Twenty First Century Practices

Processing and Repair of

Composites, Adhesives, and Sealants

White Paper

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Contributing Organizations

There is a high level of interest at a number of organizations which I have not included in this white paper because I am not that familiar with this program and did not wish to involve more organizations until I understand the scope and type of support available.

These organizations include government, large company, small company, universities, training companies and personal consultants that have participated in developmental projects supporting the white paper.

It is my understanding that the white paper is intended to identify the need and propose approach but not necessarily to provide specific detail as to how the problem will be addressed. I would be happy to provide any additional information upon request.

At the surface this program would appear to be highly appropriate for the challenge we face with innovation in composite processing. There is a real potential for failures during the development phase because the technology, while sound, has not been used in this manner and lacks the infrastructure to support it. This is problem is exacerbated by the need for multiple organizations to be involve in the support with only tenuous connections with each other and with legacy knowledge that runs contrary to the proposed goals.

At the level of final implementation, manufacturing is highly resistant to the risking participation without proof from the engineering community that the technology works and the engineering community cannot prove it works without manufacturing data.

Both engineering and manufacturing currently exist in an environment that is hostile to change and are challenged by the requirement of management to provide assurances of success and that the technology will give a proprietary competitive edge. Since much of the success of this effort relies on placing data in the public domain, it therefore cannot be kept proprietary.

Having said the above, there are individuals within these organizations who see the benefits and are prepared to champion the effort. If a funding source is available where work done for the public domain is funded by public money and where some of the cost of the high risk effort is offset, there are a number people anxious to pursue the technology.

Area of Critical National Need:

If the USA is to retain leadership in both defense and industry, there is a great need to update the approach to manufacturing from process dominated practices to material state dominated practices. This is especially important in growth industries such as composite materials.

The situation for composite is similar to the semiconductor challenges of the past where a need existed but no individual company would fund the effort because of the risks and because and results of the research would rapidly become public domain while the costs for development would accrue to the lead company. Government funding played a key role in offsetting the high risk tasks and fundamental research.

Composites have a major role to play in green technology and in the reduction of atmospheric carbon dioxide. Composites are used extensively in structures for wind power, nuclear energy, mass transit and fuel efficient vehicles. In addition to lowering cost and improving performance for these applications, it would greatly facilitate the development of multifunctional structures such as integrated batteries and 'smart' structures that would further reduce energy requirements and emissions.

There has been significant progress in the automation of manufacturing processes but far less progress in the intelligent use of computers to change the process itself. For example there have been over a hundred scientific publications of cure models relating to processes control and sensor feedback[1] for composites. None of these novel sensors or models is used at any significant level in the composite industry.

The primary barrier is the risk and disruptive nature of the change at the shop level coupled with the lack of a vehicle to simultaneously address the challenges of re-inventing and rebuilding the criteria for process control and product acceptance.

While these challenges are significant they are not insurmountable and it is only a matter of time before government funded efforts in the emerging global market adapts to the new paradigm unhampered by the methods established fifty years ago. The US has a technical potential but lacks the vehicle to place it in practice.

> Corrosion management, long term fatigue and energy use are critical in the economic future of the United States. Composite materials are the material of choice both to produce clean energy in products such as windmills, to save energy in products such as car bodies and aircraft and have superior corrosion and fatigue properties with respect to current materials.
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> By 2010, the global market for Carbon Fiber Reinforced Plastic (CFRP) composite materials is predicted to be worth $13.6 billion, representing a huge increase of 37% over 2006[2]. CFRP also has a role as a replacement for metals in infrastructure. Corrosion of metallic structures has a significant impact on the U.S. economy. In a congressional study, the total economic impact of corrosion and corrosion control applications was estimated to be $276 billion annually, or 3.1

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[1] Personal communication and Literature survey of prior publications

[2] The Carbon Fibre Industry: Global Strategic Market Evaluation 2006-2010 by Tony Roberts. For further information on the 295-page report, contact the publisher, Materials Technology Publications, UK

percent of the U.S. gross domestic product (GDP).[3] Estimates for the DoD alone are between $10-20 Billion.

While the use of composites has grown, many manufacturing and repair processes have remained stagnant. Hundreds of millions of dollars are wasted each year using specifications and practices that had their genesis in the 1950's and 1960's.

Transformational result:

Current practice for material processing relies extensively on the development of the material properties "off line". Quality assurance systems are geared to measure the results of the process rather than adapting the process to the product. Often entire manufacturing facilities have been built around a specific process rather that an adaptable system focused on material performance.

The transformational sought is an infrastructure that adapts to measured and mathematically modeled material behavior. The result would be a far greater ability to make adaptive changes that avoid rather than remediate defective products and that fully exploit the concept of continuous process improvement.

As applied to composite materials this approach would fundamentally change how composite materials are specified and managed, starting with resin formulation and carrying forward through the life and final recycling of the spent product. The basis for the anticipated growth in the use of composites is in managing fatigue and corrosion and saving energy based on weight and aerodynamics.

Justification for Government Attention

Innovation in composite manufacturing has been relegated to a lower priority because of the focus on LEAN manufacturing process developments. In some cases, the technical expertise and process understanding has been outsourced to vendors, whose primary contributions are LEAN manufacturing capabilities. Consequently, the result is stagnation around rote processes that have been used for many years; there is little incentive to innovate and to adopt new technologies, and/or to adapt to new markets (because of limitations in the accepted process techniques).Prior to computers being introduced to the production shop, it was not practical or even possible to define a cure process as a function of cure state. While this is now possible, no individual company or project can practically undertake redefine methods of material qualification without risk to the program it targets. A further barrier to private industry is the need for public domain data to demonstrate NIST tractability to support and validate reproducibility and compliance with safety and certification issues.

Government itself participates in the problem in many programs by demanding documentation of short term cost savings prior to funding manufacturing technology activities. This highly discourages risk taking and transformational activities with inherent short term risks and benefits that are often difficult to demonstrate based existing criteria.

The result is the reliance on standardized legacy processes which, if followed, pose little or no risk to the production shop which are measured on the productivity against current requirements and not on future viability.

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[3] Proceedings of the Materials Forum 2007: Corrosion Education for the 21st Century ISBN-10: 0-309-10893-4

The ***societal change sought*** is confidence in the use of computer based material state models as viable measures of product integrity. The challenge is to create a system that substantiates and supports that confidence by overcoming the multiple barriers to implementation.

Implementation requires ***high-risk efforts but potentially high reward research.*** The risks are amplified by the need for the entire system and infrastructure to be functional before any transformational change can occur. If any functional component of engineering, production or quality assurance is missing, the system benefits will not be realized. A successful integrated system will address critical needs in the areas of energy conservation, infrastructure, transportation, defense and construction by accelerating innovation and providing a path to lower cost, higher quality and enabling structures to be built that are currently too costly or difficult.

The proposed change spans too diverse a range of disciplines to fare well in the traditional peer-review process because the challenges are not well understood. Often the need for change is subtle and the research requirements are not obvious except to those directly attempting to effect the change. The involvement of government and private technology centers such as the National Center of the Manufacturing Sciences (NCMS) and the National Institute of Standards and Technology (NIST) are required to provide public domain access to data that permits effective collaboration.

To achieve the goal of model based material state management there must be a fundamental change to the specifications controlling the production of these materials and a concurrent development of specified criteria, traceable to NIST standards that are statistically correlated to performance values.

These will differ from current process based specifications in that they more accurately and precisely define the material properties critical to performance and permit far greater flexibility in the processes used to achieve a given material state. It can and has been strongly argued that these goals have been known for many years and that the technology involved is not “true” research. The reality is that there are multiple barriers to implementation that require research and development by the activities directly involve in the area of required expertise. AvPro has worked continuously in this area for fifteen years with many well supported projects that address elements of the problem and show near term return on investment. Unfortunately these peer-review efforts lack the scope and risk tolerance to make the fundamental changes required to transform this industry.

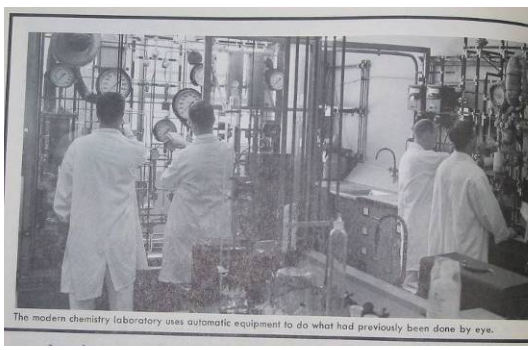
While the proposed focus area is structural composites where the impact is major, the resultant tools and paradigm are readily extendable to other materials and a similar roadmap can be followed at a much lower risk once the concept has been demonstrated.

The following is taken from another white paper and may be more specific than requested. It is provided as an example of goals outlined above.

Background

Current specifications for composite materials[4] are effectively the same as the proprietary specifications developed in the early 1970's that are now being incorporated into specifications provided professional organizations such as the Society for Automotive Engineers, (SAE) and the Society of Manufacturing Engineers (SME). The goal of these efforts is to provide standardization (which is good) but further cement the technologies of the last century as the baseline for composite production. These specifications were developed before it was possible to measure material properties directly during manufacture necessarily rely on a "no change" policy which requires the material to be processed the same way on the assumption the material stays the same and the process will yield the same result.

Modern Laboratory 1970 ***2008***



Approach

Our proposed approach is to create a new definition of properties that are now measurable and can be correlated to material performance. The goal is to instantiate sensors, provide statistical proof, and implement the specifications and tools to apply managing these properties to all phases of composite manufacturing and support.

It is recognized that this project is ambitious and requires sequential tasking based on preceding milestones. It will, for example, not be possible to process to a specified material property measurement before the basis for accepting a value is defined and accepted by industry. Currently the time history is the only real-time definition of cure in general use.

Team members with a variety of skills and resources are required along with access to multiply research and production facilities.

A simple example of the benefits gained is derived from the fact that materials cure at a faster rate when they are at a higher temperature. If cure were measured by viscoelastic state rather than a predefined time cure hold times could potentially be cut in half with no significant impact on part quality. The limits set for temperature in legacy specifications were based on laboratory prototypes and early production designs. These limits cannot be changed without violating specified requirements,

[4] For example Draft MMS_5063 prepared by Boeing in 2008 (for public release).

regardless of the benefits. The specified temperature could be changed but it would introduce a costly requalification effort and would not solve the basic problem of an indirect measurement associated with material state property rather than direct measurement of the property critical to performance.

Need

A lesson from the US automobile industry is that the neglect of a long term view makes it extremely difficult 'catch up' when market conditions change. Even if the products are later improved and are eventually the same, the market perception of having obsolete technology remains.

With new computer based equipment[5], leveraging of past processing science programs[6] and substitution methodology projects,[7] the goal of implementing advanced processing for composites is well within reach. Although a long term vision is needed, it does not require abandoning legacy specifications, short term goals or the loss of near term benefits. It does require persistence and a clear understanding of the materials, processes and facility requirements for manufacturing. Significant risk exists at each phase of the project that the planned particular approach to the problem may not work. Although the research is grounded on sound science and feasibly studies, the project will need to retain the scope to adapt as problems arise.

Opportunity

AvPro, with the aid of the National Center for the Manufacturing Sciences (NCMS), and other team members in both government and industry established a preliminary roadmap for evolution to Material State Management (MSM) of composites[8] in the 1990's. This roadmap has been followed through ad hoc efforts by team members in self funded projects and in work paralleling the funded efforts.

Significant progress has been made but the opportunity for transformational change is lost because the scope the NCMS effort is limited to Commercial Technologies for Maintenance Activities (CTMA) and does not directly address the goals of this proposal.

The framework of the CTMA project, however, has been invaluable. Beyond simply leveraging costs, it enables the exchange of ideas and resources across industries that are critical and that would be impossible without the collaboration.

For example, it has been possible to increase productivity[9] and reduce scrap by the use of computer control and by post process testing to more rapidly evaluate part quality and repair or reject the part. However the desired goal is to avoid rejection of the part in the first place and expand the window within which productivity can be improved.

The examples noted above have already demonstrated significant return on investment through better load management and better assessment of part quality. The objective of the proposed effort is to refocus the value proposition from a short term Return On Investment (ROI) to the pervasive benefits of changing the how the quality of composite materials are measured and managed.

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[5] The personal computer, unavailable at the time most specifications originated, are now common in the production shop

[6] For example the Air Force processing science program (Abrams & Browning)

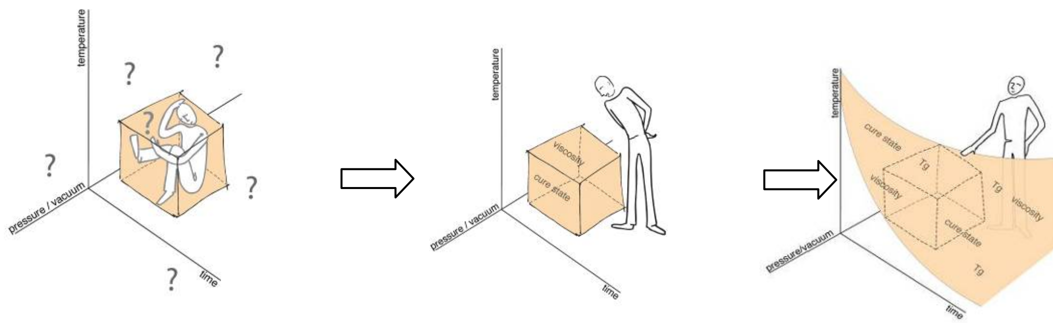
[7] More recently, CTMA projects on materials and process substitution methodologies

[8] William Wright "Systematic Evolution to Material State Based Control" Proceedings, 41st Sagamore Conference 29 August, 1994

[9] "Software-based autoclave control increases company's throughput by 35% and frees engineers for more productive work" Automating and Optimizing Autoclave Cure High Performance Composites July 2008 page 81

Approach

Legacy specifications for managing composites in the past deliberately avoided material measurements and cure models because their accuracy could not be assured. Costly material qualifications were therefore based primarily on process rather than product definitions.



LEGACY **CURRENT DEVELOPMENT** **GOAL**

While measuring a material property such as the viscoelastic state (a measure of how the material will perform) state has been used to recover rejected parts and improve processing, there are no accepted methods or cure models for general industry use. This is in part because creating an industry accepted definition of cure based on alternate sensors and material state property measurements cannot be done quickly or without a sustained team effort.

AvPro proposes a road map that recognizes the long term goals and definition of the funding requirements needed for a collaborative effort to build the technology and remove the barriers to:

- the validation (measured properties, quantifiable against standards traceable to NIST) of viscoelastic and other materials state based cure models
- provide material state targets as a basis for the definition of the state of cure
- provide a user interface to visualize the viscoelastic state of legacy cures suitable for production and quality assurance
- enable the use of viscoelastic models and validation tests outside of current time and temperature boundaries
- incorporate viscoelastic (and similar material state) limits into specifications
- enable and support manufacturing using validated material state properties

Ideally this effort would have multiyear, multi disciple funding so the team could be maintained throughout the project. Regardless of funding length of individual efforts it is desirable that the program goals are defined from the outset to enable coherent system and interface for the building blocks to achieve the final objective.

Cost Benefit

The cost of such a program is modest when compared with the gains in productivity possible and the costs associated with the loss of a large manufacturing segment. In the end, the program would likely have an impact measured in the billions of dollars given the pervasive and growing use of composites and the thousand of cures done each day.

If properly supported in government applications this effort will provide durable jobs based on a broadened domestic infrastructure. Many of these improvements can be readily transferred from the proposed aerospace settings to applications in civil engineering, wind energy, automotive, and other vital industries.