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13. ABSTRACT *(Maximum 200 words)*

The 1995 Gordon Conference on Fiber Science, held at Colby Sawyer College July 9-14, was attended by 126 conferees. The papers presented at this conference were excellent, and discussion was abundant and high level. The two poster sessions, which had a total of 40 posters dealing with very recent work in fiber science, were lively and well attended. It seemed that every one of the attendees made a point of commenting favorably to me (the Chair) on the appropriateness of the program and the high quality of the activity. Support provided for this conference by the Army Research Office made possible four of the formal sessions and greatly facilitated the poster sessions. Brief summaries of the formal sessions which are of interest to the army will be provided in this project closing report. It must be kept in mind, however, that by definition Gordon Research Conferences are "unpublished", and that only sufficient information can be reported to enable interested personnel to decide which speakers they would like to contact for a more complete picture. The final program, a list of the poster presentations and names and addresses of the speakers in the ARO supported sessions are given in Appendices.

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I certify that funds provided by the Army Research Office under Grant DAAH04-95-1-0238 were expended in accordance with the provisions of the grant and that the required scientific report is hereby delivered to the US Army Research Office.

Hawthorne A. Davis
Chair, 1995 Gordon Conference on Fiber Science

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The 1995 Gordon Research Conference on Fiber Science

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Summary

The 1995 Gordon Conference on Fiber Science, held at Colby Sawyer College July 9-14, was attended by 126 conferees. The two poster sessions, which had a total of 40 posters dealing with very recent work in fiber science, were lively and well attended. The papers presented at this conference were excellent, and discussion was abundant and extremely high level. It seemed that every one of the attendees made a point of commenting favorably to me (the Chair) on the appropriateness of the program and the high quality of the activity.

Support provided for this conference by the Army Research Office made possible four of the formal sessions and greatly facilitated the poster sessions. Brief summaries of the formal sessions which are of interest to the army will be provided in this project closing report. It must be kept in mind, however, that by definition Gordon Research Conferences are "unpublished", and that only sufficient information can be reported to enable interested personnel to decide which speakers they would like to contact for a more complete picture. The final program is given as Appendix I. A list of the poster presentations is provided as Appendix II. Names and addresses of the speakers in the ARO supported sessions are given in Appendix III.

Conclusions

- The fact that high strength polyethylene fibers do not give considerably enhanced ballistics protection relative to aramid is not understood and should be studied further.

- Substantial advancements in the ability to analyze the microstructure of fibers by diffraction and scattering of x-rays and neutrons are in place in various laboratories. These are being ignored, or only slowly implemented, in many places, including first rate USA research laboratories.

- Two laboratories, which are producing (potentially) high performance fibers of conventional polymers, are at Nara University and Tokyo Institute of Technology in Japan.

- Electrospinning offers fantastic opportunities to produce low denier, high performance fibers for specialized, or highly tailored applications.

Recommendations

- Study the mechanism of ballistics protection by aramid and polyethylene fibers and understand why polyethylene is not ~2x better than aramid. In particular remove the concept of "low melting point" from the realm of speculation.

- While the words used to describe fiber structure as determined from x-ray analysis may be imprecise, the modern data and analytical methods should be required in all significant x-ray analysis of fiber microstructure.

- Expect the (Japanese) laboratories of Masaru Matsuo and T. Kikutani to develop some substantially and significantly improved fibers from currently available polymers. These laboratories are worth keeping contact with.

Details

High performance fibers and ballistics applications

Robert Armstrong, of MIT, reported on his finite-element modeling of spinning liquid-crystal solutions, e.g. like aramid fibers are made from. The work used a dumbbell model for the molecule and included effects of Brownian motion. The key point was that intrinsic factors in flow through a capillary induce surface-to-center variabilities in the molecular orientation of these fibers. This variability exists both in the amount of orientation and in the angle of the orientation with respect to the flow direction.

Masaru Matsuo, Nara Women's University (Japan), presented work to show that high strength and high modulus fibers can be made from many different polymers including polyvinyl alcohol, polytetrafluroethylene and polyacrylonitirle. The common element in all of the processes was to set up a microstructure, analogous to the "gel" of high strength polyethylene, which would be drawn to high draw ratios.

Warren Knoff, of DuPont Fibers, discussed the transverse mechanical properties of aramid fibers. He measured the transverse stress-strain relationships for fibers produced by several different processes with a Kawabata single fiber compression tester. Based on Herzian analysis, he could determine a transverse modulus and a transverse yield stress. These properties were found to be highly correlated with fiber performance, in particular wear resistance and the failure rate of hose couplings. In both cases the highly crystalline aramids, e.g. "Kevlar", performed better than the low crystallinity aramids, e.g. "Technora". Polyethylene was not reported on.

Dusan Prevorsek (retired from AlliedSignal, Inc.) discussed the technology of survival for composites reinforced with (mainly aramid and high strength polyethylene) fibers. Basically he presented a thesis, that "Spectra" fibers made composites which are substantially more damage tolerant than composites from aramid fibers, due largely to the toughness and

plasticity (reversible kink band formation) of the polyethylene fibers. Although the results reported were certainly true, it was revealed in the lively discussion session which followed the lecture, that they represent highly specialized cases of matrix and penetrating particle, and do not support a general conclusion that polyethylene fibers are superior to aramid fibers.

Phillip Cunniff, of Natick Labs, presented his work investing the effect of ballistic impact on textile structures. As this work is doubtless well known to ARO, it will not be summarized. A key discussion point, however, will be mentioned. "Spectra" fiber, with its high modulus and low density, should be much, e.g. 2x, better at absorbing ballistic impact than aramid fiber, but the two fibers perform approximately the same. This appears not to be understood even now, after many years of studying the effect. For example the sometimes alleged negative effect of the low melting point of "Spectra" has not been proven. Clearly there is a need for more work in this area.

Analyzing x-ray and neutron scattering/diffraction

In recent years there has been a revolution in our ability to obtain and analyze x-ray and neutron diffraction data on fibers. Three papers focussed on this new technology.

Ygang Fu, of the University of Tennessee, discussed the method developed at Oak Ridge National Laboratories, for computing the entire x-ray scattering pattern of a fiber based on a three phase model of crystalline (including paracrystalline), oriented noncrystalline and unoriented noncrystalline material. It is clear that this is extremely elegant work, which makes it possible to accurately characterize the important, noncrystalline part of fibers. In the discussion session it became clear, however, that the division of the noncrystalline part into oriented and unoriented components is an arbitrary simplification of the true state of this material.

Sanjeeva Murthy, of AlliedSignal, Inc. discussed the use of neutron scattering by absorbed water to study the microstructure of nylon fibers. The most exciting part of this work is that it enabled new discoveries concerning the equatorial scattering from nylon fibers. This scattering, which could represent a "fibrillar" or axially-cracked structure could be studied in great detail. He found he could do Gunier analysis, which showed that the structure decreased in size with increasing draw ratio. In addition he found, for the first time that I am aware of, some indication of coherent scattering in the equatorial plane. This scattering, which represents roughly 50 Å, close-packed cylinders, would tend to favor the fibrillar interpretation of microstructure. Murthy seems to have created a new method for studying fiber structure which will bear considerable fruit in the future.

Norbert Streibeck, of the University of Hamburg, discussed the small angle scattering of x-rays (SAXS), by fibers. This was first of all an excellent, critical review of the modern methods for analyzing fiber structure by SAXS. For his own studies of oriented "star" block copolymers, he modified the interface distribution function originally developed by Ruland. He then used x-ray data from a synchrotron beam line to analyze the structures of these

materials drawn to different draw ratios and modified with volume fractions of mineral oil up to 33%.

The sessions on diffraction/scattering produced more discussion than could be dealt with in the allocated time. Consequently a group of about 40 people returned to the conference room during the normal afternoon-off period to continue these discussions. Two key points emerged which will doubtless form the basis of considerable future research. One has to do with the definition of the "phases" in a polymer fiber. It is clear that the two-noncrystalline-phase model, that x-ray people like, is a simplifying convenience. The question remains, however, what is a proper description? A second, related problem which emerged had to do with the interpretation of differential scanning calorimetry of polymer fibers. Because the heat flow rate after melting is usually lower than that before melting, it seems that there is considerable, unrecognized latent heat in fibers. This suggests considerable microstructure reorganization due to heating at relatively low temperatures, results which seem to support the idea that the noncrystalline part of the fiber is a microcrystalline "slush", which perhaps could be understood better in this context than in the "two-noncrystalline-phase" context which is the simplest way to interpret the x-ray data.

New fiber spinning technology

Darrell Renneker, of the University of Akron, described his work with electrospun fibers. Although this technology has been in existence for a long time, it has hardly been studied and evaluated for the production of fibers. Electrically charging droplets of polymer dissolved in suitable solvents causes the production of indefinitely long fibers with very small diameters, e.g. of the order of 10 to 500 nm. Optical and transmission electron microscope observation of aramid fibers produced by this method indicate they have roughly the same structure as those produced by dry jet wet spinning. Large amounts of the fibers can be produced readily, and strong, lightweight webs, much like spider webs can be produced. Renneker envisions uses for these fibers in composites and as foil surfaces for solar "sails" which could be used, e.g., to hold geostationary satellites in non-equatorial orbits.

T. Kikutani, of the Tokyo Institute of Technology, discussed the high speed direct spinning (HSDS) of bicomponent fibers. It is well known that HSDS produces oriented, crystalline fibers in one, low-cost step. However, the properties of these fibers never reach those of conventional spin/draw fibers, at least partly because of a radial inhomogeneity caused by attenuation of a melt stream which is cooling from the outside. Bicomponent technology offers a way to circumvent this, and at the same time to impart surface functionality. Kikutani has worked to model this spinning process as well as to characterize the resulting fibers. Some of the surprises he encountered were: when polyethylene terephthalate (PET) is spun as the core with a polystyrene (PS) sheath, the PET core develops higher birefringence than it would have by itself. When PET is spun with a polypropylene (PP) sheath, the PP develops only a low orientation smectic structure, whereas it would otherwise have crystallized. PET spun with a PS sheath develops no crystallinity even up to 7000 m/min spinning speed.

Explanations

Appendix I is the final and actual program of the conference. As this was a Gordon Research Conference there are no Conference Abstracts or Proceedings.

Appendix I
The 1995 Gordon Conference on Fiber Science
Colby-Sawyer College
July 9-14

1. Fundamentals of high performance fibers (Monday AM)
Discussion Leader- Sheldon Kavish, AlliedSignal, Inc.

   a. R.C. Armstrong "Spinning of liquid crystalline polymer solutions"
   b. Masaru Matsuo "Control factors for the production of high modulus and high strength fibers from several kinds of polymers"
   c. W.F. Knoff, DuPont, "Transverse properties of aramid fibers"

2. Properties and use of high performance fibers (Monday PM)
Discussion Leader- Janet Ward of Natick

   a. Dusan Prevorsek, AlliedSignal, Inc. "Technology of Survival for Composites Reinforced with High Performance Fibers"
   b. Philip Cunniff, Natick, "Ballistics Protection with High Performance Fibers"

3. Breakthrough technology for studying fibers by x-ray scattering and diffraction (Tuesday AM)
Discussion Leader-David Buchanan of N.C. State U.

   a. Ygang Fu, University of Tennessee, "Full pattern fitting"
   b. Sanjeeva Murthy AlliedSignal, "X-ray and neutron scattering"
   c. Norbert Stribeck Universität Hamburg, "Analysis of the SAXS of Fibrillar Two Phase Systems"

4. Structure and property understanding of textile fibers (Tuesday PM)
Discussion Leader- David Bosley (consultant)

   a. Rick Miller, Monsanto, "Effect of Suessen Processing on Nylon Fiber Microstructure"
   b. David Brown, University of Manchester Institute of Science and Technology, "Molecular Dynamics of the Fibrous State of Matter"

5. Textile processing technologies as low-cost routes to high value in use composites (Wednesday AM)
Discussion Leader and Organizer- Chris Pastore, North Carolina State University

   a. Ning Pan (UCal Davis)
   b. John Jaranson, (Ford Motor Corp) "Low Cost, High Value Composites"
   c. Benny Soebroto, (Fiber Concepts) "High Performance, Low Cost Composites"

6. Critical problems in textile production(Wednesday PM)
Discussion Leader- Michael J. Sullivan, Milliken Research

   a. Barrie Fraser, U. of Melbourne, "Effects of Nonlinearity in Textile Processes"
   b. Ralph McGregor, NCSU, "Psychophysics and the appearance of streaks in fabrics"

7. Fibers/textiles and the environment (Thursday AM)
Organizer and **Discussion Leader**- Judd Schwartz, Technical Director, AlliedSignal

   a. Bob Evans, National Renewable Energy Laboratory, "Recycling of Mixed Waste Plastics by Selective Pyrolysis"

   b. Ted Jenczewski, AlliedSignal,Inc. "Nylon 6 Recycle, Chemistry and Process Engineering"

   c. Charlie Pyle, United Recycling Industries, Inc., "Recycling Post Consumer Carpets"

8. "The Futurist: looking ahead at the past" (Thursday PM)
Speaker- Tom Doherty, Consultant

9. Science and tehcnology of high speed fiber spinning
Discussion leader Subhash K Batra, NCSU.

   a. T. Kikutani, Tokyo Inst. Tech., "High Speed Melt Spinning of Bicomponent Fibers
   b. D.H. Renneker, U. of Akron, "Electrostatic spinning of fibers"

1995 Gordon Research Conferences on Fiber Science
July 9 - 14, Colby-Sawyer College

POSTER SESSION A

1. S. Chereisky "Effect of Electronic Structure on Properties of Aromatic Polyamides"
2. S. Chereisky "Conformational Polymorphism of PABI"
3. W. W. Roberts, Jr & L. Wibberly "Industrial Fiber Processing/Machine Design: Mathematical Modeling, Computer Simulation and Virtual Prototyping"
4. Teruo Nakashima & Masaru Matsuo "Development of High-Strength and High Modulus Polyethylene-Starch Composite Films"
5. M. Minagawa, T. Yamada, S. Saito, T. Ogita and M. Matsuo "Drawing of Ultrahigh Molecular Weight Polyacrylonitrile"
6. Mario de Araujo, Hong Hu and Raul Fangueiro "A New Process for the Production of Multiaxial Weft Knit Fabrics"
7. Samir K. Mukhopadhyay "Heat Setting Mechanisms of Thermoplastic Fibers"
8. A. Straub, D. Rouse, M. Slivka and Peter Schwartz "Viscoelastic Effects of Interfacial Shear Stress"
9. D.M. Dean, R. A. Regester and L. Rebenfeld "Fiber Effects in Reinforced Composites"
10. I. Tyomkin and B. Miller "Initial Stage of Spontaneous Liquid Uptake"
11. Marie-Christine Jones and David C. Martin "Molecular Stress and Strain in an Oriented, Extended-chain Polymer of Finite Molecular Length"
12. Sidney Hornby and Y.K. Kamath "Deposition of Finish Films of Controlled Thickness on Fiber Surfaces"
13. Jim Clark "The Effect of a Control Ring on the Stability of the Ring-spinning Balloon"
14. S. Bais-Singh & B. Goswami "Prediction of Biaxial Deformation Behavior of Spun-bonded Nonwovens"
15. Sanjay Mehta, B. I. Deopura, B.P. Talwan "Fibers from Blends of PBT and Thermotropic Liquid-crystalline copolyesters"
16. Phillip Cunniff, T.F. Walsh and B.L. Lee "Low Velocity Penetration of Woven Textile Composites"
17. You-lo Hsieh "Liquid Wetting and Transport in Fibrous Assemblies"
18. Jacqueline R. Postle & Ron Postle "Modeling Compressive Buckling and Recovery of Textile Materials"
19. Masazumi Shimizu, Chunki Theta and Masaru Matsuo "Development of high strength poly (tetraethylene) fibers by the elongation at a liquid crystalline state"

POSTER SESSION B

1. T.K. Ghosh, S.K. Batra, X. Ma "Dynamics of unwinding yarn from Cylindrical Package"

2. H. Uehara, A. Kawaguchi, S. Murakam and R.S. Porter "High Temperature X-ray Diffraction study on Deformation of Ultra-high Molecular Weight Reactor Power"

3. Roger N. Ibbett "Structure and Property Development in Solvent Spun Cellulosic Fibers"

4. S. Ottani and R.S. Porter "A Latent Entanglement Model for the Draw of Semicrystalline Polymers"

5. A.P. Sawhney and L.B. Kimmel "A New, Integrated Tandom Spinning System"

6. J.F. Hotter, P.A. Tucker and J.A. Cuculo "A Uniquely Modified PET Melt Spinning Process"

7. V. Sharma "Determination of Crystallinity"

8. S.B. Thadani, Haskell Beckham and A.S. Abhiraman "Effect of Crystalline Phase Cross linking on Thermomechanical Properties"

9. S. Narayan, R. Srinivasan, P. Desai and A.S. Abhiraman "Post Fiber-extrusion Solid-state Polymerization of Polyamides"

10. John Gibbon and S. Haig Zeronian "The Application of NaOH in the Study of the Fine Structure of PET, PBT and PBT/PET Bicomponent Fibers"

11. A. Saraf and Mike Kent "Basofil ^{R}, a Heat and Flame-resistant Fiber"

12. Eui-Won Chou and John Flint "Synthesis Characterization and Fiber Properties of High MW Poly(ethylene 2, 6-naphthalate-co-4, 4' bibenzoate)

13. David Stump and W. Barrie Fraser "A Simplified Model of Fabric Drape"

14. S. Misra and J.E. Spruill "Influence of MW Distribution the Structure and Properties of Melt-spun Polypropylene Filaments"

15. Z. Ding and J.E. Spruill "Modeling the Influence of Molecular Parameters on the Melt Spinning of Isotactic Polypropylenes"

16. J.S. Che and D. H. Renneker "Fine Fibers of Polyimide and Poly(ethylene-terephthalate) spun by Electrospinning Process"

17. Marie-Ange Bueno, Pierre Viallier, Bernard Lamy and Marc Renner "Tribological Characterization of Textile Fabrics: Control of Specific Finishing Processes"

18. J. Hutchinson, E. Samulski and S. Murthy "Deuterium NMR Studies of Water in Oriented Nylon 6 Fibers"

19. G. Deng, R.J. Morgan and P. Cunniff "The Development of Polyviny Alcohol Fibers"

20. F. Doval and P. Viellier "Structure of Polyester Microfibers: Texture of the Amorphous Fraction"

APPENDIX III

Names and Addresses of Key Speakers

Prof. Robert C. Armstrong
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Prof. Masaru Matsuo
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