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Project Summary

Advanced Composites Technology Case Study at NASA Langley Research Center

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This report summarizes work conducted at the National Aeronautics and Space Administration's Langley Research Center (NASA-LaRC) in Hampton, VA, under the U.S. Environmental Protection Agency's (EPA) Waste Reduction Evaluations at Federal Sites (WREAFS) Program. Support for this study was provided by the Strategic Environmental Research and Development Program (SERDP). SERDP is a cooperative effort between DoD, DOE and EPA to develop environmental solutions that enhance mission readiness in defense operations.

The purposes of the WREAFS Program are to identify new technologies and techniques for reducing wastes from process operations and other activities at Federal sites, and to enhance the implementation of pollution prevention/waste minimization through technology transfer. New techniques and technologies for reducing waste generation are identified through waste minimization opportunity assessments and may be further evaluated through joint research, development, and demonstration projects.

Under the Chesapeake Bay Agreement, NASA-LaRC is a member of the Tidewater Interagency Pollution Prevention Program (TIPPP). At NASA-LaRC, a technique for producing advanced composite materials without the use of solvents has been developed. This assessment was focused on the production of non-refractory composite materials and aircraft structures made from those materials.

This Project Summary was developed by EPA's National Risk Management Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

To produce composites, fiber tow bundles are impregnated with a polymer resin--a process called "prepregging"--in order to produce a composite towpreg which can then be fabricated into composite material products. There are several technologies available to do this, solution prepregging being among the most common. In solution prepregging, the polymer resin is placed in a solvent carrier and applied to the tow. The liquid polymer has a limited shelf life and must be refrigerated.

At the NASA LaRC, the Polymeric Laboratory has developed a dry powder prepregging process in which the fiber strands are separated in a small air chamber and a finely-powdered polymer resin is "dusted" onto them. The polymer dust fully impregnates the fibers just before being passed through a furnace. NASA refers to this process as "dry powder towpregging." Later, the towpreg can be formed into a laminate. Two goals of the dry powder towpreg process are to eliminate the use of solvents, and reduce energy consumption because, in dry powder form, polymer resins do not require refrigeration.

For the purposes of this case study, EPA assessed the attributes of dry powder towpregging with those of solution prepregging. For comparison, NASA-LaRC provided information on the consumption of methyl ethyl ketone to manufacture thermoset composites and on the usage of n-methyl-pyrrolidone for thermoplastic materials.

Project Description

Plastic composites exhibit properties that make them attractive alternatives for other materials and metal alloys in a variety of applications both public and commercial. Weight and advantageous mechanical properties at elevated temperatures make advanced composites desirable for many aerospace uses. The cost of manufacturing is a major concern, as the process tends to be costly and laborious. The high viscosity of polymer melts and solubility limitations of polymers in solvent solutions, along with storage limitations of prepregs, have limited the use of both the "hot melt" and "solution" prepregging processes.

To evaluate the NASA-LaRC process, a direct comparison with conventional solution prepregging was made. A brief description of each process is provided below.

Solution Prepregging

In the form of solution prepregging tested, the continuous fiber tow is spread and rolled through a bath of polymer resin suspended in a volatile solvent carrier. The tow is pressed and passed through ovens to extract most of the solvent and bond the polymer to the tow fibers, generating VOC emissions. In order to keep equipment clean and keep product quality consistent, wax paper is used to prevent the impregnated tow from sticking to the rollers. This process is illustrated in Figure 1.

This process produces a composite tow "ribbon," which has to be refrigerated to prevent degradation of the polymer materials. To finish the process, the laboratory conducts "B-staging," wherein the ribbon reels are taken out of refrigeration, unraveled and passed through a final oven in order to bake out the residual solvent.

Dry Powder Prepregging

The dry powder process developed by NASA-LaRC, is shown in Figure 2. NASA-LaRC applies dry powder resin particles to the fiber tow by means of a gravity feed via a screw-type auger drawing out the polymer material from the hopper. The tow fibers are spread by passage through an air chamber just before being "dusted" by the gravity feed. Coated with the powder the fiber tow is directed into an oven by horizontal rollers that also help to spread the resin across the tow. The tow is passed through the oven, flipped over and directed back by a vertical roller. The underside is coated by a second gravity feed, and the tow enters the oven for a second heating cycle. The tow is collected on a take-up spool and can then be stored at room temperature until needed to make a laminate.

Because solvents are not added to the material, B-staging and refrigeration steps are unnecessary. Wax paper usage is eliminated for prepregging. The process has the potential to eliminate VOC emissions, reduce energy usage, and reduce solid waste.

Project Assessment

In order to conduct pilot-scale composites research, NASA-LaRC constructed both a solution prepregging process line and the dry powder towpregging line onsite. NASA-LaRC provided information and experience from running these pilot-scale production lines to EPA for this study. Estimates of environmental and energy impacts data were included. The study includes an estimate of solid waste in the form of waxed release paper and waste composite tow. Table 1 provides a summary of estimated average operating conditions during the test runs.

A flow chart comparison of solution prepregging with dry powder towpregging is illustrated in Figure 3. Each process begins with the prepared polymer resins and fiber tow, continuing through to the fabrication of a composite ribbon laminate. Information on the fabrication of fiber tow and polymer material were excluded from the study, because identical fibers and polymers were used in both processes. Also, the disposal of laminate was excluded.

The study also included economic data as an additional determinate of the feasibility of the process. Please note that all tables and results are based on a projected yearly production rate of 7,700,000 lin ft of 3 1/2" width composite ribbon for the dry powder prepregging line. The production rate estimate used for the solution line is 240,000 lin ft of 3 1/2" width composite ribbon. It is important to note that the dry process line speed is 70 ft/min, while the solution process speed is only 2 ft/min. The production rates used represent the maximum capacity of each NASA-LaRC production line to produce a comparable product.

Environmental Impacts

VOC emissions would be eliminated by the dry powder towpregging, because no VOC-generating materials are used in the process. The reduction of VOC emissions for the epoxy would be much greater than the thermoplastic, given the fact that MEK is significantly more volatile than NMP. With MEK as a common solvent in many prepregging operations, this level of reduction can generate significant cost savings in terms of environmental control equipment and maintenance.

Solid waste in dry powder towpregging is virtually eliminated. Again, this is because the waxed paper, heavily used in solution prepregging, is not required when solvents are eliminated. NASA-LaRC engineers indicated that, in their solution prepregging line, waxed release paper contributes 112.5 lb of solid waste for every 1000 ft of processed tow. Another consideration is that the release paper could become contaminated with organic solvents, complicating their proper disposal.

Energy Impacts

Energy consumption by the dry powder process runs at about 2/3 the rate of consumption by the solution process. Dry powder towpregging was calculated to consume 40,000 KwH/yr, while the solution process would consume 60,000 KwH/yr. As noted in Table 1, power consumption of the dry process is expected to be less than one-fifth that of the solution process. However, in order to meet the projected yearly production rate noted above, the bench line would have to be scaled up to handle 15 tows simultaneously. The scale-up was calculated to raise energy consumption to 2/3 that of the solution prepregging line.

In order to maintain conservative estimates, energy consumption by the refrigerators in the solution prepreg process was not included in the study. Size and efficiency of such units could vary widely and it is expected that some manufacturers might use such equipment for a variety of purposes beyond prepregging. However, for a producer equipped to process dry towpreg, it may be assumed that energy consumption would fall below 60% of the rate consumed by a comparable solution process.

Economic Feasibility

The total capital cost of a dry powder line was estimated at $402,700, which can be compared to the reported $650,000

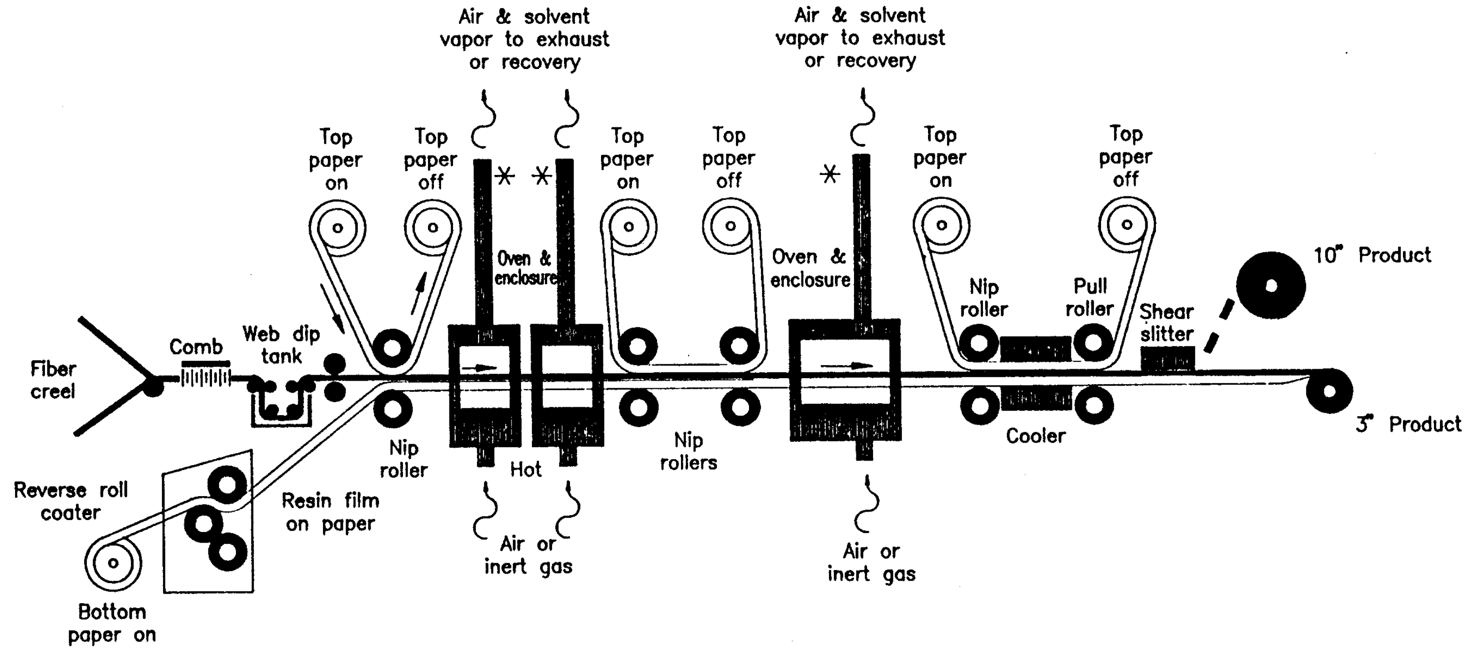

Figure1. *Solution prepegging system.*

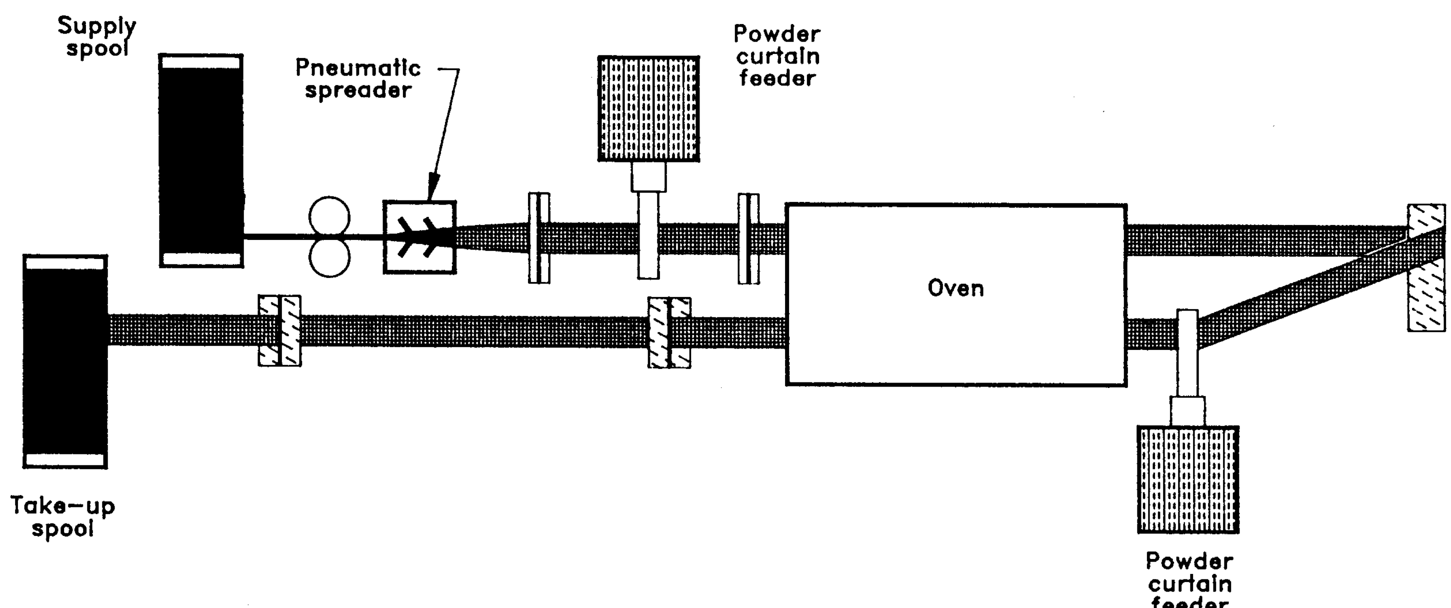

Figure 2. *NASA Langley dry powder towpregging system.*

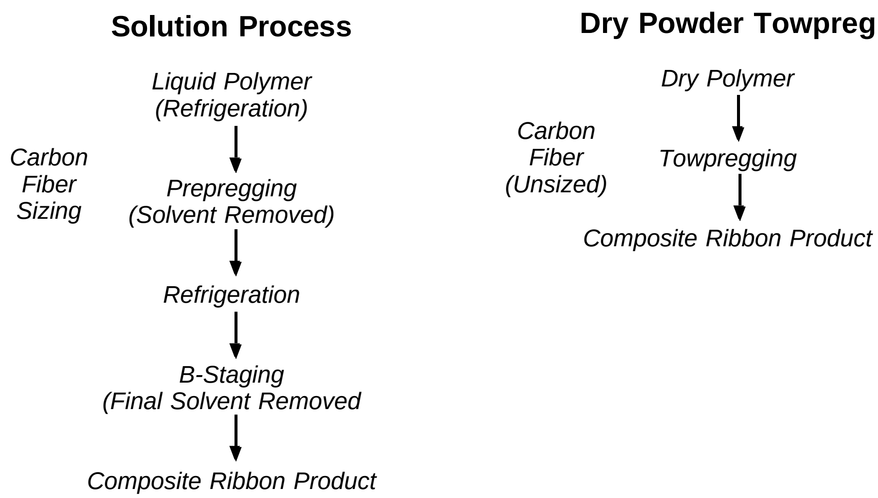

Figure 3. *Process flow diagram.*

Table 1. *Estimated Average Operating Conditions*

Polymer Polymer Type & Process	*Tow Speed ft/min*	*Total Tow ft*	*Oven Temp. OC*	*Feed Rate gr/min*	*Paper Usage ft^2*	*Power Usage Kw*
Epoxy, Dry	*40.0*	*5080*	*300*	*3.0*	*0*	*5*
Epoxy, MEK	*1.3*	*2535*	*205*	*4.4*	*670*	*27*
Polyamide, Dry	*70.0*	*8050*	*190*	*3.3*	*0*	*5*
Polyamide, NMP	*2.0*	*3375*	*71*	*4.8*	*880*	*27*

cost of the solution prepregging equipment at NASA-LaRC. Even if we grant a 50% error in the estimate, the cost of the dry process will be less than the cost of the solution line. Also, due to the higher line speed, the dry powder line will produce approximately 32 times more product annually.

Table 2 shows the cost of a 3 1/2 in. ribbon by the solution process to be $1.64/ft while the dry process cost is $.31/ft. These calculations are based on assumption, that the dry process could be engineered to run 15 tows simultaneously to produce the same composite ribbon as the solution process. Again, the production rate for the dry process is dramatically higher due to the line speed.

Conclusions

When compared to solution prepregging, the NASA-LaRC dry powder prepregging process appears to eliminate VOC emissions and significantly reduce solid waste in prepregging operations. It is also projected to be capable of providing significant reductions in energy consumption at the operational level. Continued study will be necessary to determine how well a dry powder derived laminate performs in comparison to a solution derived laminate. Performance qualities in such areas as strength of coated fibers, impact resistance, and shear strength will have to be evaluated in order to determine the product's suitability as a substitute for the commercial product.

Table 2. *Production Cost Estimate*

Dry Powder Process	
Raw Materials	*Est. Cost*
Fiber Tow (12K)($25/lb, = 1750 ft)	*$1,800,000*
Epoxy Powder (AMD0036)($95/lb)	*380,000*
Labor	
1 Operator ($20/hr x 2000 hr)	*40,000*
1 Assistant ($14/hr x 2000 hr)	*28,000*
Utilities (40,000 KwH/yr x $.10/KwH)	*4,000*
Rent (1500 ft² x $12/ft2/yr)	*18,000*
Depreciation (3 yr life, $402.7K Capital Cost)	*134,000*
Total Annual Cost	*$2,404,000*
Cost/ft (7,700,000 ft/yr) = $.31	
Solution Prepregging Process	
Raw Materials	*Est. Cost*
Fiber Tow AS-4 (12K)($25/lb, = 1750 ft)	*51,400*
Epoxy Powder (AMD0036)($95/lb)	*78,200*
Methyl Ethyl Ketone ($9.70/gal, 6.81 lb)	*800*
Waxed Release Paper	*36,000*
Labor	
1 Operator ($20/hr x 2000 hr)	*40,000*
1 Assistant ($14/hr x 2000 hr)	*28,000*
Utilities (60,000 KwH/yr x $.10/KwH)	*6,000*
Rent (2000 ft² x $12/ft²/yr)	*24,000*
Depreciation (5 yr life, $650.0K Capital Cost)	*130,000*
Total Annual Cost	*$394,000*
Cost/ft (240,000 ft/yr) = $1.64	

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The complete report, entitled "Advanced Composites Technology Case Study at NASA Langley Research Center," (Order No. PB95-264172; Cost: $17.50, subject to change) will be available only from:

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