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CONSULTANT TRIP TO INDIA - FINAL REPORT

India.

Program: Development of resins for reinforced composites.

Author: Robert S. Irwin

Job Title: Consultant — 15 March - 1 April (1985.) DP/IND/81/003/11-61/32.1.H

General Remarks

My actual itinerary is attached. I spent approximately three days at each of the following laboratories: I.I.T., Delhi; N.C.L., Pune; V.S.S.C., Trivandrum; I.P.C.L., Baroda. On the final day, before departure from India, I discussed my findings and recommendations with Drs. R. G. Kumble and Balakrishnan of the Department of Science and Technology, Government of India.

In this report I will discuss each visit separately and enumerate my findings and recommendations. Most of these were discussed with D.S.T. in Delhi, but I have included additional points which occurred to me in retrospect.

I. Indian Institute of Technology (I.I.T.), Delhi

The Principal Investigator for the resins program is Professor I. K. Varma, who heads a team of pre- and post-doctoral researchers - Ms. Sangita, Ms. Ranjana, Dr. H. S. Chaudhary, Dr. B. S. Rao, and Mr. A. K. Tomar. Key objective is identification of a preferred bismaleimide composition for broad general application and specification of synthesis and curing procedures as basis for semi-works scaled-up synthesis and evaluation at V.S.S.C. Related research is directed towards unsaturated polyester resins, for copolymerization with bismaleimides to relieve internal stresses created in high-temperature curing, and coupling agents for improved adhesion to glass.

° Lectures

I made the following presentations to the resin team and various other I.I.T. students and faculty.

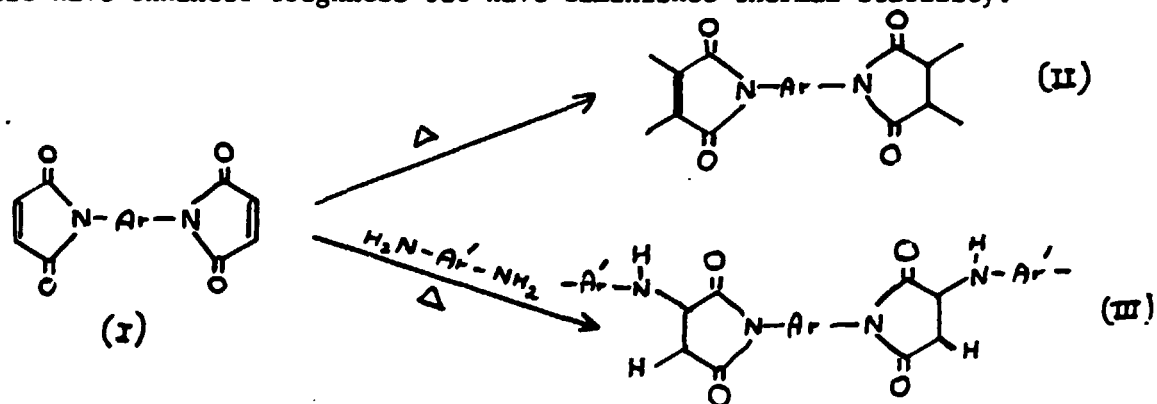
- (1) "High temperature polymers" dealt with the principles involved in the selection of polymeric compositions for use at elevated temperatures, and examples of polyimides and other types finding current application.
- (2) "Polyimides for fiber reinforced composites" covered the use of polyimides not only as matrix resins but as potentially new reinforcing fibers. Bismaleimide

resins were compared and contrasted with various other types of imide-based resins in terms of economics, processibility, and properties.

- (3) "Organic reinforcing fibers" focussed primarily on Kevlar<sup>®</sup> aramid, an aromatic polyamide, which complements the other common reinforcing fibers, glass and carbon, by providing increased toughness, non-catastrophic failure under compression, lower density, and intermediate economics.
- (4) "Structure-property relationships in mesophase polyester fibers" discussed the principles involved in the preparation of this new and still experimental class of high-performance reinforcing fibers.

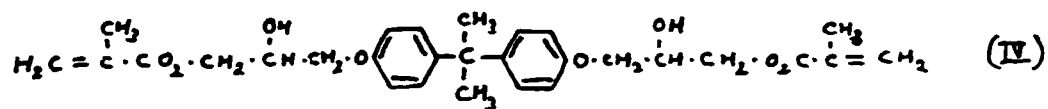
° Bismaleimide Technology - general

Bismaleimides (I) are synthesised by the combination of inexpensive maleic anhydride with a diamine (preferably aromatic). By heating (curing) up to 200°C or higher, a densely cross-linked structure (II) is produced by the addition polymerization of double-bonds; such structures are characteristically brittle. Alternatively, heating a bismaleimide in the presence of an aromatic diamine,  $H_2N \cdot Ar' \cdot NH_2$ , brings about so-called Michael addition of the amine groups to the double bonds to form more or less linear structures (III); compared with II, these have enhanced toughness but have diminished thermal stability.



Usual practice is to cure the bismaleimide (I) in the presence of a limited proportion of the diamine,  $H_2N \cdot Ar' \cdot NH_2$ , (Ar and Ar' may be the same or different), chosen to provide an optimum balance of resin toughness and thermal stability; This may vary somewhat according to end-use. The basic advantages of bismaleimide resins are (a) processibility into reinforced composites similarly to the more common epoxy-resins, (b) ceiling use temperature range up to 250°C compared with c. 125°C for epoxies, (c) low cost.

At I.I.T. a variety of bismaleimide resins have been synthesised from the more commonly used aromatic diamines, and fairly comprehensively compared, e.g. in terms of rates, temperature ranges, and heat changes in curing; cross-linking efficiency; thermal stability; mechanical properties of composites. Individual composites have shown various advantages or disadvantages but, as yet, no clearly preferred candidate composite, for scaled-up evaluation, has emerged. To counteract the deterioration of mechanical properties, attributable to internal stresses set up under high-temperature curing conditions, copolymerization of the bismaleimides in curing with a small amount of a divinyl ester (IV) appears to be effective.



° Comments and Recommendations

- (1) The absence of specific composite property goals lends a degree of indefiniteness to this program. I suggest that composites be prepared from some commercially available bismaleimide resins (preferably of known composition) to provide further experience in fabrication and perspective in terms of composite properties. According to Handbook of Composites (edited by G. Lubin, Van Nostrand Reinhold Co., New York and London, p. 109), bismaleimide prepreg materials are available from (a) Ferro Corporation, Ltd., Composites Division, Culver City, California, (b) Fiberite Corporation (advertisement attached), Winona, Minnesota, (c) Hexcel Corporation, Dublin, California, (d) U.S. Polymeric, Santa Ana, California. In addition Rhone-Poulenc produce Kerimid<sup>®</sup> resins. The attached properties for glass-fiber-reinforced thermoset polyimides and various epoxy resins ("1984-5 Modern Plastics Encyclopedia," P.O. Box 602, Hightstown, New Jersey 08520) may provide additional guidance.
  
- (2) Since the upper use temperature of bismaleimide resins is determined by the thermooxidative stability of the aliphatic maleimide adduct units, no significant improvement can be expected by the use of thermally more stable (and expensive) diamine units. On this basis 4,4'-oxydianiline, which is comparatively expensive because it is manufactured in limited quantities, is not to be preferred over the cheaper, more readily available 4,4'-methylenedianiline.

- (3) The mechanical properties of bismaleimide composites are influenced mainly by the density of the cross-linking in curing, so that the actual structure of the diamines (V), either comprising the bismaleimide or added prior to curing, of the bisaniline type (which are of most interest), is less important.



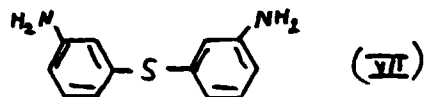
The main differences will be that flexible units (m-phenylene rings; O or S bridges) will provide somewhat lower flex modulus, but this may be of little consequence for most common applications. For this reason, 3,3'-diaminodiphenyl sulfone (VI), which is available at a very low cost in India, in principle, should provide adequate composite mechanical properties, and on this basis should be considered seriously as preferred candidate, compared with 4,4'-methylenedianiline, which is the least expensive aromatic diamine outside of India.

- (4) Several conditions to the use of the diaminosulfone (VI) for bismaleimide resins must be considered.
- (a) VI is suitable as a constituent of the bisimide but is not suitable as diamine for Michael addition. Its weak basicity in the latter use necessitates very high curing temperatures ( $\gg 200^\circ\text{C}$ ) which are likely to be unavailable to the average prepregger. However, the use of a VI-based bisimide with methylenedianiline as Michael adduct is quite satisfactory because Michael addition of less than  $200^\circ\text{C}$  is possible.

Can addition of VI be catalyzed to permit lower curing temperatures? Temperatures above  $200^\circ\text{C}$  seem to be essential for the addition reaction of the unsaturated maleimide groups with each other; can this be reduced by catalysis?

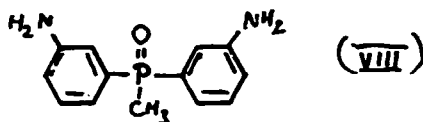
- (b) Is there a second supplier of VI, other than Hindustan Organic Chemicals? If not, users of a bismaleimide resin based on VI would be in a vulnerable position? As standard practice, the DuPont Company looks for two or more suppliers of each essential intermediate.
- (c) It is worth determining whether the manufacturers of VI can, by a

modest change in process conditions or at modest additional cost, produce the corresponding sulfide (VII).



VII would not require high curing temperatures. VII might also be formed by reduction of VI, possibly at attractive cost.

- (5) The phosphorus-containing resins such as that based on the diamine VIII have a quite outstanding level of flame resistance (L.O.I.=100) and a somewhat superior flex modulus.

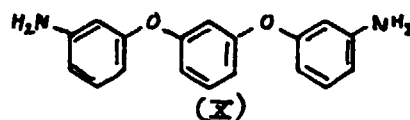
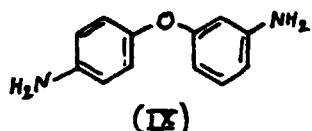


However, the other non-phosphorus-containing resins also have very good flame resistance (L.O.I.>80); and therefore, the gains in properties with VIII, et al., would not compensate for the undoubtedly higher cost and non-commercial availability of diamine VIII.

- (6) While appreciative of the reasons for incorporating a small amount of copolymerized divinyl ester in the resin to alleviate the suspected internal stresses engendered by a high cure temperature, I would point out that the presence of this material may diminish the upper use temperature by splitting out of H<sub>2</sub>O and by absorption of moisture, and may introduce further complications in application of this technology. Internal strains usually result from differential thermal expansion and contraction of reinforcing fibers, compared with the matrix resin, and will be intensified by high curing temperatures. I recommend taking all steps possible to minimize the curing temperature with 100% bismaleimide resins.
- (7) While adhesion-to-glass was not discussed with me, I judge, from the research effort on coupling agents, that it is not entirely satisfactory. This is a rather major undertaking, and I question whether the problems may not lie in a mismatch of thermal expansions (discussed above) which could be alleviated by lowered curing temperatures. I also recommend a close look at whether the fibers are properly wetted by the resin prior to and during curing, which would be associated with the melting temperature

of the neat and partially cured resin, relative to the curing temperature after removal of solvent. Plasticizers (i.e., non-volatile solvents) for the resin may be key to lowered melting point and improved wetting.

From the research point-of-view it might be worthwhile to investigate an asymmetrical diamine for lowered melting point. 3,4'-Oxydianiline (IX), available as a development chemical from Mobay Chemical Corporation, may be a good candidate because it is the basis for Teijin's HM-50 high modulus aramid fiber and if this develops, the diamine could be inexpensive.



I might also suggest an evaluation of the diamine (X), which is available from National Starch Corporation, might lead to superior processibility (and properties); melting points should be reduced by virtue of its high flexibility. The all-para analog of X, which would be stiffer, may also be obtained from Mobay.

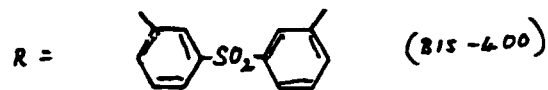
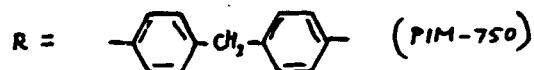
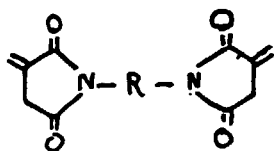
- (8) Since the resins program will be concluded in the next year or so, i.e. time is short, even though a clear technical case for preferring a particular bismaleimide candidate for scale-up is not in hand, I believe that economics plus information in hand at I.I.T., along with the experience at V.S.S.C. on the analogous bisitaconimide, provide a sound justification for scale-up, as of now, of the bismaleimide from 3,3'-diaminodiphenylsulfane (VI) as discussed earlier. If manpower and funding are available, I would favor the scale-up of the resin from 4,4'-methylenedianiline as well as the prospect for success here is very high. In both cases the latter diamine would be used as Michael adduct.
- (9) The attached notice of a short course on "High Temperature Polymers" may be of interest to resin program investigators because bismaleimides is one of the topics specifically covered.

## II. Vikram Sarabhai Space Center (V.S.S.C.), Trivandrum

Dr. K. V. C. Rao, as Principal Investigator for the resins program, directs the work of a young and relatively inexperienced group - D. Chandra, R. George, and M. Rao. Also associated with the program are S. K. Nema and Dr. R.

Ramasamy. A different group, headed by K. S. Sastri is equipped to perform scale-up resin syntheses and evaluations as required, for V.S.S.C. and other laboratories participating in the resins research; Dr. Shanmugam is a key member of this group.

The key research objective at V.S.S.C. is to determine whether bisitaconimides present a viable alternative to bismaleimide resins, in terms of processibility and composite properties. Itaconic acid can be obtained from plant sources in India and I assume that economic studies have established it as an attractive alternative to maleic acid. Currently, the V.S.S.C. program is focussed on the bisitaconimides from 4,4'-methylenedianiline (coded PIM-750) and 3,3'-diaminodiphenylsulfone (BIS-400).



° Comments and Recommendations

- (1) Discussion of maleimide work at I.I.T. (above) is applicable also to bisitaconimides.
- (2) The key elements of this program seem to me to be rather self-evident.
  - (a) Side-by-side comparison of PIM-750 and BIS-400, in all aspects of process and composite properties with their better-known, bismaleimide analogs, using optimal conditions established for the latter (I.I.T. work and bismaleimide literature).
  - (b) Optimization of bisitaconimide process technology and composite properties, and a further comparison with bismaleimides under optimal conditions for each separately. Optimal may be best defined as providing, without processing problems, the best possible combination of composite properties, suitable for the same broad-based application. The property flexibility possible with each type of resin should also be compared.



(c) Decision as to whether bisitaconimides are viable resin compositions in terms of processibility and composite properties and to proceed with a scaled-up evaluation, again making a comparison with bismaleimides, similarly scaled-up under optimum conditions.

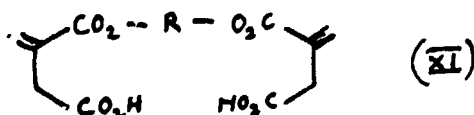
(2) I was not informed as to whether detailed comparisons of bisitaconimides and bismaleimides (as above) have been made, or whether the bisitaconimide resins have been optimized. I assume the latter to be the case because the technical problems posed to me did not bear directly on this situation but on relatively peripheral matters. I was not made aware of any basic problem to delay scaled-up evaluations of PIM-750 and/or BIS-400. Current experimentation did not appear to be addressing any problem on this issue.

I was not informed as to whether a detailed evaluation of bisitaconimide process and properties, e.g. percentage cross-linking, curing rates and temperature ranges, thermal stabilities, etc., had been completed. Such knowledge is necessary for scale-up.

(3) The bisitaconimide technology practised at V.S.S.C. seems to differ in some respects from the bismaleimide technology at I.I.T., suggesting a possible need for closer coordination. Thus, for example, the former are imidized by heating in DMF whereas the latter are imidized by acetic anhydride/AcONa. Again, with the former, diamine adducts are created with 10-20% diamine whereas, with the latter, 30% diamine has been used. I am not aware of any special reasons for such differences.

(4) I felt that much of the current research at V.S.S.C. was not addressing the key issues. E.g.,

(a) isolation and purification of intermediate amide-acids (XI) and concern with their stability in solution appears to me to be irrelevant.



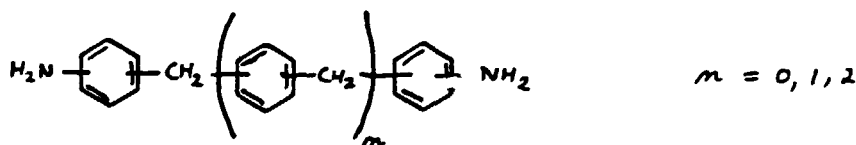
Amine-anhydride reactions are known to be quantitative, with negligible by-products, so high purity is expected. The use of

amide-acid as a resin is not a realistic option because the basic advantage of the imidized material is ability to cross-link by an addition reaction and avoidance of formation of void-forming condensation products such as water.

- (b) Copolymerization or blending of itaconimides and maleimides, while of mild interest, is unlikely to lead to a commercial product on the basis of economics. Other means are available for varying product properties, notably proportion and nature of amine adduct.
  - (c) Use of 4,4'-oxydianiline as Michael adducts for PIM-750 and BIS-400 seems impractical for economic reasons, stated earlier. Main interest should be 4,4'-methylenedianiline.
  - (d) Utilization of lower-boiling, rather than alkylamide solvents for prepregging seems to introduce complications (concerning formation of Michael adducts) which are best avoided at this stage. This could be researched later on but is not a reason to delay scaled-up evaluation.
- (5) There is some question in my mind as to whether prepolymerization of 10-20% 4,4'-diaminodiphenylsulfone with BIS-400 bisitaconimide resin in DMF is an effective reaction, in view of the I.I.T. finding that a weak base such as this diaminosulfone undergoes Michael addition at a rapid rate only at temperatures above 200°C (DMF boils at 156°C). If this is so, then adduct is formed only in actual curing of the resin. This point should be checked and consideration given as to whether 4,4'-methylenedianiline might be a superior choice of Michael adduct for BIS-400.
- (6) Some concern was expressed about shelf life (stability) of prepolymer solutions in DMF. If this is important, DMAc or NMP, which are often better solvents, should be tested. However, it would appear to be more attractive for a resin manufacturer either to ship his product as a dry solid (thus avoiding the extra bulk of a solution) or as fiber preregs - in both cases, stability of solutions is not a concern. Small increases in inherent viscosity of prepolymer, in powder form, were noted on storage at temperatures of about 60°C but not at 25°C. Since material will presumably be stored at room temperature, this

should not be a problem, especially if this small reaction has no effect on composite properties. Otherwise, one might consider the use of a polymerization inhibitor such as hydroquinone and exclusion of oxygen (air).

- (7) It was observed that cured composites of BIS-400 after exposure to air at 250°C for several hours retained room temperature mechanical properties very well on testing at 250°C. The PIM-750 actually improved in properties. This is undoubtedly the result of oxidative cross-linking of the tertiary hydrogens created in the itaconimide groups after addition reactions have eliminated the double bonds. With PIM-750 there is an additional opportunity for cross-linking via the reactive-CH<sub>2</sub>-bridge group; this is well-established with other kinds of polymer based on 4,4'-methylene-dianiline.
- (8) Dr. Rao raised the question as to how one could prepare a melt-processible bisitaconimide resin, eliminating the need for a solvent. For a lead on this I would direct attention to D. O. Hummel, et al., J. Appl. Poly. Sci., 18, 2015 (1974) - mixtures of bismaleimides of 4,4'-methylene-dianiline, 2,4-diaminotoluene, and 2,2,4-trimethylhexamethylenediamine melted in the range 75-125°C. Also, when 4,4'-methylenedianiline was replaced by "Jeffamine AP-22" in PMR-15, it was possible to eliminate



need for a solvent, use hot melt prepregging procedures, and obtain good tack and drape: see T. L. St. Clair and R. A. Jewell, National SAMPE Symposia Exhib. 23, 520-7 (1978).

- (9) Scale-up: Mr. Sastri described in detail their modus operandi for scaling-up a vinyl ester-styrene resin from I.I.T., a furfural resin from Sardar Patel University (Bombay), and a dimer acid polyamide resin (outside the UNDP project). My impression was that these were very competently handled in terms of promptness, generation of basic data for scale-up, and reaction to certain problems, such as gelation.

(10) I was consulted by other V.S.S.C. personnel who are engaged in research on aramid reinforced fibers and who had a lot of questions related to DuPont's aramid fibers.

### III. National Chemistry Laboratory (N.C.L.), Pune

In this large, well-equipped, and well-staffed laboratory, Dr. V. M. Nadkarni is Principal Investigator for the U.N.D.P. Resins Programme and supervises a young, enthusiastic research team consisting of Dr. Arun Shenoy, Dr. Jyoti Jog, and Miss Varsha, supported by D. R. Saine, and V. L. Shingarkali, technologists. Nadkarni directs concurrent work in related areas: (a) resins from liquid crystalline polymer melts, (b) cellulosic films, (c) bricks from sand and phenolic resins, (d) filled polyethylene, and (e) PET waste recovery. From consultations with various individuals, I would judge that Nadkarni leads a very capable group. I met also Dr. L. K. Doriaswamy, N.C.L. Director, Dr. R. A. Mashelkar, Head of the N.C.L. Chemical Engineering Division, and Dr. Bhide, Vice-Chancellor of the University of Pune, who is a technical coordinator of the U.N.D.P. resins program.

° Lecture on "Structure-Property Relationships in Mesophase Melt Polyester Fibers" was given to a large group of N.C.L. personnel.

° Comments

(1) The resins program focusses on polymer alloys or blends of polyethylene terephthalate and polymethyl methacrylate, which have the common features of ester groups. The objective is to provide a range of compositions having properties intermediate between P E T and methacrylate, two readily available polymer systems. Hopefully, some new, unexpected, synergistic property combination may be uncovered. Additional variations will be introduced by the use of 1,4-cyclohexanedimethanol, an inexpensive reduction product of terephthalic acid, in place of ethylene glycol. Since this diol can exist in both cis and trans forms, it is anticipated that property options may be further enhanced by controlling processing temperatures to give desired cis:trans ratios. I undertook to provide background on this isomerization process.

(2) Polymer alloys of good mechanical properties and color have been demonstrated. Structural analysis has shown that the alloys produced by a single-screw extruder are well dispersed. The opacity of the alloy is undoubtedly the result of light-scattering from the fine particles of each phase; a

molecular blend is not formed. Still more intimate dispersion should be possible when their new, twin-screw extruder is in operation. An unusual feature of these alloys is an attractive surface pearlescence which remains to be exploited. A useful characteristic of the alloy technology is that alloying accelerates the rate of crystallization of the PET, suggesting that faster rates of molding may be possible.

- (3) My impressions are that this work is progressing somewhat slowly but that otherwise it is on track. I was not informed of any unusual difficulties which are a road-block to the entire program. Dr. Nadkarni is well-informed in the field of polymer alloys. It remains to be seen whether his forthcoming, one-year's sabbatical leave at the University of Delaware will have a negative impact on the alloy programs.

#### IV. Indian Petrochemical Corporation, Ltd. (I.P.C.L.), Baroda

The work on mica-filled polyethylene by Dr. J. Anand, Dr. Xavier, and Dr. Nesqvi, under Dr. Y. N. Sharma, Principal Investigator, was the most advanced of all the U.N.D.P. resins programs that I reviewed. I also met Dr. Patel, General Manager of Research, Dr. Venkatasubramanian, Director of Research, and Dr. Ganwaly, I.P.C.L. Chairman, as well as a variety of other I.P.C.L. staff.

Lectures were presented on "Kevlar<sup>®</sup> aramid fibers" and "Mesophase melt polyesters."

#### ° Comments and Recommendations.

- (1) I.P.C.L. work is directed to the modification of a thermoplastic resin, polypropylene, which they manufacture, by incorporation of inorganic particulates (typically 30-50%) or chopped glass fiber. In early work they found that the combination of polypropylene with mica gave superior properties to alternative combinations involving high density polyethylene, CaCO<sub>3</sub>, talc, or glass. The PP/mica combination has attractive economics (20¢ and 10¢/lb. respectively) and significantly increased modulus (stiffness), depending on mica content. The latter, however, had little effect on tensile, impact, or flexural strength. Various objects have been molded from PP/mica, including a briefcase. Chief negatives, perhaps not critical for many applications, are limited toughness and shrinkage on cooling from mold.

- (2) The scientific investigations carried out on this project appear to have been systematic and comprehensive. Studies have included type of blending, coupling at interfaces with silicones and titanates, particulate shape and size and grafting (at 2-4% level) of benzophenone ultraviolet stabilizers on to the PP, via radical sites created via mixing energy at 180°C.
- (3) Current efforts are directed at studying the aspect ratio of mica particles - effect on properties. I may be able to provide some input as to rapid methods for assessing aspect ratios of mica particles other than laborious microscopic evaluation of individual particles. I also suggested that narrow particle size distributors could be separated by sedimentation methods and might give superior PP blends. One limitation on properties, in my opinion, is the interlaminar weakness of the mica particles themselves, and there seems to be no obvious way to take account of this. Otherwise, it might be possible to increase toughness by reducing the crystallinity of the PP. I would suggest applying the mechanical grafting technique to produce extensive short grafts on the PP molecules which would modify crystallization. Ideally, one would design a linear copolymer of PP for reduced crystallinity, but this may be far beyond I.P.C.L.'s terms of reference. I will endeavor to find out whether or not PP copolymers are used for molding purposes in the U.S.A. D.S.T. would like to understand why American PP filled products can provide a strength of about 900 kg/cm<sup>2</sup> compared with the 300-400 kg/cm<sup>2</sup> attained by I.P.C.L.
- (4) In summary, it seems that it is left for R. and D. at I.P.C.L. to fine-tune the filled PP product. The major task now becomes that of identifying suitable end-uses.
- (5) Because of my acrylic fiber background and the fact that I.P.C.L. are expanding in acrylic fibers and actually will be using DuPont technology, I had significant discussions with the PAN fiber marketing and technical groups concerning various problems. It is possible that I.P.C.L. in the future might be interested in producing carbon fibers from PAN on a small scale.

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AIR	LV PHILADELPHIA		645 PM	BRITISH AIR	FLT:274	BUSINESS		
16	MAR 85	-	SATURDAY					
	AR LONDON HEATHROW		810 AM	1-STOP	DINNER			
AIR	LV LONDON HEATHROW		935 AM	AIR INDIA	FLT:110	BUSINESS		
	AR DELHI		1159 PM	NON-STOP				
20	MAR 85	-	WEDNESDAY					
AIR	LV DELHI		505 PM	INDIAN AIR	FLT:518	COACH CLASS		
	AR POONA		700 PM	NON-STOP				
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23	MAR 85	-	SATURDAY					
AIR	LV POONA		620 PM	INDIAN AIR	FLT:158	COACH CLASS		
	AR BOMBAY		650 PM	NON-STOP				
24	MAR 85	-	SUNDAY					
AIR	LV BOMBAY		1045 AM	INDIAN AIR	FLT:167	COACH CLASS		
	AR TRIVANDRUM		1245 PM	NON-STOP				
27	MAR 85	-	WEDNESDAY					
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	AR BOMBAY		335 PM	NON-STOP				
AIR	LV BOMBAY		730 PM	INDIAN AIR	FLT:189	COACH CLASS		
	AR VADODARA		815 PM	NON-STOP				
30	MAR 85	-	SATURDAY					
AIR	LV VADODARA		750 PM	INDIAN AIR	FLT:418	COACH CLASS		
	AR DELHI		915 PM	NON-STOP				
01	APR 85	-	MONDAY					
AIR	LV DELHI		435 AM	AIR INDIA	FLT:101	BUSINESS		
	AR LONDON HEATHROW		1130 AM	1-STOP				
05	APR 85	-	FRIDAY					
AIR	LV LONDON HEATHROW		1100 AM	TRANS WORLD	FLT:755	BUSINESS		
	AR PHILADELPHIA		1245 PM	NON-STOP	LUNCH			

AIR TICKETS FOR IRWIN ROBERT S DR TKT NBR BA7736946927/28 1,277.00

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TOTAL AMOUNT 1,277.00

BT-115-7

# "We started out using a glass to solve a test problem. And using it in 10 million cars."

Sometimes on the road to solving just one problem, the path takes a curious turn and a host of problems are solved.

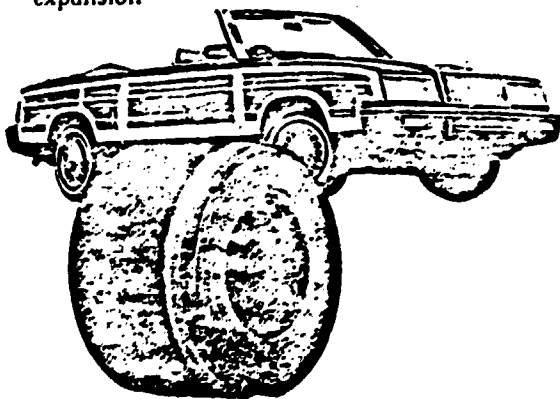
That's what happened when Chrysler Corporation product engineers discovered that a glass filled phenolic disc brake piston used for its heat resistant properties during a brake dynamometer test turned out to have outstanding dimensional stability. And it weighed less than half of the steel part it replaced. Plus it offered outstanding manufacturing advantages, solved a material supply problem, and yielded significant cost savings.

It's a sterling example of how quality improves when engineering innovations and material characteristics come together.

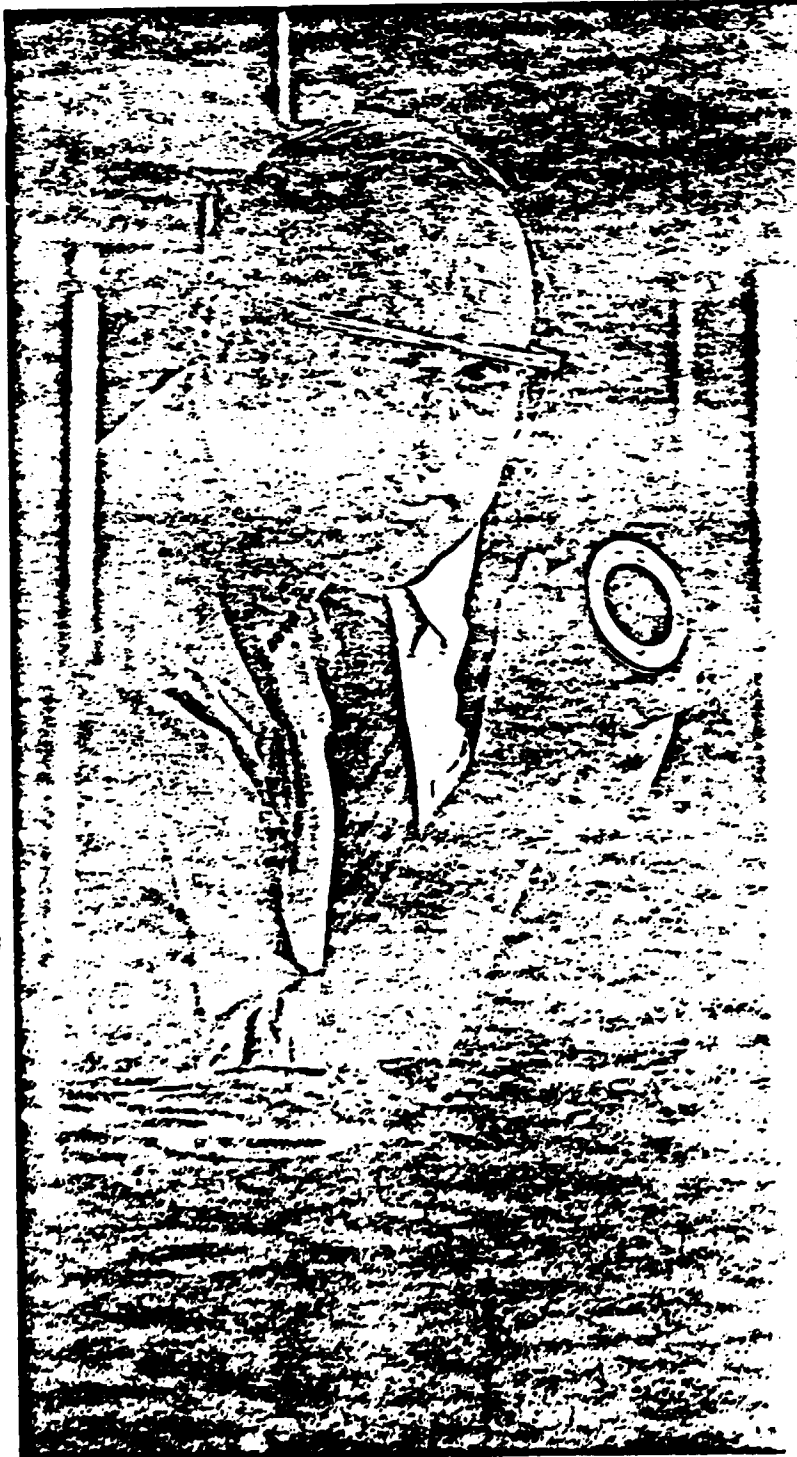
Fiberite® engineered thermosets – phenolics, epoxies, polyimides, silicones, and melamines – are finding broad applications in the automotive and transportation industries with more yet to come.

**Fiberite® thermoset compounds offer outstanding engineering, manufacturing, and cost advantages not found in other materials.**

- High heat resistance
- Dimensional stability
- Creep resistance
- High compressive strength
- Low weight
- Low thermal expansion
- Excellent adhesion to inserts
- Superior chemical and moisture resistance
- High impact strength
- Low pressure molding capability



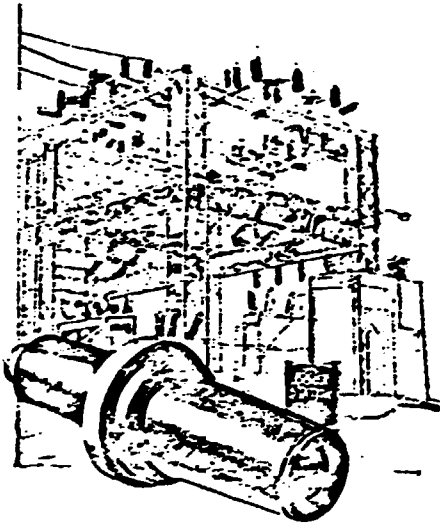
Many parts of Fiberite® compounds are already in mass production for transportation – brake systems, motor cases, drive train components, coils, timing gears, ignition systems, electronic components, EMI shielding, fuel injection systems, self-lubricated bearings.





# Asphenolic part now wound up

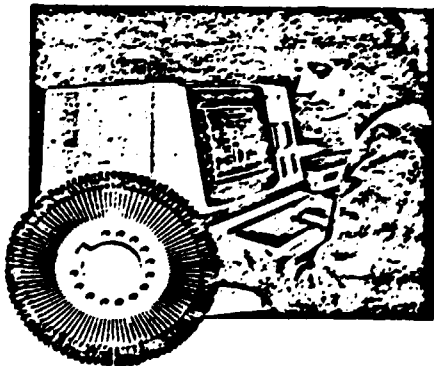
Bob Campbell, Product Engineering/Quality Control  
Chemical Division, Chrysler Corporation



**Fiberite® molding compounds for electric transmission** offer excellent insulation characteristics under wet conditions, high dielectric strength, dimensional stability under stress and easy molding for difficult configurations.

- Low and high voltage transformer bushings
- Switchgear
- Coils
- Electric motors
- Transformer housings
- Standoffs
- Insulators
- Underground transmission components
- Commutators

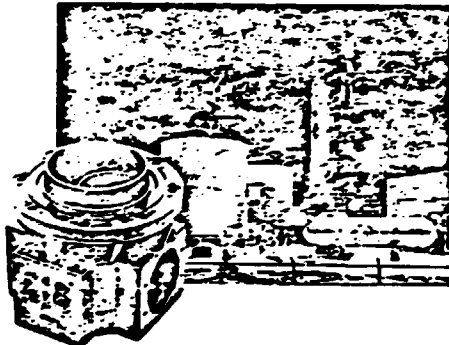
**For the computer, business machine and telecommunications industry** Fiberite® molding compounds offer parts of dimensional stability.



Circle 15 for reader service

resistance to heat stress during vapor phase soldering and other assembly operations, excellent pin retention, and the capability to meet tight tolerances.

- Daisy print wheels
- Ink jet printing components
- Coil assemblies
- Opto couplers
- Diodes
- Fiber optics devices
- EMI shielding
- Semiconducting encapsulation
- Structural components
- Connectors
- Relay racks



**In liquid and food handling systems,** Fiberite® mold... compounds offer outstanding chemical resistance, heat resistance, and the ability to mold into complex shapes.

- Impellers
- Pump housings
- Sucker rods
- Sanitary liners
- Valve bodies
- Food handling devices
- Scraper blades
- Dry bearings

**In defense and ordnance applications,** Fiberite® offers compounds that meet a wide range of MIL specs.

- Tactical rocket components
- Sabots
- Molded oblatives
- Small arms parts
- Gunstocks
- EMI shielding



**Think of Fiberite® when your design goes on the board. Or even before.** Because the unique properties of Fiberite® engineered products can get ideas going. In addition to engineered thermoset molding compounds, Fiberite® is a qualified supplier of high-performance advanced composites, and preimpregnated filament roving. Call on Fiberite® for

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# High-Temperature Polymers: Synthesis, Properties and Applications

## June 19-21, 1985

High-temperature polymers are rapidly gaining worldwide importance for many uses in aerospace, electronics and high technology industries. This course presents an overview of the most recent advances in research and development of polymeric materials useful in the range of 200°C and above. Methods for preparing high-temperature linear thermoplastics, addition-type thermosets, and elastomers will be reviewed

with emphasis on the properties of these systems. Applications of thermally stable polymers as composite matrix resins, structural and film adhesives, molding powders, films, fibers, and coatings will be discussed. The course is designed for the practicing polymer chemist, engineer, or materials scientist who is currently working with or contemplating the use of high-temperature polymers.

Wednesday, June 19

Morning

- **Historical Development of Thermally Stable Polymers**  
Overview: to include polyphenylenes, polyesters, polyphenylenesulfides, polyamides, polyimides, some polyheterocycles, and polybenzimidazoles ..... P.E. Cassidy
- **Aerospace Applications for High-Temperature Polymers**  
Discussion of reinforced graphite/polyimide composites, linear and addition polyimide adhesives, films, and coatings. Related commercial spin-offs ... A.K. St. Clair
- **Soluble Aromatic and Aliphatic Polyimides**  
Includes the synthesis and characterization of soluble phenylated aromatic polyimides and novel aliphatic/aromatic polyimides ..... F.W. Harris

Evening

- **Linear Thermoplastic Polyimides**  
Structure-property relationships, methods for increasing processability and solubility, effects of structure on adhesive properties, and techniques for modifying structure to obtain desired properties ..... T.L. St. Clair
- **Addition-Type Polymers**  
Bismaleimides and related imides. Chemistry, availability, applications, and trends ..... D.A. Scola

Thursday, June 20

Morning

- **Acetylene-Terminated Polymers**  
Synthetic routes for incorporating the acetylenic linkage into precursors and polymers; chemistry, physical, and mechanical properties of resulting polymers; use in electrical or electronic coatings, in advanced composites, or for applications calling for unusual chemical resistance ..... A.B. Naselow
- **Phosphazene Polymers: Synthesis, Properties, and Applications**  
Includes recent work on high-temperature elastomers and matrix materials. Alternate synthetic approaches to phosphazene polymers ..... R.E. Singler
- **Liquid Crystallinity in Polymers**  
Phenomenon of liquid crystallinity in polymeric systems with examples drawn from both isotropic and thermotropic materials. Structure-property relationships, liquid crystal characterization methods, and synthetic chemistry ..... A.C. Griffin

Evening

- **Aromatic Heterocyclic Polymers**  
Rigid-rod and extended-chain structures. Synthesis; liquid crystalline behavior; polymer, fiber and film properties ..... J.F. Wolfe
- **Semi-Interpenetrating Polyimide Network**  
Novel polyimide network which lends processability to linear systems, improved toughness for crosslinked polyimides, adhesive and composite properties ..... T.L. St. Clair

Friday, June 21

Morning

- **Thermotropic Polyesters and Polyamides**  
Structure-property relationships in polyester and polyamide liquid crystals. Emphasis on thermal behavior and synthetic approaches ..... A.C. Griffin
  - **New and Unusual High-Temperature Polymers**  
Potential of silane- or siloxanebenzoxoles, carbosilanes, carboranes, phthalocyanines, metal organophosphinates, and phosphinatoalanes for such uses as electrical semiconductors, liquid crystals, selective membranes, solar and geothermal energy recovery ..... P.E. Cassidy
- Scientific Program Co-Chairpersons: Anne K. St. Clair and Terry L. St. Clair.

Mrs. St. Clair is a Senior Research Scientist in the Materials Division at NASA Langley Research Center. She received a B.S. in chemistry from Queens College in 1969 and an M.S. in bioinorganic chemistry from Virginia Polytechnic Institute and State University in 1972. She is currently group leader for synthesis and development programs in the areas of metal-containing polymers and high-performance film technology.

Dr. St. Clair is Head of the Polymeric Materials Branch at NASA Langley Research Center. He received a B.S. in chemistry from Roanoke College in 1965 and a Ph.D. in organic chemistry from Virginia Polytechnic Institute and State University in 1972. He is responsible for R&D of high-temperature polymers for aerospace applications, including structural adhesives, advanced composites, films, and coatings.

Lecturers: Dr. Patrick E. Cassidy

Prof. of Chem., Dept. of Chemistry  
Southwest Texas St. Univ., San Marcos, Tex.

Dr. Andy C. Griffin

Prof. of Chemistry  
University of Southern Mississippi  
Hattiesburg, Mississippi

Dr. Frank W. Harris

Prof. of Polymer Science and Chemistry  
Institute of Polymer Science  
University of Akron, Akron, Ohio

Dr. Art B. Naselow

Manager, Materials Technology Department  
Hughes Aircraft Co., El Segundo, Calif.

Dr. Daniel A. Scola

Senior Research Chemist  
United Technologies Research Center  
East Hartford, Connecticut

Dr. Robert E. Singler

Research Chemist, Polymer Research Div.  
Army Materials and Mechanics, Research Ctr.  
Watertown, Massachusetts

Dr. James F. Wolfe

Program Manager, Ordered Polymers  
SRJ International, Menlo Park, Calif.

**REGISTRATION FEE: \$595.00 for the three day conference.**

# Crosslinked Polymers: Chemistry, Properties and Applications

## June 17-19, 1985

The objectives of this course is to acquaint scientists with the latest developments in various aspects of crosslinked polymers. The emphasis will be on the discussion of chemistry, processes, applications and fundamental principles unique to network polymers. Technologically most important classes of crosslinked polymers will be covered in greater detail. A comprehensive list of literature references for the past five

years will be provided along with other lecture notes. The course is designed for the scientists and engineers who are already involved in the formulation or use of thermosetting systems (e.g. adhesives, composites, coatings, electronics, printing inks, etc.) and would like an update on the fundamental research and technology of these system.

Monday, June 17

Morning

- **Recent Developments in Crosslinking Reactions**  
Overview of crosslinking reactions, emphasis on new crosslinking techniques with extensive literature references for the period of 1978-1983 ..... S.S. Labana
- **Crosslinking of Epoxy Resins**  
Will cover new epoxy resins, curing agents, catalysts, control of process parameters, typical formulations and uses ..... R.S. Bauer

Evening

- **Crosslinking of Acrylic Polymers**  
Compositions of crosslinkable acrylic copolymers, functional groups, reaction rates, shelf stability, typical formulations and uses ..... A. Mercurio
- **Characterization of Crosslinking Polymers**  
Investigation of molecular architecture, swelling, mechanical measurement, gel permeation chromatography, chemorheology, and concept of effective crosslinks ..... L.H. Sperling

Tuesday, June 18

Morning

- **Morphology of Crosslinked Polymers and Interpenetrating Networks**  
Theory of formation of inhomogeneties, determination of microstructures, influence on mechanical properties, segregation of different polymers in thermo setting systems, control of morphology, unique properties of interpenetrating networks ..... L.H. Sperling
- **Techniques for Measuring Kinetics of Crosslinking Reactions**  
Experimental details of differential scanning calorimetry, infrared, gas chromatography. Interpretation of kinetics data ..... I.J. Goldfarb

Evening

- **Chemistry of Radiation Induced Crosslinking Reactions**  
Fundamental principals, radiation sensitive chemical structures and side reactions ..... J.F. Kinstle
- **General Discussion of Topics Covered**  
DISCUSSION LEADER ..... S.S. Labana

Wednesday, June 19

Morning

- **Radiation Induced Crosslinking Processes**  
Compositions of polymers of commercial importance, equipment, process conditions and applications ..... J.F. Kinstle
- **Crosslinked Polymers in Electronic Applications**  
Use of polymers in video disks, computer disks, photoresists, optical fibers and other high technology areas ..... M.J. Bowden

Scientific Program Chairman: Dr. S.S. Labana is Manager of the Polymer Science Department Research Staff, Ford Motor Company. He received his Ph.D. in 1963 from Cornell University, Ithaca, New York and did one year post-doctoral research at the University of California, Berkeley. He has edited two books on crosslinked polymers and has recently completed a chapter on the subject for John Wiley Encyclopedia of Polymer Science and Engineering.

Lecturers: **Dr. Ronald S. Bauer**  
Shell Development Company  
Westhollow Research Center  
Houston, Texas

**Dr. Murrae J. Bowden**  
Head, Chemistry and Polymer  
Research Department  
Central Service Organization  
of Regional Bell Operating Laboratories  
Murray Hill, New Jersey

**Dr. I.J. Goldfarb**  
Group Leader, Polymer Characterization  
Materials Laboratory  
Wright-Patterson Air Force Base, Ohio

**Dr. James F. Kinstle**  
Polymer Research  
Polaroid Corporation  
Cambridge, Massachusetts

**Dr. Andrew Mercurio**  
Department Manager of  
Polymer Resins and  
Monomers Pioneering  
Research Laboratory  
Rohm & Haas Company  
Spring House, Pennsylvania

**Dr. L.H. Sperling**  
Professor of Chemical Engineering  
Lehigh University  
Bethlehem, Pennsylvania

**REGISTRATION FEE: \$595.00 for the three day conference.**

## General Information

### Enrollment:

The registration fee includes instruction, prepared notes (available only to those attending the courses), refreshments during coffee breaks, cocktails, mixer and banquet.

A registration form is attached. Enrollment may be made by individuals or companies. A reservation may be requested for industry, university, or government training employees who require time to obtain authorization. Advance registration is required. Check, purchase order, or government training contract should accompany the application. Check should be issued to:

#### Science and Technology Conferences.

- 1) *Crosslinked Polymers: Chemistry, Properties and Applications conference* - fee \$595.00.
- 2) *High-Temperature Polymers: Synthesis, Properties and Applications conference* - fee \$595.00.

The registration fee does not include room and meals. Each participant will be charged directly by the hotel or motel for room costs and extras.

Certificates will be awarded to participants attending the courses. Continuing Education units may be earned.

### Accommodations:

Arrangements have been made with Mohonk Mountain House (914-255-1000), located a few miles from the campus to provide accommodations for the participants at reduced rates. Rates are \$90.00 per person, per day for single accommodation and \$80.00 per person, per day for double accommodation. Rates include all meals, with a great variety of courses available for your selection, and some recreational facilities. The rates do not include gratuities or tax. A \$50.00 deposit per person is required.

There is a limousine service between the New York Airports and Albany Airport and the village of New Paltz (hourly schedule).

Complimentary transportation will be provided by the conference to Lake Mohonk from the New Paltz Bus Station and the Plaza Diner (drop-off place for the Hudson Valley Airporter and Limousine Service).

In addition to the Mohonk Mountain House, Super 8 Motel is available to our participants. Super 8 Motel is less than a year old unit, located in the town of New Paltz, seven miles from the lecture center at Mohonk Mountain House, but within walking distance for the shopping centers and restaurants. Special rates are available to our participants: Single/\$32.88 per day, Double (two persons)/\$36.88 per day, Twin (two persons)/\$38.88 per day. Prices include continental breakfast, but not sales tax. When you make reservations, (914-255-8865) indicate you are attending our conferences in order to receive the special rates.

Participants should contact the preferred hotel directly. Rooms at Mohonk Mountain House will be held a limited time (a month before the course). After that time room reservations at Mohonk Mountain House will be accepted only if space is available, however rooms will be available at the motels. Please make arrangements early.

### Schedule:

Lectures are scheduled in the mornings and in the evenings. The afternoons are free for recreation, reading, or participation in discussion groups, as the individual desires. Classes will be held at the Mohonk Mountain House. However, all college facilities will be available to the attendees. All conferences will end at 12:30 p.m. on the last day of the conference.

Exact information regarding final registration, check-in, living facilities, eating arrangements, and limousine transportation from New Paltz Bus Station or Plaza Diner to the Mohonk Mountain House will be provided upon receipt of the registration form.

A welcoming mixer on the first day of the conference enables participants and faculty to meet on an informal basis; group lunches and dinners enable further interchange of ideas; and the concluding banquet provides the occasion for awarding certificates of completion of the course.

### Recreational Facilities:

The Mohonk Mountain House, a 15-minute ride from the New Paltz campus, furnishes usual and unusual recreational activities, scenic grandeur and old-world charm. Ninety miles of hiking trails and bridle paths, clay tennis courts, one of the oldest golf courses in the area, swimming in the "Lake in the Sky" (as Mohonk Indians called it), a 305-room gingerbread-style mountain house, plus flower gardens, carriage rides, concerts, movies, art classes and lectures serve to provide you with beauty, relaxation and fun on Mohonk's 7,500 acres of fields, woods, lakes and streams.

The Sky Top Tower, at an altitude of 1,500 feet, can be seen for miles around and commands dramatic views of parts of six states. Hospitality continues to be the hallmark of Mohonk at the outset of its second century.

### Further Inquiries:

Additional information may be obtained by writing or calling:

Dr. Angelos V. Patsis, Director  
Institute in Materials Science  
State University of New York  
Coykendall Science Building  
New Paltz, New York 12561  
Telephone: (914) 257-2175

Although these are firm programs, contingencies may require a change without notice.

### Registration Form

LAST NAME	FIRST	INITIAL
COMPANY	Tel. #	
COMPANY ADDRESS		
SIGNATURE	TITLE	
CONFERENCE NAME	DATE FROM:	TO:

Registration Fee: \$595.00

I am enclosing a check for \$ \_\_\_\_\_

Checks should be issued to: Science and Technology Conferences

Please mail to: Institute In Materials Science, C.S.B. 209

State University of New York, New Paltz, NY 12561

Code 1 2

For further information call: (914) 257-2175

### Accommodation Form

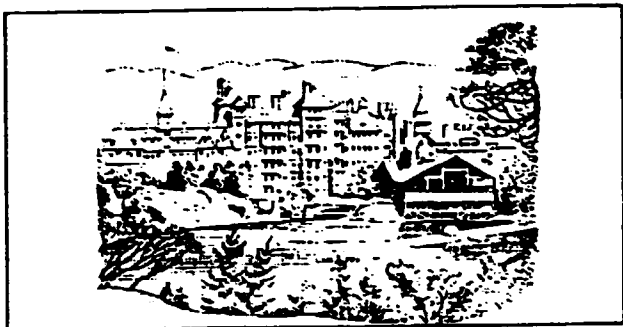
NAME	HOME TELEPHONE NUMBER		
HOME ADDRESS			
CITY	STATE	ZIP CODE	
BUSINESS ADDRESS (NAME OF COMPANY)			
STREET AND NUMBER	CITY	STATE	ZIP CODE
SPECIAL INFORMATION AND REQUESTS		NUMBER OF GUESTS	
DATE AND TIME OF ARRIVAL AT NEW PALTZ		DATE OF DEPARTURE	

Please include a \$50.00 deposit per person.

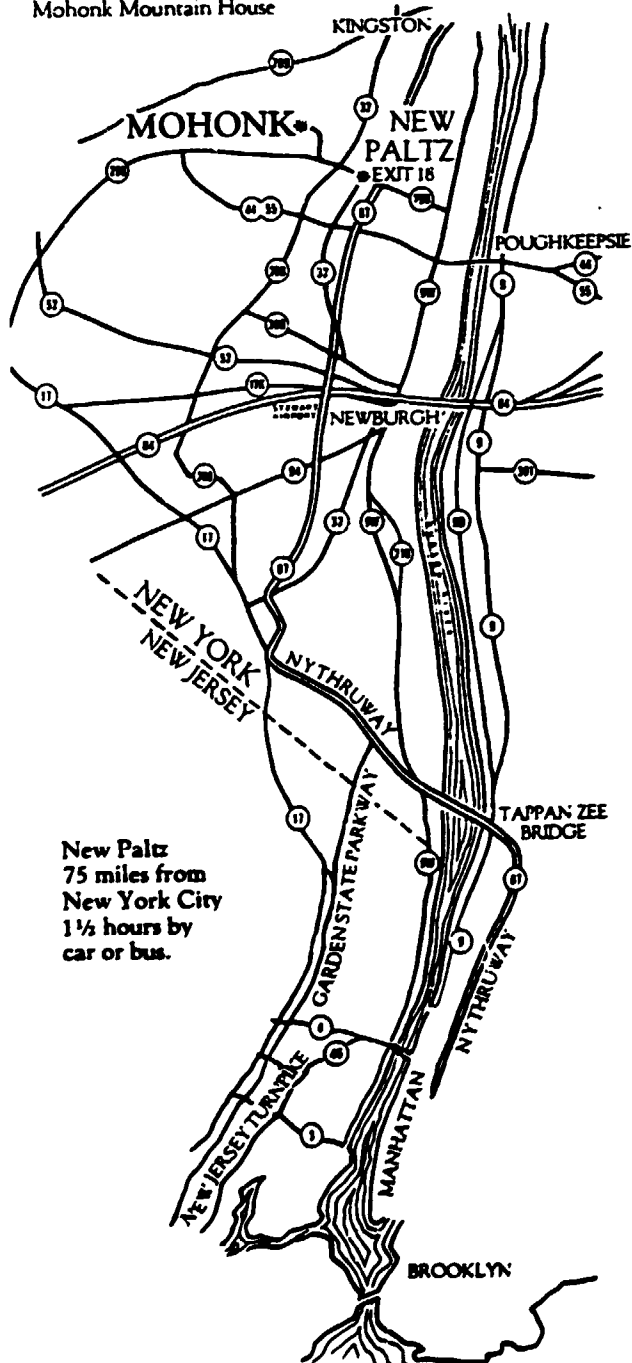
Please mail directly to: Mohonk Mountain House  
Lake Mohonk, New Paltz, NY 12561

For further information call: (914) 255-1000

Dr. Angelos V. Patsis, Director  
Institute In Materials Science  
Coykendall Science Building  
State University of New York  
New Paltz, New York 12561



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Polyethylene and ethylene copolymers (Cont'd)					Polyimide			Poly-methyl-pentene	
High density (Cont'd)			Crosslinked		Thermoplastic		Thermoset, 50% glass fiber-reinforced	Unfilled	
Copolymers (Cont'd)									
Ethylene methyl-acrylate	Ultra high molecular weight	30% glass fiber-reinforced	Molding grade	Wire and cable grade	Unfilled	40% graphite-filled			
1	83	125-135	120-140				Thermoset	230-235	
					310-365	365			
2	E: 300-350	C: 400-500	F: 400-800	C: 240-450 F: 250-300	E: 250-300	C: 625-690	C: 690 F: 390 T: 390	C: 510-550 F: 510-610 E: 510-650	
3		5-20	10-20			3-5	3-5	3-10	
4						3-4		2.0-3.5	
5		0.040	0.002-0.006	0.007-0.090	0.020-0.050		0.002	0.012-0.030	
6	1650	5600	9000	1600-4600	1500-3100	10,500-17,100	7600	6400	
7	740	420-525	1.5	10-440	180-600	8-10	3		
8	1650	3100-4000				12,500		2000-3300	
9			7000	2000-5500		30,000-40,000	18,000	34,000	
10			11,000	2000-6500		19,000-28,800	14,000	21,300	
11	12			50-500		300		160-280	
12				50-150				114-171	
13		130-140	800	70-350	8-14	450-500	700	1980	
								36	
								26	
								17	
14		No break	1.1	1-20		1.5	0.7	5.6	
15		R50	R75			E52-99	E27	M118	
				Shore D55-80	Shore D33-57			R35-85	
16		130	48	100	100	45-56	38	13	
17		110-120	250	105-145	100-173	530-680	680	660	
		155-180	265	130-225				175-195	
18			11			2.3-2.6	41.4	8.5	
19	0.942-0.945	0.94	1.28	0.95-1.45	0.91-1.40	1.36-1.43	1.65	1.6-1.7	
20	0.0	<0.01	0.02	0.01-0.06	0.01-0.06	0.24	0.14	0.7	
						1.2	0.6	0.01	
21		710	500	230-550	620-760	560		450	
	Gulf	Am Hoechst; Himont USA	Ferro; Schulman (see ad, p. 103); LNP; Thermofit; Wilson-Fiberfil	USI (see ad, p. 68); Philips	Union Carbide; USI (see ad, p. 68)	Du Pont; Upjohn; Fluorocarbon; Monsanto; Rhone-Poulenc	Du Pont; Fibertite (see ad, p. 28); Fluorocarbon; Rhone-Poulenc	Ciba-Giegy; Fibertite (see ad, p. 28); Upjohn; Rhone-Poulenc	Mitsui U.S.A.

Cellulosic (Cont'd)			Chlorinated PE	Epoxy					
1	Cellulose acetate butyrate (Cont'd)			Bisphenol molding compounds			Novolak molding compounds		
	Molding compound	Cellulose acetate propionate molding compound	Cellulose nitrate	35-42% Cl extrusion grade	Glass fiber-reinforced	Mineral-filled	Low density glass sphere-filled	Mineral- and glass-filled, encapsulation	Mineral- and glass-filled, high temperature
1.	140	190		125	Thermoset	Thermoset	Thermoset	Thermoset	Thermoset
								145-155	195
2.	C: 265-390 I: 335-480	C: 265-400 I: 335-515	C: 185-250	E: 300-400	C: 300-330 T: 280-380	C: 250-330 T: 250-380	C: 250-300 I: 250-300	C: 280-360 I: 290-350 T: 250-380	T: 340-400
3.	8-32	8-32	2-5		1-5	0.1-3	0.1-2	0.25-3.0	0.5-2.5
4.	1.8-2.4	1.8-3.4			3.0-7.0	2.0-3.0	3.0-7.0		1.5-2.5
5.	0.003-0.009	0.003-0.009			0.001-0.008	0.002-0.010	0.006-0.010	0.004-0.008	0.004-0.007
6.	2600-6900	2000-7800	7000-8000	1500-1800	5000-20,000	4000-10,800	2500-4000	5000-12,500	6000-15,500
7.	40-88	29-100	40-45	600-800	4				
8.									
9.	2100-7500	2400-7000	2100-8000		18,000-40,000	18,000-40,000	10,000-15,000	24,000-48,000	30,000-48,000
10.	1800-9300	2900-11,400	9000-11,000		8000-30,000	6000-18,000	5000-7000	10,000-21,800	10,000-21,800
11.	50-200	60-215	190-220		3000			2100	2300-2400
12.						650			660
13.	90-300	120-350			2000-4500	1400-2000	500-750	1400-2400	2300-2400
14.	1.0-10.9	0.5-No break	5-7		0.3-10.0	0.3-0.5	0.15-0.25	0.3-0.5	0.4-0.45
15.	R31-116	R10-122	R95-115		M100-112	M100-M112		M115	
				Shore A65				Barcol 70-74	Barcol 78
16.	110-170	110-170	80-120		11-50	20-60		18-43	35
17.	113-202	111-228	140-160		225-500	225-500	200-250	310-448	500
	130-227	147-250							
18.	4-8	4-8	5.5		4.0-10.0	4-35	4.0-6.0	8-31	17-24
19.	1.15-1.22	1.17-1.24	1.35-1.40		1.6-2.0	1.6-2.1	0.75-1.0	1.6-2.05	1.85-1.94
20.	0.9-2.2	1.2-2.8	1.0-2.0		0.04-0.20	0.03-0.20	0.2-1.0	0.04-0.29	0.17
								0.15-0.3	
21.	250-400	300-450	300-600		250-400	250-420	380-420	325-450	440-450
	Eastman (see ed. p. 53)	Eastman (see ed. p. 53)	Chem. Development; George, P. D.	Dow Chem.	Fiberite (see ed. p. 28); Mertac; Hysol; M & T	Fiberite (see ed. p. 28); Mertac; Hysol; M & T; Plaskon	Fiberite (see ed. p. 28); Hysol	Fiberite (see ed. p. 28); Mertac; Cosmic Plastics; Hysol; M & T; Plaskon; U.S. Prolam	Cosmic Plastics; Plaskon; U.S. Prolam



# Resins and compounds (Cont'd)

Materials	Properties	ASTM test method	Epoxy (Cont'd)					Fluoro-plastics	
			Glass-filled, high strength	Casting resins and compounds					Polychlorotrifluoroethylene
				Unfilled	Silica-filled	Aluminum-filled	Flexibilized		
Processing	1. Melting temperature, °C. $T_m$ (crystalline) $T_g$ (amorphous)		Thermoset	Thermoset	Thermoset	Thermoset	Thermoset	Thermoset	220
	2. Processing temperature range, °F. (C = compression; T = transfer; I = injection; E = extrusion)		C: 290-330 T: 290-330						C: 460-560 I: 500-600
	3. Molding pressure range, $10^3$ p.s.i.		2.5-5.0						15-60
	4. Compression ratio		6-7						2.6
	5. Mold (linear) shrinkage, in./in.	D955	0.0002	0.001-0.010	0.0005-0.008	0.001-0.005	0.001-0.010		0.010-0.015
Mechanical	6. Tensile strength at break, p.s.i.	D638 <sup>a</sup>	18,000-27,000	4000-13,000	7000-13,000	7000-12,000	2000-10,000	8000-12,000	4500-6000
	7. Elongation at break, %	D638 <sup>a</sup>		3-6	1-3	0.5-3	20-85	2-10	80-250
	8. Tensile yield strength, p.s.i.	D638 <sup>a</sup>							5300
	9. Compressive strength (rupture or yield), p.s.i.	D695	30,000-38,000	15,000-25,000	15,000-35,000	15,000-33,000	1000-14,000	15,000-20,000	4600-7400
	10. Flexural strength (rupture or yield), p.s.i.	D790	50,000-70,000	13,000-21,000	8000-14,000	8500-24,000	1000-13,000	10,000-13,000	7400-11,000
	11. Tensile modulus, $10^3$ p.s.i.	D638 <sup>a</sup>		350			1-350	495	150-300
	12. Compressive modulus, $10^3$ p.s.i.	D695							170-200
	13. Flexural modulus, $10^3$ p.s.i. 73°F. 200°F. 250°F. 300°F.	D790	2.8-4.2						190-260
	14. IZOD impact, ft.-lb./in. of notch (1/8-in. thick specimen)	D256A	25-34	0.2-1.0	0.3-0.45	0.4-1.6	2.3-5.0		2.5-5
	15. Hardness Rockwell Shore/Barcol	D785 D2240/ D2583		M80-110 Barcol 60-74	M85-120	M55-85	Shore D65-89		R75-95 Shore D75-80
Thermal	16. Coef. of linear thermal expansion, $10^{-4}$ in./in./°C.	D696		45-65	20-40	5.5	20-100		36-70
	17. Deflection temperature under flexural load, °F. 264 p.s.i. 66 p.s.i.	D648		115-550	160-550	190-600	73-250	200-450	258
	18. Thermal conductivity, $10^{-4}$ cal.-cm./ sec.-cm. <sup>2</sup> -°C.	C177		4.5	10-20	15-25			4.7-5.3
Physical	19. Specific gravity	D792	1.84	1.11-1.40	1.6-2.0	1.4-1.8	0.96-1.35	1.16-1.21	2.08-2.2
	20. Water absorption (1/8-in. thick specimen), % 24 hr. Saturation	D570		0.08-0.15	0.04-0.1	0.1-4.0	0.27-0.5		0
	21. Dielectric strength (1/8-in. thick specimen), short time, v./mil	D148	380-400	300-500	300-550		235-400		500-600
<p><b>Design and performance properties</b> For more detailed information on performance and design properties of plastics, by trade name and grade, see the following charts:</p> <p>Chemical resistance ..... p. 482 Dimensional stability ..... p. 565 Electromagnetic shielding ..... p. 556 Environmental stress-crack resistance ... p. 576 Fatigue ..... p. 566 Optical properties ..... p. 581</p> <p>In the 1983-1984 edition of MPE, see:</p> <p>Creep ..... p. 512 Dielectric loss properties ..... p. 533 Fibers ..... p. 502 Foams ..... p. 507 Impact resistance ..... p. 564 Laminates, by NEMA grades ..... p. 510 Outdoor exposure resistance ..... p. 579 Poisson's ratio ..... p. 582</p> <p>In the 1981-1982 edition of MPE, see:</p> <p>Flammability ..... p. 564 Pipe ..... p. 582</p> <p>In the 1980-1981 edition of MPE, see:</p> <p>Specifications/materials ..... p. 597 Temperature index ..... p. 632</p>		<p><b>SUPPLIERS*</b></p>	<p>U.S. Prolam</p>	<p>Ciba-Geigy; Devcon; Dow Chem.; Emerson &amp; Cuming; Epic Resins; Isochem; Hysot; Thermoset Plastics</p>	<p>Emerson &amp; Cuming; Epic Resins; Hysot; Thermoset Plastics</p>	<p>Devcon; Emerson &amp; Cuming; Isochem; Thermoset Plastics</p>	<p>Dow Chem.; Emerson &amp; Cuming; Hysot; Isochem; Thermoset Plastics</p>	<p>Union Carbide</p>	<p>Allied (see ed. p. 38); 3M</p>

a—Boldface listings identify advertisers in this issue. Where advertisements relate to the particular materials described, reference to the page number is included. See the Directory of Suppliers Classified Index, page 706, for additional suppliers of specialty materials and custom compounds.

b—Tensile test method varies with material: D638 is standard for thermoplastics; D651 for rigid thermosetting plastics; D412 for elastomeric plastics; D882 for thin plastic sheeting.