HIGH TEMPERATURE ARC-TRACK RESISTANT AEROSPACE INSULATION

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FOSTER-MILLER, INC.

- 37 year old independent technology development company
- Located in the Boston area
- About 270 employees
- Primary areas of business
  - Advanced polymers
  - Composites
  - Robotics
  - Special machinery

MATERIALS TECHNOLOGY GROUP

- Mission
  - Develop materials and processing technology to meet DoD and commercial needs
- Specific Areas of Research
  - High temperature dielectric materials
  - High performance dielectrics for capacitors
  - Electronics packaging
  - High performance structural materials
  - Microcomposite blends
  - NLO materials, devices
  - Smart processing

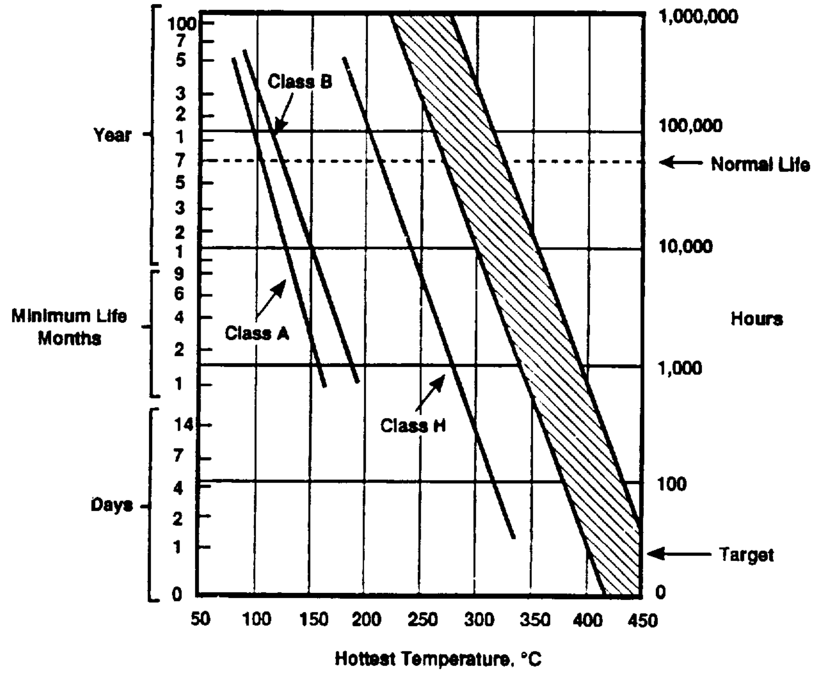
HIGH TEMPERATURE AEROSPACE INSULATION

- Goal
  - Identify and develop arc-track resistant insulation materials that can operate reliably at 300°C
- Phase I SBIR program, July 1991 to January 1992
- Monitored by Mr. George Slenski, and Mr. Eddie White of USAF Wright Laboratory/Materials Directorate
- Phase II program: October 1992 to September 1994
- Contract monitors: Lt. Tim Townsend and Mr. Robert Andes

COMPARISON OF CURRENT MATERIALS AND MATERIALS UNDER DEVELOPMENT FOR AEROSPACE INSULATION

Insulation Material	Max Use Temp. °C	Arc-Tracking	Advantages	Disadvantages	Comments
Kapton H	200°C	Yes	Lightweight. Excellent cut through resistance. Abrasion resistance. Minimal smoke generation. Not brittle when cold.	Arc-tracking. Hydrolytic instability. High moisture uptake. Subject to flashover.	Most widely used insulation material.
Tefzel Cross-linked Teflon	150°C	No	Lower moisture absorption than Kapton. Non-combustible gases when fails.	Weight and volume penalty compared to Kapton. Poor mechanical properties.	Navy has been replacing Kapton with Tefzel.
PTFE/ Polyimide Hybrids	220°C	No	Good balance of properties compared to Kapton and Tefzel. Performed better than MIL-W-81381 in MacAir tests.	Maximum use temperature. 15 percent weight penalty compared to Kapton.	Identified by MacAir program. Teledyne Thermatics has been recommended for inclusion in QPL.
Upilex-S	~250°C	Yes	Better thermal stability, arc-track resistance, and hydrolytic stability than Kapton.	Arc-tracking not eliminated. Non-domestic source. SiO_x coating susceptible to abrasion etc.	Recommended by the TRW study.

TARGET FOR NEW INSULATION



FOSTER-MILLER APPROACH TO DEVELOP A 300°C RATED, ARC-TRACK RESISTANT AEROSPACE INSULATION

Large Classes of High Performance Polymers

Phase I Program

Evaluation Based on
- Structure
- Thermal Stability
- Electrical Properties

6 Materials

Phase II Step I

- Experimental Characterization
- Rank According to Performance

2 Materials

Phase II Step II

- Experimental Evaluations in Wire Configuration
- Selection Based on Performance and Commercialization Potential

One Material System for Consideration to Include in QPL

PHASE I PROGRAM

ADVANTAGES AND THE DISADVANTAGES OF KEY STRUCTURAL FEATURES

STRUCTURAL FEATURE	ADVANTAGES	DISADVANTAGES
Fluorine content	For low dielectric constant, low loss factor, high volume resistivity, uniform electrical properties over a wide range of temperatures and resistance to arc-tracking.	Aliphatic fluoropolymers, such as Tefzel, have poor mechanical properties at high temperatures. To overcome this limitation, must incorporate other features.
Liquid crystalline	Solvent resistance, high thermal stability, excellent electrical properties and possible improved resistance to arc-tracking.	Liquid crystalline polymers are difficult to process, need to incorporate additional features, e.g., polyimide.
Polyimide	High thermal stability, abrasion resistance, good electrical properties and good processability.	Poor resistance to arc-tracking. Improved through introduction of additional features, e.g., fluorinated groups, crystallinity.

ADVANTAGES AND THE DISADVANTAGES OF KEY STRUCTURAL FEATURES (continued)

STRUCTURAL FEATURE	ADVANTAGES	DISADVANTAGES
Aromatic	High thermal stability.	Highly aromatic polymers yield conducting char upon pyrolysis.
Rigidity/ stiffness	Rigidity increases thermal and mechanical capability, and reduces susceptibility to solvents.	Highly rigid polymers can be intractable, difficult to process, and low elongation to break. Some degrees of flexibility desired.
Cross-linking	X-linking significantly increases thermal stability. This process is widely used in the development of 371°C-rated composites.	X-linking greatly reduces flexibility, reduces elongation to break, and embrittles.
Carbon /hydrogen ratio	High carbon to hydrogen ratio increases thermal capability of polymers.	High carbon to hydrogen ratio may cause the formation of conductive char and susceptibility to arc-tracking.

CLASSES OF MATERIALS EVALUATED

- Organic Polymers
  - Polyimides
    - Thermoset polyimides
    - Thermoplastic polyimides
    - Fluorinated polyimides
    - Liquid crystalline polyimides
    - Fluorinated liquid crystalline polyimides
    - Siloxane imides
  - Liquid crystalline polymers
  - Lyotropic liquid crystalline polymers
  - Thermotropic liquid crystalline polymers
  - Polyquinolines
  - Polyphenylquinoxalines
  - Polyketones
  - Polyether ketones
  - Polyarylates
  - Polysulfones
  - Aromatic polyimides
  - Polyamide-imides
  - Polybenzimidazoles
  - Aliphatic fluoropolmers
- Blends of Organic Polymers
  - Polyimide blends with thermotropic liquid crystalline polymers
  - Polyimide blends with polyether sulfones
- Inorganic Materials
  - Polysilsesquioxanes
  - Polycarbosilane

SUMMARY GOALS AND ACHIEVEMENTS OF THE PHASE I PROGRAM

GOAL	ACHIEVEMENT
Establish insulation requirements	Thermal, electrical, mechanical and physical requirements established
Prepare an evaluation matrix to rank materials	Selection criteria to screen polymers developed: • Key structural features that contribute desired performance • Key electrical properties • Key thermal properties
Conduct screening tests	Eleven candidate materials were acquired and prepared for testing Dielectric measurements (25°C to 300°C, and 20 Hz to 1 MHz) on all available polymers with potential for 300°C were conducted
Select most promising materials	Six polymers have been identified with the potential for: • No arc-tracking • 300°C rating • Better hydrolytic stability than Kapton • Better mechanical properties and solvent resistance than Tefzel
Proposed strategy for implementation	A two step program to develop an insulation system for consideration to include in QPL: • Experimental investigation and ranking of performance to narrow the field to two • Evaluation in wire construction to select one material system on the basis of performance, cost and manufacturability
Conduct cost/benefit analysis	Deferred to Phase II

PHASE II
PROGRAM DETAILS

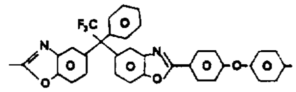
PERFORMANCE GOALS FOR SELECTED MATERIALS

- Arc-track resistance
  - >300 sec using ASTM D495
  - Concern: 0.125 in. thick samples
  - Develop alternate test for thin films
- Lifetime > 15,000 hr at 300°C
- Cost comparable to Kapton
- Amenable to manufacture into aerospace wire configurations on current equipment with little or no modification

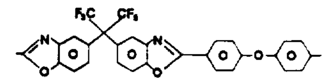
MATERIALS UNDER EVALUATION IN PHASE II

3F-PBO-PE	Fluorinated benzoxazole polyether
6F-PBO-PE	Thermoplastic fluorinated benzoxazole polyether
6F-PBO-PI	Fluorinated benzoxazole polyimide
36FDA-PDA	Fluorinated copolyimide
6FDA-PMDA-4BDAF	Fluorinated copolyimide
Low char polyimide	DuPont proprietary polyimide
Siloxane-polyimide	Polydimethylsiloxane polyimide
Phosphine oxide polymer	Poly(arylene ether phosphine oxide)
Xydar blends	Liquid crystal polyester

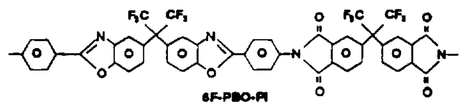
MOLECULAR STRUCTURES OF CANDIDATE POLYMERS



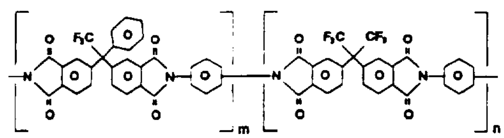
3F-PBO-PE



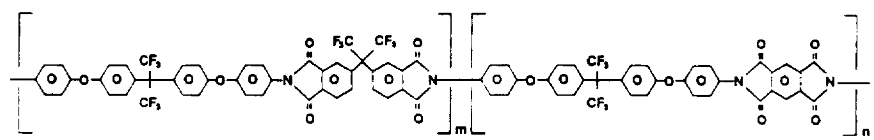
6F-PBO-PE



6F-PBO-PI

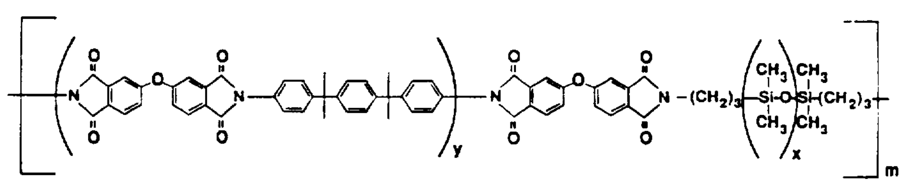


36FDA-PDA

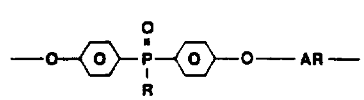


6FDA-PMDA-4BDAF

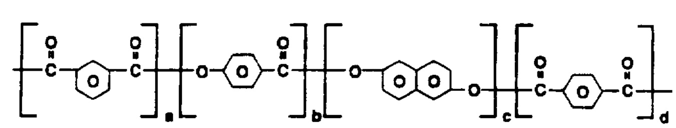
MOLECULAR STRUCTURES OF CANDIDATE POLYMERS



Siloxane Polyimide



Phosphine Oxide Polymer



A739-2

Xydar

CANDIDATE POLYMER PROPERTIES

POLYMER	SOURCE	Tg (°C)	PROPERTIES
3F-PBO-PE	Prof. J.E. McGrath VPI & SU Blacksburg, VA	299	5% wt loss at 547°C in air. Inherent viscosity (THF) = 0.80 Able to form 12 wt % solution in THF.
6F-PBO-PE	Daychem Laboratories Dayton, OH	290	Degradation onset in N_2 at 521°C. Able to form 18 wt % solution in THF.
6F-PBO-PI	Foster-Miller, Inc. Hoechst-Celanese	367	3% wt loss at 350°C after 64 hr. Dielectric constant (1MHz) = 2.82 Dissipation factor (1MHz) = 0.0004 Excellent solvent resistance.
36FDA-PDA	Foster-Miller, Inc. United Technologies	406	2% wt loss at 371°C after 100 hr in air. Films tend to be brittle with all p-PDA.

CANDIDATE POLYMER PROPERTIES

POLYMER	SOURCE	Tg (°C)	PROPERTIES
6FDA-PMDA-4BDAF	Prof. J.E. McGrath VPI & SU Blacksburg, VA	299	Using 30% 6FDA/70% PMDA ratio. 5% wt loss at 540°C in air. M_n = 30,000. Able to form 25 wt % PAA solution in DMAc.
Low char polyimide	DuPont	-	Able to form 14 wt % PAA solution in DMAc.
Siloxane - polyimide	Prof. J.E. McGrath VPI & SU Blacksburg, VA	-	34% PDMS (M_N = 4.5K) -66% polyimide (M_N = 11K) Able to form 20 wt % solution in $CHCl_3$ 52% PDMS (M_N = 4. 5K) -48% polyimide (M_N = 4K) Able to form 25 wt % solution in $CHCl_3$
Phosphine oxide polymer	Prof. J.E. McGrath VPI & SU Blacksburg, VA	245	R = ø and Ar = biphenyl 5% wt loss at 520°C in air.
Xydar	Amoco Performance Products	150	300 sec arc-track resistance. T_M = 348°C Dielectric constant (1MHz) = 2.8 Dissipation factor (1MHz) = 0.06

FILM PROPERTIES

- **Measure properties of candidate polymers and Kapton using Air Force approved test plan**
- **Arc-track resistance tester built by Foster-Miller**
- **Proposed properties to be measured**

THERMAL	ELECTRICAL	MECHANICAL	PHYSICAL
T_g T_m 5% weight loss	Dielectric constant Dissipation factor Dielectric strength Volume resistivity Surface resistivity Arc resistance*	Tensile strength, break Tensile strength, yield Tensile elong., break Tensile elong., yield Flexural modulus C.T.E.	Humidity resistance Water absorption after 24 hr Fluid immersion Aging stability

***Use ASTM D495 or alternative arc resistance test**

DETAILED PROGRAM PLAN