS – GRAPHITE REINFORCED STRUCTURES**

A subsequent investigation revealed that the standard transform section theory applied to study the steel reinforced panels failed to provide accurate results when the elastic modulus ratio exceeded 20 and a modified transform section theory was developed to determine the deflections and stresses in such highly compliant structures [6]. The investigation involved using the rule of mixtures to determine a set of effective material properties for a graphite reinforced composite. Steel was replaced by graphite because the latter is ten times stronger and five times lighter than steel.

Tensile tests were conducted on composite samples reinforced with a single graphite layer to verify this approach; and, when the effective material properties were used to characterize the deflections of multi-layered composite beams subjected to pure bending, an excellent agreement was obtained.

The study initially focused on a composite reinforced with two layers of graphite mesh. Fibers in each mesh were aligned in perpendicular directions and both meshes had fibers oriented in the same directions. Then laminated plate theory was used to
analyze more complex composites having graphite layers oriented differently. Multi-layered composite beams were analyzed by incorporating material properties established from tensile tests and finite element modeling was used to verify results. Considering the complexity of the samples, a very good agreement was obtained.

In this study, a relatively flexible concrete was designed with the following mix proportions: Portland cement \([393 \text{ kg/m}^3 \ (25.5 \text{ lb/ft}^3)]\), latex \([78.2 \text{ kg/m}^3 \ (4.9 \text{ lb/ft}^3)]\), acrylic fortifier \([24.3 \text{ kg/m}^3 \ (1.5 \text{ lb/ft}^3)]\), micro-balloons \([154 \text{ kg/m}^3 \ (9.6 \text{ lb/ft}^3)]\), and water \([247 \text{ kg/m}^3 \ (15.4 \text{ lb/ft}^3)]\). The air content by volume in a standard compression test cylinder was 14 percent and the water to cement ratio of the mix was 1.19. Tension and compression tests revealed 28-day tensile and compressive strengths of 1.77 MPa (256 psi) and 4.80 MPa (696 psi), respectively. The elastic modulus and Poisson’s ratio were 0.8 GPa (115 ksi) and 0.28, respectively.

The composite samples were reinforced with a layer of a non-impregnated graphite mesh having 3,000 fibers per tow spaced at 3.18 mm (0.125 in.) intervals. Each tow was 0.19 mm (0.007 in.) thick by 1.07 mm (0.042 in.) wide. The fibers were held in place using 0.08 mm (0.003 in.) diameter Kevlar strands. The fibers were held in place using 0.08 mm (0.003 in.) diameter Kevlar strands. The elastic modulus and tensile strength of the graphite were 231 GPa (33.5 Msi) and 3.65 GPa (529 ksi), respectively. Tensile tests were conducted to determine the elastic modulus [2.8 GPa (406 ksi)] and Poisson’s ratio (0.14). Iosipescu specimens were used to determine the shear modulus [517 MPa (75 ksi)]. Figure 4 illustrates that the beams consisted of two layers of mesh confined within the cementitious matrix.

**Figure 4.** A cementitious composite section is reinforced using two layers of graphite mesh.

The mesh has the same elastic modulus in the x and z directions. However, because of the very large difference in stiffness between the matrix and the graphite (approximately 300 times), rotating the mesh changes the effective modulus of the composite section significantly. A photograph of a typical specimen is shown to the left in Fig. 5.

The orientation of the graphite reinforcement is \([90^\circ,90^\circ]\) in the first beam, \([45^\circ,45^\circ]\) in the second beam and \([45^\circ,90^\circ]\) for the third beam. The dimensions of a beam after sanding are 22.86 cm (9 in.) long, 2.84 cm (1.12 in.) wide and approximately 0.635 cm (0.25 in.) thick. Since the construction process was not exact, small variations in orientation and thickness were present.

The photograph to the right in Fig. 5 shows how each beam was subjected to bending. The ends of the beams were placed on rollers to produce the desired boundary conditions. Beam deflection data was measured using a dial gage located at the center of each beam.

The results of the composite beam tests were compared to analytical results based on the effective elastic modulus values calculated from the constitutive equations. To achieve this, an elastic beam equation was developed to calculate the beam deflections corresponding to loading and geometry at hand. A MathCad solution sheet was used to determine the integration constants and perform the calculations required to solve the elastic beam equation.
Figure 5. Reinforced cementitious composite specimens were subjected to pure bending.

The test data shown to the left in Fig. 6 shows the predicted deflections for Beam 1 [90°, 90°] are in good agreement with the test results. The effective elastic modulus used in the predictions, $E_x = 2.84$ GPa (412 ksi), adequately predicted the behavior of this two-layer composite. The test data for Beam 2 [45°, 45°], shown to the right in Fig. 6, also compared very well with the test results. The effective elastic modulus calculated for this beam, $E_x = 1.72$ GPa (249 ksi), indicates that the solution methods for the constitutive equations remain accurate regardless of the orientation of the composite layers.

Figure 6. Deflection for two different multi-layered beams having symmetrical lay-ups.

The test data for Beam 3 [45°, 90°], shown in Figure 7, also compared very well with the test results. This is significant, since the lay-up is non-symmetrical. The effective elastic modulus calculated for this beam, $E_x = 2.29$ GPa (332 ksi), was computed using the same method applied to obtain those corresponding to the symmetric cases.
Figure 7. Deflection for a multi-layered beam having a non-symmetrical lay-up.

COMPOSITE LAMINATED PLATE THEORY

The work described in the last section fueled another investigation that quantified the dynamic characteristics of graphite-reinforced composite laminated plates, having three layers of reinforcement, using composite laminated plate theory [7]. The constitutive equations for graphite reinforced, anisotropic laminates may be written as:

\[
\begin{bmatrix}
N_x \\
N_y \\
N_{xy} \\
M_x \\
M_y \\
M_{xy}
\end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{13} & B_{11} & B_{12} & B_{13} \\
A_{21} & A_{22} & A_{23} & B_{21} & B_{22} & B_{23} \\
A_{31} & A_{32} & A_{33} & B_{31} & B_{32} & B_{33} \\
B_{11} & B_{12} & B_{13} & D_{11} & D_{12} & D_{13} \\
B_{21} & B_{22} & B_{23} & D_{21} & D_{22} & D_{23} \\
B_{31} & B_{32} & B_{33} & D_{31} & D_{32} & D_{33}
\end{bmatrix} \begin{bmatrix}
\varepsilon_{0x} \\
\varepsilon_{0y} \\
\gamma_{0xy}
\end{bmatrix}
\]

where \( (A_i, B_i, D_i) = \sum_{r=1}^{N} \int_{Z_r}^{Z_{r+1}} Q^{(r)}_i(z, Z^2) dz \)

\( N_x, N_y, N_{xy} \) = resultant force and shear force in x-axis, y-axis, and x-y plane, respectively.

\( M_x, M_y, M_{xy} \) = resultant moment and twisting about x-axis, y-axis, and x-y plane, respectively

\( Z_r, Z_{r+1} \) = thickness coordinates of the lower and the upper surface of the r-th ply

\( Q^{(r)}_i \) = material stiffnesses of the r-th ply

\( Z \) = laminate transverse direction, normal to x-y plane

\( N \) = number of plies in the laminate

\( \varepsilon_{0x} \) = midplane strain in x-axis

\( \varepsilon_{0y} \) = midplane strain in y-axis

\( \gamma_{0xy} \) = midplane shear strain in x-y plane
\[ K_x = \text{plate bending curvature in the x-z plane} \]
\[ K_y = \text{plate bending curvature in the y-z plane} \]
\[ K_{xy} = \text{plate twisting curvature in the x-y plane} \]
\[ A_{ij} = \text{extensional stiffnesses} \]
\[ B_{ij} = \text{bending-extension coupling stiffnesses} \]
\[ D_{ij} = \text{bending stiffnesses} \]

The \( A, B, \text{ and } D \) matrices are computed based on the laminate material properties, geometry, and stacking sequence. For a three-ply specially orthotropic laminate (laminate whose principal material axes are aligned with the natural body axes), these matrices were computed based on previously obtained material properties. In this configuration, the bending-extensional coupling coefficients, \( B_{ij} \), the bending-twisting coefficients, \( D_{13}, D_{23} \), and the shear-extensional coupling coefficients, \( A_{13}, A_{23} \), are all zero.

**PLATE TESTING AND FINITE ELEMENT MODEL VERIFICATION**

Plates were constructed having an adaptive section reinforced with three layers of graphite mesh and the study involved plates with aspect ratios ranging from 0.5 to 4.5 [2,3]. Natural frequencies, damping, and mode shapes were measured to validate material properties for further theoretical studies and a dynamic finite element model was developed to evaluate the natural frequencies and mode shapes for structures subjected to different boundary conditions.

Figure 8 illustrates how test plates were struck with an impact hammer attached to a load cell while suspended by elastic cords in a free-hanging configuration and frequency response functions (FRFs) were measured over an array of points using an accelerometer.

![Figure 8. Impact hammer tests were conducted to obtain modal parameters of composite plates.](image)

Modal test data was collected using a Hewlett-Packard 3565 data acquisition system. The mode shapes, natural frequencies, and damping were determined with Leuven Measurement System (LMS) Cada-X software using the rational fraction polynomial method. The procedure is to first estimate how many modes there are in the bandwidth of interest and then estimate a pole for each mode. A residue is estimated for each mode. Mode shapes are curve fitted and computed based on these estimates using the software. During the experiments, measurements were made in the transverse direction (z-axis).
only, over a relatively coarse array. Since the focus of this investigation involved determining the first few lowest frequencies, a low spatial resolution corresponding to a minimum of nine measurement points on a plate was determined to be adequate.

As mentioned above, tests were performed on plates having aspect ratios (AR) ranging from 0.5 to 4.5. Figures 9-12 show the first four mode shapes measured for four plates having different aspect ratios; the corresponding natural frequencies are included in the figure captions. The coherence transfer functions evaluated during the tests were close to 1.0 for most of the modes and the modes obtained after curve fitting all of the FRFs corresponded well with individual FRFs. The largest off-diagonal value in the cross modal assurance criterion (MAC) matrix was 0.2. Damping coefficients were approximately 1% for all of the plates tested and these values remained fairly consistent regardless of aspect ratio and frequency.

Figure 9. AR = 1.0. Experimental results for a 152.40 mm x 152.40 mm (6 in. x 6 in.) GRSPMC plate, (a) 1st mode, frequency = 489.07 Hz, (b) 2nd mode, frequency = 854.48 Hz, (c) 3rd mode, frequency = 958.26 Hz, (d) 4th mode, frequency = 1292.66 Hz.

Figure 10. AR = 1.5. Experimental results for a 152.40 mm x 228.60 mm (6 in. x 9 in.) GRSPMC plate, (a) 1st mode, frequency = 342.11 Hz, (b) 2nd mode, frequency = 426.64 Hz, (c) 3rd mode, frequency = 799.43 Hz, (d) 4th mode, frequency = 955.82 Hz.

Figure 11. AR = 3.5. Experimental results for a 152.40 mm x 533.40 mm (6 in. x 21 in.) GRSPMC plate, (a) 1st mode, frequency = 80.16 Hz, (b) 2nd mode, frequency = 148.11 Hz, (c) 3rd mode, frequency = 223.41 Hz, (d) 4th mode, frequency = 313.78 Hz.
Figure 12. AR = 4.0. Experimental results for a 152.40 mm x 609.60 mm (6 in. x 24 in.) GRSPMC plate, (a) 1st mode, frequency = 59.34 Hz, (b) 2nd mode, frequency = 128.23 Hz, (c) 3rd mode, frequency = 162.71 Hz, (d) 4th mode, frequency = 261.95 Hz.

Finite element models for the laminated plates were developed based on the classical laminated plate theory. The models were generated using physical dimensions and the material properties of test plates. MSC/NASTRAN was selected as the finite element code because of its multi-layered composite element capabilities for normal mode analysis. The latter was achieved by using a real eigenvalue analysis that determines the natural frequencies and mode shapes of the plates with damping neglected.

Each model consisted of quadrilateral isoparametric membrane-bending plate elements with uniform thickness. The finite element models were initially run with uniform element grids of 25.40 mm x 25.40 mm (1 in. x 1 in.). Refinements in element sizes were made until the natural frequencies converged. The resulting element mesh of 12.7 mm x 12.7 mm (0.5 in. x 0.5 in.) was used for each of the models.

The composite properties were defined by considering the geometric properties of a 3-ply composite material laminate. The material properties were defined using an orthotropic material input for an isoparametric shell element. This data was developed from standardized material property testing.

The pre- and post-processing of the finite element data was accomplished using MSC/PATRAN. The mode shapes and their corresponding natural frequencies were recovered, plotted, and animated in three-dimensions to provide a visual understanding of the dynamic response for each plate.

Only the lower natural frequencies and mode shapes are of interest because they can adequately describe the dynamic behavior of the laminate. Figures 13-16, for example, show the first four mode shapes predicted for the cases illustrated in Figs. 9-12; the corresponding natural frequencies are included in the figure captions.

Figure 13. AR = 1. Finite element results for a 152.40 mm x 152.40 mm (6 in. x 6 in.) GRSPMC plate, (a) 1st mode, frequency = 394.30 Hz, (b) 2nd mode, frequency = 849.20 Hz, (c) 3rd mode, frequency = 933.05 Hz, (d) 4th mode, frequency = 1164.60 Hz.

Figure 14. AR = 1.5. Finite element results for a 152.40 mm x 228.60 mm (6 in. x 9 in.) GRSPMC plate, (a) 1st mode, frequency = 269.50 Hz, (b) 2nd mode, frequency = 410.86 Hz, (c) 3rd mode, frequency = 674.20 Hz, (d) 4th mode, frequency = 913.14 Hz.
Figure 15. AR = 3.5. Finite element results for a 152.40 mm x 533.40 mm (6 in. x 21 in.) GRSPMC plate, (a) 1st mode, frequency = 73.63 Hz, (b) 2nd mode, frequency = 108.65 Hz, (c) 3rd mode, frequency = 202.25 Hz, (d) 4th mode, frequency = 233.38 Hz.

Figure 16. AR = 4.0. Finite element results for a 152.40 mm x 609.60 mm (6 in. x 24 in.) GRSPMC plate, (a) 1st mode, frequency = 55.96 Hz, (b) 2nd mode, frequency = 93.95 Hz, (c) 3rd mode, frequency = 153.89 Hz, (d) 4th mode, frequency = 199.43 Hz.

In general, an agreement is observed between the experimental results and the finite element predictions indicating that the material properties used in the finite element models are valid.

Small discrepancies between the measured and calculated frequencies can be partially attributed to two problems in signal processing. The first is the noise present in the force or response signal as a result of a long time record. The second is the leakage present in the response signal as a result of a short time record.

Other reasons for frequency differences are that impact signals may be poorly suited for the frequency response function measurements; resolution bias errors may be present in the spectral estimates; and, the system relating the output and input may not be linear. But the main difference between the measured and calculated frequencies is most likely due to aberrations encountered while experimentally determining the material properties and the subsequent inaccuracies introduced into the constitutive equations used in the finite element models.

A frequency shift of approximately 3% was observed due to the mass loading of the 0.0017 kg (0.045 ounce) accelerometer employed for testing. The smaller plates exhibited more deviations in the frequency shift than the larger plates due to their lower masses. Another frequency shift was noted when additional tests were conducted two weeks after the initial tests were performed. The additional curing time and the hydration of the GRSPMC materials stiffened the plates and caused the frequencies to increase by approximately 3%.

**STRUCTURAL TESTING AND DYNAMIC ANALYSIS**

The finite element model used to study the plates was refined and used to study the dynamic performance of racing canoes designed to function as STARS [4,8]. Student teams from the University of Alabama in Huntsville (UAH) built the boats for the American Society of Civil Engineer's (ASCE) National Concrete Canoe Competitions [9]. The students relied on the large difference in stiffness between the constituents in their composite section to drive the internal stress from a flexible cementitious matrix to three layers of relatively stiff reinforcement. They placed materials symmetrically to form an adaptive section optimized to resist stress reversals and strategically positioned fiber layers to tune the modal response.

The finite element model was developed based on classical laminated plate theory using shell elements. The model was generated using physical dimensions and the material properties taken from prior research on GRSPMC materials [4,5]. MSC/NASTRAN was selected as the finite element code because of its multi-layered composite element capabilities for normal mode analysis.
The finite element model consisted of quadrilateral membrane-bending plate elements with uniform thickness. Damping was neglected in the analysis and refinements in element sizes were made until the natural frequencies converged. Only the lower natural frequencies and their associated mode shapes in a free-free boundary condition were determined because they can adequately describe the dynamic behavior of the canoe.

Figure 17 shows exaggerated plots of the first six mode shapes predicted by finite element analysis for a boat called “Survivor”. The corresponding natural frequencies are listed in the figure caption.

![Figure 17: Finite element results showing the first six modes of “Survivor.”](image1.png)

(a) 1st mode, frequency = 7.31 Hz, (b) 2nd mode, frequency = 10.76 Hz, (c) 3rd mode, frequency = 12.06 Hz, (d) 4th mode, frequency = 15.38 Hz, (e) 5th mode, frequency = 15.95 Hz, (f) 6th mode, frequency = 18.52 Hz.

The finite element analysis shows that the first mode shape corresponds to an anti-symmetrical torsional deformation where the center of the canoe remains stationary and the sides of the canoe open. The second mode is a bending mode in which the canoe flutters like a butterfly. The other modes are much more complex.

Standard impact hammer tests were also conducted on the canoes to determine their modal parameters (natural frequencies, modes shapes, and damping). As illustrated in Fig. 18, the boat was suspended using elastic cords in a free-hanging configuration. The hull was struck using an impact hammer. A load cell, located at the tip of the hammer, was used to measure the force input while a tri-axial accelerometer was employed to measure the acceleration in G’s along three perpendicular directions. Frequency response functions (FRFs), collected at different locations on the hull, were combined to produce the mode shapes.

![Figure 18: Modal tests were conducted on “Survivor.”](image2.png)
Table 1 shows tabulated data for the natural frequencies and experimental damping coefficients obtained for “Survivor.” Comparison of the finite element predictions of the natural frequencies with the experimentally measured values shows that, with the exception of the frequencies obtained for the first mode, the results agree quite well.

Even though the number of points at which experimental measurements were made was small, the experimental mode shapes were representative of those predicted by the finite element analysis.

<table>
<thead>
<tr>
<th>Mode Shape Number</th>
<th>Finite Element Frequencies, Hz</th>
<th>Experimental Frequencies, Hz</th>
<th>Relative Difference, Hz</th>
<th>Experimental Damping Coefficient</th>
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<td>7.31</td>
<td>4.59</td>
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</tr>
<tr>
<td>2</td>
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<td>11.54</td>
<td>0.78</td>
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</tr>
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<td>6</td>
<td>18.52</td>
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</tbody>
</table>

Table 1. Comparisons of finite element predictions with modal test results for “Survivor.”

STRUCTURALLY EQUIVALENT STARS

A method was developed to duplicate the structural performance of STARS as the mix proportions and constituents of the matrix were varied [10]. This was accomplished by placing a test specimen constructed using a modified mixture over a reinforcing scheme identical to that of a control standard and then matching the end deflection of these samples (see Fig. 19).

Steps are also being taken to monitor the structural health of STARS by making modifications to a Remote Readiness Asset Prognostic and Diagnostic System (RRAPDS) [11,12]. The latter is being developed by the U.S. Army Aviation and Missile Research, Development, and Engineering Center (AMRDEC) and the U.S. Army Tank Automotive and Armaments Command, Armaments Research, Development and Engineering Center (TARDEC) to monitor structural health conditions and deliver advanced diagnostics/prognostics while an asset (i.e., missile) is tactically deployed, in storage, and/or being transported.

Figure 19. The end deflection of cantilevered samples provides a measure of their flexural rigidity.
CONCLUSION

Highly compliant graphite reinforced composites can be produced by placing a relatively flexible concrete over a stiff mesh. The stress can be driven from the cementitious matrix to the reinforcement and the system can be designed to absorb or store large amounts of strain energy. Although the structural behavior of these composites is somewhat different from that of traditional composites, it can be studied by using a modified transform section method or composite laminated plate theory.

STARS are designed based on the strength, stiffness, and the position of the component materials in the composite section and their ability to store and release energy depends upon a complex interaction between the shape, modal response, and the forcing function applied to drive the structure. Results show that STARS can sustain very large deformations without compromising structural integrity. This is an inherent advantage for future systems because relatively crude and insensitive experimental devices can be used for structural health monitoring and to assess dynamic performance.

The compliant nature of STARS makes them ideal candidates for unique applications such as structural morphing and, in the future, we expect to apply STARS technology to build mechanical energy storage devices that can be incorporated into advanced propulsion and tactical weapons systems. Since the materials used to build STARS are inert and less sensitive to corrosion, nuclear bombardment, and electromagnetic radiation than their traditional counterparts, STARS should function better in the hostile environments found in space or on the battlefield.

ACKNOWLEDGEMENTS

Portions of this work were conducted under Army Contract No. W31P4Q-05-C-R103. During the time that members of the American Society of Civil Engineering Student Chapter at UAH constructed their concrete canoes, Dr. Houssam Toutanji and Dr. John Gilbert acted as the Chapter’s faculty advisors.

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