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EVALUATION OF MATERIALS FOR USE IN ELECTRONIC SYSTEMS OF HYPERSONIC SPEED VEHICLES

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GENERAL DYNAMICS | FORT WORTH

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ERR-FW-069
Structures and
Materials

EVALUATION OF MATERIALS
FOR USE IN ELECTRONIC SYSTEMS
OF
HYPERSONIC SPEED VEHICLES

A. C. PORTER

MAY 1962

ENGINEERING DEPARTMENT

This work was supported under General Dynamics/Fort Worth sponsored Research Program 14-60-591.

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EVALUATION OF MATERIALS FOR USE IN ELECTRONIC SYSTEMS OF HYPERSONIC SPEED VEHICLES

A. C. Porter

SUMMARY

Wire and Printed Circuit Wiring Coatings

Five (5) combinations of ceramic insulated wires and coatings were exposed to 700°F for 10 hours. The Teflon* resin sealed ceramic insulated wire, supplied by Hi-temp Wires Inc., exhibited satisfactory dielectric strengths after aging and after humidity exposure, and was capable of being formed into 2 D bends.

Electric Potting Compounds

Four elastomeric and one ceramic potting compounds were molded into test specimens, and then aged for 10 hours at 700°F. Volume change and evidence of reversion were determined. Although the elastomeric compounds exhibited severe deterioration, one compound, G.E. RTV-60, retained its elastomeric properties. The ceramic compound, Durock 0307 was essentially unaffected by temperature but showed hydroscopic tendencies.

Flexible Cushion Inserts

Twenty five (25) elastomers were aged for varying periods of time at 700°F. The effect of heat was determined on the R.T. tensile strength, elongation and hardness properties. Although, none of the compounds were suitable for test after 10 hours at 700°F, six had measurable properties after aging 7 hours at 700°F. These were General Electric compounds SE751, XE404 plus HiSil *303 and XE505 plus HiSil* 303, Dow Corning's Silastic* 2071; duPont's Viton* 607 and Viton* 608; and Connecticut Hard Rubber Company's M738.

* See Appendix for manufacturers of trade name products.

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IV. INTRODUCTION -

The advent of supersonic aircraft created new environmental requirements which are vastly different from those of conventional aircraft. Specific information as to the exactness of such conditions is lacking. Indications are that the environment is so severe that existing electrical and electronic equipment cannot operate satisfactorily for any reasonable period of time because of its deteriorative effects. As aircraft become more sophisticated, the time duration under these adverse conditions is extended and the more dependent the aircraft becomes upon its electronic systems for successful flights. Many of the present day electronic parts have utilized the same materials of construction for the past 10 years, and are inadequate for future considerations. To alleviate this condition, a better understanding of materials, material compositions and properties, versus environmental conditions, functions, and characteristics is needed.

In order to stay abreast of the developments and utilization of electronic materials and components, the following activities were proposed:

1) Review of government and industry developments.
2) Evaluate the most promising of newly developed electronic materials, such as wiring, potting compounds, by functional tests.
3) From data obtained, establish limitations for the materials.

The objectives of this program as originally proposed were to evaluate materials and components suitable for use at 700°F in electronic systems. The components considered for evaluation were capacitors, resistors, connector plugs, and hook-up wire. The materials considered were to be for printed wiring, base plates, encapsulation, potting, and insulation. Because of the limited funds allocated, the overall task was reduced to the following:

1) Review of governmental industry programs on high temperature operational components and materials.

2) Evaluation of materials made from newly developed polymers (for only potting and cushion insert applications)

3) Evaluation of sealing methods for ceramic insulated wire.

This report summarizes the information obtained from literature surveys (government and industry) and from vendor and GD/FW test data.

V. LITERATURE SURVEY

A limited literature survey was conducted during the research period for this program. Information obtained indicated that a number of the major electrical and electronic producers are conducting their own research projects to develop higher temperature resistant materials and components. Government sponsored research projects were limited with respect to number of contracts, although one such contract with Armour Research Foundation (8) was broad with respect to number of different materials and components investigations.

General Electric's Missile and Ordnance Systems Department, Burlington, Vermont (4) - assembled a demonstration model amplifier to conventional circuitry (pre-amplifier and push-pull power amplifier) to drive a standard servo-motor. This system was operated satisfactorily at an ambient temperature of 750°F for more than 100 hours. Some of the materials studied by them were those for plating for corrosion protection and electrical contacts, and for springs, hardware, and sheet metal parts. Components including tube sockets, connectors, relays, printed circuits, potentiometers, capacitors, resistors, thermistors, insulated hook-up wire, terminals, transformers, and resistor boards were investigated, developed, and evaluated.

Scintilla Division, Bendix Aviation Corp., (5) described in their Technical Bulletin E-315-1 the electrical characteristics of Bendix E-315 capacitors throughout a temperature range of -67°F to 600°F. After 1,000 hours of thermal cycling at rated voltage, the capacitance had not changed more than 10% of its initial value.

Cannon Electric (6), in their Technical Bulletin #12(T-111) reported the availability of their HR(Heat and Radiation resistant) series multipoint connectors suitable for use at 1000°F continuous duty rating.

Physical Sciences Corporation (7) reported, in their technical bulletin, the availability of a 1000°F aluminum wire, boron-free, having a 400 volt rating and 5D flexibility.

Armour Research Foundation (8) reported their efforts toward determining essential properties and requirements of basic material types from which all components to be considered could theoretically be fabricated. Degradation of the materials tested were experienced at 930°F, as was expected, concluding that this characteristic must be considered in the use of such components at extreme temperatures. At the writing of their report is was stated that there were no capacitors or resistors commercially available which will operate at 930°F. However, feasibility of such components was demonstrated in their materials screening.

NOTE: (Numbers) See Reference - Page 18 - for sources of information.

Vandracek, et al (9) reported the development of a process for insulating coils by vacuum impregnating with Formula No. M103* water suspended potting compound. The coil was fired at 650°C and then vacuum impregnated with molten lead oxide - boric oxides eutectic at 625°C. The secondary impregnant reacts with the reactive components of the primary impregnant system to form a new composition which has a higher softening point and volume resistivity than the original impregnant.

WADC TR 58-12, Parts I, II, and III, (1) reported the efforts of the University of Illinois to develop and evaluate high temperature electrical insulating inorganic coatings for copper wire, and to develop methods for applying these materials to wire. An insulation system consisting of a prime coating of Composition** 58C followed by an overcoating of Composition 58C plus 50% silica was considered to be the best combination of all formulations tested. Even though fine surface cracks were present as a result of flexing the coated specimens, the room temperature dielectric constant and dissipation factor were essentially unaffected. Suggested methods of sealing the wire with a high temperature resistant organic coating were proposed which would reduce the sensitivity of the ceramic insulation to the effects of humidity. It was felt that this sealer coating would burn out at the upper predicted operating temperature of the wire, and that the high temperature exposure would then cause the ceramic insulation to seal itself.

WADC TR 58-13, Parts I, II and III (11), report the efforts of Georgia Institute of Technology to develop possible methods of insulating electrical wire for high temperature applications. Initial efforts were to develop a suitable plating for copper wire which would provide better adhesion of subsequently applied ceramic coatings. One system which appeared promising was gold plating on copper followed by an aluminum plating. Efforts towards developing a corrosion and oxidation resistant coating for copper were discontinued after an aluminum clad copper wire became commercially available. The aluminum was anodized in a sulphuric acid-magnesium chloride bath and then sealed with a frit resin coating. The wire was capable of operating at 800°F.

*Formula M 103

Materials	Parts by Weight
60 Mesh Zircon	25
200 Mesh Zircon	100
220 Mesh Fused Al_2O_3	100
1000 Mesh Fused Al_2O_3	100
200 Mesh Vitro Frit #VG260	35
Water	80
Methocel -1% Sol.	0.5
Marasperse CB	0.5

**Composition 58C

Materials	% by Weight
Soda Ash	6.55
Quartz	7.55
Anhydrous Borax	28.10
Soda Nitre	4.7
Barium Carbonate	19.8
Keystone Feldspar	18.8
Flourspar	6.55
Zinc Oxide	1.88
Copper Carbonate	6.07

VI. MATERIAL DESCRIPTION

Technical data sheets and test reports published by duPont Elastomer Chemical Department, Dow Corning, General Electric Co. Silicone Products Dept., Union Carbide-Silicones Division, and Connecticut Hard Rubber Co., were reviewed for selection of compounds which exhibited best retention of physical properties after heat aging. These compounds were further screened after discussions with technical representatives of each of the companies.

Cushions and Inserts - Elastomeric-

1. Dow Corning Corp., Midland, Michigan

   A. Silastic 52, a vinyl containing dimethyl polysiloxane with fumed silica and diatomaceous earth fillers; post cured 24 hours at 480°F. (Hardness - 50 Durometer)

   B. Silastic 82, a vinyl containing dimethyl polysiloxane with fumed silica filler; post cured 24 hours at 480°F (Hardness - 80 Durometer)

   C. Silastic S2071, a vinyl containing dimethyl polysiloxane pigmented with red iron oxide with fumed silica and novaculite fillers; post cured 8 hours at 480°F(Hardness-50 Durometer)

   D. Silastic 651, a vinyl and phenyl containing dimethyl polysiloxane pigmented with red iron oxide with fumed silica filler; post cured 12 hours at 480°F (Hardness - 50 Durometer).

   E. Silastic 675, a vinyl and phenyl containing dimethyl polysiloxane pigmented with red iron oxide with fumed silica filler; post cured 12 hours at 480°F (Hardness - 75 Durometer).

2. Union Carbide Corp., Silicones Division; Tonawanda, N. Y.

   A. K-1045R, a methyl vinyl containing dimethyl polysiloxane: press cured 15 minutes at 250°F, and post cured 24 hours at 480°F.

   B. K 1235R, a phenyl vinyl containing dimethyl polysiloxane; press cured 15 minutes at 250°F, and post cured 4 hours at 350°F.

   C. Y3058R, a phenyl vinyl containing dimethyl polysiloxane; press cured 15 minutes at 250°F, and post cured 24 hours at 400°F.

   D. Y3145R, a methyl vinyl - phenyl vinyl blend containing dimethyl polysiloxane; press cured 15 minutes at 250°F, and post cured 24 hours at 480°F.

3. Connecticut Hard Rubber Co., New Haven, Connecticut

A. M 738 - Type gum, fillers and catalyst, and cure are CHR Proprietary Data.

B. M 777 - Type gum, fillers and catalyst, and cure are CHR Proprietary Data.

4. E.I duPont deNemours, Inc., Wilmington, Delaware; Elastomer Chem. Dept.

A. #606, Viton A compound containing Maglite W and MT Carbon Black fillers and Diak 1 Catalyst; press cured 30 min. at 300°F, and oven cured 24 hours at 400°F.

B. #607, a Viton B compound containing, Maglite W and MT Carbon Black fillers, Copper Inhibitor 65, and Diak 3 Catalyst; press cured 30 min at 300°F, and oven cured 24 hours at 400°F.

C. #608, a Viton-B compound containing Litharge and MT Carbon Black fillers, and Diak #3 catalyst; press cured 30 minutes at 300°F, and oven cured 24 hours at 400°F.

5. General Electric Co., Waterford, New York; Silicone Products Department.

A. SE 751, a methyl-phenyl polysiloxane, containing iron oxide and HiSil 303 fillers and 0.6 pbw Cadox SG catalyst; cured 4 hours at 400°F.

B. SE 555, a methyl-phenyl-vinyl polysiloxane, containing iron oxide and Cab-O-Sil HS-5 fillers, and 0.6 pbw Cadox SG catalyst; cured 4 hours at 400°F.

C. SE472, a methyl-vinyl polysiloxane, containing iron oxide and Cab-O-Sil HS-5, Celite 350, and Titanox fillers, and 0.6 pbw Cadox SG catalyst; cured 4 hours at 400°F.

D. XE4401, a methyl-vinyl polysiloxane, containing iron oxide and Cab-O-Sil HS-5 fillers and 0.6 pbw Cadox SG catalyst; cured 4 hours at 400°F.

E. XE5401, a methyl-phenyl-vinyl polysiloxane, containing iron oxide and Cab-O-Sil HS-5 fillers and 0.6 pbw Cadox SG catalyst; cured 4 hours at 400°F.

F. SE525, a methyl-phenyl-vinyl polysiloxane, containing iron oxides and Cab-O-Sil HS-5 fillers and 0.6 pbw Cadox SG catalyst; cured 4 hours at 400°F.

G. XE404, a methyl-vinyl polysiloxane, containing iron oxide and Cab-O-Sil HS-5 fillers and 0.6 pbw Cadox SG catalyst; cured 4 hours at 400°F.

H. XE404, a methyl-vinyl polysiloxane, containing iron oxide and HiSil X303 fillers and 0.6 pbw Cadox SG catalyst; cured 4 hours at 400°F.

I XE505, a methyl-phenyl-vinyl polysiloxane, containing iron oxide and Cab-O-Sil HS-5 fillers, and 0.6 pbw Cadox SG catalyst; cured 4 hours at 400°F.

J. XE505, a methyl-phenyl-vinyl polysiloxane, containing HiSil X303 and iron oxide fillers, and 0.6 pbw Cadox SG Catalyst; cured 4 hours at 400°F.

K. RTV 90, a methyl polysiloxane, and 0.1% Thermolite 12 catalyst; cured 4 hours at 400°F.

The essential differences between 5D and 5G, and 5B, 5E, 5F, and 5I are the percent combinations of polymers and fillers.

Potting Compounds - Elastomeric

1. Dow Corning Corporation - Midland, Michigan

A. Silastic RTV521, a dimethyl polymer with diatomaceous earth, zinc oxide and zirconium silicate fillers; catalyzed with 4% Silastic RTV 521 catalyst, a heavy metal organic salt; post cured 1 hour at 400°F

B. Silastic RTV 5335, a dimethyl polymer with diatomaceous earth, zinc oxide, and zirconium silicate fillers; catalyzed with 4% Silastic RTV 5335 catalyst, a heavy metal organic salt; post cured one hour at 400°F.

Essential difference between Silastic RTV 521 and Silastic RTV 5335 is the percent combinations of the fillers.

2. General Electric Company, Waterford New York, Silicone Products Department.

A. RTV 60, a methyl polysiloxane, plus a Silicure L-24 catalyst post cured 24 hours at 400°F.

3. Products Research Company, Burbank, California

A. PR1940 base compound consisting of a room temperature vulcanizing polysiloxane plus fillers, and an accelerator consisting of fillers, modifiers, and metallic drier type catalyst; post cured 8 hours at 400°F.

Potting Compound - Rigid

1 Physical Sciences Corporation, Pasadena, California

A Durock #0307 consists of a mixture of ceramic powder, water and catalyst (454 100 150); precured at 160°F, cured 4 hours at 450°F, post cured 2 hours at 1000°F

Wire - Coatings and Specimens.

1. Hanna Paint Manufacturing of Texas; Dallas, Texas (Formulations given are GD/FW -Fort Worth developments).

XC5350 (Coating #1) consisting of 25 parts by weight of Crystal M filler, 10 parts by weight of Ferro 3794 pigment, and 35 parts by weight of Epi Rez C274 binder.

XC5351 (Coating #2) consisting of 40 parts by weight of water ground mica filler, 10 parts by weight of Ferro 3794 pigment and 50 parts by weight of Epi Rez C274 binder.

XC5352 (Coating #3), consisting of 75 parts by weight of waterground mica filler and 25 parts by weight of Epi Rez C274 binder.

Sources of raw materials

Crystal M - Minnesota Mining and Manufacturing Company Central Research Laboratory - St. Paul, Minn.

Ferro #3794 - Ferro Corporation - Cleveland, Ohio

Epi Rez C274 - Jones Dabney Company - Resins and Coatings Division; Louisville, Ky.

Water Ground Mica - Franklin Mineral Products Company, Franklin, North Carolina

2. EI duPont deNemours & Company., Incorporated - Wilmington, Delaware

(a) 851-204 Teflon Enamel, a pigmented Teflon resin suspension in an aqueous solution.

3. Physical Sciences Corporation. Pasadena, California - Durock 22 gage - Ceramic Coated Aluminum wire.

4. HiTemp Wires Incorporated; Mineola, New York. HiTemp 22 gage ceramic insulated, Teflon sealed wire. #TGTA-20-1932.

Specimen Preparation -

1. Hanna XC5350, XC5351, and XC5352, sealers were applied to the Durock wire as follows:

   (a) Vapor degrease Durock wire in a stabilized trichloroethylene for 10 minutes.

   (b) Dilute each Hanna sealer by adding 20% volume of acetone.

   (c) Immerse the wire in diluted sealer. Withdraw the wire at a constant rate such that a 0.002" $\pm$ 0.001" thick film of coating will be applied about the wire.

   (d) Air dry 2 hours. Force dry at 160°F for 1 hour, followed by a cure at 350°F for 1 hour.

2. duPont 851 - 204 Teflon enamel was applied to the Durock wire as follows:

   (a) Vapor degrease Durock wire in stabilized trichloroethylene for 10 minutes.

   (b) Apply by spray, a coat of Teflon enamel 0.002" $\pm$ 0.001" thick to the Durock wire.

   (c) Air dry two hours and force dry 4 hours at 260°F. Fuse the enamel coating for three minutes in a sodium nitrite salt bath operating at 750°F.

VII. TEST PROCEDURES

In order to determine changes in physical or electrical properties, certain screening tests were selected which would best show the changes which occurred as a result of thermal aging. The test procedures for each category of material evaluated are described as follows:

Elastomers - Cushions and Inserts

Twenty five elastomeric compounds were supplied in standard ASTM slabs - 6" x 6" x .070", and had received the optimum post cure as recommended by their respective manufacturers. Five tensile test specimens conforming to Die C of ASTM D-412 method were cut from each ASTM slab for each test condition. Shore Durometer Type A was used to determine the hardness at room temperature, before and after oven aging, per ASTM D-676 except that the test specimens consisted of multiple plies of tensile coupons of the same compound and aged condition measurements were made on the grip ends of the coupons. Tensile and elongation determinations were made at room temperature, before and after oven aging, per ASTM D412, using a Model L-6 Scott Tester having a jaw separation of 20 inches per minute. Test specimens were oven aged in accordance with ASTM D-572. The screening selection of compounds for additional studies were based in the optimum retention of physical properties after each oven aging condition.

(a) All materials were tested at room temperature and at room temperature after oven aging for one hour at 700°F.

(b) Twelve materials were selected based on results from (a), and were tested at room temperature after oven aging for three hours at 700°F.

(c) Eight materials were selected based on results from (b), and were tested at room temperature after oven aging for seven hours at 700°F.

(d) Four materials were selected based on results from (c), and were tested at room temperature after oven aging for ten hours at 700°F.

Potting Compounds - Flexible and Rigid

Four flexible and one rigid potting compounds were supplied in the "as manufactured" condition. Each compound was mixed in accordance with its manufacturer's instructions, and was cast into a 1" x 2" x 1/2" specimen. The elastomic compounds were allowed to cure 72 hours at room temperature prior to post curing. The rigid compound was cast in successively applied layers approximately 0.1" thick. Each layer was precured for 15 minutes at 160°F, after which the next layer was added. One test specimen was molded from each manufacturer's compound for each test condition. Hardness determinations were made at room temperature, before and after each oven aging exposure, per ASTM D676 using a Shore Durometer Type A for elastomeric compounds and using a Shore Durometer Type D for rigid compounds The volume determinations were made at room temperature, before and after each oven aging exposure per ASTM D471 for elastomeric compounds, and by using the mercury - displacement method for the rigid compound. Oven aging of the test specimens was in accordance with ASTM D573. Specimens of each of the test materials were subjected to the following high temperature oven aging exposures:

(1) 1 hour at 700°F;
(2) 3 hours at 700°F;
(3) 7 hours at 700°F; and
(4) 10 hours at 700°F.

Coatings - Wire Insulation

Four coatings were supplied in the "as manufactured" condition, and were applied to the ceramic insulated wire test specimens by dipping and were then cured in accordance with the manufacturer's instructions. Test specimens were prepared from the GD/FW coated wires and vendor supplied wire in accordance with MIL-W-583A. Flexibility tests were conducted in accordance with MIL-W-583A, paragraph 4.4.4.1 except that a mandrel with a diameter twice that of the bare wire was used. One unaged specimen and one specimen aged for 10 hours at 700°F, per sealer, were evaluated. After flexing, the specimens were examined for cracks in the sealer coating. Dielectric strength tests were conducted in accordance with MIL-W-583A paragraph 4.4.3.2 using two specimens per type sealed wire per condition. Two were tested after each of the following conditions.

(1) As cured or as supplied,
(2) After 10 hours at 700°F,
(3) As cured or as supplied after 100 hours exposure to 95% relative humidity at 120°F,
(4) After 10 hours at 700°F, then 100 hours exposure to 95% relative humidity at 120°F.

Heat shock tests were conducted per MIL-W-583A, except for temperatures, per paragraph 4.4.6 on specimens which passed the flexibility tests. The temperature used was 700°F.

VIII TEST RESULTS

1. Effects of high temperature aging on room temperature properties of elastomers.

   Table II gives the results of tests conducted on unaged and aged specimens. None of the materials which were aged 10 hours at 700°F could be tested in tension or elongation because of their extreme brittleness. After oven aging seven hours at 700°F, seven of the original 25 elastomers had measurable properties. These materials were General Electric SE751 + color, XE 404 plus HiSil 303, and XE505 plus HiSil 303; Dow Corning Silastic S2071; Connecticut Hard Rubber Co. M-738; and duPont Viton 607. The Viton 607, during the 700°F oven aging, liberated volatile by-products which were corrosive to unprotected low carbon steel (oven racks).

2. Effects of high temperature aging on room temperature properties of potting compounds.

   Table III gives the results of tests conducted on unaged and aged specimens. Visual examination of the specimens following the various exposures to 700°F revealed that S521, S5335, and PR1940 swelled, ruptured and became brittle. After 1 hour at 700°F, PR 1940 exhibited partial depolymerization. The RTV 60 swelled excessively during the first hour at 700°F. As specimens were aged at 700°F for longer periods of time, the swelling reduced considerably. RTV 60 test specimens did not crack or rupture during the aging tests. The ceramics potting compound, Durock 0307, exhibited essentially no change during the aging tests.

3. Effects of high temperature aging on sealer coatings for ceramic insulated wire.

   Table IV gives the results of tests conducted on unaged and aged specimens. Wire test specimens which were coated with Hanna sealers exhibited poor flexibility and could not be wound about a 2D (twice bare wire diameter) mandrel without severe cracking of the sealers. Wire test specimens coated with fused Teflon 851-204 sealer exhibited slight cracking of the sealer when wound about a 2D mandrel.

The Teflon sealer on the Hi-Temp wire did not crack as a result of the flexibility tests, but failed in adhesion to the ceramic insulation. The thermal shock test was not conducted on the Hanna sealers or the Teflon 851-204 enamel because of their initial poor flexibility properties. The dielectric strengths of Teflon 851-204 sealed wire and the Hi-Temp wire were not adversely affected by exposure to 700°F for 10 hours or to 95% relative humidity at 120°F. The dielectric strengths of Hanna XC5350 and XC5352 sealers were adversely affected by exposure to 700°F for 10 hours but were not adversely affected by exposure to 95% relative humidity at 120°F. The dielectric strengths of the Hanna XC5351 was adversely affected by exposure to 700°F for 10 hours and to 95% relative humidity at 120°F.

IX. CONCLUSIONS

Elastomers for Cushions and Inserts

The results of tests on elastomers which were aged at 700°F indicated that there were serious limitations in their usefulness for total time periods greater than 7 hours. GHR-M738 silicone rubber compound, of the twenty two evaluated, exhibited less deterioration than the others.

Viton 607 compound showed promise. However, it has two drawbacks -

(1) Low temperature flexibility about -30°F, and
(2) liberation of corrosion gases during high temperature oven aging. This would require CRES connector shells and clamps, and a review of surrounding structure to assure that there would be no detrimental effects caused by the corrosive gases.

Potting Compounds - Elastomeric and Rigid

None of the elastomeric compounds, as cured and aged, would be considered satisfactory for use. However, one compound, GE RTV60, exhibited elastomeric properties even after oven aging for 10 hours at 700°F. The swelling was attributed to volatile by-products expanding within the compound causing it to sponge. This could probably be overcome by utilizing a step-post cure cycle which would permit the volatile gases to bleed off prior to the outer skin of the compound curing tightly.

The one rigid potting compound evaluated showed very slight changes in hardness and in volume. This compound requires a controlled programmed cure cycle to avoid rupture or large voids from being formed. The cured compound is porous thus needing a ceramic glaze to seal the outer surfaces to prevent moisture or absorption.

Coatings - Wire Insulation

Even though the Teflon sealer on the HiTemp wire exhibited some adhesive failure to the ceramic primary insulation, the insulated wire exhibited satisfactory electrical characteristics to warrant further investigation of its capabilities. None of the other sealers were considered satisfactory.

X. RECOMMENDATIONS

Elastomers for Cushions and Inserts

Elevated temperature aging effects should be continued on the CHR M738 compound used in typical fabricated shape applications Also coordinated efforts with the vendor should be established to study new fillers and compounding techniques to improve high temperature aging characteristics. The vendor has agreed to study fillers for M 738 to improve its extruding characteristics for possible use as primary insulation on hook-up wire.

The Viton 607 compound will require additional compounding modifications to incorporate acid acceptor fillers, such as asbestos shorts, to neutralize the corrosive gases given off during the oven aging tests. The duPont elastomer laboratory would do this portion of the task. If an acceptable reformulation can be developed, then this compound should be re-evaluated in typical fabricated shapes only.

Potting Compounds - Elastomeric and Rigid

Durock 0307 rigid compound exhibited porosity after curing. Because of this, it is necessary that a suitable sealer be developed. The manufacturer of Durock has one such sealer, Durock 0900, which may be suitable for the intended purpose. Other ceramic glazes may be available which are also suitable. Evaluation of these with respect to sealing and electrical characteristics versus temperature should be investigated.

GE RTV 60 exhibited elastomeric characteristics after 10 hours at 700°F. Although this compound sponged during the oven aging tests, it is felt that a programmed post cure would reduce the sponging tendency. Other catalyst systems which do not cure as rapidly should be investigated based on manufacturer's recommendations. Information recently received from Dow Corning Corporation indicates that one of the newly developed room temperature vulcanizing compounds Q 2-0103, after oven aging 10 days at 600°F, had an increase in hardness of 15 points to a Shore A Durometer of 65. This new family of RTV's should be evaluated in typical applications.

Coatings - Wire Insulation

The Hi-Temp construction utilizing the Teflon seal on the ceramic insulated wire exhibited the best properties as compared to the sealed wires tested. The Hi-Temp wire should be further investigated as a coil winding for magnets and/or motors - using the "Motorette" as developed by AIEE or similar set-up.

American Super-Temperatures Wires Inc., has developed a 750°F rated electrical hook-up wire. It is of standard construction, and uses impregnated mica tape as the primary insulator. The secondary insulation is silicone impreganted fiberglass braid. Preliminary data supplied by the manufacturer indicates reliability up to 750°F for extended periods of time. Representative harness subassemblies should be constructed using this wire, and the Cannon 1000°F connector plugs. The electrical characteristics versus temperature of the sub-assembly would be determined.

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APPENDIX

SOURCE OF MATERIALS

Trade Name	Source
Teflon	E. I. duPont de Nemours & Co., Inc. Wilmington, Delaware
Durock	Physical Sciences Corp., Pasadena, California
HiSil 303	Columbia Southern Chemical Corp., Pittsburg, Pa.
Viton A & B	E. I. duPont de Nemours & Co.,Inc. Wilmington, Delaware
Silastic	Dow Corning Corp., Midland, Michigan
Vitro Frit #VG260	Chicago Vitreous Corp., Cicero, Illinois
Methocel	The Dow Chemical Co., Midland, Michigan
Marasperse CB	Marathon Div., Chemical Sales Dept. Mensha, Wisconsin
M T Carbon Black	R.T. Vanderbilt Co., New York, N.Y.
Diak 1 & 3	E. I. du Pont de Nemours & Co., Inc., Wilmington, Delaware
Copper Inhibitor #65	E. I. duPont de Nemours & Co., Inc. Wilmington, Delaware
Maglite W	Merck and Company, Rahway, N. J.
Cadox SG	McKesson and Robbins, Inc., New York, N.Y.
Cab-O-Sil HS 5	Godfrey L. Cabot, Inc., Boston, Mass.
Celite 350	Johns-Manville Corp., New York, N.Y.
Titanox	Titanium Pigment Corp., New York, N. Y.
Thermolite 12	Metal and Thermit Corp., Rahway, N. J.
Silicure L-24	Nuodex Products, Co., New York, N. Y.
Crystal M	Minnesota Mining & Mfg. Co., St. Paul, Minn.
Ferro 3794	Ferro Corporation, Cleveland, Ohio
Epi Rez 274	Jones Dabney Co., Louisville, Ky.

TABLE I

TYPICAL PROPERTIES OF INVESTIGATED ELASTOMERIC MATERIALS

VENDOR DATA

	Tensile Strength PSI	Elongation Percent	Hardness Shore A	Tear Die B	Permanent Set-Percent
Silastic 52	850	250	50	60	--
Silastic 82	725	175	80	85	--
Silastic S2071	825	270	52	--	--
Silastic 651	900	400	50	100	--
Silastic 675	650	200	75	75	--
UCC-K1045R	950	500	42	75	--
UCC-K1235R	1550	600	53	155	--
CHR-M738	1400	400	55	170	--
CHR-M777	2050	600	50	325	3
GE-SE751 + Fe_2O_3	753	170	56	36	2
GE-SE555 + Fe_2O_3	1715	620	48	134	10
GE-SE472 + Fe_2O_3	1200	300	70	93	7
GE-XE4401 + Fe_2O_3	950	630	42	55	6
GE-XE5401 + Fe_2O_3	1175	520	45	93	5
GE-SE525 + Fe_2O_3	904	660	32	46	6
GE-XE404 + Cab-O-Sil + Fe_2O_3	1270	520	60	121	7
GE-XE404 + HiSil 303 + Fe_2O_3	1170	450	60	98	9
GE-XE505 + Cab-O-Sil + Fe_2O_3	1550	700	65	198	9
GE-XE505 + HiSil 303 + Fe_2O_3	1250	690	58	181	10
GE-RTV90 + 0.1% Thermolite 12	680	130	62	63	3

TABLE II (1)

EFFECT OF HIGH TEMPERATURE AGING ON PHYSICAL PROPERTIES OF [illegible]GATED ELASTOMERIC MATERIALS - GD/FW TESTS

COMPOUND	SE751- COLOR			SE 555- COLOR			SE472- COLOR			XE4401 COLOR		
Condition Property	Min	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.
Control:												
Tensile, psi	750	790	768	1390	1670	1516	810	1105	980	880	1090	974
Elong.%	170	175	171	530	570	556	210	280	244	580	660	628
Hard. ShoreA			57			48			71			45
Aged 1 Hr @700°F												
Tensile	310	340	326	100	140	118	240	350	298	120	190	152
Elong.%	110	120	116	20	40	30	50	60	56	40	60	46
Hard.Shore A			46			56			74			60
Aged 3 Hrs @ 700°F												
Tensile, psi	320	350	338									
Elong. %	40	50	46	See Note 1			See Note 2			See Note 2		
Hard. Shore A			72						85			80
Aged 7 Hrs @ 700°F												
Tensile,psi	510	520	514									
Elong.%	10	10	10	See Note 1			See Note 1			See Note 1		
Hard.Shore A			95									
Aged 10 Hrs @ 700°F												
Tensile,psi	See Note 2											
Elong.%				See Note 1			See Note 1			See Note 1		
Hard. Shore A			96									

	XE5401- COLOR			SE525- COLOR			XE404- HISIL303			SE404- HISIL303		
Control												
Tensile-psi	750	1020	946	620	960	820	980	1120	1044	950	1000	971
Elong.%	370	480	448	480	660	570	430	470	448	370	410	386
Hard.Shore A			46			35			62			62
Aged 1 Hr @700°F												
Tensile-psi	90	120	104	20	40	30	170	290	206	180	230	200
Elong. %	50	80	64	20	30	24	20	50	30	90	140	110
Hard.ShoreA			40			32			71			64
Aged 3 Hrs @ 700°F												
Tensile,psi												
Elong.%	See Note 2			See Note 1			See Note 1			360	410	380
Hard. ShoreA			76							40	50	42
												85
Aged 7 Hrs @ 700°F												
Tensile,psi												
Elong.%	See Note 1			See Note 1			See Note 1		330	390	370	
Hard.Shore A									10	15	13	
											95	
Aged 10 Hrs @ 700°F												
Tensile, psi												
Elong. %	See Note 1			See Note 1			See Note 1			See Note 1		
Hard. Shore A												

NOTE 1: Specimen not tested at this condition.

NOTE 2: Specimen too brittle to test.

TABLE II (Continued)

EFFECTS OF HIGH TEMPERATURE AGING ON PHYSICAL PROPERTIES OF INVESTIGATED ELASTOMERIC MATERIALS - GD/FW TESTS

COMPOUND CONDITION PROPERTY	DC52 Min.	DC52 Max.	DC52 Avg.	DC675 Min.	DC675 Max.	DC675 Avg.	DC82 Min.	DC82 Max.	DC82 Avg.	DC2071 Min.	DC2071 Max.	DC2071 Avg.
Control												
Tensile, psi	790	1010	912	610	760	692	710	830	792	830	970	886
Elong. %	300	380	342	210	250	228	210	230	220	270	320	284
Hard. Shore A			55			77			77			54
Aged 1 Hr @ 700°F												
Tensile, psi										290	310	298
Elong. %	See Note 2			See Note 2			See Note 2			80	110	96
Hard. Shore A			70			74			90			62
Aged 3 Hrs @ 700°F												
Tensile, psi										370	400	380
Elong. %	See Note 1			See Note 1			See Note 1			40	50	46
Hard. Shore A												82
Aged 7 Hrs @ 700°F												
Tensile, psi										450	760	610
Elong. %	See Note 1			See Note 1			See Note 1			10	20	15
Hard. Shore A												95
Aged 10 Hrs @ 700°F												
Tensile, psi												
Elong. %	See Note 1			See Note 1			See Note 1			See Note 2		
Hard. Shore A												95

	Y-3145 Min.	Y-3145 Max.	Y-3145 Avg.	K-1235 Min.	K-1235 Max.	K-1235 Avg.	Y-3058 Min.	Y-3058 Max.	Y-3058 Avg.	DC651 Min.	DC651 Max.	DC651 Avg.
Control												
Tensile, psi	1210	1300	1244	1040	1110	1090	920	1000	978	650	740	700
Elong. %	590	600	594	750	820	788	500	560	528	430	460	446
Hard. Shore A			49			40			53			52
Aged 1 Hr @700°F												
Tensile, psi	110	120	118				210	320	280			
Elong. %	110	130	118	See Note 2			20	50	35	See Note 2		
Hard. Shore A			53			65			79			89
Aged 3 Hrs @ 700°F												
Tensile, psi												
Elong. %	See Note 2			See Note 1			See Note 1			See Note 1		
Hard. Shore A			85									
Aged 7 Hrs. @ 700°F												
Tensile, psi												
Elong. %	See Note 1			See Note 1			See Note 1			See Note 1		
Hard. Shore A												
Aged 10 Hrs @ 700°F												
Tensile, psi												
Elong. %	See Note 1			See Note 1			See Note 1			See Note 1		
Hard. Shore A												

NOTE 1: Specimen not tested at this condition.

NOTE 2: Specimen too brittle to test.

T A B L E   I I   (Continued)

EFFECTS OF HIGH TEMPERATURE AGING ON PHYSICAL PROPERTIES OF INVESTIGATED ELASTOMERIC MATERIALS - GD/FW TESTS

COMPOUND / CONDITION / PROPERTY	XE505-Cab-O-Sil Min.	Max.	Avg.	XE505-HISIL 303 Min.	Max.	Avg.	RTV-90 Min.	Max.	Avg.	K-1045 Min.	Max.	Avg.
Control												
Tensile, psi	1240	1350	1278	890	950	930	560	750	670	960	1210	1118
Elong.%	580	610	592	460	500	470	110	140	126	550	640	600
Hard.Shore A			65			67			68			43
Aged 1 Hr @ 700°F												
Tensile, psi	160	1180	168	170	190	178	160	180	168			
Elong.%	20	40	26	30	50	40	50	60	56	See Note 3		
Hard. Shore A			70			70			35			55
Aged 3 Hrs @ 700°F												
Tensile,psi				360	390	375						
Elong. %	See Note 1			20	30	22	See Note 1			See Note 1		
Hard. Shore A						85						
Aged 7 Hrs @ 700°F												
Tensile,psi				310	350	330						
Elong.%	See Note 1			10	15	13	See Note 1			See Note 1		
Hard. Shore A						92						
Aged 10 Hrs @ 700°F												
Tensile,psi												
Elong. %	See Note 1			See Note 1			See Note 1			See Note 1		
Hard.Shore A												

	Viton 606 Min.	Max.	Avg.	Viton 607 Min.	Max.	Avg.	Viton 608 Min.	Max.	Avg.	CHRM 738 Min.	Max.	Avg.
Control												
Tensile,psi	2375	2560	2449	2460	2590	2507	1410	1900	1658	1330	1420	1374
Elong.%	190	210	202	260	290	275	330	390	380	340	360	346
Hard. Shore A			73			68			64			62
Aged 1 Hr @ 700°F												
Tensile, psi	610	1280	968	1170	1360	1268	710	740	720	180	210	200
Elong,%	40	130	72	150	200	168	460	530	490	80	110	100
Hard.Shore A			84			72			63			56
Aged 3 Hrs @ 700°F												
Tensile,psi	1040	1200	1120	820	920	870	80	160	140[3]	130	190	160[3]
Elong. %	30	40	36	110	130	126	150	280	224[3]	30	40	34[3]
Hard. ShoreA			95			78			50[3]			58[3]
Aged 7 Hrs @ 700°F												
Tensile,psi				620	650	638	60	80	68[3]	230	240	236
Elong.%	See Note 2			40	50	44	30	40	38[3]	30	40	32
Hard. Shore A			100			92			45			74
Aged 10 Hrs @ 700°F												
Tensile, psi												
Elong. %	See Note 1			See Note 2			See Note 1			See Note 2		
Hard. Shore A						100						96

NOTE 1. Specimen not tested at this condition.

NOTE 2. Specimen too brittle to test.

NOTE 3. Specimen partially depolymerized.

TABLE II (Continued)

EFFECTS OF HIGH TEMPERATURE AGING ON PHYSICAL PROPERTIES OF INVESTIGATED ELASTOMERIC MATERIALS - GD/FW TESTS

COMPOUND CONDITION PROPERTY	CHR M-777 Min.	 Max.	 Avg.
Control			
Tensile, psi	1790	1860	1830
Elong.%	650	600	666
Hard. Shore A			52
Aged 1 Hr. @ 700°F			
Tensile, psi			
Elong. %	See Note 2		
Hard. Shore A			76
Aged 3 Hrs @ 700°F			
Tensile, psi			
Elong. %	See Note 1		
Hard. Shore A			
Aged 7 Hrs @ 700°F			
Tensile, psi			
Elong.%	See Note 1		
Hard. Shore A			
Aged 10 Hrs @ 700°F			
Tensile, psi			
Elong. %	See Note 1		
Hard. Shore A			

NOTE 1: Specimen not tested at this condition.

NOTE 2: Specimen too brittle to test.

TABLE III (2)

POTTING COMPOUNDS - HIGH TEMPERATURE AGING TESTS

COMPOUND NUMBER	SPECIMEN NUMBER	TEST AGING TIME AT 700°F	*INSTANT HARDNESS BEFORE POST CURE	AFTER POST CURE	AFTER AGING	** INITIAL VOLUME CC's	VOLUME AFTER CC's	VOLUME CHANGE %
1. S521	1	1 Hr	52	50	20	15.44	25.19	63.1
	2	3 Hrs	52	50	20	16.10	25.15	56.2
	3	7 Hrs	52	50	33	16.61	25.13	51.3
	4	10 Hrs	52	50	53	16.19	23.89	47.5
2. S5335	1	1 Hr	50	53	30	15.48	19.05	23.1
	2	3 Hrs	50	53	30	16.19	21.18	30.8
	3	7 Hrs	50	53	52	16.15	21.44	32.7
	4	10 Hrs	50	53	68	16.43	20.20	22.9
3. RTV60	1	1 Hr	60	50	32	16.73	33.52	100.4
	2	3 Hrs	60	50	40	16.68	24.97	49.7
	3	7 Hrs	60	50	87	16.87	22.63	35.3
	4	10 Hrs	60	50	97	16.65	18.72	12.4
4. PR 1940	1	1 Hr	47	50	17	16.55	29.50	78.3
	2	3 Hrs	47	50	17	16.29	32.39	98.8
	3	7 Hrs	47	50	40	16.66	22.58	36.0
	4	10 Hrs	47	50	40	16.72	20.43	22.2
5. 0307	1	1 Hr	--	82	84	15.8	15.8	0
	2	3 Hrs	--	82	86	16.8	16.8	0
	3	7 Hrs	--	82	84	17.9	17.9	0
	4	10 Hrs	--	82	84	18.0	18.0	0

* Shore Type A Durometer used to determine Hardness - Compounds 1 - 4.

Shore Type D Durometer used to determine Hardness - Compound 5.

** Initial Volume Taken after post cure.

TABLE IV (3)

COATING - WIRE INSULATION - HIGH TEMPERATURE AGING TESTS EFFECTS ON FLEXIBILITY OF COATINGS ON SEALED CERAMIC INSULATED WIRE

SPECIMEN NUMBER	SEALER	SEALER AVG. THICK-INS	CONDITIONING	OBSERVATIONS AFTER WINDING ON 20 MANDREL
1	Hanna XC5330	.0026	As cured	Sealer Extremely cracked
2	" XC5350	.0022	10 Hrs @ 700°F	" " "
3	" XC5351	.0010	As cured	" " "
4	" XC5351	.0010	10 Hrs @ 700°F	" " "
5	" SC5352	.0021	As cured	" " "
6	" XC5352	.0029	10 Hrs @ 700°F	" " "
7	Teflon 851-204	.0010	As cured	Teflon Slightly Cracked
8	" 851-204	.0012	10 Hrs @ 700°F	" " "
9	Hi Temp	.0005	As Cured	No cracks - observed*
10	" "	.0005	10 Hrs @ 700°F	" " "

*Some Adhesion failure of Teflon sealer.

9	Hi Temp	.0005	As Cured	No change observed
10	"	.0005	10 Hrs @ 700°F	" " "

T A B L E I V (Continued)

COATING - WIRE INSULATION - HIGH TEMPERATURE AGING TESTS
EFFECTS ON DIELECTRIC STRENGTH OF SEALED CERAMIC
INSULATED WIRE

SPECIMEN NO.	SEALER	SEALER - AVG. THICKNESS INS.	TEST CONDITION	ROOM TEMPERATURE VOLTAGE AT PUNCTURE
1	Hanna XC5350	.0025	As Cured	1100
2	" "	.0025	" "	1150
3	" "	.0024	10 Hrs @ 700°F	800
4	" "	.0014	" "	600
5	" "	.0018	As Cured + RH	1150
6	" "	.0026	" "	1100
7	" "	.0017	10 Hrs @ 700°F+RH	550
8	" "	.0014	" " "	650
9	" XC5351	.0025	As Cured	1100
10	" "	.0030	" "	1400
11	" "	.0012	10 Hrs @ 700°F	800
12	" "	.0018	" " "	700
13	" "	.0016	As Cured +RH	800
14	" "	.0016	" " "	850
15	" "	.0020	10 Hrs @700°F+RH	450
16	" "	.0009	" " "	550
17	" XC5352	.0030	As Cured	800
18	" "	.0029	" "	850
19	" "	.0012	10 Hrs @700°F	590
20	" "	.0019	" "	800
21	" "	.0029	As Cured+RH	1200
22	" "	.0016	" " "	900
23	" "	.0029	10 Hrs @700°F+RH	600
24	" "	.0012	" " "	500
25	Teflon 581-204	.0012	As Cured	750
26	" "	.0010	" "	700
27	" "	.0010	10 Hrs @700°F	750
28	" "	.0014	" " "	750
29	" "	.0014	As Cured +RH	700
30	" "	.0014	" " "	700
31	" "	.0012	10 Hrs @700°F+RH	550
32	" "	.0013	" " "	900
33	HiTemp	.0005	As Cured	650
34	" "	.0005	" "	550
35	" "	.0005	10 Hrs @ 700°F	450
36	" "	.0005	" "	550
37	" "	.0005	As Cured + RH	700
38	" "	.0005	" " "	500
39	" "	.0005	10 Hrs @ 700°F+RH	600
40	" "	.0005	" " "	500