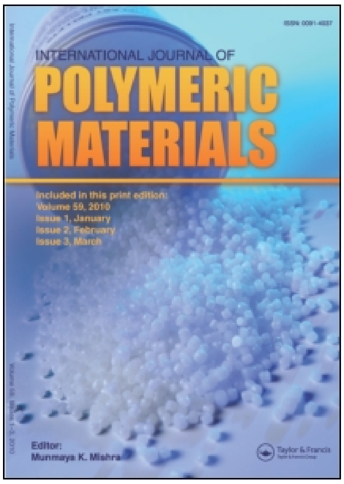

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Polymers in High Performance Structures

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Polymers in High Performance Structures†

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The continuing need for "high performance" in the application of polymers will provide a driving force for modification of polymers to achieve these characteristics. Some specific considerations with respect to polymers, properties and uses are presented as possible guides to future developments.

This paper is not a scientific paper! I'm not going to present any data or develop any correlations—rather I'm going to do something very unscientific—namely, extrapolate into the future and predict where polymer science and engineering will have an impact on high performance structures in the next decade. I am going to consider various areas for innovative R&D, indicate the critical performance parameters involved, suggest approaches for satisfying identified needs, and point to various scientific and engineering problems requiring solution. Since my subject is polymers and not "processing", I will refer to processing only generally.

Prognosticators are currently in poor repute in almost every field, so I suggest that you look at my remarks as a broad brush outlook. I should say, also, that the opinions which I will offer are my own, rather than representing a company position, but I believe they will coincide with the views of at least some of my colleagues. Hopefully, what I have to say will provide some framework for discussion. My topic today requires some definition at the start. I don't think we need to define "polymer", but "high performance" is another matter. What "performance", and how high is "high" are important. For purposes of this discussion we will limit performance to mechanical behavior including rigidity vs. weight; resistance to extreme environments such as

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thermal, chemical, and fire; and certain special factors such as diffusion, friction and wear, and mechanical and acoustical damping. The word "high" to me implies performance well above normal in these selected categories.

"Structure" also requires some definition. I will use the term in reference to "shaped articles" such as moldings, extrusions, pultrusions, stampable sheets, composites, fibers, films and membranes.

Let us consider for a moment the driving force for pursuing higher performance in structures containing polymers. In general, there are two types of driving forces; one generated by demand or need for a product with specific high performance characteristics, which I shall term "demand-pull"; and the other generated by scientific breakthroughs resulting in new technology looking for a market, which I shall term "technology-thrust". Superimposed on these driving forces is the overall business and economic climate which creates priorities in terms of the level and direction of R&D spending.

A general comment is in order here. As a result of current economic conditions, as well as increased expenses of process and product development, toxic substances control and environmental requirements, it seems clear that in the next decade a large proportion of the polymer industry will focus on energy conservation, new lower cost processing, and modification of existing polymers rather than the creation and marketing of a number of major new polymer systems. The challenge will be to upgrade existing polymers to meet the demand for higher performance.

Because product innovation via "demand-pull" stands a greater chance of success due to the possibility of early definition of markets and market needs, it will become increasingly important and command an ever increasing share of Corporate R&D dollars during the next ten years, primarily to minimize risk and maximize short-term return. "Technology-thrust" will represent a much smaller segment of the Corporate R&D effort, particularly where the heavy expenditure of development funds is involved. Of course, the Government will continue to encourage "technology-thrust" at the feasibility level and at the development level in those areas where "mission orientation" can be foreseen.

Let's look now at specifics: Areas for innovation via "demand-pull" include metal replacement, upgrading of existing applications, products for use in extreme environments, ceramic replacement, and "other" (which I will define later).

Metal replacement probably offers the greatest area of opportunity in high performance structures during the next 10 years. Why? Not only because metal refining tends to be energy intensive and have effluent problems, but because the lighter weight of polymeric structures contributes strongly to energy savings during use, particularly where transportation is concerned. Costs on a "per-piece" basis may also be substantially lower, especially where machining is concerned. For instance, graphite fiber composites today costing \$25–30/lb as prepeg are cost-effective in place in aircraft applications, competing with aluminum, because of the tremendous cost of machining the aluminum into a finished part. Thus the aerospace and transportation (particularly automotive) markets represent a major focus for metal replacement.

The critical performance parameters in this area of application involve very high stiffness with light weight, good dimensional stability and adequate strength and fatigue resistance. The current commercial state-of-the-art is based on engineering resins such as nylons, polyacetals, polycarbonates, and filled polyesters, including glass-reinforced moldings and sheets. Approaches now being explored which are destined for major growth are: fiber reinforced composites, including unidirectional tapes, hybrid sheets (with glass and graphite or organic fibers) for stamping or molding, injection molding compounds (thermoplast and thermoset) with chopped high modulus fiber and pultrusions for standard shapes; foam molding, particularly to replace large, heavy structures; and perhaps internal composites, where the same polymer forms both the matrix and the reinforcement through manipulation of crystallization behavior. Also, the use of U.H.M.W. polymers in unreinforced applications.

There are a number of major problems in these areas requiring scientific and engineering research for a solution:

1) Epoxy resins with greater temperature and moisture resistance.

2) Polyimide resins with substantially improved processability.

3) Second generation high temperature matrix resins (like PPQ). [The first three are primarily related to aircraft and space applications.]

4) Faster cure epoxy and polyester resins, including possibly room-temperature curing.

5) Lower cost high modulus reinforcing fibers.

6) Lower cost fabrication methods—major emphasis will be placed here.

7) Improved understanding of structure–property relationships and the role of processing in developing the desired microstructure.

8) Expanded development of design concepts for utilization of anisotropic materials.

A second, and perhaps obvious, area for demand driven innovation lies in upgrading the performance of existing engineering materials to expand current markets. Here the critical performance parameters include, for example, strength, toughness, and dimensional stability in major engineering resin end uses and in tire cord.

I would suggest that the key approach here may be the development of ultra high molecular weight in existing polymer systems. This is already known to improve strength and toughness of a number of polymers in both the resin and fiber fields.

Two areas which will require substantial research are (1) low cost processes for producing U.H.M.W. polymers, and more important (2) innovative means for processing such polymers into shaped articles.

In the area of performance in extreme environments I would like to consider briefly flammability, thermal resistance and chemical resistance.

Probably more polymer related R&D funds have been spent on flammability research, during the last seven or eight years, than on any other project area—driven, of course, by legislation relating to consumer product safety. As far as I can see, not one major product has resulted from all this effort—not because improved performance was not achieved, but because the cost of improved performance was too great for the derived benefit in the opinion of the consumer. As a result, Government regulations are being modified or interpreted to pass most existing polymers in current applications. However, I believe the need for better flammability performance will continue to grow slowly, thus eventually making use of much of the good R&D which has already been accomplished.

The critical performance parameters in this area involve ignition, and generation of smoke and toxic gases, in such major end uses as apparel, home and institutional furnishings and public transport interiors. Ignition can be, in fact has been, suppressed by a number of approaches. I look for development of ignition quenching through catalytic methods as a new approach here. Reduced smoke and toxic gas emission will, however, most likely require synthesis of expensive new polymers and their use will therefore likely be restricted to critical applications.

In the field of thermal resistance, or high temperature polymers, I do not foresee any significant innovations occurring other than small scale development of very specific polymers for DOD and NASA purposes. In general, the cost and lack of commercial availability of the required monomers makes high temperature polymer development a very risky undertaking.

In the field of chemical resistance there appears to be one type of high performance structure which will become increasingly important—namely membranes for various types of separation systems. Here we are dealing with separators for batteries and fuel cells operating at extremes of pH and oxidation potential, or separation systems for removal of salinity or corrosive industrial pollutants from water. I anticipate that a number of new polymers for membrane applications will be developed in the next decade, each tailored to rather specific separation performance. In addition, the technology of membrane formation to provide tailored flux and rejection characteristics is expected to grow. Formation of "tight" ultrathin membrane on very porous substrates is expected to result in significantly improved performance.

Another major area for innovation lies in ceramic replacement, which as I see it impinges on the end uses of glazing, containers, and plumbing fixtures. Here the driving forces are weight saving, safety, and energy cost associated with ceramic production. Certainly shatter proof industrial and institutional glazing will be in some demand, and it appears that shatter proof carbonated beverage bottles will enjoy considerable growth in spite of current potential setbacks. Large part molding will increasingly be exploited for producing lightweight plumbing fixtures from existing engineering resins. The critical performance parameters involved are clarity, scratch resistance, impact strength and specific gravity.

Logical extensions of existing technology will be utilized principally to obtain the necessary improvements in performance.

A special area of high performance involves friction and wear characteristics, and mechanical and acoustical damping. Such applications as self-lubricating bearings, drive shafts, sporting goods and acoustical enclosures are involved. Graphite fiber composites appear to satisfy many of the requirements in these special applications and can be tailored for specific end uses by selection of fiber modulus and matrix resin characteristics.

Now, I would like to spend just a few minutes on innovations arising from "technological thrust". This is much harder to predict, but there appear to be three areas where major technical efforts are currently underway. These are (1) polymer alloys, (2) lyotropic and thermotropic liquid crystal polymers, and (3) extreme ordering of crystallizable flexible chain polymers.

Polymer alloys up until now have been approached largely on an empirical basis—a "try and see" blending approach. It appears that a more concerted effort to understand polymer interactions in blends will lead to the ability predictively to tailor-make polymer alloys with specific property spectrums. Of considerable potential interest is the development of processable polymers from known cheap but intractible polymers, through alloying with another polymer. Understanding the physical structure of polymer alloys and how it may be altered by processing will also play an important part in the growth of such materials.

The field of lyotropic and thermotropic liquid crystal polymers is expanding rapidly. Already Kevlar aramid fibers and X7G polyester resin are commercial, and patents on a large number of polymers have appeared. The linear stiff polymers are characterized by high molecular weight, a highly ordered melt or solution which allows the high molecular weight polymer to be processed at reasonable viscosity, and a highly ordered extended chain morphology in the solid state, leading to high strength, modulus and dimensional stability. Broad usage for such polymers in fibers, films and molding resins are possible, provided reasonable cost and innovative processing techniques can be developed.

High mechanical performance may also be achieved from cheap, flexible chain polymers such as nylons, polyesters and polyolefins, provided they can be organized into extended chain crystal structures which are relatively defect-free. That such an approach is possible has been recently demonstrated with polyethylene by several investigators. It appears only a matter of time before other relatively inexpensive and well known polymers are similarly manipulated. However, the extension of such feasibility demonstrations to commercial reality is quite another matter, and it is anticipated that highly sophisticated process innovations will be required. I am confident that they will be successful, and that within the next decade we will find many familiar polymers filling new end use roles, particularly where fibers and films are concerned.

This leads me to a final comment. In my opinion, perhaps the greatest needs and potential payoffs in the next decade are associated with polymer engineering, and more specifically, the understanding of how forming or shaping processes control microstructure, and therefore, properties. We already have a vast array of polymers, many of which are low in cost and have desirable properties. The technological challenge for the future is to utilize these polymers more fully by exploiting their physical structure potential, by utilizing them in combinations or alloys with other polymers, and by combining them with high modulus, high strength fibers to form advanced composites.