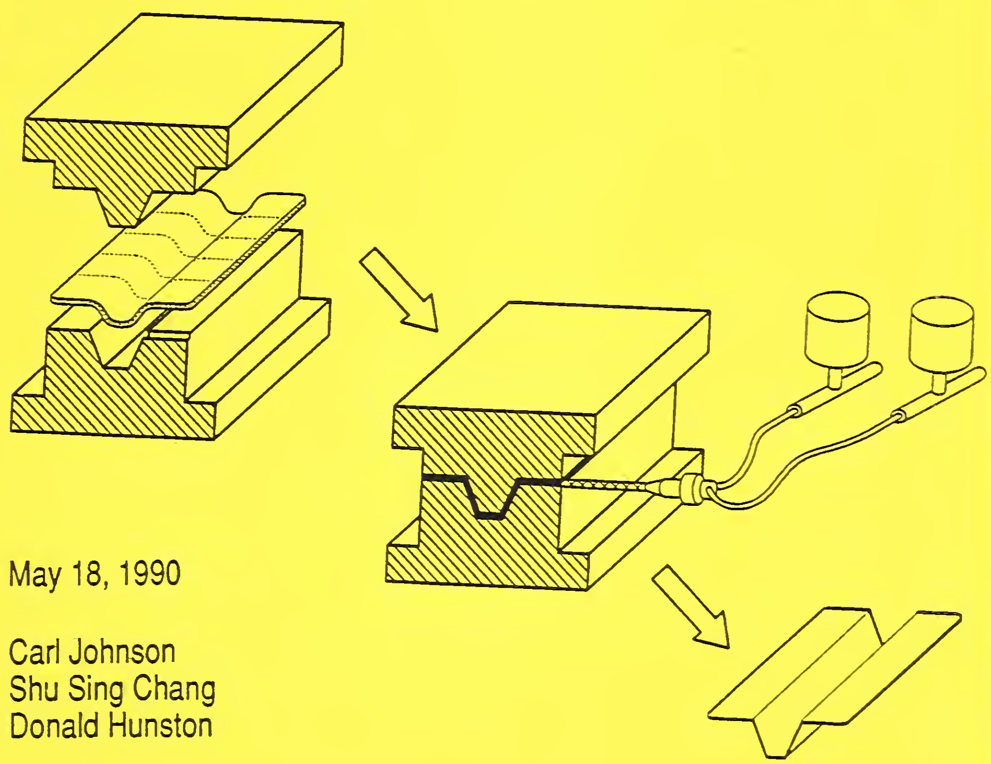
NISTIR 4461

NEW NIST PUBLICATION
January 1991

Polymer Composite Processing

2nd Industry Workshop



May 18, 1990

Carl Johnson
Shu Sing Chang
Donald Hunston

U.S. DEPARTMENT OF COMMERCE
National Institute of Standards and Technology
Materials Science and Engineering Laboratory

MSEL

NISTIR 4461

Polymer Composite Processing

2nd Industry Workshop

Held at NIST, Gaithersburg, MD
May 18, 1990

Carl Johnson
Shu Sing Chang
Donald Hunston

U.S. DEPARTMENT OF COMMERCE
National Institute of Standards and Technology
Materials Science and Engineering Laboratory
Gaithersburg, MD 20899

Issued December, 1990

U.S. DEPARTMENT OF COMMERCE, Robert A. Mosbacher, Secretary
National Institute of Standards and Technology, John W. Lyons, Director

ACKNOWLEDGEMENT

The authors wish to express their appreciation to Joan Ruff, Patrice Boulanger, and Lori Philips for providing arrangements and organization that made the Workshop possible.

SUMMARY

Industry representatives identified the most important processing methods, scientific and technical barriers to improved processing, and performance issues for the time period from 5 to 15 years from now.

Two processing methods were selected as most important: pressure molding and liquid molding. Pressure molding includes press, compression, and autoclave molding. The liquid molding describes resin transfer molding (RTM) and structural reaction injection molding (high speed RTM). Three additional processing methods were identified as being important for the future: filament winding, thermoforming, and pultrusion.

Seven scientific and technical barriers to the full exploitation of these processing methods were identified. The three highest priority items are the need to understand and control resin flow and fiber orientation, to develop process monitoring sensors for on-line control, and to understand and control the fiber-matrix interface. The remaining areas where there is a need for improvement are data validation and testing standards, determination and control of morphology, surface quality and dimensional stability, and understanding of heat flow.

The Workshop also identified and prioritized eight technologies that complement processing and are important for the future. The three highest ranked items were fiber placement, new methods to prepare prepreg, and joining. The remaining items are preform preparation, recycling, environmental safety, tooling, and alternate sources of energy.

The majority of people at the Workshop felt that thermosets were still the dominant resin system in most applications, but all felt that thermoplastics had significant potential and should be watched closely for future development. Four other classes of materials were also viewed as having potential for the future: liquid crystal polymers, molecular composites, smart materials, and specialized polymer system.

The Workshop also selected seven performance issues that they felt were critical for the future. In order of priority these issues are: impact, environmental attack, delamination, dimensional changes, thermal stability, fatigue, and creep. There was a surprising consensus on impact and environmental attack with each industry sectors ranking these two items in their top three priorities. Beyond this point, the order of importance depended on the industry involved.

The attendees at the Workshop represented a wide variety of industries including: aerospace, automotive, electronics, marine, and construction. They were divided about equally among users, suppliers, and those involved in both. The companies represented were:

Applied Physics Laboratory
Aristech Chemical Corp.
AT&T Bell Laboratories
Automated Dynamics
BF Goodrich
Construction Technology
Dow UTCP
E.I. DuPont, Central Research
E.I. DuPont, Composites
Emerson & Coming
Fibrite (ICI)
Ford Motor Company
GenCorp Research
General Electric Corp. R&D
Grumman Aircraft -
Hercules Corp., Magna
Hercules Corp., Wilmington
IBM, Endicott
ICI Composite Structure
Industrial Fiberglass Specialties
Martin Marietta Aero and Naval Systems
Martin Marietta Laboratories
PDA Engineering
Technology Catalysts, Inc.

TABLE OF CONTENTS

INTRODUCTION

The issue of international competitiveness has received much attention lately, and rightly so. One example is a recent Department of Commerce (DOC) study that was conducted to identify emerging technologies since they are critical tools for the development of better, more competitive products in the future. The results, which are detailed in a report[1] entitled "Emerging Technologies - A Survey of Technical and Economic Opportunities," have identified Advanced Materials as one of the key technologies. This same conclusion was reached by a number of other industry and Government sponsored studies including those by the Aerospace Industries Association[2] ("Key Technologies for the 1990s") and the Department of Defense[3] ("Critical Technology Plan"). The Congress's Office of Technology Assessment (OTA) reports $2 billion worth of advanced materials are currently replacing conventional materials annually[4] and predicts this will rise to $20 billion by 2000. The OTA study warns, however, that the emphasis on commercialization by Japan and Europe could put them in a very good position to compete for these markets. This warning is echoed by the DOC report which concludes that the U.S. is rapidly losing its lead in advanced materials.

The largest single item in the advanced material category is polymer based composites. The annual growth rate for polymer composites[5,6] is very high, 16%, but the continuation of this growth requires the expanded use of composites in mass-market, civilian applications. The major barrier to this is the high cost, and this is increasingly a concern for military and aerospace applications as well. A report[7] by Kline & Co. estimated that more than 70% of the cost for advanced composites is in the fabrication and, like a similar report[5] by Business Communications Co., concludes that improvements must be made if the potential of these materials is to be realized. The problem has arisen because the pressure for rapid implementation of composites has led the applications to outstrip the development of a corresponding science and technology base in fabrication. It is now generally recognized that a major effort is needed to correct this problem.

Purpose of Workshop

The field of composite fabrication is very complex with many potential areas to study, and thus, to be effective, the research activities must be focused on those aspects of the science base which will have the most direct impact on the development of cost effective processing. To identify these areas, an Industry Workshop on Polymer Composite Processing was held at the National Institute of Standards and Technology (NIST) on October 7, 1987. The recommendations[8] from that meeting were used in planning a major expansion of the NIST composites program in 1988.

After more than two years, it was felt that the recommendations of the 1987 Workshop should be updated and refined so a second Industry Workshop was held at NIST on May 18, 1990. This Workshop also provided an opportunity to tell industry about the progress made by NIST's composites research program since 1987. Of particular interest were the projects designed to address the recommendations of the 1987 meeting. A final objective in the Workshop was to seek industries' advice and guidance for planning a program expansion in the NIST effort which is proposed in the FY91 budget. This increase would address the scientific and technical questions associated with testing and prediction of performance properties in composites. To examine this area, the Workshop was asked to identify and discuss the performance issues that are most important to their industries. The results and discussions of the second Industry Workshop are summarized in this Report.

Information Sought

To accomplish these goals, the attendees were asked to consider the time period from 5 to 15 years from now and answer three questions. First, what are the generic processing methods that will be of most interest to industry during this time period? Second, what are the scientific and technical barriers that hinder the implementation and effective use of these methods? Third, what are the performance issues that are most important for your industry?

Workshop Composition

The meeting involved only industrial participants so that the results would reflect the position of industry. There were a total of 26 attendees representing 24 different company organizations. The attendees were asked to indicate which industry sectors they could represent and the breakdown was: 35% aerospace, 21% automotive, 15% electronics, 11% marine/hydrospace, 6% construction, and 12% other which includes prepreg fabrication, industrial applications, general part manufacturing, and data base/design management. The attendees were split about evenly among users, suppliers, and those involved in both. The suppliers included manufacturers of resins and fibers as well as starting materials, such as preimpregnated fiber tape and cloth, and fabricators of small parts for the larger industrial users. A full attendance list is given in Appendix I. In addition, comments were supplied by scientists from two companies (Ferro Corp. and Monsanto Chemical Co.) that could not participate in the Workshop but expressed great interest in the NIST research effort.

Workshop Program

The Workshop was a day long meeting whose agenda is given in Table I. It began with a review of the conclusions of the 1987 Workshop, and a brief overview of the NIST's composites research program with emphasis on how it had responded to the 1987 recommendations. This was followed by presentations from representatives of four industry sectors: automotive, electronics, aerospace, and data base/design. Each speaker reviewed the current relevance of the conclusions from the 1987 Workshop for their industries and suggested where revisions were

Table I: Workshop Agenda

May 17, 1990 Evening

7:45 - 9:45	Reception and Registration (Cheese and Desserts, Cash Bar) Marriott Hotel - Check at Desk for Room

May 18, 1990

7:45	Bus leaves from front of Marriott for NIST
8:00 - 8:30	Registration, Coffee and Donuts Lecture Room C, Administration Building
8:30 - 8:45	Welcome and Comments R. Kammer, Deputy Director of NIST
8:45 - 9:15	Past Workshop Conclusions, NIST Processing Program Overview, and Performance Issues D. Hunston
9:15 - 10:05	Industry Updates Automotive - C. Johnson, Ford Electronic - G. Schmitt, IBM Aerospace - S. Dastin, Grumman Design/Data Base - Ed. Stanton, PDA Eng.
10:05 - 10:30	Survey and Coffee
10:30 - 11:20	Resin Transfer Molding F. Phelan R. Parnas
11:20 - 12:10	Interface Studies W. Wu P. Herrera-Franco
12:10 - 1:10	Lunch
1:10 - 1:30	Processing Sensors D. Hunston
1:30 - 1:50	Crystalline Texture F. Khoury
1:50 - 2:00	Survey Results
2:00 - 3:00	Industry Discussion of Future Needs C. Johnson, Ford
3:00 - 3:15	Coffee
3:15 - 3:30	Conclusions C. Johnson, Ford
3:30 - 4:00	Lab. Tour for those interested.

needed for the 1990's. Knowledgeable members of the audience augmented the presentation with comments based on their own experience and expertise.

After the industry presentations, a questionnaire was given to each attendee. This questionnaire, which is described below, provided an opportunity for each person to answer the questions posed in the Workshop and furnish other comments as well. While the attendees were completing this form, a more detailed look at the NIST research program was provided with presentations on six processing related projects. This occupied the remainder of the morning and early afternoon schedule. The questionnaires were collected before lunch and the evaluation begun at once so their results would be available for discussions in the afternoon.

During the last part of the meeting, Carl Johnson of Ford led discussions on processing methods, technical barriers, and performance issues. The preliminary results from the questionnaire were used to focus the deliberations. The goal was to reach a consensus among all industry sectors on answers to the three Workshop questions and other issues raised during the discussions. To a large extent, this was achieved although in a few cases, the answers were industry dependent. In addition, the issue of technologies that complement processing produced a large number of new ideas which made it difficult to finalize priorities during the discussions. As a result, a second questionnaire was sent to attendees by mail following the meeting so they could prioritize the topics in this area. The Workshop was closed with a summary of the discussions and conclusions by Carl Johnson.

Questionnaire

The first questionnaire was divided into four sections. The initial page requested information on which industry sector or sectors the attendee could represent. The first section asked each respondent to identify and rank the most important scientific and technical barriers that hinder cost effective processing in their industry. The second section expanded each barrier by listing four to six subtopics so attendees could specify in more detail exactly where they saw the biggest challenges. The third section asked the respondent to identify and prioritize the performance issues that are of most concern to their industry. The final section requested an update on the ranking of items in three categories: processing methods, important technologies that complement processing, and materials with potential for the future.

Each section of the questionnaire contained a list of possible answers based on the results of the 1987 Workshop and suggestions made by the attendees on their meeting registration forms. In addition, space was provided so last minute items could be added, and the attendees took advantage of the opportunity to include several important new topics, particularly in the area of technologies that complement processing.

The second questionnaire contained a list of all the suggestions for technologies that complement processing. It was mailed to each Workshop attendee, and they were asked to indicate their priorities and return the list for evaluation. Appendix II contains a copy of both questionnaires.

WORKSHOP PRESENTATIONS

The meeting presentations began with a review of the conclusions from the previous Workshop. A brief summary of these conclusions is presented here.

Review of 1987 Workshop

Industry representatives at the previous Workshop were asked to determine the processing methods that would be the most important in the future (5 to 15 years) and the scientific and technical barriers that prevent the optimal use of these methods today. The results are briefly outlined below and in Table II.

Processing Methods

The 1987 Workshop produced a consensus among the industry representatives on five processing methods. In order of decreasing priority they are: pressure molding, transfer molding, filament winding, thermoforming, and pultrusion. Pressure molding included both compression molding and autoclave processing. The first two methods were ranked about evenly and were rated significantly higher than the other three.

Technologies that Complement Processing

In addition, two other technologies were identified as very important, but they can not really be classified as processing methods. Consequently, a new category was defined, namely technologies that complement processing. The first of two items in this list was alternate sources of energy input. This included heating by microwaves, lasers, hot gas jets, and similar techniques which have the potential for highly controlled energy input. The second technology was resin coating of fibers. Powder prepregging, commingled fibers, and similar methods for combining the two constituents in unique ways were included in this item.

Scientific and Technical Barriers

In the area of scientific and technical barriers, the Workshop developed a list of six problem areas. Four of them involved the inability to understand and control various processing events: resin flow and fiber orientation (rated first), heat flow (rated second), morphology in partially crystalline systems and in multiphase toughened resins (rated fifth), and surface quality and dimensional stability (rated sixth). These areas are particularly important since they provide the targets for on-line process control which the Workshop regarded as the key to more rapid and

Table II: Conclusions of 1987 Workshop

MOST IMPORTANT PROCESSING METHODS (RANK)

Pressure Molding (1)
Transfer Molding (2)
Filament Winding (3)
Thermoforming (4)
Pultrusion (5)

IMPORTANT TECHNOLOGIES THAT COMPLEMENT PROCESSING

Alternate Sources of Energy
Resin Coating of Fibers: Preparation and Processing

MOST IMPORTANT SCIENTIFIC AND TECHNICAL BARRIERS (RANK)

Inability to Understand and Control
- Resin Flow - Fiber Orientation (1)
- Heat Flow (2)
- Morphology (5)
- Surface Quality - Dimensional Tolerances (6)

Fiber-Matrix Adhesion (3)
Data Validation - Test Standardization (4)

POTENTIALLY IMPORTANT MATERIALS FOR THE FUTURE

Thermoplastics
Liquid Crystalline Polymers
Molecular Composites

reliable processing. The third most important area was fiber-matrix adhesion. It was felt that the measurement techniques for fiber-matrix adhesion needed to be improved while the factors which determine the bond strength must be better understood and controlled during processing. The problem area listed as fourth most important was data validation and test standardization. Of interest here were quality control tests, materials acceptance tests, and performance prediction tests.

Material Systems with Potential for the Future

The final topic discussed in the 1987 Workshop was material systems. Although thermosetting resins were felt to be the most important at the present time, the attendees suggested three classes of materials that have great potential for the future and should be closely watched. These are thermoplastics, liquid crystal polymers, and molecular composites.

NIST Research Program

The presentations continued with a review of the NIST composite research program which represents a major and expanding area of emphasis. Complete details on the program can be found in the Polymer Division's Annual Report[9] so only a brief summary will be presented here. The focus of the program is material science. The work generally uses existing materials, often model systems, and studies the changes that occur during processing. Processing invariably introduces microstructure which influences properties and so a second portion of the program concentrates on developing techniques to characterize this microstructure. Finally, the properties of the finished test piece are determined. The NIST program generally does not include synthesis of new materials although there are cooperative efforts with universities and industries where the co-participant performs the synthesis. At the other extreme, the performance of large structures is also outside the scope of the NIST effort which usually stops at the level of plates, tubes, or other very simple structures.

The two major program goals are: (1) to monitor, model, and ultimately control the chemical and physical changes that occur during processing in order to develop the tools needed for more rapid and reliable fabrication, and (2) to establish processing-microstructure-property relationships so improved performance and performance prediction can be achieved. As outlined in Table III, the projects are divided into three tasks: Processing Science, Microstructure Characterization, and Laminate Performance.

Processing Science

Research in the Processing Science Task falls into four areas. The first is process monitoring. NIST has developed equipment and expertise in 10 different process monitoring techniques which include ultrasonics, dielectrics, optical, spectroscopic, thermal, and chromatographic methods. Both laboratory and on-line measurements are included. This capability is directly relevant to the conclusions of the 1987 Workshop which identified process monitoring as an important need. The capabilities at NIST also provides industry with an impartial source of knowledge and expertise when they have questions related to process monitoring.

The second effort in processing science is the development of fabrication facilities which can be used both to make test specimens and to investigate the implementation of on-line process control. In response to the 1987 Workshop recommendations, facilities were added in the two

Table III: NIST Composite Research Program

PROCESSING SCIENCE

- Process Monitoring - 10 Monitoring Techniques
- Processing Facilities
  - Resin Transfer Molding (RTM)
  - Automated Press
  - Autoclave/Prepregger
- Process Modelling - RTM
  - Computation
  - Flow Visualization
- Process Control

MICROSTRUCTURE CHARACTERIZATION

- Resin
  - Thermoset - Network Structure
    - Undeformed State
    - Deformed State
  - Thermoplastic - Crystallinity
- Fiber
  - Gel Spun Fiber - Gel Structure
- Interface
  - Structure of Glass/Resin Interface
- Composite - Thick Section
  - Through Thickness Variations

LAMINATE PERFORMANCE

- Test Methods
  - Delamination
  - Fiber-Matrix Interface Strength
- Modelling
  - Delamination
  - Buckling in Compression
- Failure Mechanisms - Resin, Adhesive, Composite
  - Crack-Tip Visualization
  - Toughening
  - Physical Aging

highest rated areas: resin transfer molding and pressure molding (automated press and autoclave/prepreg equipment).

Although research will be conducted with all three methods, limited resources make it important to focus the major thrust on one technique, and resin transfer molding was selected. The program in this area involves a combination of computer modeling and flow visualization for filling of molds with model complexities such as solid inclusions, cut lines, heterogeneous preforms, etc. In the near future, the program will be extended to curing systems with on-line cure monitoring in the mold. Ultimately, the program will investigate on-line process control which the 1987 Workshop identified as a critical long term goal.

Microstructure Characterization

The second task area is Microstructure Characterization. Although it includes features like flaws, voids, and defects, the existing characterization techniques for these features are relatively well developed. Consequently, the NIST program focuses on more localized structure. The work is divided into four areas: resin, fiber, interface, and composite structures. The resin work has developed a technique to characterize the molecular network structure in cross linked thermosets, and this method has been applied to analyze the structure of both model and commercial systems. The method has also been used to determine how the microstructure changes when the samples are macroscopically deformed. This information provides important guidelines for the development of tougher materials. A second project on resins is investigating crystallinity in partially crystalline thermoplastics. Of particular interest is the effect of the fiber surface on the amount and kind of crystallinity.

The second area of study in microstructure determination is gel spun fibers and films. The structure of the gel and the nature of the gelation process are being investigated and related to the performance of the gel spun fiber or film. The third project is investigating microstructure of the glass-resin interface. Neutron reflectance techniques are being used to investigate microvoids and the kinetics of the wetting process on a molecular level for thermoplastic resins. The results are correlated with experimental studies of interface strength. A major reason for the work in the area of interface strength is the high priority it was given in the 1987 Workshop.

The final study in the microstructure area is the investigation of characterization techniques for thick section composites. With the increased interest in thick section structures comes a concern about the possibility of variations in the material through the thickness. A summary of the techniques that have potential to address this problem was conducted.

Laminate Performance

The final task, Laminate Performance, involves work in three areas: test method development, modeling, and failure mechanisms. In the area of test method development, the work has focused on delamination and fiber-matrix interface strength. Both test method development and interface strength were rated as very important topics by he 1987 Workshop.

In association with ASTM and other groups, standard fracture tests are being developed for interlaminar crack growth in composites. Model experiments are also being performed using very thin adhesive bonds to simulate the constraint that the resin sees in a composite when the resin is confined between plies.

In the area of fiber-matrix interface strength, two programs are underway. The first is conducting a comparison of the three most commonly used methods: the fragmentation test, the bead pull-off test, and the indentation test. By testing and comparing results for a series of composites samples specially prepared to have different interface strengths, the advantages and limitations of each method can be assessed. All of these tests, however, require specially prepared specimens. Consequently, a second project is developing a new test that can be applied to prepreg material and real parts. In this method, a laser is used to rapidly heat a very small area, and the differences in thermal expansion coefficient between the resin and the fiber produces high stresses at the interface. This produces cracks, and the cracking process can be monitored by acoustic emission. For stronger interfaces, the detected acoustic emission is much less.

The modeling activity in the Laminate Performance Task supports the test method development work with studies on delamination test geometries and buckling in compression. A new effort is studying the stress fields present in the fiber-matrix interface tests to develop a more quantitative understanding of what these tests are measuring.

The final area of work on Laminate Performance is the study of failure mechanisms in composites and structural adhesives. One program is examining the micromechanics of the crack tip region by using video tape recordings made through a microscope. A second program studies two phase toughened systems. The goal is to understand the toughening mechanisms in terms of the morphology and how it is generated during processing. This was another topic listed as very important by the 1987 Workshop. The final program in this area studies physical aging. The properties of glassy polymers are known to change with time even when chemical degradation is not present. It is important to determining what changes occur and if they affect performance in composites.

Industry Presentations

The program continued with presentations from four industry sectors. The viewgraphs from these presentations are contained in Appendix III. The following sections contain brief summaries of what was said in the presentations and associated discussions.

Automotive Industry

Carl Johnson from Ford reviewed the Automotive Composites Consortium which is an organization formed by Ford, Chrysler, and General Motors under the U.S. National Cooperative

Research Act of 1984. The purpose is to conduct precompetitive research on composites in recognition of the great potential of composites and the significant benefits to be achieved by coordinating fragmented research efforts and leverage existing resources to enhance competitiveness. The focus is on technologically feasible but unproven concepts.

As part of their work, the consortium has identified and prioritized the most important technical challenges for application of composites in the automotive industry, and this provides very useful information for this Workshop. The consortium's program is directed toward structural composites with the primary emphasis on thermosets. Thermoplastics are of interest but need to establish cost effectiveness. The parts being considered are 40% volume fraction reinforcement. This reinforcement is primarily glass fibers although some carbon or arimide fibers may be used for particular applications.

The consortium has selected three critical areas of technology: Processing, Materials, and Crash Energy Management, and organized working groups to address each. In addition there is a demonstration project where the results of the work in the three separate areas will be combined to produce a composite structural part. As part of their studies, the three working groups have prioritized the problem areas in both processing and performance.

The Processing Group has selected liquid molding as the most important processing technology. Liquid molding includes both resin transfer molding (RTM) and structural reaction injection molding (SRIM) which is a high speed version of RTM. The current research program focuses on preform development, joining/certification, and trimming.

The Materials Group is establishing test procedures, setting up a data base, and developing tests for durability. The first two items are nearing completion so the current focus is on the third. In the area of durability the consortium has identified four topics as most important in the automotive industry: impact, fatigue, creep, and environmental attack.

The Crash Energy Management Group is investigating ways to improve the crash worthiness of production feasible composites structure. Crash worthiness is the ability to absorb the impact energy produced by a crash and minimize the effects on the passengers. The Group is identifying the critical parameters and design features, evaluating their importance to crash energy management, developing predictive models, and ultimately demonstrating an effective structure made with the latest processing concepts as part of the focal project.

Electronics Industry

George Schmitt from IBM presented a view from the electronics industry. He expressed the belief that the conclusions of the last Workshop are still valid. In the electronics industry the problems remain the same. Multilayer circuit boards which have up to 40 layers with 20,000 or more interconnections between layers in a 50 cm by 50 cm area are current technology but the density and tolerances are expected to become more stringent in all three directions. This places severe demands on dimensional stability, thermal expansion characteristics, residual stresses, and creep. Other packaging applications are expected to see similar increase in requirements. Operating temperature will continue to rise and the need for better electrical properties--particularly lower dielectric constant--will increase. Thus, materials with superior properties will be needed.

In the processing area, autoclave, resin transfer molding, and flat bed press molding continue to have highest priority. Flow behavior of thermosets as neat polymers and in the composites are important areas that need study. The interface is also an important topic, and this includes polymer-metal, polymer-inorganic, and polymer-polymer interfaces. The magnitude of the challenge can be illustrated with current circuit board technology where the large numbers of layers and interconnections mean that the total area of interfaces is not only extremely complex but also very large even in a modest size board. An obvious consequence is that the closely related topics of joining and bonding are and will continue to be very important.

A comparison of the state of technology now with that three years ago suggests that the rate of introduction of new concepts is more rapid than was believed at the last Workshop. Consequently, scientific areas farther away from production must be considered seriously. Examples are the need for lower loss dielectric constant, tighter control of thermal expansion coefficient, and the introduction of high performance thermoplastics. In addition, the use of optoelectronics for communications and data processing is expected to grow faster than anticipated two and a half years ago, and therefore, this represent an area where research needs to be increased.

Other important areas for further research include process monitoring, particularly on-line techniques, microstructure characterization in composite resins, the relationship of microstructure to performance, and the fiber-matrix interface. Finally, the NIST Workshop on electronic packaging which was held in May of 1990 was timely and appropriate, but there is a need for increased communications between NIST and the electronics industry.

Aerospace

Sam Dastin from Grumman presented an aerospace perspective on the current needs and barriers to composites utilization. The emphasis in aerospace is on high performance materials with fiber volume fractions of 55% and higher. A comparison of the technology today with that two and a half years ago when the first Workshop was held reveals several important changes. These include increased automation in fabrication and NDE, higher processing temperatures and pressures (177°C/0.7 MPa to 316°C/1.4 MPa or 300°F/100 PSI to 600°F/200 PSI), and more complex parts that increase tooling costs. Things which have not changed are the use of autoclave/prepreg fabrication, press molding, and the high cost of materials and labor.

Current aerospace efforts are aimed at reducing costs and increasing performance. A major approach to reduce costs is the investigation of other processing methods such as RTM, thermoforming, filament winding, fiber placement technologies, and matched die compression and pultrusion. To improve performance there is a great deal of interest in toughening for both thermosets and thermoplastics. 3D reinforcement through stitching, weaving, or braiding is also being studied.

Scientific and technical needs include processing science for thick section composites, and improved understanding and control of microstructural features such as fiber-matrix interface strength, voids, and fiber volume fraction. In addition to lower costs, more reliable processing is being sought along with improved NDE. A better understanding of the role of microstructure in failure behavior including compression/delamination in composites and neat resin failure behavior is needed.

A suggested list of processing methods in order of importance was given: autoclave, filament winding, vacuum bag and press molding, thermoforming, injection molding, pultrusion, and RTM. A possible list of current problems and scientific barriers was given: poor impact/delamination resistance, void and porosity formation, high cost materials and processing methods, fiber-matrix interface variability, poor control of fiber volume fraction and orientation, inadequate control of dimensional tolerances, poor property repeatability and validation, and inadequate control of heat flow and morphology.

Some important technologies that complement processing were discussed: surface coating, joining, and automation. Materials suggested as having potential for the future were suggested: high temperature resins (177°C to 316°C or 350°F to 600°F long term exposure), toughened thermosets and thermoplastics, polymer blends, liquid crystal polymers, interpenetrating networks, conductive polymers, and molecular composites.

Data Base / Design

Ed Stanton of PDA Engineering presented the viewpoint of those involved in database development and design. He emphasized the importance and potential impact of the trend toward concurrent engineering and manufacturing. This trend involves integrating the various aspects of the product development, production and maintenance. These aspects include product design, materials selection, manufacturing process development, automation, cost management, repair, maintenance, and nondestructive evaluation. A key barrier to this trend is the lack of adequate data and the absence of an appropriate database structure so the information can be effectively utilized. Three tools are needed to overcome this barrier: materials data generation standards, materials data exchange standards and database systems.

A number of groups are active in the development of materials data generation standards which include not only test method descriptions but also data reporting formats. There are also a variety of efforts on formulating data exchange standards. The goal here is to design standard data reporting formats and/or conversion methods so that different kinds of data and data for different purposes can be integrated into the same data base or exchanged between data bases.

Current efforts seek to exchange data between groups whose missions include processing and manufacturing, materials selection, and finite element analysis.

Another critical area involves software for database systems. The need for new software is complicated by the long lead time required for software development. New databases will need multilayer systems so that many categories of information like material, specimen, environment, source, etc can be adequately specified. Inclusion of appropriate qualifying information (sometimes called meta data) is particularly important in composites. The software must also be more user friendly. Finally, the new software must be able to handle information such as graphical and image data. Current programs are only beginning to address these issues.

There are a number of types of information that are very useful for a concurrent engineering approach but are not usually included in current databases. New ways to deal with this information are needed. A good example is scale up information on test specimen results. If such results are to be used in design, it is vital to know if the information is independent of test specimen size. Another area is repair and maintenance data along with the appropriate information on NDE techniques. Recycling data would also be very useful in developing designs, as would health and safety data. Since information of this type is critical for concurrent engineering, a way must be found to make it available.

DISCUSSION

Following the industry overviews, the first questionnaire was distributed, and while attendees filled it out, presentations were made on six NIST projects related to processing science. These presentations will not be described here, but are covered in the Polymer Division's Annual Report.[9] The remainder of the meeting was then directed to a general discussion of the three questions the Workshop was asked to address. The results of the questionnaire formed the basis for the discussions. Before summarizing this portion of the meeting, however, it is useful to describe the method used to evaluate the questionnaires.

Questionnaire Analysis

The results from the questionnaire provide a good representation of the discussion and consensus in the Workshop. The questionnaires were evaluated with a point system. Each attendee was asked to rank in order of importance the answers to each question. Multiple answers could be given the same rank if they were equally important. The first place ranking for each question was given 4 points while the second place received 3 points, the third place 2 points, and the fourth place 1 point. The total points for each answer was then divided by the maximum points possible (i.e. if ranked number one by everybody) and multiplied by 100. This produced a scale which ranged from 100 to 0 where 0 indicated no one ranked the item in their top four. Since the questionnaire contained information on which industry sector the respondent represented, the results could be analyzed for differences between specific industries as well as general trends. The Workshop composition permitted examination of four industries: automotive, electronics, aerospace, and marine. Because the number of respondents in each sector is limited, the industry specific analysis is regarded as qualitative. Nevertheless, the results are quite informative.

Processing Methods

The first issue addressed in the discussion was the selection of the most important processing method. A suggestion was made that the category of resin transfer molding be expanded to include related processes such as structural RIM (SRIM). Such fabrication methods are very closely related, share the same problems, and are appropriate to consider together. The term liquid molding was recommended as a more inclusive term. This change was made and is reflected in Table IV which summarizes the results of the first questionnaire.

An analysis of the results by industry sector indicates that automotive listed liquid molding

Table IV: Processing Methods	
Method	Score
Pressure Molding	84
Liquid Molding	82
Filament Winding	39
Thermoforming	29
Pultrusion	21

as most important method with pressure molding a second. Electronics listed press molding as the dominate area, but expressed interest in autoclave (pressure molding) and liquid molding as well. Aerospace listed autoclave as first but other methods, particularly liquid molding, were listed quite high. Marine also had a broad range of interests in all methods but listed pressure molding and liquid molding highest.

The general list of priorities is almost identical to that obtained at the last Workshop. Only two changes of any significance were noted. First, there was considerably more interest in fabrication by press under the category of pressure molding. Although led by the electronics industry, other sectors also expressed a stronger interest in this method than they did at the last Workshop. The second difference is the relative importance given to the top two ranked items, pressure molding and liquid molding, relative to the method ranked third. At the last Workshop pressure molding and liquid molding were clear winners, but now the advantage over the third place method is even greater than before. The high ranking given to these two methods reflects the fact that a broad range of industries considers them very important. The increased interest in press molding mentioned above is one example. Moreover, both the aerospace and marine industries expressed interest in a broader range of methods than was the case two years ago and liquid molding and press molding receiving much of the increased attention. In the last survey aerospace ranked transfer molding as 10th and liquid molding was not listed at all. This time liquid molding ranked a close second. The potential cost advantages of these methods obviously pays a major role here.

Scientific and Technical Barriers

The second item discussed was the scientific and technical barriers to utilization of improved processing methods. The results of questionnaire one are shown in Table V.

Table V: Processing Barriers	
Barriers	Score
Resin Flow / Fiber Orientation	69
Process Monitoring and Control	52
Fiber-Matrix Interface	44
Data Validation / Test Standards	33
Morphology Understanding and Control	28
Surface Quality / Dimensional Tolerance	23
Heat Flow	21

An analysis of the results by industry indicates that aerospace rated the first four topics in this order while electronics rated the first two in this order but lists fiber-matrix adhesion, morphology, and surface quality/dimensional tolerance as tied for third. Automotive listed resin flow/fiber orientation as one, surface quality/dimensional tolerance as two, data validation/test standards as three and process monitoring and control as four. Marine listed process monitoring and control as one, fiber-matrix adhesion as two and resin flow/fiber orientation as three.

The results here were very similar to those in the last Workshop including the interest of automotive and electronics in surface quality and dimensional tolerance. There were, however, two important changes. First, heat flow and temperature gradients fell from number two to number seven. One possible explanation for this is that improvements in modeling capabilities have made the prediction of heat flow more accurate and reliable than it was two years ago. The second major change was the inclusion of process monitoring and control as a separate item rather than have it included implicitly as was done last time. The reason for this was that the technology had developed to the place where it is now useful to address this topic directly. When listed in this way, every industry sector rated it as either first or second in importance.

An important point mentioned several times during the discussion was the trend toward more complex parts. Current production often involves fabrication of large, three-dimensional components. In addition, there is much interest in thick section composites (25 cm or more) for a number of applications. This increase the need to address the barriers above both because the processing is more complex and the costs associated with failure are far greater.

Detailed Analysis of Barriers

After an overall ranking of the barriers, the questionnaire asked attendees to explore the importance of specific topics related to each barriers. The following section provides a summary of the results from the questionnaire and associated discussions during the meeting.

Resin Flow / Fiber Orientation

The item in this category listed as most important was void formation followed closely by fiber wetting and fiber alignment and control. A note was made by the automotive industry that a major cause of void formation was inadequate mold filling and improper edge and corner flows. These three items were ranked at the top by all industry sectors, but aerospace had less interest in fiber wetting while electronics and marine placed less importance on fiber alignment and control. This is understandable since the aerospace emphasizes autoclave processing where fiber wetting is the prepregger's problem and electronic and marine applications often have less need for high strength and stiffness that requires careful fiber alignment and control.

The attendees also discussed the need to include testing of high viscosity fluids in research programs in addition to measuring the lower viscosity materials normally used. The motivation for this is the increasing interest in cyclic oligomers, thermoplastics (particularly for filament winding), high temperature resins, and processing by thermoforming since each case involves higher viscosity flows. There is also a trend toward larger and more complex parts which combined with the interest in higher viscosity materials means significant increases in processing pressures. There are few studies in this area. Finally, the importance of resin flow in void removal was discussed. It is not always possible to prevent void formation, and consequently, void removal by flow can be very important in some applications.

Process Monitoring and Control

The overwhelming choice by all industry sectors as the most important item in this category was monitoring sensors. This includes the development of new sensors, but an even more important point here was the need to make the sensor smaller and less perturbing to the part and to make the sensor and electronics more rugged to facilitate moving the technology to the factory floor. Another important aspect of monitoring sensors is the need for a better understanding of what they are measuring and how the results can be converted into information useful for process control. It was somewhat surprising that this item was ranked so highly. One possible reason is that most of the on-going programs in industry, research laboratories, and universities are not addressing this area. These efforts generally use existing sensors and focus on the development of models and process control technology. Thus, monitoring sensors was seen as a technology gap.

Fiber-Matrix Interface

Two items were ranked equally high in this category: test methods and surface treatments.

Current interface test methods were considered difficult to use and interpret and not developed to the point where clear correlations with composite properties have been established. More research in this area was recommended. Surface treatment of fibers was also considered a problem area since there are gaps in understanding the factors which determine wetting and adhesion at the fiber matrix interface and little ability to control these factors during processing. The Workshop also felt that there was a need to develop a better connection between the fiber-matrix bond strength in a composite and the consequences of this in composite performance.

Data Validation / Test Standards

Test data and standards for performance properties were listed as the top priority by all industrial sectors. This was followed by tests for quality control and acceptance. Viscosity data and degree of cure tests were tied for third. The latter topics were more highly ranked by marine and electronics industries than be other sectors. Electronics also ranked residual stresses as a major concern. The discussion raised a number of specific areas where improvements were needed. These include a better classification system for composites, better information of scale-up from coupon tests, improved sample selection guidelines, more data on the influence of processing variables, and a better way to include such information in a database. It was concluded that there was a clear lack of good data on well characterized composites.

Morphology

In morphology the item of toughening received the overwhelming vote as most important followed by phase separation and crystallinity. This is a reflection of the fact that every industry sector listed toughening as highest priority. The interest in crystallinity was strongest in aerospace and automotive.

Surface Quality / Dimensional Tolerance

In this area the priorities were spread equally over a range of topics including creep and stress relaxation, thermal stresses, and cure shrinkage. The physics of a class A finish was mentioned as an item that is not understood and needs work.

Heat Flow

The item ranked as most important here was residual stress with resin kinetics a close second. Thermal conductivity ranked next followed by temperature gradients. Variations among the different industry sectors was minor.

Technologies that Complement Processing

The Workshop discussed the technologies that complement processing and identified a number of areas that had not been mentioned either at the previous Workshop or in suggestions offered on the meeting registration forms. Consequently, a second questionnaire which included these new technologies was developed and completed by mail. For several of the technologies, a number of specific topics were listed, and attendees were invited to indicate if they considered any of these topics to be particularly important. The results of the questionnaire are given in Table VI. For those cases where a number of attendees indicated a high degree of interest in a specific topic for a technology, these topics are also included in the Table.

Table VI: Technologies that Complement Processing

Technology	Score
Fiber Placement	53
Prepreg Preparation Powder Prepregging Commingled Fibers	47
Joining Adhesive Bonding	40
Preform Preparation	33
Recycling	23
Environmental Safety	21
Tooling	21
Alternate Sources of Energy Microwave Heat Assisted Fiber Placement	17

The highest ranked technology is fiber placement. This refers to an advancement on filament winding in which a number a toes are applied simultaneously. Each toe has its own pressure roller that positions and attaches it to the part using either tack (thermosets) or on-line consolidation (thermoplastics). This makes it possible to do complex shapes with concave regions and other desirable features. The individual toes can be cut and stopped or restarted when desired during processing. The result is a very versatile and rapid fabrication process. The second technology is alternate forms of prepreg preparation. This includes a number of new technologies, but the attendees selected powder prepregging and commingled fibers as particularly important. Joining is the technology rated third. Joining can mean thermoplastic welding, adhesive bonding, mechanical fasteners, etc. A number of attendees singled out adhesive bonding as particularly important for the future. The technology ranked fourth was preform preparation which includes trimming, stitching, braiding, etc as well as automation of these processes. This technology was followed by recycling, environmental safety, and tooling in the list of priorities. The final technology listed was alternate sources of energy. A number of examples were discussed during the Workshop, but the responses to the questionnaire gave special attention to microwave radiation and heat assisted fiber placement.

Relative to the results in the 1987 Workshop, the major difference is the increased number of technologies with high interest. Only two topics, prepreg preparation and alternate sources of energy, were chosen in 1987. A detailed analysis for specific industry sectors indicates that the top four aerospace priorities were in agreement with this list. The highest rated automotive items differ in that preform fabrication was listed number one and recycling was rated number four instead of prepreg preparation. Electronics ranked prepreg preparation, joining, and alternate sources of energy as top priorities. In the list for marine, preform preparation was not ranked highly while fiber placement, environmental safety and tooling were.

The high ranking given to preform fabrication by the automotive sector was expected although some attendees from this sector rated it rather low. Perhaps, this reflects the difference between those interested in primary structure applications and those involved in sheet molding compound for body panels. A high rating was given to recycling by both automotive and marine, but this was counterbalanced by aerospace where everyone rated this topic quite low. This is understandable in light of the production volumes involved for the different industries.

Materials with Potential for the Future

The Workshop also discussed material systems that have potential for the future and therefore should be watched closely. Everyone agreed that thermosets are very important today and will continue to be widely used in the future. Some attendees felt that thermoplastics (TPs) were also viable candidate materials at present, while others believe the cost effectiveness of TPs is sill unproven. There was general agreement, however, that TPs had great potential. Both amorphous and partially crystalline TPs were considered and no distinction was made during the discussions.

In addition to TPs, four other material systems were identified as having great potential. All five are listed in Table VII. The first three were included in the initial questionnaire and the ranking by attendees was equally distributed among them. During the discussions, two additional items were added. These items were also considered as very important so no effort was made to prioritize this list.

The term smart materials was used to designate a variety of material systems which are either active, i.e. piezoelectric, pyroelectric, etc., or contain built-in sensors, i.e. fiber optics, piezoelectric layers, etc. The category of specialized polymer systems includes blends, interpenetrating networks, cyclic oligomers, etc. Such systems have the potential for significantly

Table VII: Materials with Potential for the Future
Liquid Crystal Polymers
Thermoplastic Polymers
Molecular Composites
Smart Materials
Specialized Polymer Systems

improved properties relative to simple polymers. The area of molecular composites was also discussed, and it was concluded that they have much potential but cost and processing difficulties present barriers to their use. Finally, liquid crystal polymers were considered, and there was much excitement about their potential to build-in specific properties, i.e. anisotropy generated by controlled molding. The ability to obtain excellent properties in one direction, however, can be compromised if the properties on other directions are poor. A better understanding of these materials and their processing was viewed as the key to realizing their potential.

Performance Properties

The final issue addressed by the Workshop was performance properties. The list of possible problem areas included on the questionnaire began with the four topics identified by the Automotive Composites Consortium and then added items known to be of interest to aerospace and electronics as well as topics suggested by attendees on their registration forms. Table VIII shows the results from the questionnaire for the seven topics rated as most important.

A detailed analysis by industry sector shows that automotive listed impact and environmental effects as one and two while thermal stability was third and dimensional stability forth. Electronics listed environmental effects first with impact and dimensional stability tied for second. Thermal stability tied delamination for fourth. Aerospace listed delamination as first while electronics listed it as fourth. This is the main reason delamination appears so high since others ranked it quite low. Aerospace listed impact as second, environmental effects as third, and dimensional and thermal stability as tied for fourth. Marine listed fatigue and impact as first with creep and environmental effects tied for third.

Table VIII: Performance Properties	
Property	Score
Impact	61
Environmental Effects	57
Delamination	43
Dimensional Changes	43
Thermal Stability	31
Fatigue	27
Creep	21

The results showed impact (which probably includes crash worthiness for automotive) and environmental effects as high priorities for all industry sectors. Beyond that the need depended on the industry. In aerospace the overriding concern was delamination; in electronics it was dimensional stability, and in marine, it was fatigue. There was also concern in a number of industries about creep, particularly for applications using thermoplastics, and thermal stability in applications where dimensional stability (thermal expansion) or high temperature are important. The discussion suggested, however, that these differences between industries may become less important as time passes. For example, the reason fatigue was not ranked higher in automotive and aerospace is that the designs are now dominated by crash worthiness and delamination. Once these problems are solved, fatigue may become an important concern. The discussion also emphasized the importance of processing in determining the microstructure that controls performance. The lack of understanding in this area was considered an important problem.

CONCLUSIONS

Two processing methods were selected as by far the most important fabrication techniques for the future: pressure molding and liquid molding. Pressure molding was defined to include flat bed press molding, compression molding, and autoclave molding. The term liquid molding was used to describe resin transfer molding (RTM) and structural reaction injection molding (high speed RTM).

The marine industry expressed a broad range of interests, while automotive's primary focus is liquid molding, aerospace's is autoclave molding, and electronic's is press molding. Surprisingly, however, all industry sectors expressed interest in a variety of pressure and liquid molding techniques.

Three additional processing methods were identified as being important for the future: filament winding, thermoforming, and pultrusion.

Seven scientific and technical barriers to the full exploitation of the processing methods outlined above were identified. The highest priority was the need to understand and control resin flow and fiber orientation. The importance of resin flow was associated with the problems of void formation, mold filling, and edge and corner flows. In connection with fibers, the major concerns were fiber wetting, fiber alignment, and orientation control.

The second highest priority barrier was the need for process monitoring sensors for on-line process control. This included the development of new techniques and the improvement of existing methods. Current sensors and electronics need to be made more rugged to operate effectively on the factory floor, and the output of the sensors must be better understood and more closely linked to process control.

The third highest ranked barrier was the need to understand and control the fiber-matrix interface. Of particular concern is the area of test methods where current techniques are difficult to use and interpret, or not developed to the point where clear correlations with composite properties exists. Another area where it was felt that more understanding was needed was surface treatment.

Data validation and testing standards was another area that needed more study. Measurements related to performance were a particular concern, but quality control testing was also of great interest. Measurement of viscosity and degree of cure were particularly important here since the focus was processing.

The inability to determine the optimum morphology and achieve it during processing was another area of great concern. All industry sectors felt this was important since morphology often plays a significant role in toughness. The aerospace and automotive industries also expressed a concern about the control of crystallinity in partially crystalline thermoplastics.

The sixth most important barrier was the inability to adequately control surface quality and dimensional stability. Although all industry sectors had concerns in this area, automotive and electronics rated this area as second and tied for third respectively in their priority lists.

The final barrier selected was heat flow. This area was second on the priority list generated at the 1987 Workshop. This change may be due to the improvements that have occurred during the past several years that now make modelling of heat flow easier and more accurate.

The Workshop also identified and prioritized eight technologies that complement processing and are important for the future. The two highest ranked items were fiber placement and new methods to prepare prepreg. i.e. powder prepregging, commingled fibers, etc. Joining was listed as third, and although both adhesive bonding and mechanical fasteners were mentioned, the former received by far the most attention. Preform preparation was listed next primarily on the strength of the number one ranking given by automotive. Recycling, environmental safety and tooling were listed next in that order. As might be expected, the greatest interest in these topics was for mass production markets, i.e. automotive and marine. Alternate sources of energy, which includes microwave heating, heat assisted fiber placement, etc., was ranked eighth but had several strong supporters in electronics and marine.

The majority of people at the Workshop felt that thermosets were still the dominant resin system in their applications. A number of attendees, however, were actively engaged in thermoplastic development and everyone felt these materials had great potential for the future if their cost effectiveness could be established. Thermoplastics were therefore classified as a material to be watched closely for future development. Four other classes of materials were also included on this list: liquid crystal polymers, molecular composites, smart materials, and specialized polymer system. Smart materials include systems with either built-in sensors or active components such as piezoelectric layers. Specialized systems include blends, interpenetrating networks, cyclic oligomers, etc. The last two categories were not on the this list at the Workshop three years ago and represent new technologies. In addition, the interest in liquid crystal polymers was somewhat greater than it was three years ago.

The Workshop also selected seven performance issues that they felt were critical to the future use of composite materials. In order of priority they are: impact, environmental attack, delamination, dimensional changes, thermal stability, fatigue, and creep. For the highest ranked topics there was a surprising consensus with all industry sectors ranking impact and environmental attack in their top three items. For automotive impact included crash worthiness. Beyond this point, the priorities differed for each industry. Aerospace listed delamination as their highest priority and dimensional changes as fourth. Automotive added thermal stability and dimensional changes as third and forth. Electronics was similar to automotive with slight differences in ordering. Marine listed fatigue and impact as first with creep and environmental attack as tied for third. The differences generally reflect one or two overriding concerns for the particular application, for example, delamination in aerospace. As these concerns are successfully addressed, other problem areas will become more important, i.e. fatigue will become more of a concern to aerospace if and when the delamination problem is solved.

REFERENCES

1. Department of Commerce, "Emerging Technologies - A Survey of Technical and Economic Opportunities," 1990.

2. Aerospace Industries Association, "Key Technologies for the 1990s," 1988; and "Key Technologies for the 1990s Targeted," C&EN, p. 18, January 4, 1988.

3. "Technologies Vital to U.S. Defense Selected," C&EN, p. 24 & 24, April 3, 1989.

4. A. Naj, "U.S. Loses Edge in Composite Materials," Wall Street Journal, December 26, 1989.

5. "Study sees High-Volume Advanced Composites Use in 1990s," Advanced Composites, p. 18 & 20, September/October, 1988.

6. J. McDermott, "Assessing the Advanced Composites Market," Advanced Composites, p. 47-52, March/April, 1988.

7. "Fabrication 70 percent of Cost for Advanced Composites," Advanced Composites, p. 12, July/August, 1988.

8. P. Beardmore, and D. Hunston, "Polymer Composite Processing, an Industry Workshop," NBSIR 87-3686, National Bureau of Standards, Gaithersburg, MD, February, 1988.

9. "Polymers: Technical Activities 1989," Polymers Division, National Institute of Standards and Technology, NISTIR 89-4150, 1990.

APPENDIX I: ATTENDANCE LIST

Mark Alberding
Martin Marietta
Aero and Naval Systems
103 Chesapeake Park Plaza
Mail Point 95
Baltimore, MD 21220

Paul Biermann
Johns Hopkins University
Applied Physics Laboratory
Johns Hopkins Road
Room 14-704
Laurel, MD 20723

David Boll
Hercules Corporation
P.O. Box 98
MS 8193
Magna, UT 84044

Jose Castro
GenCorp Research
2990 Gilchrist Road
Akron, OH 44305

Samuel Dastin
Grumman Aircraft
Systems Division
Stewart Avenue
MS B44-35
Bethpage, NY 11714

John DeLong
BF Goodrich
9921 Brecksville Road
Brecksville, OH 44141

LaMar Hill
Automated Dynamics
105 Jordon Road
Troy, NY 12180

Ray D. Hoffman
Aristech Chemical Corporation
1000 Technical Center Drive
Monroeville, PA 15146

Benjamin S. Hsiao
E. I. DuPont
P.O. Box 80302
Experimental Station
E302/212
Wilmington, DE 19880-0302

Mahammad Ibrahim
Martin Marietta Laboratories
8001 Mayfield Avenue
Baltimore, MD 21227

Carl Johnson
Ford Motor Company
2000 Rotunda Drive
S-2046
Dearborn, MI 48124

Ronald G. Kander
E. I. DuPont
P.O. Box 80356
Experimental Station
Wilmington, DE 19880-0356

Arnold Lustiger
AT&T Bell Laboratories
600 Mountain Avenue
Room 7E-207
Murray Hill, NJ 07974

Kevin McAlea
General Electric Corporate
Research and Development
1 River Road
P.O. Box 8, K-1 4B24
Schenectady, NY 12301

Kostas Papathomas
IBM
1701 North Street
T22/257-2
Endicott, NY 13760

James Reynolds
ICI Composites, Incorporated
2055 E. Tech. Circle
Tempe, AZ 85284

George Schmitt
IBM
T22-257-2
1701 North Street
Endicott, NY 13760

Martin Schneider
Construction Technology Division
1062 Lancaster Avenue
Rosemont, PA 19010

C. Robert Shertzer
Hercules Incorporated
Research Center
EPTC Building
Wilmington, DE 19894

Anthony Smiley
ICI Composite Structures
DCI 1-3
Wilmington, DE 19897

Ed Stanton
PDA Engineering
2975 Red Hill Avenue
Costa Mesa, CA 92626

Jeffrey Strank
Martin Marietta
Aero and Naval Systems
103 Chesapeake Park Plaza
Mail Point 95
Baltimore, MD 21220

Noel Tessier
Emerson & Cuming
59 Walpole Street
Canton, MA 02021

Martin Wai
DOW-UTCP
975 Oronoque Lane
Stratford, CT 06497

Paul Weitz
Technology Catalysts, Incorporated
605 Park Avenue
Falls Church, VA 22046

Roger Wright
Industrial Fiberglass
Specialties, Incorporated
4867 Chambersburg Road
Dayton, OH 45424

NIST and Outside Observers:

Stanley Wolf
Department of Energy
1000 Independence Avenue, S.W.
CE 232
Washington, DC 20585

Ray G. Kammer
Deputy Director
Administration Building
Room A1134
Gaithersburg, MD 20899

Lyle H. Schwartz, Director
James G. Early, Scientific Advisor
Daniel B. Butrymowicz, Scientific Advisor
Materials Science and Engineering Laboratory
Materials Building
Room B309
Gaithersburg, MD 20899

Leslie E. Smith, Chief
Shu-Sing Chang
Martin Chiang
Andrea Hampe
Donald Hunston
Freddy Khoury
Walter McDonough
Richard Parnas
Frederick Phelan
John Tesk
Francis Wang
Wen-li Wu
Polymers Division
Polymers Building
Gaithersburg, MD 20899

APPENDIX II: QUESTIONNAIRES

Copies of two Questionnaires

used to determine Workshop Priorities

FIRST QUESTIONNAIRE

2nd INDUSTRY WORKSHOP ON POLYMER COMPOSITE PROCESSING
NIST
May 18, 1990

Are you a SUPPLIER ____________________ or USER ______________

Which industry sector(s) can you respond for

1. Aerospace _______ 4. Construction ________
2. Automotive _______ 5. __________ ________
3. Electronics _______ 6. __________ ________

I. SURVEY OF SCIENTIFIC AND TECHNICAL BARRIERS

Please rank the major barriers in order of importance to your industry or the industry you supply (most important item marked as 1, etc.). You can respond for more than one industry if you like.

		Industry	Industry
INDUSTRY (USE # ABOVE IF RESPONDING FOR MORE THAN 1)	------------→	________	________
NEED TO UNDER-STAND MEASURE AND PREDICT	Resin Flow and Fiber Orientation	________	________
	Heat Flow Conductivity, Gradients, Exotherms	________	________
	Fiber-Matrix Adhesion	________	________
	Data Validation, Test Standard-ization, QC, Acceptance Testing, etc.	________	________
	Morphology Crystallinity, Multiphase Toughened Systems, etc.	________	________
	Surface Quality/ Dimensional Tolerance	________	________
	Process Monitoring & Control	________	________
	Other ________________	________	________
	________________________	________	________

II. REFINE SCIENTIFIC AND TECHNICAL BARRIERS

For each Barrier that you listed as high priority above, please rank the subtopics in order of importance (highest as 1). Use a separate ranking for each barrier. Feel free to add any additional items that are not already listed.

	Industry ______	Industry ______
<u>NEED TO UNDERSTAND & CONTROL</u>		
Resin Flow and Fiber Orientation		
Void Formation	______	______
Fiber Wetting	______	______
Edge and corner flows	______	______
Fiber Alignment & control	______	______
Fiber wash	______	
______________________	______	______
______________________	______	______
Heat Flow		
Thermal conductivity	______	______
Reaction kinetics	______	______
Crystallization kinetics	______	______
Temperature gradients	______	______
Residual stresses	______	______
______________________	______	______
______________________	______	______
Fiber-Matrix Adhesion		
Test methods	______	______
Material type ___________	______	______
Surface treatment	______	______
Surface topography	______	______
______________________	______	______
______________________	______	______
Data Validation, Test Standardization		
Viscosity	______	______
Resin cure kinetics	______	______
Performance properties		
Quality control & acceptance	______	______
Residual Stress	______	______
Degree of Cure	______	______
______________________	______	______
______________________	______	______

Morphology

Phase separation

Multi-phase morphology

Toughening

Amount of crystallinity

Type of crystallinity

Surface Quality/Dimensional Tolerance

Creep

Thermal stresses

Cure shrinkage

Process Monitoring & Control

Monitoring Sensors

Prediction Models for

Controls Models for

Other

III. SURVEY ON PERFORMANCE ISSUES

	Industry	Industry
	______	______
Impact	______	______
Environmental (Moisture, UV, etc.) Effects	______	______
Creep	______	______
Fatigue	______	______
Delamination	______	______
Dimensional Changes	______	______
Thermal Stability	______	______
____________________	______	______
____________________	______	______

IV. UPDATE OF PROCESSING METHODS AND OTHER CONCLUSIONS FROM LAST WORKSHOP

In addition to the technical barriers, the last Workshop identified the important processing methods, several technologies that compliment processing, and materials potentially important for the future (see list below). Do you see any important changes in priority or significant additions or deletions to this list? If so please indicate this below.

<u>Processing Methods</u>

Methods	Rank
Pressure Molding Compression Molding Autoclave Molding	1
Resin Transfer Molding	2
Filament Winding	3
Thermoforming	4
Pultrusion	5

<u>Important Technologies that Compliment Processing</u>

Alternate Sources of Energy
Microwave, Laser, etc.

Resin Coating of Fibers
Powder impregnation, commingled fibers, etc.

<u>Potentially Important Materials for the Future</u>

Thermoplastics

Molecular Composites

Liquid Crystalline Polymers

SECOND QUESTIONNAIRE

NIST Workshop Survey

We would appreciate your help in completing our survey by indicating your opinions on the technologies that compliment processing. The results will not be attributed to a person or company so you can respond freely. Please return the completed form to:

Donald Hunston
National Institute of Standards and Technology
Polymers Division, Bldg. 224/Room A209
Gaithersburg, MD 20899

Are you a SUPPLIER ________________ or USER ______________________

Which industry sector(s) can you respond for

1. Aerospace ____________		4. Construction	______________
2. Automotive ___________		5. ____________	______________
3. Electronics __________		6. ____________	______________

SURVEY OF TECHNOLOGIES THAT COMPLEMENT PROCESSING

Please rank the technologies in order of importance to your industry or the industry you supply (most important item marked as 1, etc.). <u>In the first 4 items, circle any subtopic that you consider particularly important</u>. You can respond for more than one industry if you like. Please feel free to add any comments you like in margins or on back.

	Industry	Industry
INDUSTRY (USE # ABOVE IF RESPONDING FOR MORE THAN 1) ----------------	________	________
Alternate sources of energy: Microwave, heat assisted fiber placement, etc.	________	________
Fiber-polymer preparation: Powder prepregging, commingled fibers, etc.	________	________
Joining: Adhesive bonding, mech. fastening, etc.	________	________
Preform preparation: Trimming, stitching, etc.	________	________
Environmental and safety issues	________	________
Recycling	________	________
Fiber placement technology	________	________
Braiding	________	________
Tooling	________	________

A full report describing the workshop will be distributed to you in about three months, but meanwhile some people have requested copies of the viewgraphs. If you would like a copy of the viewgraphs, please list your name here.

____

APPENDIX III: INDUSTRY VIEWGRAPHS

Copies of Viewgraphs from
Industry Presentations by

C. F. Johnson, Ford Motor Company

G. Schmitt, IBM

S. Dastin, Grumman Aircraft

E. Stanton, PDA Engineering

Industry Update: Automotive

C.F. Johnson

Ford Motor Company

Dearborn, MI

AUTOMOTIVE
COMPOSITES CONSORTIUM

Ford

GM

Principal Objective

To establish joint research programs between Chrysler, Ford, and General Motors on structural polymer composites in pre-competitive areas that leverages existing resources and enhances their competitiveness.

Background

- Composite materials technology is an area of great potential but clearly needs further development

- Cooperative activities focus the fragmented research in this area

Guidelines

- Research must be out of the product cycle
- Technology developed should be feasible for eventual production application
- Research sites determined as a function of capability
- Share facilities, people and information, coordinate existing dollars

Structure

- Joint R&D partnership (Chrysler, Ford, General Motors)

- Legal protection under the U.S. National Co-operative Research Act 1984

- Equal funding of projects

- Royalty free licensing to partners and their majority owned subsidiaries

- Partnership has a maximum life of 12 years

ACC Programs

- The ACC is **only** concerned with:
  - pre-competitive research and development
  - structural composites and **not** with surface critical parts

Board of Directors

CHRYSLER

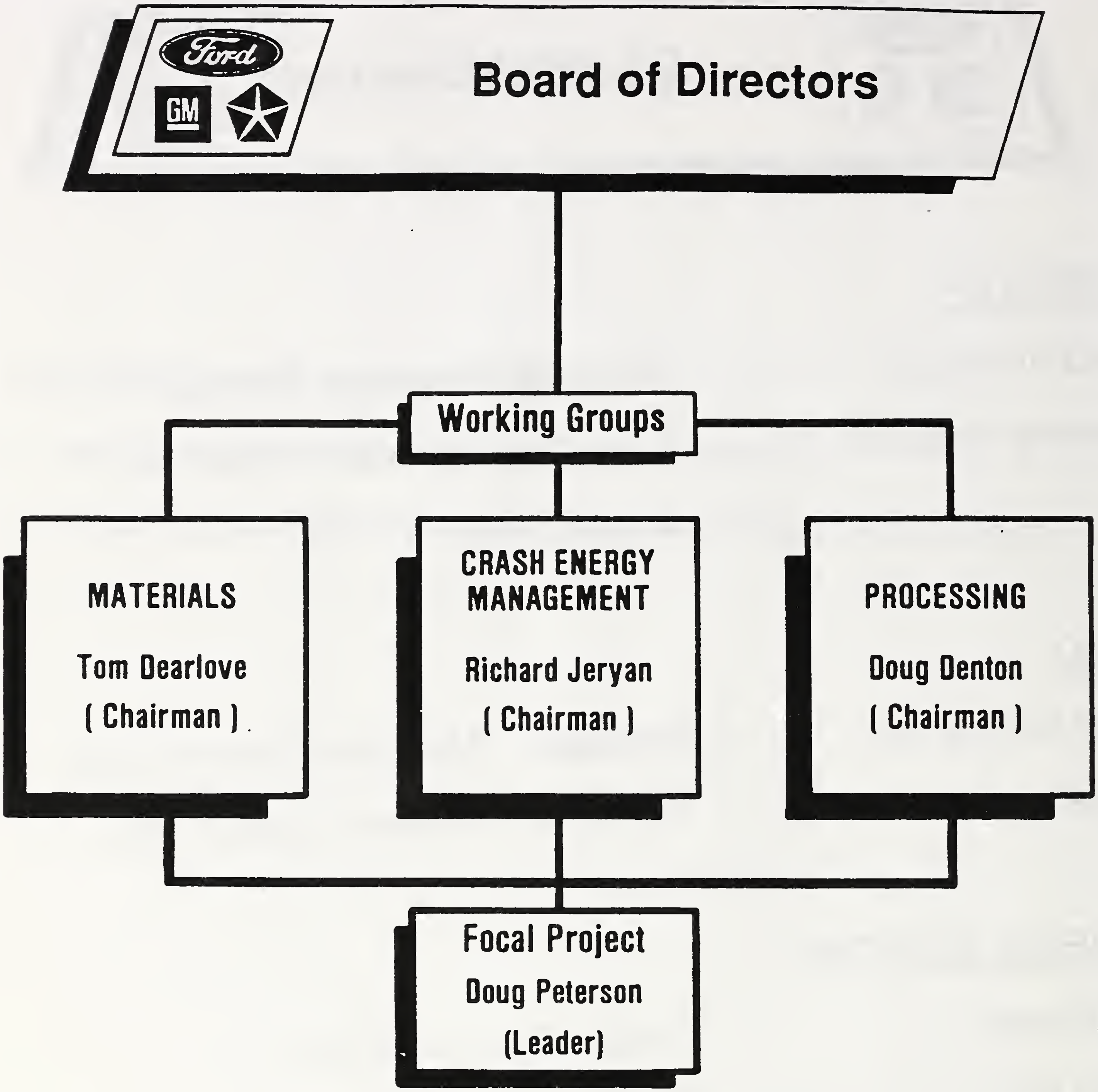
Saad Abouzahr	Technical Programs Manager
Bernard Swanson	Executive Engineer – Materials Engineering

FORD

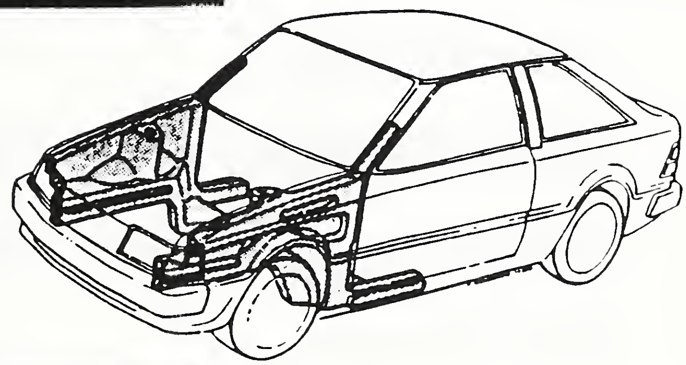
Peter Beardmore	Manager – Materials Science Dept.
Richard Kowalske	Manager – Chassis System Dept.

GENERAL MOTORS

Elio Eusebi	Head – Polymers Dept.
Jamie Hsu	Director – Power Train & Components Mfg.


Ford
GM
Board of Directors
Working Groups
MATERIALS
Tom Dearlove
(Chairman)
CRASH ENERGY MANAGEMENT
Richard Jeryan
(Chairman)
PROCESSING
Doug Denton
(Chairman)
Focal Project
Doug Peterson
(Leader)

Composite Structure



Processing Work Group

CHAIRMAN:

Doug Denton	-	Chrysler

MEMBERS:

Norm Chavka	-	Ford
Mike Czaplicki	-	Ford
Claude Di Natale	-	GM
Carl Johnson	-	Ford
Mike Mao	-	Chrysler
Dean Perelli	-	GM
Doug Peterson	-	Chrysler
Barb Stevens	-	GM
Nippani Rao	-	Chrysler

Processing Work Group

Goal and Scope

GOAL: Develop and demonstrate processing technology capable of producing reliable structural composite parts in high volume at a competitive cost.

CURRENT SCOPE: Liquid Molding Process (RTM/SRIM)

Materials Working Group

CHAIRMAN:

Tom Dearlove	-	General Motors

MEMBERS:

Greg Bretz	-	Ford
Doug Denton	-	Chrysler
Ed Hagerman	-	General Motors
Carl Johnson	-	Ford
Norm Kakarala	-	General Motors
Jean Lynn	-	Chrysler
Doug Peterson	-	Chrysler

Materials Working Group

Goal and Objectives

GOAL: A common automotive "database" containing comparable information on structural composite materials.

OBJECTIVES:

- Develop a test procedures manual to guide the measurement of key composite properties for structural analysis
- Set up an ACC database
- Develop test conditions and methods for durability

Energy Management Working Group

CHAIRMAN:

Richard Jeryan	-	Ford

MEMBERS:

Mark Botkin	-	GM
Doug Denton	-	Chrysler
Larry Lalik	-	Chrysler
Bob Frutiger	-	GM
Doug Peterson	-	Chrysler
Dave Schmueser	-	GM
Peter Thornton	-	Ford
Ron Wlosinski	-	Ford

SUPPORTERS:

Norm Chavka	-	Ford
Mike Czaplicki	-	Ford
Dan Houston	-	Ford
Barb Stevens	-	GM

Energy Management

Goal

Develop and demonstrate the technology required to apply **production feasible** structural composites in energy management applications.

ACC FOCAL PROJECT

Goals and Objectives

GOALS:

- Coordinate relevant activities and technical directions of the Processing, Energy Management and Materials Working groups.

- Showcase Energy Management design features and parts utilizing the latest Processing concepts

OBJECTIVES:

- Build the ACC Composite Front End

- Demonstrate acceptable structural and energy management characteristics while using a manufacturable preform configuration

Industry Update: Electronics

G. Schmitt

IBM

Endicott, NY

ELECTRONIC PACKAGING

STATUS AT THE TIME OF THE N.I.S.T. WORKSHOP IN OCT. 1987

---

* BETTER UNDERSTANDING OF POLYMER RESPONSE TO PROCESSING:

  . FLOW DURING THERMOSETTING CURE
    - NEAT RESIN
    - COMPOSITES

  . POLYMER COMPOSITE INTERFACES
    - POLYMER - METAL
    - POLYMER - INORGANIC
    - POLYMER - POLYMER

* FUTURE REQUIREMENTS

  . TIGHTER SPACING (X, Y, Z)
  . HIGHER OPERATING TEMPERATURE
  . BETTER ELECTRICAL PROPERTIES

ELECTRONIC PACKAGING
STATUS AT THE PRESENT TIME

* MAJORITY OF REQUIREMENTS ARE STILL THE ONES NOTED IN 1987
  - POLYMER FLOW
  - POLYMER COMPOSITE INTERFACES

* FUTURE IS CLOSER THAN WE REALIZED.
  - HIGH PERFORMANCE THERMOPLASTICS
  - THERMOPLASTIC COMPOSITES
  - LOW LOSS DIELECTRICS
  - TIGHTER CTE CONTROL

* OPTOELECTRONICS
  - COMMUNICATION
  - DATA PROCESSING

* SUMMARY
  - CONTINUE AUTOCLAVE, RESIN TRANSFER, FLAT BED PRESS PRESSURE MOLDING STUDIES
  - CONTINUE ON-LINE MONITORING OF PROCESS ADVANCEMENT
  - CONTINUE WORK ON POLYMER COMPOSITE STRUCTURES
  - CONTINUE INTERFACE STUDIES (WEN-LI WU)
  - ELECTRONIC PACKAGING WORKSHOP TIMELY
  - MORE THERMOPLASTIC COMPOSITE WORK
  - EXPAND OPTOELECTRONICS WORK
  - MORE FREQUENT COMMUNICATION OF PROGRESS

Industry Update: Aerospace

S. Dastin

Grumann Aircraft

Bethpage, NY

SECOND INDUSTRY WORKSHOP ON
POLYMER COMPOSITE PROCESSING
AT
NIST GAITHERSBURG, MD 20899

AEROSPACE UPDATE

BY
S. J. DASTIN
GRUMMAN AIRCRAFT SYSTEMS
BETHPAGE, NY 11714
ON
MAY 18, 1990

GRUMMAN

AEROSPACE POLYMER COMPOSITE PROCESSING FROM FIRST INDUSTRY WORKSHOP ON OCTOBER 1987

- HAND LAY-UP + SEMI AUTOMATIC LAY-UP
- PREPREG AUTOCLAVE CURING (350°F/100 PSI)
- ULTRASONIC & X-RAY SEMI-AUTOMATIC NDT
- HAND FASTENING FOR ASSEMBLY
- AUTOCLAVE FILM ADHESIVE BONDING (350°F/25 PSI)
- PRESS MOLDING ALSO UTILIZED

BARRIERS FOR INCREASED UTILITY

- HIGH ACQUISITION COSTS (MATERIALS & LABOR)
- HIGH REWORK COSTS (TO ASSURE HIGH QUALITY)
- HIGH TOOLING COSTS (FOR PRODUCTION PROGRAMS)

GRUMMAN

AEROSPACE POLYMER COMPOSITE PROCESSING
SECOND INDUSTRY WORKSHOP
MAY 18, 1990

- AUTOMATED LAY-UP AND PLY CUTTING
- PREPREG AUTOCLAVE CURING (600°F/200 PSI)
- AUTOMATED ULTRASONICS - SEMI AUTOMATIC X-RAY
- AUTOMATED (ROBOTIC) FASTENING ASSEMBLY
- INTEGRAL ASSEMBLIES IN-LIEU OF ASSEMBLY BONDING
- PRESS MOLDING ALSO STILL BEING USED

BARRIERS FOR INCREASED UTILITY

- HIGH ACQUISITION COSTS (MATERIALS & LABOR)
- PRODUCTION RELIABILITY/SCHEDULE
- HIGH TOOLING COSTS FOR COMPLEX SHAPES

GRUMMAN

CURRENT AEROSPACE POLYMER COMPOSITE PROCESS DEVELOPMENTS TO REDUCE ACQUISITION COSTS

- 3D-TEXTILE REINFORCEMENTS (STITCHING, WEAVING, BRAIDING)
- TOUGHENED THERMOSETS/THERMOPLASTICS MATRICIES IN LIQUID AND POWDER FORMS FOR INFILTRATION
- HIGH FIBER VOLUME FRACTION RESIN TRANSFER MOLDING (RTM)
- THERMOFORMING WITH THERMOPLASTIC MATRIX COMPOSITES
- PREPREG TOW PLACEMENT - AUTOCLAVE CURE
- FILAMENT WINDING - VACUUM BAG/AUTOCLAVE CURE
- RESIN FILM INJECTION OF 3D PREFORM - AUTOCLAVE CURE
- SOME SEMI-AUTOMATED MATCHED DIE COMPRESSION & PULTRUSION

-3-

GRUMMAN

AEROSPACE SCIENTIFIC/TECHNICAL NEEDS

- PROCESSING SCIENCE FOR THICK POLYMER MATRIX COMPOSITES (1.0 to 10.0 INCH) AND PROCESS MODELING
- FIBER-MATRIX INTERFACE SUITABILITY/NDI FOR DELAMINATION CONTROL ON IMPACT AND FOR ASSEMBLY
- FIBER VOLUME AND VOID FRACTION CONTROL AND NDI METHODOLOGY
- AFFORDABLE REPEATABLE FIBER & MATRIX MATERIALS
- LOW COST - HIGH RELIABILITY PROCESSES FOR PRODUCTION
- RELIABLE FIELD NDT FOR LAMINATES AND BOND STRENGTH
- MICROSTRUCTURE UNDERSTANDING FOR FAILURE ANALYSIS
- COMPRESSION/DELAMINATION FAILURE MODELS
- NEAT RESIN FAILURE BEHAVIOR

GRUMMAN

CURRENT (1990) AEROSPACE RANKING FOR POLYMER MATRIX COMPOSITES (PMC) PROCESSING

(1) AUTOCLAVE MOLDING

(2) FILAMENT WINDING

(3) VACUUM BAG MOLDING

(4) PRESS MOLDING (COMPRESSION MOLDING)

(5) THERMOFORMING

(6) INJECTION MOLDING (BOTH TP/TS)

(7) PULTRUSION

(8) TRANSFER MOLDING (RESIN TRANSFER MOLDING)

GRUMMAN

CURRENT (1990) AEROSPACE TECHNICAL BARRIER RANKING FOR PMC PROCESSING

(1) IMPACT/ASSEMBLY DELAMINATION

(2) VOIDS AND POROSITY - PROCESS/TOOLING INDUCED

(3) HIGH COST MATERIALS AND PROCESSES

(4) FIBER-MATRIX INTERFACE VARIABILITY

(5) FIBER VOLUME FRACTION/ORIENTATION

(6) DIMENSIONAL TOLERANCES

(7) PROPERTY REPEATABILITY/VALIDATION

(8) HEAT FLOW/MORPHOLOGY

GRUMMAN

CURRENT (1990)
AEROSPACE IMPORTANT TECHNOLOGIES THAT COMPLEMENT PMC PROCESSING

(1) SURFACE COATING

(2) JOINING

(3) AUTOMATION FOR PREPREG CUTTING, LAY-UP, CURING, INSPECTION AND ASSEMBLY (IPAM)

POTENTIALLY IMPORTANT PMC FOR THE FUTURE

(1) HIGH TEMP (350°F - 600°F) RESINS FOR LONG EXPOSURE

(2) TOUGHENED TS/TP

(3) POLYMER BLENDS

(4) LCP

(5) IPN

(6) CONDUCTIVE RESINS

(7) MOLECULAR COMPOSITES

GRUMMAN

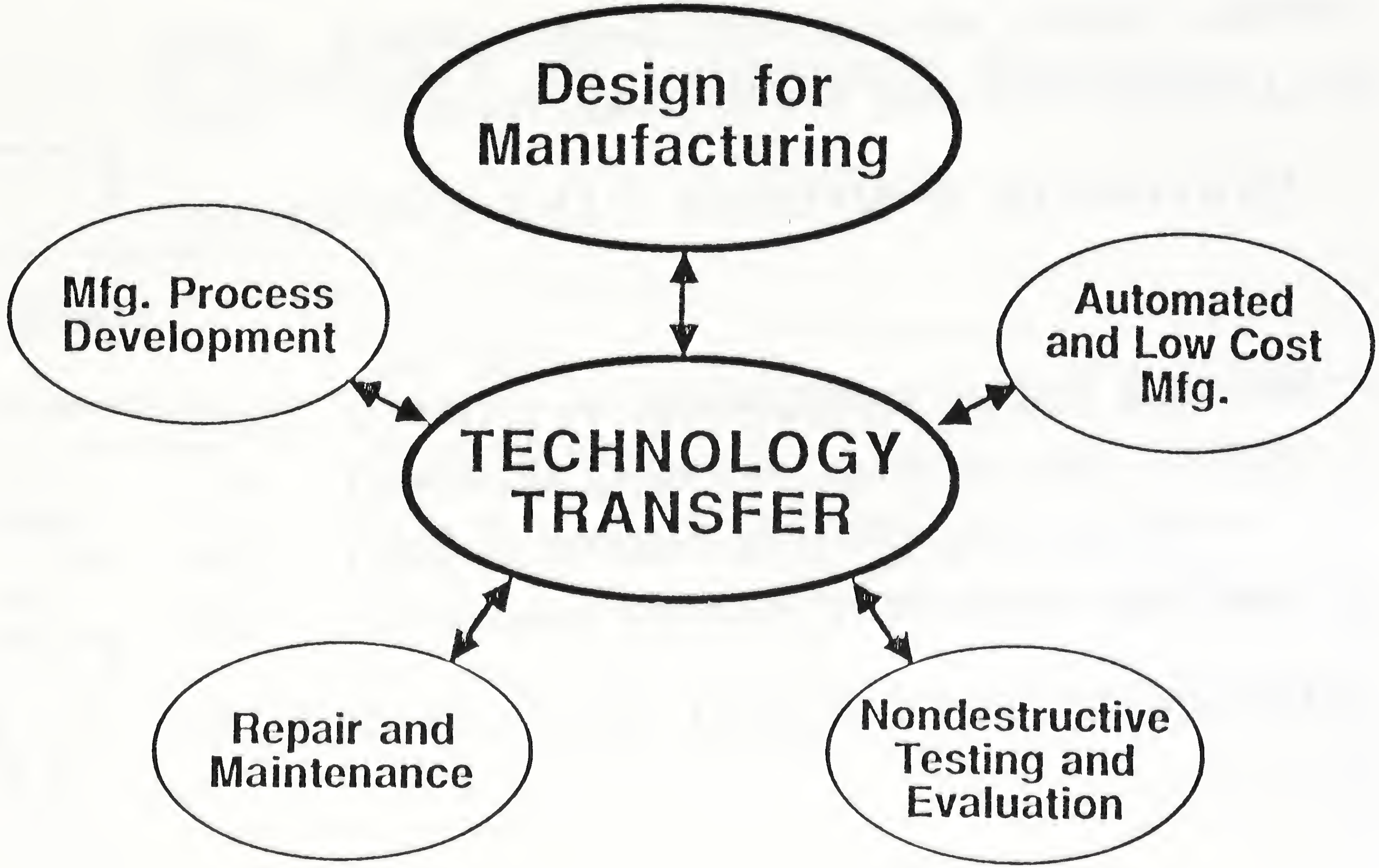
Industry Update: Design/ Data Base

E. Stanton

PDA Engineering

Costa Mesa, CA

PDA ENGINEERING



PDA ENGINEERING

COMPOSITE STANDARDS ACTIVITIES

MATERIALS DATA GENERATION STANDARDS

ISO	International Standards Organization (BSI, DIN, . . .)
NIST	Office of Standard Reference Data (MIST, . . .)
DoD	Composites Technology Program Area
ASTM	Standards for Testing Materials (D20, D30, C28)

MATERIALS DATA EXCHANGE STANDARDS

NIST	Center for Manufacturing Technology (IGES, PDES)
DoD	Computer-Aided Acquisition and Logistics Support
ASTM	Computerization of Material Property Data (E49, . . .)
ACC	Automotive Composites Consortium

pda ENGINEERING

A Structure for Composite Metadata

Material	Specimen	Environment	Source
Designation	Ply Manufacturer	Temperature	Table
Common Name	Lot	Humidity	Book
Fiber	Volatiles	Atmosphere	Author
Matrix	Resin	Test Lab	—
Preform	Gel Time	—	—
—	—	—	
—	—		

CAD DATABASE>> COMMIT TO DATABASE BACK QUERY SELECT DATA END

MATERIAL

SPECIMEN

ENVIRONMENT

TEMP (deg F)	HUMID
-67.	Dry
72.	Dry
72.	.69-.78% Wt Gain
72.	1.28-1.76% Wt Gain
350.	Dry
350.	.71-.79% Wt Gain
350.	1.24-1.73% Wt Gain
450.	Dry

DESIG T300/V378A
CNAME Graphite/ Polyimide
FIBER T300
MATRIX V378A (Bismaleimide)
FIBSG 1.75 (MFDATA)
MTXSG 1.27 (MFDATA)
FORM Laminate
MTXPCT 25.6 Wt % (Acid Digestion)
FIBPCT 67. Vol % (Acid Digestion)
SG 1.58 (D792)
PLYMF U.S. Polymeric
VOLS 5.5 Wt % (QCI-C-V-14)
RESINWT 30.6 Wt % (R-15)
GEL 32.2 min (G-2, @ 210 Deg F)
VOIDS 1.4 Vol % (D2734)
PLYTH 0.0051 in
TGDRY 702. deg F (DMA(DP981) [0:8])
TGWET 702. deg F (DMA(DP981) [0:8])

SPECIMEN 4 specified
You can now select with the cursor; hit <RETURN> when done

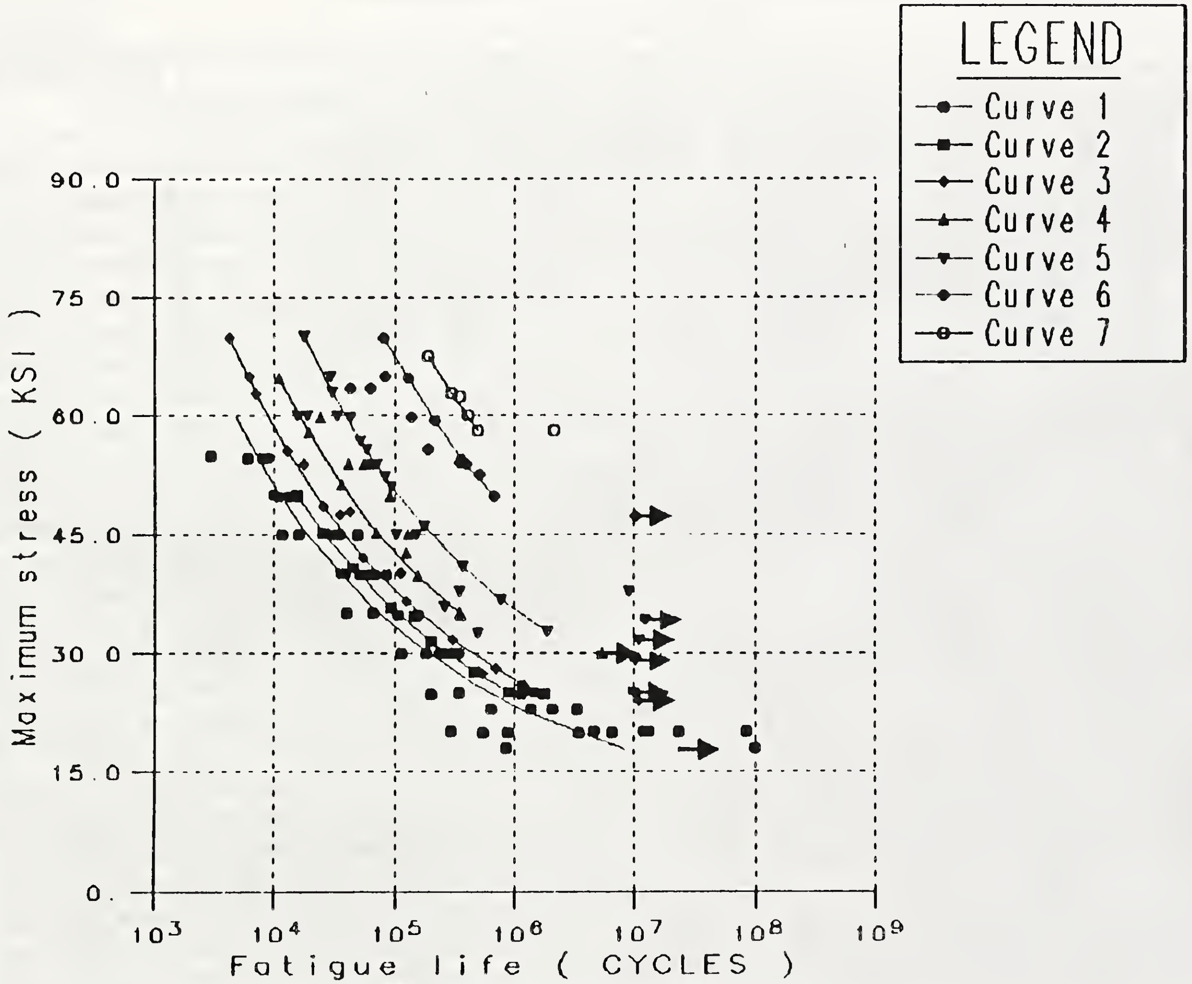
TST CAD FEA HELP UTILITIES STOP

```
CAD>>  FILE  SCHEMA  DATABASE  ASCI  RUN
CAD,ASET>>  MAIN  REDUCE  ROLLBACK  ACTIVE  CLEAR  CONSTRUCT  END

 Properties of G-160/6535-1 Composite Laminates at 350 F          DESIG    G-160/6535-1
                                                                  CNAME    Graphite/Epoxy
E11C     21.4 Msi                  D3410 [0:21]                   FIBER    G-160
E22C      1.0 Msi                  D3410 [90:21]                  MATRIX   6535-1
NU12      0.31                     D3039 [0:6]                    FIBSG    1.75 (MEDATA)
G12       0.81 Msi                 D3518 [(45/-45):4]             MTXSG    1.26 (MEDATA)
CTE11     -.1 micro in/in deg      TMA(TMS-2) [0:40]              FORM     Laminate
CTE22     10. micro in/in deg      TMA(TMS-2) [90:40]             MTXPCT   25.7 Wt %
CTC33     0.66 BTU ft/ft**2 h deg                                 (Acid Digestion)
              F                                                   FIBPCT   68.4 Vol %
E11F     16.05 Msi                 D790(3PT) [0:14]               (Acid Digestion)
E22F      1.34 Msi                 D790(4PT) [90:14]              SG  1.61 (D792)
VS11T   166.7 ksi                  D3039 [0:6]                    PLYMF  AVCO
VS22T     2.42 ksi                 D3039 [90:15]                  VOLS  0.2 Wt %
VS11C   101.9 ksi                  D3410 [0:21]                        (QCI-C-V-14)
VS22C    11.4 ksi                  D3410 [90:21]                  RESINWT  41.5 Wt %
US11T   171.3 ksi                  D3039 [0:6]                          (R-15)
US22T     3.49 ksi                 D3039 [90:15]                  GEL  30.2 min (G-2,
US11C   151.4 ksi                  D3410 [0:21]                      @ 327 Deg F)
US22C    10.0 ksi                  D3410 [90:21]                  VOIDS  0. Vol %
US11F   101.7 ksi                  D790(3PT) [0:14]                      (D2734)
US22F     8.5 ksi                  D790(4PT) [90:14]              TGDRY  507. deg F
US12S     0.24 ksi                 D3518 [(45/-45):4]             (DMA(DP981) [0:8])
US13S     9.27 ksi                 D2344 [0:15]                   TGWET  471. deg F
UE11T   8390. micro in/in          D3039 [0:6]                    (DMA(DP981) [0:8])
UE22T   2270. micro in/in          D3039 [90:15]                  TEMP  350. deg F
UE11C   8530. micro in/in          D3410 [0:21]                   HUMID  Dry
UE22C  11750. micro in/in          D3410 [90:21]   Max observed value, not ultimate. 4    TABLE  76,77,80,81,82,
                                                   specimens exhibited evidence of buckling      87
CP        0.333 BTU/lb deg F       DSC [0:1]
 Working . . .
 You can now select with the cursor; hit &lt;RETURN&gt; when done

TST   CAD   FEA   HELP   UTILITIES   STOP
```

CAD>> FILE SCHEMA DATABASE ASET RUN

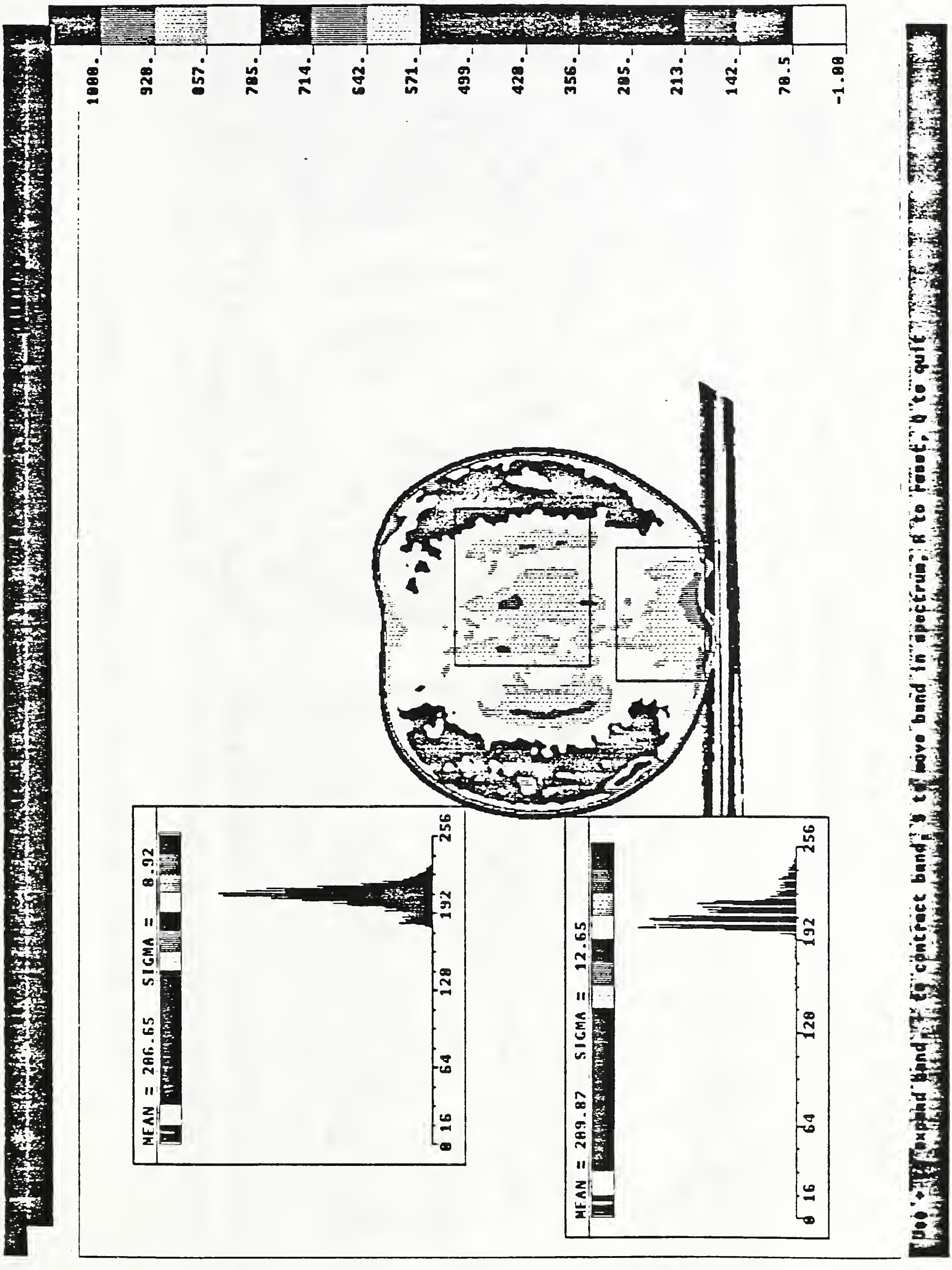


** SIG11 vs N **
<< COMMON DATA >
CNAME 2024 Aluminum Alloy
FORM Bare Sheet {(longitudinal direction)}
TREAT T3
DIMS 0.090 inch
DETAIL Unnotched
TEMP 70. deg F
LOADING Axial
FREQ 1100 to 1800 cpm
LOTSNO Not specified
FIGURE 3.2.3.1.8(E) {[CAUTION:The equivalent stress model may provide unrealistic life predictions for stress ratios beyond those represented above] NOTE: Stresses are based upon net section
BOOK MIL-HDBK 5E
REF 3.2.3.1.8(A) and (F)

<< CURVE 1 >>
RATIO -1.

>9
You can now select with the cursor; hit <RETURN> when done

TST CAD FEA HELP UTILITIES STOP

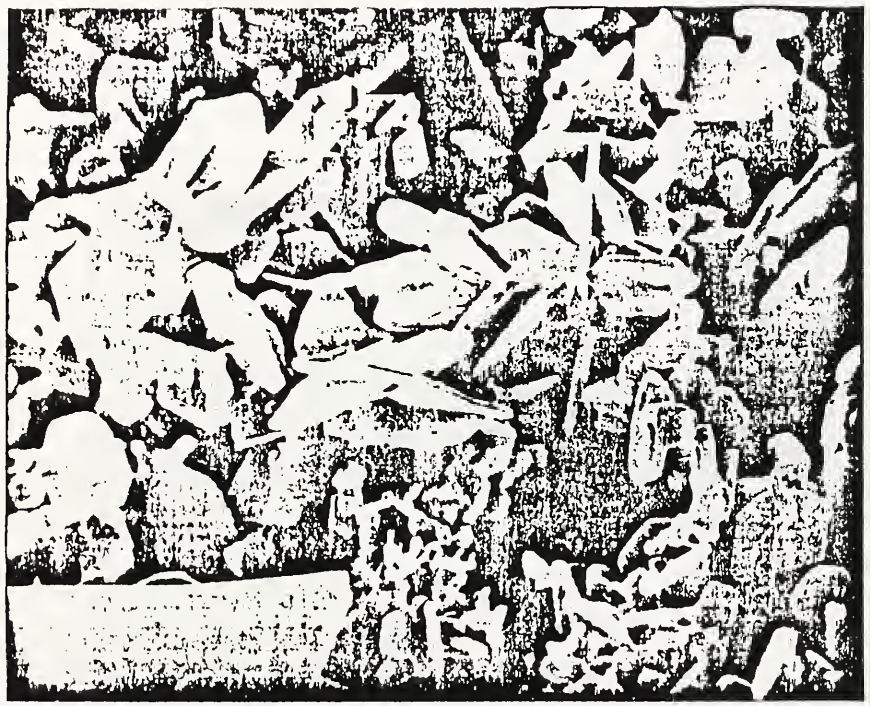


MEAN = 286.65 SIGMA = 8.92
MEAN = 289.87 SIGMA = 12.65
1000.
928.
857.
785.
714.
642.
571.
499.
428.
356.
285.
213.
142.
70.5
-1.00

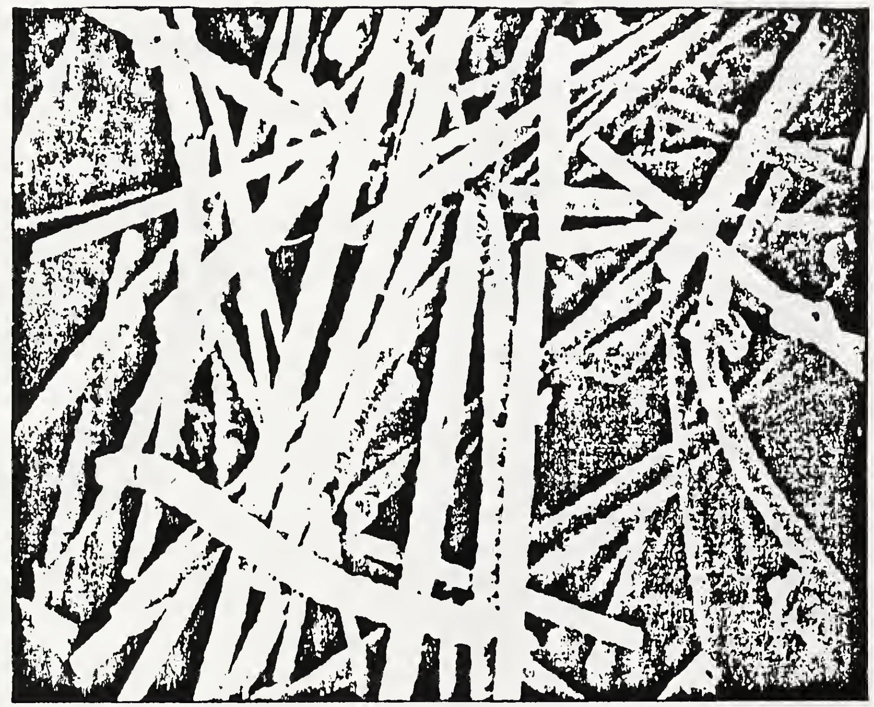
pda ENGINEERING

DESIGNING SAFE COMPOSITE MATERIALS

ASTM E34 OCCUPATIONAL HEALTH AND SAFETY
ASTM E34.70 SINGLE CRYSTAL CERAMIC WHISKERS [SIC]



Silicon Carbide Platelets 8μm



Silicon Carbide Whiskers 1.5 μm

Very small fibers < 0.2 μm pose a health hazzard.

Ref: Sam C. Weaver, ASTM Standardization News, April 1990

PDA ENGINEERING

COMPOSITE DESIGN FOR MANUFACTURING

- CONCURRENT ENGINEERING IS REQUIRED TO PRODUCE COMPOSITE DESIGNS WITHOUT UNACCEPTABLE MANUFACTURING RISKS OR UNACCEPTABLE SCHEDULE DELAYS.

- MCAE SOFTWARE IS A KEY ENABLING TECHNOLOGY FOR CONCURRENT ENGINEERING. THAT IS A PROBLEM TODAY.

- A TRULY COMMON ENGINEERING DATABASE REQUIRES EMERGING STANDARDS LIKE PDES TO HAVE MATERIALS AND PROCESS INFORMATION.

NIST-114A
(REV. 3-90)

U.S. DEPARTMENT OF COMMERCE
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY

BIBLIOGRAPHIC DATA SHEET

1. PUBLICATION OR REPORT NUMBER
NISTIR 4461

2. PERFORMING ORGANIZATION REPORT NUMBER

3. PUBLICATION DATE
December 1990

4. TITLE AND SUBTITLE
Second Industry Workshop on Polymer Composite Processing

5. AUTHOR(S)
Carl Johnson, Shu-Sing Chang and Donald Hunston

6. PERFORMING ORGANIZATION (IF JOINT OR OTHER THAN NIST, SEE INSTRUCTIONS)
U.S. DEPARTMENT OF COMMERCE
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
GAITHERSBURG, MD 20899

7. CONTRACT/GRANT NUMBER

8. TYPE OF REPORT AND PERIOD COVERED

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS (STREET, CITY, STATE, ZIP)

10. SUPPLEMENTARY NOTES

11. ABSTRACT (A 200-WORD OR LESS FACTUAL SUMMARY OF MOST SIGNIFICANT INFORMATION. IF DOCUMENT INCLUDES A SIGNIFICANT BIBLIOGRAPHY OR LITERATURE SURVEY, MENTION IT HERE.)

The Polymers Division recently sponsored an industry workshop on polymer composite processing with participation by 24 organizations representing the automotive, electronics, aerospace, marine, construction and material supplier sectors of U.S. industry. The meeting was designed to update and expand on the results of an earlier meeting which identified the most promising processing methods for the future and the technical and scientific barriers that currently hinder the use of these methods. The attendees strongly advised that pressure molding and liquid molding are the most important processing methods for the future. The industry's present inability to control resin flow and fiber orientation were considered the most important technical barriers, while process monitoring and the measurement and control of fiber-matrix adhesion were also deemed important. The recent workshop was also asked to identify the most important issues in the performance of composites. Two topics, impact damage and environmental attack, were selected as critical to performance by all industry sectors. The results of the workshop will be used to guide the development of the NIST composites program.

12. KEY WORDS (6 TO 12 ENTRIES; ALPHABETICAL ORDER; CAPITALIZE ONLY PROPER NAMES; AND SEPARATE KEY WORDS BY SEMICOLONS)

industrial workshop; polymer composites; processing methods; scientific and technical barriers; thermoplastics; thermoset

13. AVAILABILITY

X	UNLIMITED
	FOR OFFICIAL DISTRIBUTION. DO NOT RELEASE TO NATIONAL TECHNICAL INFORMATION SERVICE (NTIS).
	ORDER FROM SUPERINTENDENT OF DOCUMENTS, U.S. GOVERNMENT PRINTING OFFICE, WASHINGTON, DC 20402.
X	ORDER FROM NATIONAL TECHNICAL INFORMATION SERVICE (NTIS), SPRINGFIELD, VA 22161.

14. NUMBER OF PRINTED PAGES
86

15. PRICE
A05

ELECTRONIC FORM

IR 4462

UNAVAILABLE FOR BINDING