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FUTURE COMPOSITE RESEARCH AND DEVELOPMENT PROGRAMS TO SUPPORT AEROSPACE NEEDS

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SUMMARY: This paper establishes the guidelines for selection and development of research projects and programs that can significantly impact the future use of composites for aerospace and other users. It identifies current and near future opportunities to improve both materials and processes. The needs included below were derived from a Composite Manufacturing Association/Society of Manufacturing Engineers (CMA/SME) interview of key persons in commercial composites industries and major US aerospace companies[1]. The paramount needs for the composites industry can be summarized and simply stated as an ongoing search for high performance materials that can be produced at a low cost. Many avenues have been and continue to be explored in pursuit of this goal but research that leads to breakthrough technologies or improves the materials and processes in a manner that can significantly reduce these costs are essential to rescue and revive the enthusiasm that once existed for these valuable materials.

The aerospace needs outlined in this paper represent opportunities for invention and development of solutions that can not only impact the selection and use of composites but may also lead to future redirection and growth of the industry. Even though many technological innovations and improvements have been applied to the production of fiber reinforced composites, today's manufacturing processes remain as costly and labor intensive. There are many emerging processes that promise significant reductions in fabrication labor. Some could lead to path altering technological breakthroughs. Hope still lies in the future. The big hurdle is cost. Appropriately directed and focused technology developments can meet the challenge.

Most of the needs for the overall industry can be projected by close examination and extrapolation of current aerospace needs. Today aerospace is searching for "bigger", "faster", and "lower cost" composite structures without loss of properties. These opportunities can be grouped and categorized as needs for: major scale up in the size of structures and volume of materials applied in parallel; automated processes, streamlined designs, improved materials and increased environmental protection.

Even though the technology needs are large and increasing today's business environment has lowered the level of funding for composite research and development. In order to respond development efforts must be focused to avoid overlap and redundancy. Funding is no longer adequate to support multiple independent studies. Coordination, development, and application will be best accomplished by collaboration of university, governments and industries.

KEYWORDS: Composites, manufacturing, processes, future, needs, development

INTRODUCTION

The superior properties and extended capabilities provided by composites have led them into today's standard list of building materials. Like most new or emerging products they came with high startup costs. Unfortunately, the early year promises for near term costs that would be competitive with their metal counterparts are still just a glimmer of hope for the future.

Military aircraft applications were the primary catalyst for the initial development and early growth of composites. They were developed in response to aerospace industries' need for stronger, lighter weight materials. These programs inspired and led the early development, application, and use of composites. From their inception fiber-reinforced composites were perceived and justified as special materials for a narrow set of applications that met the military's demand for discriminating performance. The demanding requirements were often used to justify their high costs. The success of early aerospace applications and the potential for improved performance allowed composites to quickly spread to other military sectors that shared the need for high strength, improved stiffness, and lower weight materials. The growth of composites has been restricted not only by their cost but also by demand.

US military spending for new airframe programs has experienced drastic declines over the last two decades. This has likewise led to a reduction in the number of aerospace companies vying for the few remaining opportunities. The combination of companies through mergers, buy-outs and teaming has become standard practice. For example in 1945 there were 16 major US companies building military aircraft, by 1980 that number had reduced to 11, then down to 6 in 1990, and at the beginning of 2000 only 3 remained. The combination of reduced government spending and fewer aerospace companies also led to major reductions in the number of defense suppliers. The smaller number of defense related programs also dropped the demand for composites, which naturally created a downward trend for shipments. The lack of sales gradually led to consolidation and loss of material suppliers. Many companies were forced to leave the industry. By the late 80's the remaining material suppliers were forced to decrease or redirect their investment in research and development to support their commercial customers. Most of the new materials being developed were focused on commercial applications that offered potential for high volume uses rather than on declining military products. Composites were already considered expensive alternatives but this reduced supply further increased the cost.

The decrease in the number of military programs and business opportunities also created a highly competitive environment. The awareness and relative importance of cost reduction and control as a primary ranking criterion moved up the scale for selection of materials and processes during design studies. Unfortunately, the combination of economic and life cycle timing resulted in composites suffering another negative impact for expanded aerospace applications and overall growth.

During the past few years several airframes that were originally conceived to be constructed totally from composite materials later evolved to hybrids containing much lower percentages of composites than were included in the early studies. A search for the answer reveals that composites lost to their metallic predecessors and counterparts when the cost trades were employed. These examples represent missed opportunities and are indicative of a trend that must be modified if these materials are to achieve the levels of usage that were originally envisioned. All these factors combined have led to a significant slowing effect for selection of new composite applications for military aircraft.

Today new uses of composites by the US Department of Defense continue to grow slowly; however, the rate of growth has declined since the mid 1980s. It appears that in order to continue growth that the application leader must change. Fortunately, much of the composite technology that precipitated from successful aerospace applications has matured and spread into commercial industries. This transition from military to commercial users could be both good and timely for the successful evolution of composites. Commercial industries have long been driven by cost and are constantly and aggressively streamlining processes, improving materials, and expanding their usage. The commercial developers and users will likely stimulate the industry and ultimately reinforce and revitalize the use of composites for aerospace.

Commercial industries including aircraft have always considered cost as a key driver and primary criteria for design evaluation and concept selection. They emphasize quality and survive by providing their customers with acceptable solutions at the most cost competitive price. The early promises of composites to increase performance and reduce costs enabled them to move quickly from military developments into commercial aircraft applications. When the commercial aircraft producers first began to utilize composites the military aerospace industry watched with anticipation that they would immediately expand the applications and increase the usage to a level that would motivate and entice new material suppliers and ultimately drive reductions in the cost of materials. Unfortunately, even commercial aircraft developers have been unable to significantly lower the cost of these materials and their associated processing. Rather than reducing the cost, they too fell prey to escalation. Just as with the early military programs these disappointments are slowing their adoption process and further discouraging the material suppliers. The reduction in customer demand for materials in turn led to significant decreases in the quantity of suppliers.

On the positive side the performance improvements that can be achieved with composites are a known and proven entity. Cost issues remain on the top of the concern lists for both commercial and military customers and will continue to restrict the use of composites to niche areas until the problems are resolved. Even though many technological innovations and improvements have been applied to the production of fiber reinforcement composites, today's manufacturing processes remain as costly and labor intensive. There are many emerging processes that promise significant reductions in fabrication labor. Some could lead to path altering technological breakthroughs. Hope still lies in the future. The big hurdle is cost. Appropriately directed and focused technology developments can meet the challenge. The following aerospace needs represent opportunities for invention and development of solutions that can not only impact the selection and use of composites but may lead to future redirection and growth of the industry.

Technology needs

The future improvements required for other composite industries can be projected by a close examination of current aerospace. Today's aerospace needs can be summarized as a demand for "bigger", "faster", and "lower cost" products without loss of properties. These opportunities can be grouped and categorized as needs for: major scale up of structure size and large volumes of concurrently applied materials, automated processes, streamlined design, improved materials and environmental protection.

Scale up size

The need for "bigger is driven by two forces: (1) the desire for larger structures and (2) the need to combine small multi-piece assemblies into larger lower cost integral components. Technologies must be developed to produce high quality composite structures without the use of autoclaves in order to produce these large units economically. Extremely large components will not only require out-of-autoclave laminate compacting and curing but they will also demand onsite construction, pre-impregnation processes and material handling methods analogous to the construction techniques currently used for large buildings, dams, and bridges.

The U.S. Navy has several programs developing ship structures that will use carbon-reinforced composites. The marine industry has produced large boats with glass fiber reinforced composite materials for many years. Their smooth blended surfaces enable boats to race or glide easily through water. These boats are produced with improved material properties and without the high cost and size limitations of autoclaves. As industries look to optimize performance fiber reinforced composites still emerge as the best candidate. For the marine industry composites provide smooth flowing surfaces and enable boats to be designed and built as large integral structures often including the hull, decks, and support structures. This significantly reduces the quantity of parts, assembly time, and costs. Carbon fiber composites are much lighter and stiffer than fiberglass but like aerospace the savings from weight alone often cannot meet the low cost demanded from marine customers.

Scale up volume

Today dry and resin impregnated fibers can be precisely positioned using auto weaving, braiding, knitting, and linear fiber placement. These processes are automated to reduce the manual labor. They also improve the quality of "preforms" and "composite lay ups" but methods must be developed to reduce their costs. To meet the demands for the enormous unitized structures of the future these processes must be scaled to enable large volumes of materia ls to be concurrently applied. Conventional processes for filament winding and fiber placement are complex, flexible, and precise. They must not only be scaled in size they must also enable placement of very large tows, on-the-fly consolidation and curing that results in void and porosity free structures. Software must be developed to automate the generation and programming for low cost winding patterns. Real time quality controls for monitoring, and process correction systems will be mandatory for their success. The large volume needs of infrastructure will likely drive these changes as a natural evolution to their demands for "bigger" and "faster". However, research and development will be required to overcome the property reductions that would result from simply expanding today's technologies. Significant speed increases will be required to process big structures as well as consume large quantities of material. Large unitized structures are proving to be essential for affordable composite products. It is reasonable to assume by examination of today's uses and limits that infrastructure too will always be pushing the size envelope for larger and larger integral components.

This demand for large size components will further drive the development of out-of-autoclave consolidation, curing and onsite or field fabrication without degrading structural properties. As the component size increases and moves into open air the need for room and low temperature curing adhesives and resins will become essential for fabrication and assembly in these harsh environments. Materials must be developed with longer pot life and resistance to humidity. Resins will be needed that will completely wet-out dense or complex fibers prior to preforming as well as during injection into, or more likely onto, the preforms after they are positioned on the lay-up molds.

Other industries are also beginning to move from fiberglass to carbon fiber reinforced composites for improved performance. For example, sporting applications are offering lightweight competitive materials for increased safety. Most of these products have evolved as fiberglass substitutions for increased strength, toughness or to reduce weight. Carbon fiber composites have the strength to replace steel while saving weight for certain high performance sports equipment. Carbon fiber composites are earning their way as a glass replacement for a few recreational and sports industries where the consumers will pay the difference for the added performance. Like the early aerospace industries sporting equipment suppliers often boast of cutting weight by 65 to 75 percent while improving safety and increasing strength. However, unlike the low volume aircraft industries the higher volume producers of sporting equipment predict cost reductions between 50 and 85 percent. Most of their claims for savings are attributable to automation. Today the carbon fiber sports applications are restricted to high-end products. Golf clubs, fishing rods, skis, skateboards, rollerblades, surfboards, wind surfers, classic car replicas, formula race cars, motorcycle parts, helmets, and other protective gear are just a few of the rapidly growing sports products currently using carbon fiber reinforced composites. These are all high volume products. Therefore, if the cost of these composite products ever drops below their conventional material counterparts they will dominate the market.

Automation

Composite processes of today remain as labor intensive. Automation often holds the keys to reducing labor. Therefore, processes must be developed to enable rapid high volume dispensing of fiber via tows, sheets, or preforms. Automated fiber placement using spray and injection apparatus that rapidly apply discontinuous fibers, with controlled overlap, alignment, and accelerated curing offer great potential for lowering cost. Rapid cutting, kiting and dispensing of fiber and accelerated curing will shorten the cycle time and reduce cost. For products that require hand labor streamlined processes and point of use work instructions are needed to automate manual functions. Intelligent sensors that are capable of monitoring and controlling the cure processes will improve quality and reduce labor. Similar sensors are needed to monitor the health of completed structures. Health monitoring sensors are available today but technology improvements are needed to make then acceptable to users. Automated processes along with supporting materials will be required to enable on-the-fly, insitu, or room temperature curing of components that meet or exceed the properties achieved by autoclaves today.

Assembly and joining represent a big challenge but the savings potential is significant. Welding is accepted as a fast and is generally considered a low cost method for joining metals. Thermoplastics can be welded today. However, major process and material developments will be required to support continuous and portable welding of large components without the expensive tooling currently required. These processes must also yield joints that approach the properties of autoclave consolidation.

The ultimate in automation will evolve as concept-to-reality methods can be improved to generate finished parts directly from 3-D graphic designs. The advancement of high speed laminating machines and fiber reinforcement resins that support automated processes such as stereo lithographic construction will enable usable parts to be grown directly from 3-D design data. Processes like stereolithography and 3-D printing of components exist today but their products are limited in size, strength, and toughness. Overcoming these limitations presents a major opportunity for productivity and cost reduction improvements. This will require revolutionary changes to both processes and materials used by current rapid prototype systems, but if successful the benefits would be overwhelming.

Streamlined Design

Large unitized structures are essential for affordable composites but the tools for design of these structures are minimal today. CAD and analysis tools are needed to optimize designs for large structures, reduce part count, and eliminate or minimize tooling and assembly costs. Software tools are needed to streamline the design/build process. Graphic simulation tools are also needed to reduce cycle time to market and automate accurate cost estimating methods.

Infrastructure industries will likely drive the development of automated fabrication processes that use standard shapes and structural members similar to the extruded or rolled steel currently used in large construction. Along with these standard shapes will come standardized analytical algorithms to speed the design and analysis process. New methods that automate the design process and re-utilize design data to drive automated build processes for tools and structural components must be developed.

Military aircraft have always emphasized performance over affordability. While performance is still dominate the increased price that a program is willing to pay for this performance is much lower today than has been in the past. Therefore, design for affordability must be incorporated in the early design process. Special tools must be developed to encourage and enable collaborative design and analysis between multi disciplines from concept through transfer of the product to the customer. These systems must be tightly coupled to the business cost systems and provide immediate feedback to the designer for effective cost trades. University, industry, and government labs must work together to develop virtual enterprises that can support design at remote locations.

Design properties must be established and automated in a way that standard test methods and material properties can be easily compared without costly and timely destructive testing. Structural analysis must be available for use by everyone on the Design & Build teams. Design and analysis methods including physics based simulation and modeling capable of analyzing all functions from design to assembly, simplified heat transfer modeling, and user friendly mold filling flow models for design and analysis of tools must be developed. This will enable virtual analysis of the complete product and design prior to commitment to build. Tools to validate models for material processing, tool design, producibility, and manufacturing planning functions are also needed. In order to achieve true affordability industry must discard the methods previously used for metals. Not only must revolutionary new methods be established but a new approach to the design of composites must be incorporated. Dramatic reductions in part count and assembly costs can be achieved with designs that minimize the number of piece parts in large components and optimize the capabilities of composites. Innovative design approaches and tools will be required to achieve parts consolidation and reduce the cost of composite structures to a point that they can compete with their metal counterparts.

Some of the tools exist today, but most do not work together and do not support integrated product team environments. Others need research, development and validation to become user friendly and acceptable for large-scale programs. Many opportunities for design and development of specialized tools are on the horizon. The current evolution into Concurrent Engineering is creating and increasing the need for low-cost, fast-build, reusable prototype tools, materials, and associated processes.

Materials

Materials and processes must be developed to produce and apply large tow fibers that can yield high quality structures with little or no "knock down" factors in order to meet the high volume requirements of the future. Adhesives that cure in less than one hour but have indefinite pot life or no shelf life degradation are needed for situations where component assembly is required. They must be insensitive to surface conditions and possess a high degree of molecular bonding. Robust resin systems with extended pot life, long out times or no requirement for storage at sub-ambient temperatures must be developed. These materials should also possess a high tolerance for humidity without degradation of properties. As the size of structures increase the demand for resins and adhesives that can achieve thin bond line properties from very thick bond lines will also increase. Similar resins are needed for "mold-in-place" and "quick set" structural liquid shims. The search for repair processes that can return damaged composite components to their original configuration with minimal or no structural property or weight penalty continues.

Tooling material improvements are needed for low cost prototype injection molds and for materials with coefficients of expansion that match the composite structure. Cutting tools that resist wear, maximize speed, prevent breakout and delaminations are essential for quality and cost reduction.

Environmental

Today's processes and materials are creating environmental changes but the demand for new resins, adhesives, and support materials that are needed to construct oversize structures with out-of-autoclave processes will require even more. These materials must withstand severe environmental conditions and still provide strong molecular bonds and structural properties. To compete they must retain this strength to weight superiority and perform equivalent to or better than components produced in an autoclave. Autoclaves consume a significant amount of energy and in some cases expel hazardous materials. Alternate low energy systems that will enable large structures to be produced without the high costs and negative environmental impacts of autoclaves will become even more important as composite usage increases. The extremely large volumes of materials that can be generated through this process could also significantly increase the need and demand for new materials that can be reprocessed or reused to avoid large accumulations of environmentally hazardous waste. Recycling along with lower costs continues to give aluminum an advantage over fiber reinforced composites. Along with the large volume usage comes a need to efficiently and economically reduce or eliminate the associated packaging waste forms such as separator paper, cores and shipment boxes.

Composites have proven to be suitable for a vast number of commercial and military products but expansion within the existing industries is being slowed or eliminated by their increasing costs. The recent decline in material suppliers coupled with the reductions in defense spending have led to slow or even negative growth in some areas. Obviously, if this trend continues and composites usage fails to expand or even worse declines the cost problem will compound. The two major cost contributors are materials and labor-intensive processes. In order to overcome these obstacles it is essential that composite technology be expanded into high-volume users. Large volume usage in at least one industry sector is essential to enable all industries to exploit the known and explore the vast potential of new applications for composites. New large-scale usage in infrastructure, marine, automotive and sports are expanding the use of composite materials. They are also contributing to the development and exploitation of streamlined automated processes and increased usage. No longer is the future of composites exclusively dependent on aerospace. New commercial applications are opening new markets and creating new opportunities for development. Even the declining defense industry stands to benefit from these changes. New technologies and larger scale applications are providing improved and automated processes. The new applications are also expanding material usage which promises reduction in the cost of materials for all users including the high performance applications. Infrastructure is likely the most promising industry to sustain or expand the future use of carbon fiber reinforced composites. Not only does it represent a major opportunity to expand into new applications for large buildings, bridges and other structures it also may be the means to reduce the materials and processing costs for other industries. Applications such as golf shafts, tennis rackets, cycle frames, automobile bodies, truck frames, wind turbines, rail cars, lightweight bridges and bridge reinforcements for earthquake resistance etc., are using composites to reduce weight and increase performance. Even though there are many opportunities they will never be exploited to their fullest potential until the costs of fabricated components are decreased. The challenge is arising. The goal should be to make composites the most affordable solution to any design problem.

The Infrastructure industry appears to offer the level of scale-up that will be necessary to develop new markets, drive major increases in the demand for composite materials, entice new suppliers, promote revolutionary process development, and significantly reduce the costs of composite structures. This application could potentially require more composite materials than all other applications combined. Early indications are that these materials could revolutionize the construction process. Not only will the material utilization be increased the newer and larger scale processing methods will also be improved to meet the needs of this giant industry. This may lead to a significant cost breakthrough just in time to revitalize some of the other industries like aerospace that are approaching their maximum cost effective applications.

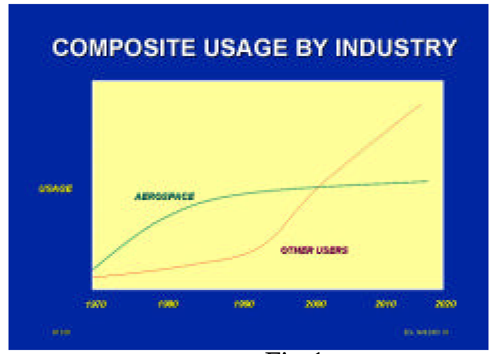

Fig 1

As shown in Figure 1 the use of composites is approaching an asymptotic plateau for defense. Fortunately infrastructure and other users are projecting increasing demands for composite materials. If this occurs as shown it will likely lead to significant reductions in the cost of materials, more cost efficient processing and could ultimately re-energize the slowing of aerospace applications.

If the Infrastructure industries accept and apply composites to buildings, bridges, and other large structures not only will they revolutionize the construction industry, new markets will be established, demand for materials will increase, new suppliers will be enticed and technology developments will be pushed to new levels. This expansion is essential to retain the supplier base, reduce the costs, mature technologies, expand existing applications and assure continued acceptance and growth of composites. This will also increase the demand and drive the development of new materials. The increased availability will reduce the cost of production and consequently reduce the cost of products. The reduced cost of production and increased availability of materials should further reduce the product cost and ultimately preserve suppliers, expand the technology, and reduce costs for all industries.

CONCLUSION

Unfortunately, today wide gaps exist between research and industrial applications. These gaps are not only costly they could become even larger with the demands from emerging sectors. Future research must be directed, focused, and planned for specific industrial applications to close these voids. In the fairly recent past researchers had the latitude to explore and develop solutions for a wide variety of composite applications. The large quantity of programs to fund these broad studies are no longer available. Today's business environment has lowered the level of funding for composite research and development to a point that these efforts must be coordinated and focused to avoid overlap and redundancy. Funding is no longer adequate to support independent studies. This coordination, development, and application will be best accomplished by collaboration of universities, governments and industries. In the past adequate staff and research

& development budgets were available to satisfy a company's specific and unique processes. With the decline of today sharing has become the key to keeping pace and making composites competitive. Aerospace industries previously developed proprietary processes, methods, analysis tools, data and other systems in the name of maintaining a competitive edge. However, with the increased teaming and just a few remaining aerospace companies not many secrets remain.

Today the demand for composites in the United States has made a turn upward and is growing again. In the middle of the year 2000 the Composite Fabricators Association (CFA) made a forecast for sales of composite materials to increase by 150 million pounds for the year 2000 over the year 1999, representing a 4% growth rate. Transportation is the largest market claiming 1.27 billion pounds with the construction industry using 175 million pounds. Automotive applications have approximately doubled since the mid1990s according to the Automotive Composite Alliance (ACA). Automotive was projected to use approximately 30 million pounds for the year 2000 representing a 67% increase since 1996[2].

The technology needs addressed herein must be pursued in a cooperative spirit with all of the parties working together. A coordinated effort is essential to develop, validate and transition processes, systems, data and methods directly to application programs and industrial users. This approach can benefit all participants and significantly advance and increase the growth and application of composites to a wide variety of commercial products. This will improve the quality of life for all by lowering cost and increasing safety. If affordable issues are not resolved we can expect the future to bring diminishing use of composite materials.

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