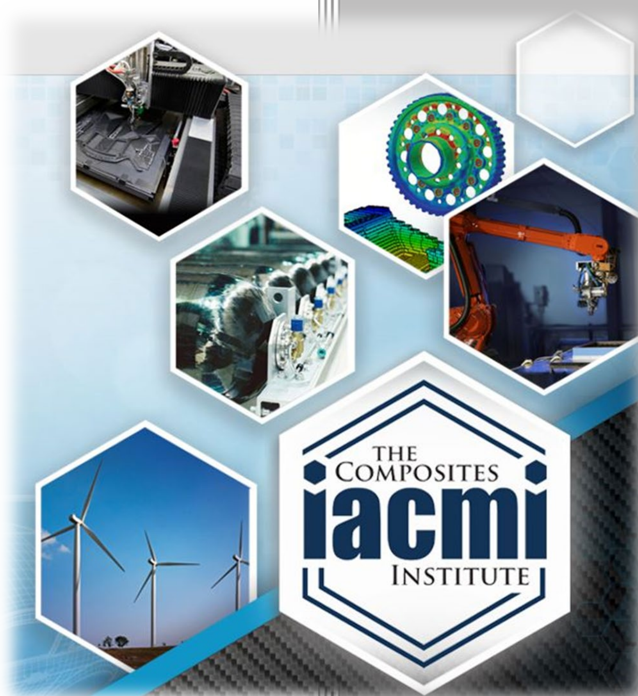
IACMI/R005-2020/6.12

Textile Carbon Fiber Packaging and NCF Production



Author: Kevin Ahlstrom
Date: 1/25/22

Final Technical Report
PA16-0349-6.12-01

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The information, data, or work presented herein was funded in part by the Office of Energy Efficiency and Renewable Energy (EERE), U.S. Department of Energy, under Award DE- EE0006926

Textile Carbon Fiber Packaging and Non-Crimp Fabric Production

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Date Published: (January, 2022)

Prepared by:
Institute for Advanced Composites Manufacturing Innovation
Knoxville, TN 37932
Managed by Collaborative Composite Solutions, Inc.
For the
U.S. DEPARTMENT OF ENERGY
Under contract DE- EE0006926

Project Period:
(02/2018 – 12/2019)

Approved For Public Release

TABLE OF CONTENTS

1. LIST

1.1 LIST OF ACRONYMS

CFTF	Carbon Fiber Technology Facility
HP	Horsepower
IACMI	Institute for Advanced Composites Manufacturing Innovation
NCF	Non-Crimp Fabric
ORNL	Oak Ridge National Laboratory
PAN	polyacrylonitrile
tCF	textile Carbon Fiber

1.2 List of Figures

1.3 List of Appendices

2. EXECUTIVE SUMMARY

This Technical Collaboration Project focused on packaging large tow (≥ 10 grams/meter) textile carbon fibers, for which currently there is no suitable method. Prior to this project, Oak Ridge National Laboratory (ORNL) used a crude packaging approach to deliver (approximately) 100-meter packages for evaluation by intermediates producers, composites fabricators and other collaborators. That packaging approach was simply a hoop wrap on a standard 75 mm (3 inch) cardboard tube, with paper interleaved between layers and little or no tension control during spooling. While this approach was very effective for initial fiber development and sample fiber and small composite sample evaluation, these packages were inadequate for larger-scale demonstrations and more extensive applications development. The paper-interleaved packages were inconsistent, wasteful, and too small for commercial utilization; they were designed as a quick and simple means to package material for delivery into prototyping operations and were never expected to satisfy industrial requirements for commercial production. This project aimed to develop a commercially relevant approach for packaging large tow textile carbon fibers for robust delivery into downstream commercial intermediates and composites production operations. The development of robust packaging equipment that delivers packages meeting industrial requirements is essential to commercial implementation. In this project, the team identified packaging requirements, created a design, and prototyped a new packaging concept at ORNL's Carbon Fiber Technology Facility (CFTF) and resulting packages were tested in production of non-crimp fabric (NCF).

3. INTRODUCTION

Carbon fiber composites have capability to enhance energy savings in transportation by reducing mass of vehicle structures as well as on-board compressed natural gas and/or hydrogen fuel storage vessels. In wind turbine applications, carbon fiber composites also have capability to enable longer blades which enhance energy capture per turbine at lower weight due to increased stiffness and strength per unit mass in comparison to fiberglass composites. For these applications, conventional carbon fiber manufacturing approaches based on traditional precursor forms yield products that are cited as being too expensive for implementation at levels that could make greatest impact. Carbon fiber production based on utilizing textile acrylics as precursor has been demonstrated at 10 – 100 ton/year scale with estimated 50% cost reduction and 30% embodied energy reductions for commercial scale (1,000+ tons/year) and mechanical properties that meet the requirements of many automotive and other high volume industrial applications. This represents a significant advancement toward IACMI's technical cost and embodied energy metrics. One of the remaining barriers to commercial deployment of textile carbon fibers is the current lack of capability to package these textile carbon fibers so that they can be efficiently and reliably used for producing composite intermediates or composite structures.

4. BACKGROUND

This Technical Collaboration Project focused on packaging large tow (≥ 10 grams/meter) textile carbon fibers, for which currently there is no suitable method. Industrial grades of carbon fiber now are commercially produced in tow sizes of up to about 50,000 (or 50K) individual filaments and linear densities at up to about 5g/m. These carbon fiber products are wound onto cardboard tubes in helically wound packages of about 75mm in diameter and about 250mm in length. The significantly larger tow sizes under consideration in this project are made from textile tows >150K filaments and are difficult to helically wind in practical packages since the helical wind patterns of such large tows generate inefficient packing factors due to the rapid diameter buildup where the tows continuously cross over previously deposited tow in the helical pattern. Prior to this project, ORNL used a crude packaging approach to deliver (approximately) 100-meter packages for evaluation by intermediates producers, composites fabricators and other collaborators. That packaging approach was simply a (non-helical) hoop wrap on a standard 75 mm (3 inch) cardboard tube, with paper interleaved between layers and little or no tension control during spooling. While this approach was very effective for initial fiber development and sample fiber and small composite sample evaluation, these packages were inadequate for larger-scale demonstrations and more extensive applications development. The paper-interleaved packages were inconsistent, wasteful, and too small for commercial utilization; they were designed as a quick and simple means to package material for delivery into prototyping operations and were never expected to satisfy industrial requirements for commercial production. This project aimed to develop a commercially relevant approach for packaging large tow textile carbon fibers for robust delivery into downstream commercial intermediates and composites production operations. The development of robust packaging equipment that delivers packages meeting industrial requirements is essential to commercial implementation. In this project, the team identified packaging requirements, created a design, and prototyped a new packaging concept at ORNL's Carbon Fiber Technology Facility and resulting packages were tested in production of non-crimp fabric (NCF).

5. RESULTS AND DISCUSSION

User Survey

A key initial portion of this work was to define one or more approaches for packaging of the larger tow formats >150K filament count to facilitate down-stream commercial insertion of the textile precursor-based carbon fiber. Although the DOE Low-Cost Carbon Fiber program has received a lot of interest from potential end users, essentially all of these organizations have experience and equipment based on conventional commercially available carbon fiber formats up to 50K tow sizes. An early task was to more formally survey potential end users of the larger tow textile carbon fiber to evaluate their needs and preferences for more effective formats in future implementation of this product form. The idea was to foster out-of-the-box thinking about what approaches would be ideal for best use of this unique fiber form in both near-term and long-term processes that could utilize this material. While it was understood that existing equipment largely dictates short-term needs for evaluation materials, the longer-term approaches should be relatively unconstrained by current investments if better approaches are brought online to take advantage of this new carbon fiber approach.

The survey outline is presented in Appendix 1. The objective of this survey was to capture feedback from the wide-ranging community of users expressing interest and initiate continuing dialog for cultivating ideas and complementary approaches for formatting in going forward beyond this project. Approximately 8-10 organizations were approached in seeking feedback. Most of these organization were IACMI members and/or entities having previous interest and experience in evaluating the larger tow formats from CFTF and most were focused on applications involving prepregging, pultrusion, or fabric preforms where low cost, relatively wide fiber input forms were thought to provide greatest manufacturing benefits. Some of those surveyed responded directly with input to the outline while others provided more input in follow-up discussions with project team members, utilizing the survey form as a starting point for those discussions. However, since Chomarat was a project team member who has already demonstrated value for the Textile Carbon Fiber (TCF) in their well-established NCF process, the project requirements were focused on their needs as follows:

- Minimum spool diameter of 6-inches and maximum of 29.75-inches with a 14-inch product width between the spool edges on a flanged spool.
- Product would be protected on edges and OD by being limited to about 28-inches diameter on the flanged spool.
- Product length would be defined by mass with previous acceptable experience of up to about 300 lbs of product.
- Flat, tape type product form that can be of various thicknesses spool to spool but must be pretty uniform (accuracy not specified) on each spool is preferred.

A summary of the overall survey results is provided in Appendix 2 and the Statement of

Requirements is shown in Appendix 3.

Equipment Design

The goal of this take-up/packaging project was defined as to develop a state-of-the-art winding solution that is capable of handling up to ~600K tow bundles, without sacrificing performance, accuracy, and/or tension control. Currently, there are no lab or commercial techniques or machinery available for processing this large format tow. To date, the technology for carbon winding/take-up has been borrowed from the textile sector and utilizes helical or cross-winding/pattern technology. This new approach will provide a more flexible winder with nearly unlimited winding/traverse combinations to accommodate the large tow and package requirements, and quite possibly other downstream requirements and applications.

A new method of winding/take-up of the fiber was required, as the overall tow area (both wider and thicker than commercial carbon fiber tows) did not lend itself to conventional execution via "stock" carbon fiber cross-wound winders, commonly found in the fiber production marketplace. Thus, a system would be required to take-up the new wider format tow, with both a paper interleave and non-interleave execution. The latter is the preferred method, to reduce consumable expenses to both the fiber producer, and the downstream processors. The system would need to have an integrated tension control loop for processing consistently, repeatably and continuously, to ensure the highest quality package tension and formation. To get enough fiber on a package, a new packaging requirement was needed, and we chose to start with an off-the-shelf, flanged, blow-molded, plastic bobbin, in varying diameters to begin. This was not considered a final solution, but a means to get fiber on the package, and downstream for further evaluation and processing. This change in the overall package dimensions, a far cry from "standard", would also create a new need for downstream processing creels and control systems, as we suspected from the beginning.

Take-up/Winding System Fabrication

A modular and mobile design was adopted for this first pass at a robust and effective take-up/winding system. McCoy ran several trials with the previously produced fiber to determine how much horsepower and torque would be required on a typical 457K tow coming directly off the fiber line at the CFTF. McCoy determined that a 5HP motor coupled to a 25:1 gearbox and drive, with a 25lb load cell with a 30-degree, three roll, fixed break angle execution, would perform as needed. Software and hardware were designed and engineered to produce the most compact packaging form (approx.. 36"L x 24"W x 40" H)we could safely manage and coupled the control system to an 8" color HMI monitor for operator and maintenance interfacing. The completed take-up system is shown in Figure 1.

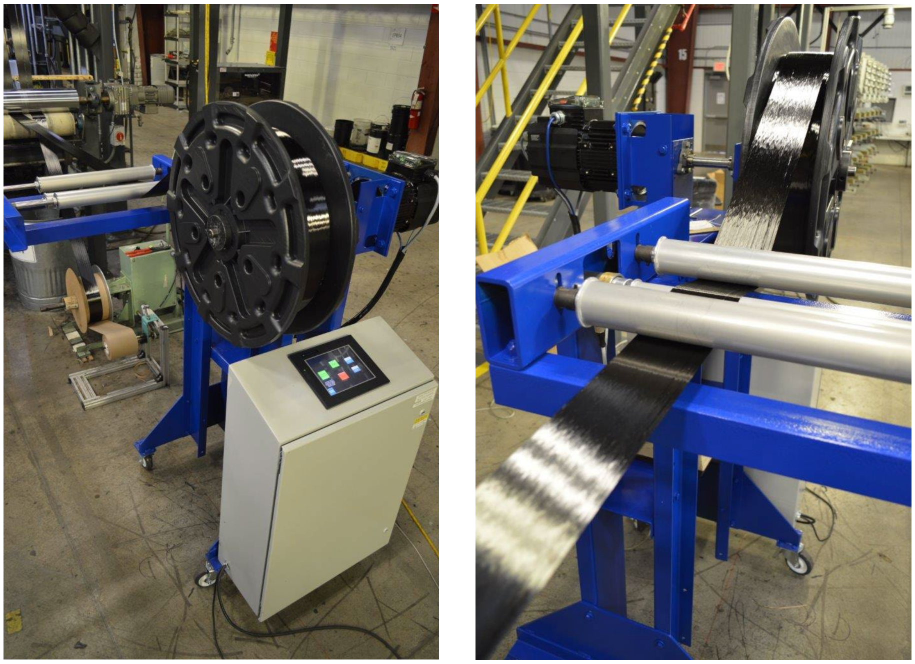

Figure 1. Photographs of the pick-up winding system

Creel Design and Fabrication

It was known from the beginning of this project that a new downstream creel or payoff system would be required. The advantage of this larger format tow was that the customer would not need hundreds of packages of fiber to produce similar width products, thus not requiring a large investment to re-tool their material handling equipment. McCoy set out to engineer and design a new means of paying off or delivering fiber from the larger spools, up to 24" diameter, in an effective and flexible execution, so more than one downstream application could benefit from the new fiber format and creel design. McCoy settled on a live bearing, heavy duty shaft and drive dog/brake hub combination. This would allow the large plastic spools to be used, as well as traditional 3" cardboard core fiber packages. A pneumatic uni-directional, single o-ring cylinder and Garlock brake strap would be designed to control the tension throughout the creel and would allow for manual tension adjustments to be made at any time during the downstream processing cycle. Allowances in the design for future "spreading" of the fiber were included, as well as the possibility of adding a closed loop tension control device/system to the existing design. Figure 2 shows the rendering of the creel design.

Figure 2 Rendering of the 12-station creel rack for 24" diameter spools. Single sided configuration shown above.

Packaging Validation Trials

There were several challenges to overcome with this package choice, but the very low price and immediate availability of these spools, far outweighed any other possible solutions. The spools, in their standard configuration, were too wide for the initial 457K tow the CFTF was processing. This led to poor winding execution, because the fiber would "travel" or "walk" off the edge of the previously laid tow, and thus causing soft selvage (selvage is the term for the far outside edges of a package with fiber wound on it). This also led to tension consistency issues during the initial winding process. It was also noted that bands or sections of filaments within the tow would randomly go slack or be crossed up during the take-up process. This is due to uneven tension across the tow. Once the fiber is carbonized and set, there is nothing that can be done when 2, 5 or 10% of the filaments in the tow just go slack, so this led to some winding issues as well. The fiber tow would also change width, from batch to batch or sample to sample. The CFTF team were diligent in their efforts to keep the precursor supplier's quality in focus, to improve on these conditions and phenomenon being experienced. In an effort to combat the reduction in width of the fiber tow, the team at the CFTF came up with a very good idea to add an additional flange between the standard existing flanges, to reduce the width and get better fiber formation. This is shown in Figure 3. Unfortunately, as the overall quality improved in the precursor, the end product went through some more width changes, and the additional spacer was not enough to reduce the width enough to "trap" or better confine the tow between the flanges. The 24" package spools gave us 1,200-1,500 meters of fiber on the spool, at a weight of approximately 30-33 lbs.

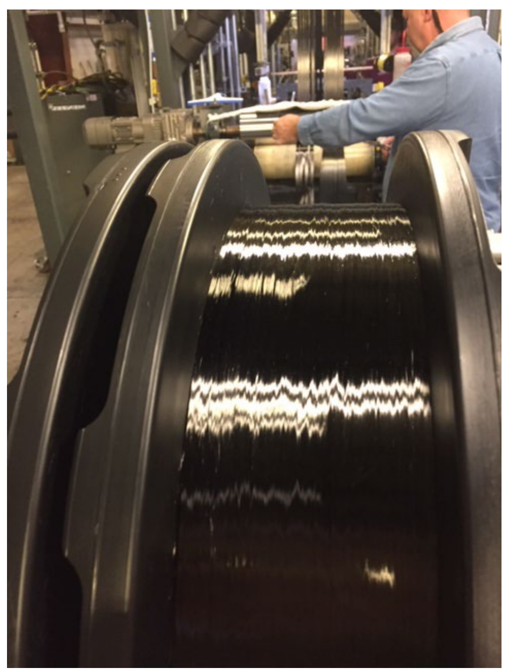

Figure 3. Photographs of the spool with the addition of a spacer (left) and wrapped with carbon (right)

Manufacturing of Non-Crimped Fabric (NCF)

Chomarat made several attempts with varying levels of success to convert the fiber into spread tapes that could be used to manufacture Non-Crimped Fabric (NCF). Here are some observations:

- Plastic spools
    - Allows more fiber to be added to a single package, increasing the efficiency, and reducing the waste during production.
    - Provide more protection during handling.
- Tension variation filament bundles within the tow
    - This tension variation caused the loose filaments to wrap around processing rollers causing gaps and breaking of the tow.
    - It was difficult to set winding parameters due to the uneven loading of the filaments when some are slack and others tight, the winder we are using for our regular production would often break the tow when not all the filaments were loaded evenly.
- Fiber lapping
    - Initial packaging of this fiber included an interleaving paper that separated the layers of tow as it built on the core. This worked well but required additional consumable materials and a means to account for it during payout.
    - The new spools packages did not have the interleaving paper allowing some of the filaments to roll off the edges as the package built. This caused tension variation within the tow as well as entanglement with other layers.
    - The entanglement often would lead to breaking of the tow.

Figure 4 show pictures identifying the varying tension within the tow as well as the lapping:

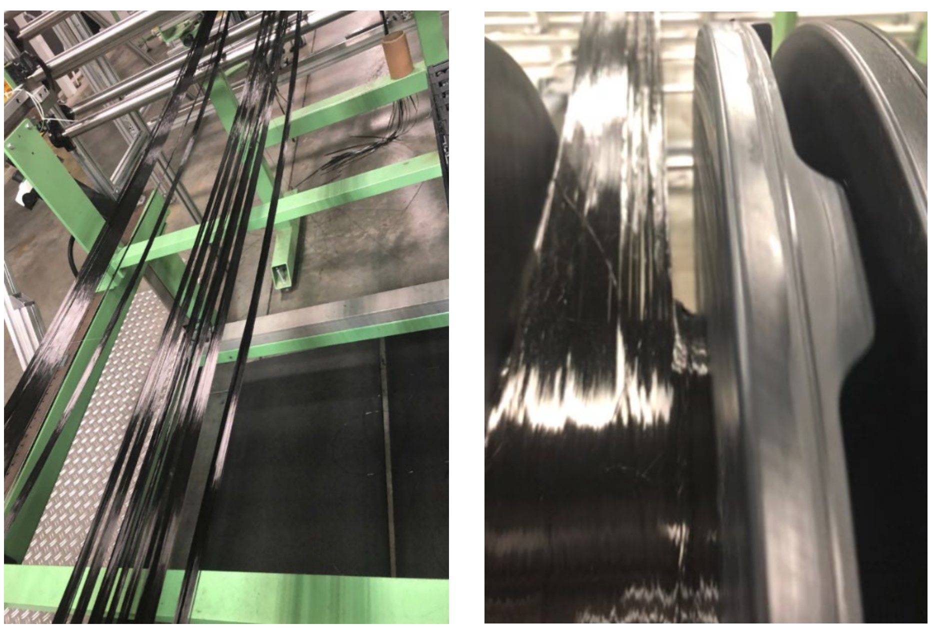

Figure 4: Tension variation in filaments (left) Overlapping issue (right)

6. BENEFITS ASSESSMENT

There is no commercially deployed machinery for packaging large tow textile carbon fibers. This is a critical technology gap that has been partially addressed by this project. Inadequate packaging is suppressing the utilization of textile carbon fibers in production of continuous fiber intermediates and composites. ORNL-IACMI modeling clearly shows that textile carbon fibers offer significant reductions in cost and embodied energy vs. baseline carbon fibers. The larger tows could reduce the cost of manufacturing the NCF because of the reduction is number of spools that need to be handled. The packaging approach demonstrated in this project made improvements in making a more efficient, smaller diameter package primarily by eliminating the interleaved paper layers from the earlier packaging approach and adding tension control in the spool winding. However, success was limited by the non-uniform tension inherent with the large tow product in its current form. This packaging approach warrants further evaluation for the NCF as well as other applications as both the carbon product development and packaging design enhancements described below continue.

7. COMMERCIALIZATION

The design and build of the new commercial take-up will be modular and symmetrical in design to maximize performance, efficiency, and facilitate any need for expansion or additional capacity. The control system will be PLC based that will allow for multiple supplier choices, should a preference be required in the future. The goal is to have several packaging options for other downstream applications/uses for this large format fiber. This will also allow tuning and perfecting of each individual application for future commercialization with specific design criteria and performance capabilities. A final design of a custom, purpose-built, DIN bobbin or spool would be required, but would allow for exchanging of spools from the fiber producer to the end user, over and over, until their life cycle was completed. Then they could be recycled, and supply replenished as needed and as the market volume dictated.

McCoy Performance Enhancements:

- Axial winding execution
- Modular design for expansion
- Live closed loop tension feedback/control
- Flexible core package selection
- Downstream creel & fiber delivery solutions

McCoy would have the main responsibility for implementing these objectives, based on final customer needs and market targets desired. Commercialization should be realized in 24 months or less and we anticipate the delivery time to a new customer would be in the 6–8-month window. The short-term upside is that this will be the only commercial solution available for a period, and should allow for penetration and capital gains, without much, if any, competition. Long term, this technology needs to be cost effective and performance rich, to outpace inevitable competition from outside companies or machinery builders.

8. ACCOMPLISHMENTS

The team accomplished the goal of designing and building a fiber take up system for large carbon fiber tow. In doing so the following was accomplished:

- Documented the statement of requirements.
- Designed and fabricated a fiber take up system for large carbon fiber tows.
- Demonstrated that the system can generate ≥ 100 kg of packaged carbon fiber with tow linear density ≥ 10 grams/meter, and each continuous tow ≥ 500 m long,
- The packaged carbon fiber was used to produce ≥ 50 m^2 of NCF with fiber areal weight ≥ 200 grams/m^2.

9. CONCLUSIONS

The new packaging approach is a step forward, although additional work is still required to achieve the ultimate success the team feels is within reach. Elimination of the paper interleaving provides definite improvements in overall handling, both in fiber take-up at CFTF and payout at Chomarat for NCF production, as well as in fiber creeling for pultrusion. The paper itself (or any interleaving material) is an additional expense a carbon fiber manufacturer would like to avoid. The interleaving adds additional labor and potential failure routes at both fiber collection and payout points , not just additional paper costs alone. While the overall width variability in the flat fiber tape has been reduced by using the controlled spool gaps provided by the guides on either sides of the spool and the higher levels and more uniform tension delivered by the new winding system, this can be further improved by using spacers and/or other means to better adjust this width to fit observed natural tape widths coming out of fiber conversion. The "harder" package achieved in winding with more tension, elimination of the interleaved paper, and restraint from the side guides to mitigate tow spreading on the package is also improving package uniformity and eliminating, or at least significantly reducing, fibers rolling off the package sides or getting rolled under multiple layers that were experienced in previous take-up approaches. It is expected that remaining issues will be significantly improved with the capability to make minor adjustments in roll width with the proposed addition of spacers. All of these enhancements to the packaging approach developed in this project will be of benefit to overall commercialization of TFC products, especially when combined with other planned work to improve precursor uniformity at the precursor manufacturer and improve fiber handling practices and equipment capabilities in conversion at CFTF.

10. RECOMMENDATIONS

Further studies are highly recommended on the correct width of the spools. Also as noted above, areas for improvement of the precursor uniformity at the precursor manufacturer and continuing improvements in fiber handling at CFTF are also key to achieving overall package uniformity targets. The suggestion to have plastic "spacers" made, once the precursor supplier/partner was finished tuning and improving their product, would have resolved the loose or low-tension selvage issues. It should also be noted that significant effort to "clean up" the existing equipment in the CFTF, especially the size box portion, of the fiber line would go a long way in diminishing broken/damaged filaments in this process.

11. REFERENCES AND/OR BIBLIOGRAPHY

None

12. APPENDICES

Appendix 1 - LARGE TOW CARBON FIBER PACKAGING REQUIREMENTS SURVEY

Potential Controlling Category		Parameter Value and/or Description	Required	Preferred
End Use Application		SMC/Structural applications		
Spool Info				Doft, inner pull
	Min Diameter	12 inch, with 3 inch core		
	Max Diameter	18 inch doft,		
	Min Length	TBD		
	Max Length	TBD		
	Construction Material	cardboad core, or individually wrapped inner pull doft. Multi end roving preferred		
Finished Package Info		finished skid size, with 27 or 36 ends per skid, stacked 3 or 4 layers high		
	Max Diameter			
	Max Length			
	Protective Covering			
	Carrier materials allowable			
	Max product weight or length			
	Max Total Package Weight			
Product Geometry (Assume Tow Size is 10-20 g/m or 3-6X Typical 50K tow)				
	Metered Accuaracy			+/- 1 grams/meter
	Product shape (flat, round, etc)	bundle		
	Max thickness			
	Min Thickness			
	Max Wdith			
	Min Width			
	Preferred Wdith			
	Winding Pattern	multi-end with		
Processing Info as Applicable				
	Take-up Speed			
	Pay-out Speed	tbd		
	Horizontal/Vertical Pay-Out	vertical		
	Process Tension on Pay-Out			
Additional Comments				
	Other categories/parameters.We would be very interested in categories that can be identified for later flexibility/negotiability			

Note: Not all information is applicable to all end uses and some data is derivable from the others. Please provide what you believe to be most important to your operations.

Appendix 2 - SUMMARY OF REQUIREMENTS SURVEY RESULTS

BACKGROUND

The initial project team activity was to document a “Statement of Requirements” addressing continuous tow length, metered accuracy, take-up speed, pay-out speed, package volume and weight, and other critical parameters identified in discussions with stakeholders. The team identified several industries and members of those industries thought to be key targets for initial introduction and utilization of commercial scale quantities of large tow textile grade low-cost carbon fibers as currently represented by the ORNL Carbon Fiber Technology Facility (CFTF). Among those targets, prepreggers, pultruders, intermediate producers, and compounders would be most likely to utilize the carbon fiber coming directly out of the factory; representatives of those industries were contacted to determine preferences for how they would like to see these new carbon fibers packaged and delivered to their operations. To facilitate discussion, a survey form was developed by the project team to identify the various factors that would/could influence packaging preferences and decisions.

Initial feedback indicates there are at least 3 thought streams as preferred approaches. One is that a significant number of respondents would prefer packaging more like current standards with some specific highlights on certain parameters for initial evaluation and process development with CFTF fibers. The second is that there is a key partner and project team member who already has experience in working with the CFTF fiber and has clearly thought through a pathway to more widespread utilization. The third is that several potential partners and end users can see where very specific, but not yet fully defined packages could have very large advantages to certain business cases. Both of the first two streams have significant merit for near-term investigation, and we will keep seeking input on how best to address the third approach as we go forward.

Preferred Option 1 – Wide Beam Packaging

As per previous discussions, project participant Chomarat has shared very specific targets. They would prefer a format with minimum spool diameter of 6-inches and maximum of 29.75-inches with a 14-inch product width between the spool edges on an aluminum spool. Certain of their product forms may prefer a narrower width such as 9-inches. Product would be protected on edges and OD by being limited to about 28-inches diameter on the spool. Product length would be defined by mass with previous acceptable experience of up to about 300 lbs of product. Chomarat prefers a flat, tape type product form that can be of various thicknesses spool to spool but must be pretty uniform (accuracy not specified) on each spool. They also prefer to have paper interleaving which could also serve as outer protection after completing spool build-up. With these parameters, the winding and payout of the fiber would be straight (not having a winding pattern).

Preferred Option 1A – Conventional Packaging

While maybe not a total consensus, feedback starts with conventional packaging consisting of the standard 3-inch cardboard spool with a tube maximum length of 12 -inch with 11-inches preferred. Maximum 6-8 kg of product with a preferred size of up to 4 kg was mentioned. Product length and ultimate packaging diameter at this point would be predicated on that mass, assuming that most of the spool length is covered by very uniformly wrapped fiber. It is critical that the winding be centered on the spool with a consistently uniform built-up edge approximately 1-inch from each end. No feedback was given that the fiber winding pattern itself was critical but did get a loud message that uniform fiber tensioning and uniform fiber payout, no "sloughing" or catching of the fiber when pulled uniformly, is very much desired. Paper or other cardboard carrier material is discouraged by almost all respondents. While most of the feedback indicates that horizontal payout will be employed, that same feedback indicated that high speed stability is not required as would be the case of high-speed filament winding where vertical axis alignment and very rapid payout and specific winding patterns would be more important. Being supplied with an outer wrap such as shrink wrapping for protecting the spool from environmental and handling damage is important. No feedback was given at this point that product shape (flat or round tow for example) or specific parameters such as tow width or thickness were as critical as uniformity at this point. None of the respondents to this point had sharable packaging specifications or requirements documents.

Future Packaging

Other respondents indicated that they could envision other formatting that could be beneficial to specific applications but would need further analysis and experience with the larger tow and its characteristics to develop detailed targets. Supplying fiber for prepregging in wide widths was specifically cited as an area of interest, especially since this could conceivably reduce creel setup time and by reducing number of positions, cut creeling equipment cost. In this application area, low-cost carrier materials such as paper or poly interleaving, might be more acceptable than with other areas and could potentially provide other stabilizing benefits, although it is hard to imagine that with all other factors being equal, elimination of this processing aid would not be viewed favorably. Unfortunately, at this point, these discussions are not mature enough to capture as targets for this project. However, it does point out need for continuing discussion with potential partners and benefit of conveying an openness to format change for the low-cost carbon fiber arena.

Summary of Findings and Project Approach

The project team agrees that there is significant rationale and support for pursuing both the more conventional formatting approach and the approach specifically geared to meeting the needs of Chomarat in the near term, as well as continuing discussion about alternatives. Because Chomarat is a project team member, already has direct experience with the CFTF fiber, and can clearly articulate their needs and plans to utilize this fiber in near-term production, the project team will concentrate on this configuration as Priority 1 while continuing to pursue more conventional packaging as Priority 1A. The team will continue discussions with the wider audience who have expressed interest in alternative formatting as it is believe this may be the avenue to largest utilization in the future albeit the preferred formatting cannot be clearly articulated now and requires more experience with the unique fiber characteristics from potential end users as well as more commitment from licensees and other potential producers of low-cost carbon fiber forms.

Appendix 3 - Statement of Requirements

Scope

Contained herein is the Statement or Requirements (SOR) for a flexible winding/packaging solution for DIN Bobbin, Conventional Cardboard Tube, and Chomarat Max5 Reels that would all contain Textile PAN-based carbon fiber as related to production at ORNL and be suitable for direct replacement of current conventional packaged CF products being processed today.

This SOR is intended to communicate the basic initial requirements of the system. Any departure from the SOR to improve on performance and/or other applications is encouraged but should be discussed as a group to determine feasibility.

Requirements

The system must be capable of winding the Textile PAN-based carbon fiber under controlled, pre-determined tension, constant throughout package build, and present fiber uniformly and consistently from package to package. The first two packaging requirements are the Chomarat Max5 Reels and Plastic DIN Bobbins (for general testing and use).

The fiber must unwind uniformly under controlled tension and at a payout rate consistent with the downstream converting process, including rewinding/repackaging, NCF fabrication, pultrusion and prepreg manufacture. The fiber must unwind without entanglement with fibers inside or outside of the tow form. This may require the use of an interleaving layer (paper or film) and will be determined during processing trials.

Proposed Operation

Equipment supplier will need to identify any adaptation required of dispensing creels used in downstream processing of the fiber and work with ORNL and the greater team to supply bushings or other inserts to help downstream companies achieve maximum success with paying out the fiber and feeding their equipment during fiber evaluation. Supplier should also consider what creel modifications could enhance this processing and propose creel designs that could improve productivity, tension control and quality of products using Textile PAN-based carbon fiber.