NASA STTR 2020 Phase I Solicitation

T12.01 Thin-Ply Composite Technology and Applications

Lead Center: LaRC

Participating Center(s): GRC

Technology Area: TA12 Materials, Structures, Mechanical Systems and Manufacturing

Scope Description

The use of thin-ply composites is one area of composites technology that has not yet been fully explored or exploited. Thin-ply composites are those with cured ply thicknesses below 0.0025 in., and commercially available prepregs are now available with ply thicknesses as thin as 0.00075 in. By comparison, a standard-ply-thickness composite would have a cured ply thickness of approximately 0.0055 in. or greater. Thin-ply composites hold the potential for reducing structural mass and increasing performance due to their unique structural characteristics, which include (when compared to standard-ply-thickness composites):

- Improved damage tolerance.
- Resistance to microcracking (including cryogenic-effects).
- Improved aging and fatigue resistance.
- Reduced minimum-gage thickness.
- Thinner sections capable of sustaining large deformations without damage.
- Increased scalability of structures.

The particular capabilities requested for potential Phase I proposals in this subtopic in line with the critical gaps between the state of the art and the technology needed are:

- New processing methods for making repeatable, consistent, high quality thin-ply carbon-fiber prepreg materials, (i.e., greater than 55% fiber density with low degree of fiber twisting, misalignment and damage, low thickness non-uniformity and minimal gaps in the material across the width) using currently used and commercially available fiber/matrix combinations. The intent of this requirement is to provide thin-ply prepreg material with the same quality as the standard-ply material of the same material system in order to facilitate substitution of thin-ply into structural concepts, and while continuous fiber forms are sought, this does not preclude development of new and novel prepreg material forms. Prepreg product forms of interest have area weights below 60 g/m2 for unidirectional tape with tape widths between 6 and 300 mm wide, and below 120 g/m2 for woven/braided prepreg materials. Matrices of interest include both toughened epoxy resins for aeronautics applications, and resins qualified for use in space.
- Development of novel low creep and low stress relaxation polymer thin-ply composites for inflatable and rollable/foldable space structures. Amongst others, approaches of interest are: designing new molecular structures showing high restriction of distortion of atomic bond angle under stress; controlling cross-linking density by reactive functional groups of molecular chains to keep a good balance between restriction of

molecular rearrangement and material brittleness; restricting large scale rearrangements of polymer molecules by second phase of components; and securing strong interfaces between reinforcing fibers and polymer matrix by chemical bonding or fiber sizing improvements to prevent fibers and polymer molecules slippage under load. The temperature dependent viscoelastic-plastic properties of the developed thin-ply material shall be characterized to predict the long-term behavior of the system under continuous loading.

- Fabrication of large, thin-gauge structures, such as deployable/rollable thin-shell booms or wing skins, are often limited in size by autoclave constraints. Innovative out-of-autoclave processing methods for thin-gauge structures are sought to facilitate the production of large structures. Additionally, the innovative method shall guarantee the curing process variables (temperature, pressure, etc.) are uniform over the long parts to achieve better final products with less process-related defects and part-to-part variability.
- Cure-induced deformation of thin composite structures such as the spring-in effect is a known phenomenon that affects part accuracy during fabrication. Simulation software compatible with general purpose finite element environments such as ABAQUS or ANSYS for predictions of the manufacturing process-induced deformations and residual stresses are sought. These software tools should be tailored to the modeling needs of thin-ply composite structures, especially for structures with a final thickness under 1.5 mm. In addition, simulation capability of sequential multi-step processes (cure and post-bonding) as well as complex process (composite sections co-cure and/or co-bond) are of special interest. The goal is to develop recommendations for geometric tool compensation, as well as cure cycles and tooling that meets cure cycle specifications.
- Fracture mechanics models for thin-shell, thin-ply polymer composites subjected to large continuous and cyclic bending strains (>2%) for which the nonlinear and viscoelastic-plastic response of the material plays an important role on the damage initiation and progression in the foldable/rollable/deformable structural member. Multi-scale failure models for spread-tow woven/braided lamina, as well as laminates that combine these with spread-tow unidirectional plies are sought. The study of material creep rupture, thermal fatigue, mechanical fatigue and resin micro-cracking at lower strains (< 1%), as related to environmental ageing, durability and dimensional stability of the final thin-ply composite structure is of special interest as part of a larger goal to qualify thin-shell, flexible composite structures for space flight.
- Testing and micromechanics models capable of identifying damage initiation and growth for hybrid thin-ply composites are sought. Specifically, methods for composites comprising thin and standard unidirectional plies, and composites combining different forms, such as combining unidirectional plies with woven or braided plies of the same or dissimilar areal weights.

References

https://www.nasa.gov/aeroresearch/programs/aavp

https://www.nasa.gov/aeroresearch/programs/tacp

https://www.nasa.gov/directorates/spacetech/home/index.html

https://gameon.nasa.gov/projects/deployable-composite-booms-dcb/

Expected TRL or TRL range at completion of the project: 4 to 5

Desired Deliverables of Phase II

Prototype, Analysis, Software, Research

Desired Deliverables Description

The Phase II deliverables will depend on the aspect addressed, but in general will be manufacturing processes, documentation of the analytical foundation and process, maturing the necessary design/analysis codes, and validation of the approach through design, build, and test of an article representative of a component/application of interest to NASA.

State of the Art and Critical Gaps

Thin-ply composites are attractive for a number of applications in both aeronautics and space as they have the potential for significant weight savings over the current state-of-the-art standard-ply materials due to improved performance. For example, preliminary analyses show that the notched strength of a hybrid of thin and standard ply layers can increase the notched tensile strength of composite laminates by 30%. Thus, selective incorporation of thin plies into composite aircraft structures may significantly reduce their mass. There are numerous possibilities for space applications. The resistance to microcracking and fatigue makes thin-ply composites an excellent candidate for a deep-space habitation structure where hermeticity is critical. Since the designs of these types of pressurized structures are typically constrained by minimum gage considerations, the ability to reduce that minimum gage thickness also offers the potential for significant mass reductions. For other space applications, the reduction in thickness enables: thin-walled, deployable structural concepts only a few plies thick that can be folded/rolled under high strains for launch (and thus have high packaging efficiencies) and deployed in orbit; and, greater freedom in designing lightweight structures for satellite buses, landers, rovers, solar arrays, and antennas. For these reasons, NASA is interested in exploring the use of thin-ply composites for aeronautics applications requiring very high structural efficiency, for pressurized structures (such as habitation systems and tanks), for lightweight deep-space exploration systems, and for low-mass high stiffness deployable space structures (such as rollable booms or foldable panels, hinges or reflectors).

There are many needs in development, qualification and deployment of composite structures incorporating thin-ply materials – either alone or as a hybrid system with standard ply composite materials. In particular, there is substantial interest in proposals that address manufacturability and production of composite structures utilizing thin-ply composites that at minimum develop the process and plan for the production of one prototype in Phase 1, and demonstrate reproducibility of prototype manufacturing and key parameter validation of repeated samples in Phase 2. Available predictive manufacturing-cure-induced deformation/residual stress software uses solid finite elements to represent the composite plies and those result in high aspect ratios elements when thin-ply materials are used, which ultimately derive in computationally expensive models or loss of convergence. New ways of modeling thin-ply materials are thus needed on these specialized software, particularly for complex-shaped, thin-shell structures just a few plies thick. Another area requiring development is in fracture initiation/progression mechanism models, efficient homogenization methods for spread-tow textile fabrics and hybrid (textile and unidirectional plies) laminates that include viscoelastic-viscoplastic and thermo-mechanical response, and new large deformation testing and analysis methods adapted for thin-ply composites subjected to high bending strains (>1.5%) for foldable and/or rollable thin-shell structures. Finally, polymer matrix composites subjected to high strains for a long-period of time are particularly susceptible to stress relaxation or creep. New thin-ply polymer composites materials for space applications tailored for low relaxation/creep response under large bending deformations and high strains, such as for rollable or foldable thin-shell structures, are needed.

Relevance / Science Traceability

The most applicable Aeronautics Research Mission Directorate (ARMD) program is Advanced Air Vehicles Program (AAVP), and within that is Advanced Air Transport Technologies (AATT). Additional projects withing AAVP that could leverage this technology are: Commercial Supersonic Technology (CST), Hypersonic Technology (HT), and Revolutionary Vertical Lift Technologies (RVLT). Projects within Transformative Aeronautics Concepts Program (TACP) could also benefit. That is, any project in need of lightweight structures can benefit from the thin-ply technology development.

Within Space Technology Mission Directorate (STMD), projects with deployable composite booms, landing struts, foldable reflectors, and other very lightweight structures can benefit from the thin-ply technology.