ERDA/JPL-954527-77/2
Distribution Category UC-63

ANNUAL REPORT

INVESTIGATION OF TEST METHODS, MATERIAL PROPERTIES, AND PROCESSES FOR SOLAR CELL ENCAPSULANTS

JPL Contract 954527

For

JET PROPULSION LABORATORY
4800 Oak Grove Drive
Pasadena, California 91103

ENCAPSULATION TASK OF THE LOW-COST
SILICON SOLAR ARRAY PROJECT

This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, under NASA Contract NAS 7-100 for the U. S. Energy Research and Development Administration, Division of Solar Energy.

The JPL Low-Cost Silicon Solar Array Project is funded by ERDA and forms part of the ERDA Photovoltaic Conversion Program to initiate a major effort toward the development of low-cost solar arrays.

P. B. Willis
B. Baum
R. White
R. Kucejko

By

SPRINGBORN LABORATORIES, INC.
Formerly DeBell & Richardson, Inc.
Enfield, Connecticut 06082

July 1977

ABSTRACT

This is the first annual report in a program to identify and recommend polymers for use as encapsulants in solar cell arrays. Material properties are reported for controls and specimens exposed to indoor accelerated aging conditions. Trial encapsulations of miniaturized solar modules are described.

CONTENTS

LIST OF TABLES

...Continued

LIST OF TABLES (Continued - 2)

...Continued

LIST OF TABLES (Continued - 3)

...Continued

LIST OF TABLES (Continued - 4)

1. SUMMARY

Springborn Laboratories is engaged in a study of evaluating potentially useful encapsulating materials for Task 3 of the Low-Cost Silicon Solar Array project (LSSA) funded by ERDA. The goal of this program is to identify, evaluate, and recommend encapsulant materials and processes for the production of cost-effective, long-life solar cell modules.

Materials for study were chosen on the basis of existing knowledge of generic chemical types having high resistance to environmental weathering. The materials varied from rubbers to thermoplastics and presented a broad range of mechanical properties and processing requirements. Basic physical and optical properties were measured on the polymers and were redetermined after exposure to indoor artificial accelerated aging conditions covering four time periods. Strengths and weaknesses of the various materials were revealed and data was accumulated for the development of predictive methodologies. A few marginally suitable plastics of low cost have been upgraded in order to improve weathering resistance and are being retested.

Outdoor exposure testing in Arizona and Florida has been recently included. Trial encapsulations and processing studies on miniature solar cell modules is in progress. Completed modules are being exposed to both natural and artificial aging conditions with subsequent physical and electrical evaluations.

Although many of the initially selected materials will not in themselves be recommended as encapsulants, studies of their properties have been useful in determining trends in materials and processing requirements. To date, silicone rubbers. fluorocarbons, and acrylic polymers appear to have the most promising combination of characteristics. The fluorocarbons may be used only as films, however, because of their high cost.

Encapsulation with pourable thermoset resins has posed relatively few difficulties, but the high-temperature, high-modulus thermoplastic polymers require the development of specific techniques for their successful use.

Experiments with powder coating, solution coating, and plasma spray processes are currently under way. In general, the encapsulant must be fabricable at a temperature below the melt point of the cell metalization.

Future activities will emphasize low-cost, readily processable materials.

2. INTRODUCTION

This study is in support of the Encapsulation Task of the ERDA Low-Cost Silicon Solar Array (LSSA) project. The over-all program is aimed at a target date of 1982 and completion of the development of photovoltaic arrays that demonstrate:

- Cost of less than $0.50 per watt
- Mass-production capabilities
- Useful lifetimes of 20 years
- High conversion efficiencies

The goal of the program is to identify and test materials and encapsulation or coating processes suitable for the protection of solar cells to provide an intermediate service life of five to ten years and eventually a long-term twenty-year service life in a terrestrial environment. The work is being conducted at Springborn Laboratories* facilities in Enfield, Connecticut, with cell performance being evaluated by Solar Power Corporation under subcontract.

Twenty-four materials selected for this program have been chosen for three general properties: clarity, toughness, and weatherability. The testing program incorporates evaluation of initial properties and subsequent retesting after exposure to accelerated aging conditions. The aging environments consist of combinations of heat, humidity, and ultraviolet light, with sample testing at four time intervals. The testing program consists of the following three basic areas:

(1) Mechanical - tensile strength, modulus, brittleness, impact strength, etc.

(2) Optical - total integrated transmittance, haze, absorption versus wavelength, infrared attenuation, etc.

---

* Formerly DeBell & Richardson, Inc.

(3) Miscellaneous - water vapor permeability, insulation resistance, fungus resistance, abrasion resistance.

In addition to the testing of aged materials, efforts will be made to develop predictive methods to aid in the correlation of natural to artificial indoor weathering processes.

Provision has been made for the natural weathering of candidate polymers in Arizona and Florida.

The over-all program is also structured to include four other technical endeavors: cost analysis, selection of primers and enhancement of adhesion, upgrading UV stability, and processing/encapsulation studies.

Actual encapsulation of small solar cell modules with the more promising polymers is currently under way. Completed modules are also being exposed to accelerated and natural weathering conditions to assess their viability.

The final report will encompass an over-all performance analysis and will include recommendations for optimum materials and designs for complete solar panels.

3. PROGRAM APPROACH

The ultimate goal of the program is to find encapsulant materials for the solar cell that will provide protection for twenty years. A second, intermediate goal, is to generate encapsulants for shorter term protection of five to ten years. To accomplish this, the program outline shown below was followed:

A. Review of Test Standards and Specifications

B. Testing and Evaluation of Properties and Processes

   1. Procure Materials
   2. Sample Preparation
   3. Determine Initial Properties and Provide Test Descriptions
   4. Test Specific Properties Over a Temperature Range
   5. Conduct a Cost Analysis
   6. Upgrade Adhesion of Coated/Encapsulated Solar Cell and Retest Specific Properties
   7. Investigate Processability and Amenability to Repair

C. Parametric Testing

   1. Expose Samples to Accelerated Aging
   2. Test Specific Properties After Exposure
   3. Upgrade UV Resistance, Re-Expose, and Retest
   4. Expose and Test Coated/Encapsulated Solar Cells

D. Data Storage and Retrieval, Recommendations and Reports

A. REVIEW OF TEST STANDARDS

This constitutes a survey of standard test methods for the evaluation of potential encapsulant materials for photovoltaic arrays. Tests for solar array encapsulants were selected and recommended on the basis of the following criteria:

- Applicability to the property being evaluated
- Conformity to standardized or well-known test methods (where available)
- Accuracy of measurements
- Reproducibility

The various information sources surveyed for tests and specifications relevant to coated/encapsulated products, especially under outdoor weathering, were: ASTM (American Society for Testing Materials), Federal Test Methods, MIL Specs, ANSI (American National Standards Institute), ISO (International Standards Organization), NEMA (National Electrical Manufacturers Association), UL (Underwriters' Laboratories), and other smaller organizations that may have published test standards.

B. TESTING AND EVALUATION OF PROPERTIES AND PROCESSES

A list of materials was selected with emphasis on performance and cost effectiveness. These materials were then subjected to the exposure and testing scheme discussed below.

On the basis of the parameters established in Section A, Review of Test Standards, a testing program was set up for property determination and failure analysis of materials. These tests were divided into general property areas of: Clarity, Toughness, Heat Resistance, Strength and Stiffness, Adhesion, Electrical and Miscellaneous. The more critical properties were run on all materials and less important properties run only on materials that were promising - as evidenced by resistance to accelerated aging.

C. PARAMETRIC TESTING

Samples were exposed under five conditions of accelerated indoor aging: circulating air oven at 55°C and 100°C; RS-4 sunlamp at 55°C and 100°C; Weather-Ometer at 55°C; and RS-4 sunlamp at 55°C and 70 percent relative humidity with subsequent removal for testing at four time periods - 30, 60, 120, and 240 days. Measurement of tensile strength, modulus, ultimate elongation, and optical transmittance are reported.

The criteria of stability after aging was retention of tensile properties and optical transmission.

Polymers that were still promising after 120 days of accelerated aging are being used to encapsulate miniature solar cell arrays.

Processability and methods of encapsulation are a critical part of the program. Also essential was the upgrading of adhesion between the polymeric encapsulant and the silicon solar cell, metal interconnect, and substrate. The encapsulated solar cells will be again exposed to accelerated aging - but for two time periods of 60 and 120 days and under RS-4 at 55°C and Weather-Ometer at 55°C. After each aging period, electrical and adhesion properties will be checked.

Five materials that were at the lower end of the cost scale and of either borderline or moderate stability were chosen for upgrading of their UV resistance by compounding or coating with six UV absorbing formulations.

The polymers chosen for encapsulation were analyzed for system costs on a first-cut basis to obtain a perspective on the LSSA goal of $0.80 per square foot.

Promising encapsulant materials are also currently being exposed to outdoor natural weathering, both as flat sheets in Florida and Arizona and as encapsulated cells in Arizona under EMMAQUA outdoor accelerated aging conditions. Adhesion and electrical properties are being examined at various exposure intervals.

Most of the parametric testing is complete and current efforts are focused on processing problems and encapsulation techniques.

A recent extension of the program involves the development of lower cost encapsulant systems, comprising a low-cost, less stable polymer as primary encapsulant and a higher cost, highly stable, UV-protective outer film or coating.

The accelerated indoor aging and outdoor weathering data will be analyzed in order to provide a basis for the correlation and prediction of twenty-year lifetimes from short-term aging.

4. MATERIALS CHARACTERIZATION

MATERIALS UNDER TEST

As structural materials, plastics offer attractive opportunities for outdoor use. Like most organic materials, however, they are reactive to atmospheric oxygen, moisture, and light. Thus in extended outdoor use they gradually deteriorate by discoloration, loss of gloss, crazing, chalking, erosion, and cracking; embrittlement, loss of strength and extensibility, and deterioration of electrical properties; and eventually they may even crumble away entirely.

In general, the weathering of polymers proceeds through a complex series of interrelated mechanisms that make prediction of performance difficult to establish. There is, however, a fair amount of information available on the actual outdoor weathering resistance of many polymers that permits certain structure-activity relationships to be drawn.

An appropriate order of weather resistance of some familiar polymers is as follows:

Polymer	Resistance
Polytetrafluoroethylene	High
Polymethyl methacrylate	High
Polyethylene terephthalate	Medium
Polycarbonate	Medium
Polyethylene	Low
Polyvinyl chloride	Low
Cellulose	Low
Polystyrene	Low
Natural rubber	Low
Nylon	Low

Encapsulant materials for evaluation in this program were selected from generic chemical classes of plastics already known for their desirable properties.

The fluorocarbons are of particular interest in solar-cell encapsulation because of their excellent weatherability, chemical inertness, and very good electrical and mechanical properties. Although thick sections of many of these materials are hazy, thin films have adequate transmittance.

The entire family of commercial fluorocarbons is based on five fluorinated monomers. These are tetrafluoroethylene, chlorotrifluoroethylene, vinyl fluoride, vinylidene fluoride, and hexafluoropropylene. Tetrafluoroethylene also is available in a modified form in which perfluoroalkoxy side chains (PFA) have been substituted.

Unprotected specimens of polytetrafluoroethylene (Teflon TFE - DuPont) have been exposed outdoors in Florida for a period of thirty years with little change in properties. Polytetrafluoroethylene is transparent to the ultraviolet component of sunlight and has carbon-carbon and carbon-fluorine bonds with high dissociation energies.

All of the fluorocarbon polymers show excellent resistance to ultraviolet radiation, and Tedlar (polyvinyl fluoride) film is available with an inherent UV absorber compounded in. Although the fluorocarbon polymers are expensive on a cost per pound basis, their outstanding properties may still result in cost-effective encapsulation designs when used as thin films.

Acrylic polymers are an obvious choice of materials to be investigated. Low cost, ready availability, high transparency, and ease of fabrication are desirable characteristics that make acrylics attractive candidates. Long-term field experience also shows these materials to have excellent weathering resistance, and a wide variety of grades are available, permitting design flexibility. Two types based on polymethyl methacrylate (PMMA) were selected for this study.

Silicone rubbers are semiorganic polymers based on silicon-oxygen bond units and are prepared from vulcanization (usually at room temperature) of liquid monomers. They have the ability to be poured into place prior to curing and are available in consistencies ranging from glass-like to rubbery to gelatinous. They typically demonstrate high resistance to ultraviolet radiation and a broad range of environmental conditions. Two medium-modulus (stiffness) formulations were selected from this class of compounds, and one gel material.

Three polycarbonate resins were also included on the basis of their high impact resistance, transparency, and weatherability. Two types are thermoplastic (Lexan and C-4), and one is a thermoset composition (CR-39).

One cellulosic resin, Tenite 479 - cellulose acetate butyrate, was also selected due to its transparency and very low cost. Although this material is not inherently weatherable, it has potential for the upgrading of its stability to a useful material.

A total of nineteen polymers were initially selected for complete evaluation and are listed in Table 1. Appropriate grades were chosen on the basis of three general characteristics: optical clarity, outdoor weatherability, and "toughness". Additional considerations were given to cost, availability, processability, and UV screening additives. Technical brochures were requested with each material and have been kept on file. To date, all materials on the list have been obtained and are in the process of being evaluated.

The resins were thoroughly dried under vacuum for 24 hours prior to molding and were stored in sealed jars. Compression molding of thermoplastics into sample plaques was conducted using conventional press-platen and chase techniques. Records were kept of all variations in procedure as the optimum conditions were determined by a series of trial moldings to produce uniform bubble-free plaques. All moldings were made between sheets of polished nickel plate to yield smooth optically clean surfaces, and the use of release agents that might add a slight haze to the surface was avoided as much as possible. Thermoset materials (silicones, urethanes) were prepared by coating the liquid formulations into open molds and then heat-curing according to the manufacturer's recommended procedure.

Generally, no difficulties were encountered in any moldings, but with a few exceptions. Tefzel 280 and Kynar 460 developed small voids around the edges in thick (over 1/4 inch) moldings. Udel 1700 polyaryl sulfone and Lexan 123 polycarbonate both required additional drying times in order to produce bubble-free plaques. The silicone thermoset resins, Sylgard 184 and RTV 615, both required extensive cycling under alternating vacuum/pressure conditions to break th. foam and deaerate the formulation after mixing in the catalyst. The self-healing dielectric gel silicone Q3-6527 was easily mixed and cured, but the resulting resin was extremely tacky and of such low modulus and tensile strength that it was impossible to prepare test specimens from this material. Testing, however, was done for initial and degraded properties by placing the material in UV transmissive quartz cells that were placed directly in the spectrophotometer for attenuation measurement.

Table 1 shows the optimum molding conditions for the materials being examined at present.

Test specimens for use in the determination of baseline properties and all accelerated weathering testing were prepared by die-cutting or hot die-cutting where applicable. In the case of very high modulus, brittle materials (CR-39, diallyl glycol carbonate resin), the specimens were prepared by machining.

Microtensile "dogbone" (ASTM D-1708) samples were used throughout the accelerated aging program, and circular (1-inch disk) specimens were used for optical evaluation.

The investigation of other potentially useful encapsulants is also under way. These materials were included late in the program and consequently no data will be presented in this report:

Glass

Glass is an obvious choice of material to be investigated in this program because of its low cost, high strength, and high availability. Compared to polymers, most common glasses have lower expansion coefficients, lower moisture permeability, and better weatherability. The lower coefficient of thermal expansion may also reduce fatigue problems resulting from temperature cycling.

Because of the lower impact resistance of ordinary window glass, chemically strengthened glass was selected as a superior material. Chemically strengthened glass (Corning 0313) has been received from Corning Glass and has been included in all accelerated aging and test conditions. This material is a recent addition and consequently does not yet appear on the lists of test results.

It is of interest that it is apparently possible to "tailor" the UV transmission cutoff to any value required by modification of the formula.

Polyvinyl Butyral (PVB)

Another potentially useful encapsulant has been included in the program - polyvinyl butyral (PVB), the resin widely used for laminating shatterproof glass. The film cannot be used as received, however, because of the opacity created by the rough surface and release coating of powdered talc.

Pressing the clean film between polished nickel plates at approximately 150°C gives clear plaques that have been used to prepare test specimens. This material will be exposed to the accelerated aging conditions behind window glass and will also be used in trial cell encapsulations.

Aliphatic Urethanes (Three Formulations)

Three aliphatic urethane formulations are being investigated, two low-modulus encapsulants:

a. Multron R-12A, cured with Desmodur N100 (Mobay Chemical Company)

b. Desmophen 651A-65, cured with Desmodur N75 (Mobay Chemical Company), a compound formulated particularly for high UV stability

and one high-modulus coating:

c. Chemglaze V001 (Hughson Chemical Company)

Chemglaze V001 is being used as a 5- to 10-mil coating on glass for the purpose of determining optical stability versus accelerated weathering conditions.

Specimens prepared from the (a) and (b) urethane formulations (Multron R-12 and Desmophen 651/Desmodur N100) were coated with a thin (1-2 mils) protective layer of Chemglaze V001 prior to exposure. Only tensile and optical evaluations will be performed on these materials after selected exposures to indoor aging conditions.

OPTICAL PROPERTIES

The most significant property to be measured in the testing program is the amount of usable solar energy passing through the encapsulant material versus exposure to the various aging conditions.

Various test methods have been examined and compared in order to determine the most efficient test. Briefly, the deficiencies in test methods ASTM D-1746 (Transparency of Plastic Sheeting), ASTM D-1003 (Haze and Luminous Transmittance), and ASTM E-424 (Solar Energy Transmittance) are as follows:

- Limited beam spread with no provision for measurement of scattered light.
- Limited frequency range.
- Multiple runs required for both haze and narrow-beam transmittance.
- Inaccuracy of measurements with high-haze specimens.

A procedure combining the desired characteristics of each method has been developed. A Beckman 505 spectrometer has been modified to provide rapid and accurate assessment of total integrated transmittance from 350 nm to 800 nm. This was achieved by relocating the sample compartment to a position in which an optically reflective integrating sphere would be used to measure both direct beam and 60° angle scatter transmission simultaneously.

A Monroe 1860 programmable calculator was then used to record the percent of transmittance every 50 nm throughout the range and integrate the results to give total percent transmittance. The function is normalized to a 20-mil specimen thickness and the test results are tabulated based on 100 percent transmittance.

A separate procedure is required for ultraviolet transmission over the 290-350 nm range. The use of an optically reflective integrating sphere appears to be unsuccessful over this range because of the low reflectivity at short wavelengths. The test is conducted by placing the test specimen directly in the beam path between the lamp and photomultiplier tube and reporting the results of ultraviolet absorption separately. All transmission readings are again recalculated and normalized to a 20-mil thickness. In all cases the transmission values can be seen to decrease from the control measurement made on unaged material (Tables 3-7). The two most severe conditions are the carbon arc Weather-Ometer and the RS-4 Sunlamp exposure at 100°C. In some cases the material did not survive to be tested. Tedlar 20 film, C-4 polycarbonate, and Tenite 479 (cellulose acetate butyrate) degraded to the point of crumbling in the worst case and consequently no measurements were made.

Tables 3 and 4 give the results of optical testing for each accelerated aging condition at 30 and 60 days' exposure, respectively. It may be seen from the columns showing the percentage of control values that very little change is evident in any of the specimens aged for 30 days (Table 4) under any condition. Only Udel 1700 (polysulfone) was significantly affected, dropping to 52 percent of control after Weather-Ometer exposure and 74 percent after RS-4 exposure at 100°C.

The results of 60-day aging (Table 5) are much more dramatic, many resins being severely affected and Weather-Ometer being the worst condition. The poor performance of the fluorocarbons (Kynar, Halar, Tefzel, FEP, PFA, Tedlar, etc.) was surprising.

Sylgard 184 silicone rubber performed quite well with respect to the other materials, and Plexiglas DR-61K (methyl methacrylate copolymer) appeared to be the least affected of all.

Although some polymers suffered drastic losses, Udel 1700 retaining only 6 percent of control value in the Weather-Ometer, there were others that were encouraging. CR-39, Plexiglas DR, and Plexiglas V-811 retained 99 percent, 89 percent, and 86 percent, respectively, of their control values after 120 days of Weather-Ometer exposure.

The greatest effects can generally be noticed in conditions incorporating ultraviolet light sources.

After 240 days under all exposure conditions (Table 7), transmittances continued to decline in most cases, although at a slower rate. The previously good materials - CR-39 and Plexiglas V-811 - could not be evaluated due to severe mechanical degradation. Halar, FEP, and PFA fluorocarbons still retained high percentages of control values, as did the acrylics, in the conditions under which they survived (all but RS-4 at 100°C). The best over-all performance of any encapsulant material tested is found in Q3-6527 dielectric gel. Although some void spaces developed near the walls of the quartz-constraining cell and discoloration became quite strong, the transmittance remained over 90 percent throughout the exposure periods in all aging conditions.

Ultraviolet transmissions (290-350 nm) for the exposure periods are shown in Tables 8-11. Again, the general trend is to decrease in transmission with time and severity of condition. Exceptions are Kynar 460, PFA 9705, and Sylgard 184, all of which appear to become more transparent to the shorter wavelengths.

The low UV transmission and fairly good stability of Kynar 460 might make it a useful protective film candidate in subsequent studies.

Several months after the initiation of the test program, as outlined in the contract work plan, a decision was made to include an additional aging condition incorporating both fluorescent lamp radiation and high humidity (70 percent RH). This would permit observation of any synergistic effects occurring from both. Tables 12 and 13 list the 30-, 60-, and 90-day transmission values in the visible and ultraviolet ranges, respectively. The measurements again reflect a general decrease in value with increasing exposure time. Sylgard 184 appeared to decrease in UV transmittance under the high humidity condition, as opposed to increasing in the dry chamber. All other materials showed approximately the same trend as before.

In an attempt to further evaluate optical performance, a table was constructed of transmission index values (Table 14) for all materials under the first five conditions.

To account for the initial transmittance and the degree of change after exposure, the baseline integrated transmittance value was multiplied by the percent of transmittance after aging (T % times % Control). The resulting dimensionless number (transmission index) is indicative of the overall performance of the material, the higher values representing better suitability.

A separate table was prepared to further reveal the effects of humidity. Table 15 lists data for RS-4 and Weather-Ometer exposure at 55°C, and RS-4 at 55°C and 70 percent RH conditions, these being regarded as the most significant. The exposure conditions are arranged from left to right in order of increasing water vapor content to observe any obvious decrease in transmission index value.

Materials demonstrating hydrolytic sensitivities with increased water exposure are Sylgard 184, Udel 1700, Lexan 123, and C-4 polycarbonate. These polymers would perhaps be less suitable for use in high-humidity climates.

Table 16 is an abstract of Table 15, listing transmission indexes for Weather-Ometer and RS-4/55°C aged specimens after 240 days. These two conditions were selected because of their similarity to actual weathering conditions. Addition of the two index values gave figures that could then be arranged in order of magnitude to give a ranking number. This number takes into account both the inherent transmittance of the material and its resistance to optical degradation, permitting a more accurate selection of a viable encapsulant. The first three are, in order, Q3-6527 silicone, Plexiglas DR acrylic, and PFA fluorocarbon.

Provisions will be made later in the program to recalculate the results of optical testing including a compensation for solar cell power output versus wavelength. This method will permit the total "power transmission" of the encapsulants to be calculated.

MECHANICAL PROPERTIES

Mechanical properties determined after intervals of accelerated aging exposures consisted of yield strength, modulus, elongation at break, hardness, and visual inspection. All of the values were determined using conventional stress-strain techniques (Instron - TM) except for hardness, which used procedure ASTM D-2240 on the tabs of the tensile specimens.

Hardness Determination

The procedure for hardness determination relies on an instrument known as a Durometer and is based on the penetration of a specified indentor forced into the material under specified conditions. The indentation hardness is inversely related to the penetration and is dependent on the elastic modulus and viscoelastic behavior of the material.

This method covers two types of durometers - A and D - and the procedure for determining the indentation hardness of materials ranging from soft vulcanized rubbers to some rigid plastics. Type A is used for measuring the softer materials, and Type D for the harder materials. This method permits measurements either of initial indentations or of indentations after specified periods of time, or both.

Tables 17-21 record hardness values of exposed and unexposed materials after one second and fifteen seconds of indentation time. For all materials and all conditions, surface hardness was found to decrease with increasing exposure time except for the two silicone rubbers - Sylgard 184 and RTV 615. Both of these materials show steady increases in surface hardness with time regardless of aging condition and are probably continuing the process of curing at a very slow rate. This is not supported by the tensile results, however, which show general trends toward decreased tensile strengths and increased elongations. In general, the larger changes in hardness were found for Weather-Ometer and RS-4 fluorescent sunlamp exposure at 100°C. Least affected were the fluorocarbon resins.

This method is an empirical test intended primarily for control purposes. No simple relationship exists between identation hardness determined by this method and any other single material property tested.

Tensile Properties

Tensile properties of the nineteen materials were determined according to procedure ASTM D-1708 using an Instron mechanical test machine. Information resulting from this study has permitted quantitative observations of property changes versus aging to be made, and may help to establish specifications for encapsulants at a later date.

Tables 22-47 record the four most useful tensile properties of the materials under study after 0, 30, 60, 120, and 240 days of exposure to the five accelerated aging conditions previously described. The four properties determined are briefly defined as follows:

- Yield Strength

  The stress measured at the onset of nonreversible, nonelastic deformation is the yield strength. Plastics usually show a distinct yield point at which the specimen becomes permanently elongated and continues to stretch at a constant stress level. Rubber materials show no such departure from linearity but gradually elongate to break under applied stress.

- Tensile Modulus

  The elastic modulus ("tangent modulus" or "tensile modulus") is the ratio of stress to strain below the proportional limit of the material. It is the most useful tensile data because parts should be designed to accommodate stresses to a degree well below this.

  In plastics where the stress-strain relationship is initially linear and equal to a constant, the property is also known as Young's Modulus. In very elastic materials where a constantly changing stress-strain curve is encountered, it is customary to report "apparent modulus" or "secant modulus" which is simply the stress measured at a specified elongation. Three elastomeric materials under study - Viton AHV, Sylgard 184, and RTV 615 - were reported in this manner.

- Elongation at Break (Ultimate Elongation)

  As a material is stressed to its breaking point, the degree of elongation (strain) is expressed as the percentage of increase in length. For some applications where almost rubbery elasticity is desirable a high ultimate elongation may be an asset. For rigid parts, there is little benefit in the fact that they can be stretched extremely long.

  There is great benefit in moderate elongation, however, since this quality permits absorbing rapid impact and shock. Thus the total area under a stress-strain curve is indicative of over-all toughness. A material of very high tensile strength and little elongation would tend to be brittle in service.

- Tensile Strength at Break

  The stress measured at specimen rupture is the ultimate tensile strength and is expressed in pounds per square inch of cross-sectional area.

The first three tables in this series (Tables 22, 23, and 24) summarize physical properties (contained in Tables 25-43) and are perhaps the most useful in observing trends taking place in the accelerated aging of the plastics under test. The widest variations are found in the values for elongation at break, the most sensitive indication of polymer degradation. Two general trends may be seen: (a) fluorocarbons tend to increase in elongation, and (b) most other resins increase during the first 30 days and decrease during the remaining exposure periods. This indicates that several mechanisms of degradation are at work - probably involving competing reactions of crosslinking and chain scission.

Tensile modulus increased in all cases under all conditions with the exception of the silicone rubbers, which showed erratic changes but general loss of modulus.

Tensile strength at break showed the least variation in values of the three properties tabulated. Apart from the specimens that could not be tested due to degradation failure, the only dramatic losses were found for the two acrylics - Plexiglas V-811 and Plexiglas DR-61K - that dropped to 33 percent and 28 percent of original values.

An additional condition was included to reveal hydrolytic instabilities of the candidate encapsulants by RS-4 fluorescent sunlamp exposure at 70 percent relative humidity at 55°C. After 30 days' exposure time, differences can be found in elongation values between the humid (Table 46) and nonhumid (Table 29) conditions. Considerable reduction in percent elongation can be noticed for Lexan, C-4 polycarbonate, Tenite 479 cellulosic, and Plexiglas DR-61K, which also showed a 60 percent reduction in tensile strength. Ninety days of exposure (Table 47) resulted in the disintegration of Plexiglas DR-61 and of Tedlar, the remaining results being similar to 120-day exposure under dry sunlamp conditions.

The Weather-Ometer and RS-4/55°C conditions probably come the closest to simulating natural environmental conditions. Using these two conditions as criteria of performance, the most attractive candidate resins are the fluorocarbon polymers PFA, FEP, and Halar, along with the two silicone rubbers, RTV 615 and Sylgard 184.

In the course of accelerated aging, some specimens did not survive certain aging conditions to be tested; they are as follows:

Material	Condition	Type of Failure
Tefzel 280	RS-4/100°C - 60, 120 days	Degraded
Tedlar 20	RS-4/100°C - 60, 120, 240 days	Degraded
Kel-F 800	Air oven/100°C	Flowed
	RS-4/100°C	Flowed
C-4	RS-4/100°C - 60, 120, 240 days	Degraded
Tenite 479	Weather-Ometer - 120, 240 days	Flowed
	Air oven/100°C - 120, 240 days	Flowed
	RS-4/55°C - 120, 240 days	Degraded
	RS-4/100°C	Degraded
Plexiglas DR-61K	RS-4/100°C - 60, 120, 240 days	Degraded
Plexiglas V-811	RS-4/100°C - 60, 120, 240 days	Degraded

Materials failing by degradation either embrittled to the point that they were too fragile to test or were already broken when removed from the weathering condition.

For materials failing by flow, the glass transition temperature or flow point has been exceeded, causing the specimen to deform too badly to be tested. This does not indicate degradation, however, except in the case of Tenite 479, which discolored noticeably, and flowed only in the 55°C conditions where ultraviolet light was present.

FUNGUS TESTING

The initial nineteen materials selected for evaluation were tested for fungus attack resistance using standard ASTM procedure G-21, "Determining Resistance of Synthetic Polymeric Materials to Fungi".

The resin portion of these plastics is usually fungus resistant in that it does not serve as a carbon source for the growth of fungi. It is generally the other components such as plasticizers, cellulosics, lubricants, stabilizers, and colorants that are responsible for fungus attack on plastic materials.

Often the changes in electrical properties are due principally to surface growth and its associated moisture and to pH changes caused by excreted metabolic products. Other effects include preferential growths caused by nonuniform dispersion of plasticizers, lubricants, and other processing additives. Attack on these materials may result in increased modulus, dimensional changes, loss of optical transmission, and the creation of ionized conducting paths that could cause short-circuit difficulties.

Pronounced physical changes are observed more often on products in film form or as coatings, where the ratio of surface to volume is high, and where nutrient materials such as plasticizers and lubricants continue to diffuse to the surface as they are utilized by the organisms.

Three specimens of each material were placed in petri dishes of inoculated agar and incubated for 21 days at 28°C - 30°C. A mixed spore suspension of five fungi known to attack synthetic materials was used to inoculate the medium. At the end of the incubation period the polymer discs were removed, washed, and examined for persistent growth. The results are presented in Table 49.

Most materials - 13 out of 19 - supported light coverings of fungi but showed great evidence of surface attack. Three materials, however, were very obviously damaged. Tenite 479 (cellulose acetate butyrate) showed surface hazing and many large dark green splotches of adhering fungus. The two silicone rubbers, Sylgard 184 and RTV 615, were much less affected but still had a light covering of readily visible persistent green dots. These materials may require fungus-resistant coatings in field use, or the compounding of fungicides and bacteriostats into the polymers prior to encapsulation.

The G-21 rating system is based on visual observation and is consequently very subjective in nature; however, it appears to be a useful method. Specimens of all the plastics used in this study are being tested for optical transmission effects in order to obtain quantitative and objective information. The results will be reported in a subsequent communication.

SOIL ACCUMULATION STUDY

Uncut plaques of the nineteen candidate encapsulant materials were mounted on a rack (45^{o} inclination due south) on the roof of the Springborn Laboratories facility in Enfield, Connecticut, for a period of six months. The plaques (20 mils in thickness) were routinely inspected for damage and accumulation of surface debris. All but three materials were found to have clean surfaces covered by a very thin layer of dust that could be easily removed with a soft cloth. The exposure time ran from summer (August 1976) to winter (January 1977) to accommodate seasonal variations in climate.

After 2, 4, and 6 months of exposure to natural weathering conditions, the three plastics showing permanently adhering accumulation of dirt were evaluated by optical transmittance. Measurements were made of total transmittance (%) (350-800 nm) and are as follows:

	Viton AHV	Sylgard 184	RTV 615
Control - total transmittance	83	78	82
2-Month (percent of control)	86	84	78
4-Month (percent of control)	83	39	62
6-Month (percent of control)	80	81	58

Steady decreases in transmittance are found in all cases except for the Sylgard 184, which mysteriously attained the lowest value at four months of exposure and increased after six months. Succeeding measurements were made on the same specimen, and duplicate tests gave identical results.

The anomolous values observed in the case of Sylgard 184 are most likely due to "natural cleaning" processes. The plaques were left exposed during the winter months and snow or ice formation over the specimens probably caused the removal of some soil during freeze/thaw cycles.

Decreases of 20 - 40 percent transmission from the control values indicate that these encapsulants of low modulus and surface hardness may have to be used under a cover plate or soil-resistant coating. This is already an accepted practice among current manufacturers of solar cell panels that employ silicone rubber pottants as the primary encapsulant.

At the end of the six-month outdoor exposure period, all materials were evaluated for transmission losses and the results appear in Table 51. In a few cases (Tefzel 280 and Kel-F 800) the measurements were in excess of control value and probably due to long-term changes in the crystalline structure. Apart from the three materials with obviously contaminated surfaces, three other materials showed losses in transmission. Kynar dropped to 80 percent of control value - probably due to crystallinity changes; Udel 1700 dropped to 67 percent of control due to obvious degradation; and Tedlar film dropped to 73 percent of control. In the last case the decrease is presumably due to changes in surface morphology. As crystalline variations would not be very observable in a thin (2-mil) film, degradation is unlikely and no appreciable quantity of soil was found on the surface.

In the future, antistatic agents may also be useful in retarding soil accumulation due to surface charge.

MISCELLANEOUS PROPERTIES

The necessity for evaluation of optical and mechanical properties of candidate encapsulation materials is obvious. There are, however, a series of other related properties which may be of equal importance in the determination of a viable design for solar cell panels. A series of additional tests was selected on the basis of potential usefulness and conducted on unaged specimens of the nineteen polymers. A discussion of these follows.

Abrasion Resistance

The results of abrasion resistance are given in Table 52 and show the relative resistance of the candidate polymers to marring and surface damage. The test method ASTM D-673 - "Mar Resistance of Plastics" - utilizes a falling stream of 80-mesh silicon carbide grit to abrade the test specimen, which is mounted at a 45° angle. This test is probably close to the type of abrasion that would be encountered in the field and might closely simulate the effects of windblown sand - as would be found in desert installations.

Readings were taken with a Gardner Glossmeter after 200, 1000, and 2000 grams of abrasive had impinged on the sample. Gloss diminished steadily in all cases, the greatest losses being noticed in the cases of Resin 81 and Kel-F 800 - two materials with low surface hardness. The more significant test was measurement of over-all loss in total integrated transmittance, measured before and after the final abrasive exposure.

The most resistant plastics were CR-39 and Plexiglas V-811, which retained 97 percent and 94 percent, respectively, of their original transmittances. Most other plastics performed fairly well, retaining 70-80 percent of original value, except for the silicone elastomers. The grit adhered to the surfaces of these materials so tenaciously that optical measurements were not practical.

Refractive Index

When light strikes the surface of a material, it is reflected, transmitted, or absorbed - depending on the optical properties of the material. As light passes through a transparent (encapsulant) material, reflection losses occur at the surface due to differences in refractive indexes. The less the difference in refraction, the lower are the reflective losses.

Refractive index values may be used in calculations to maximize "optical coupling" by appropriate selection of materials and the sequence in which they are used. Other relationships of importance dealing with single-layer and multilayer anti-reflection coatings are also dependent on refractive index properties and may be found in the literature dealing with the physics of optics. Refractive index values for the candidate polymers are listed in Table 53.

Glass-Transition Temperature (T_g)

As the temperature of a plastic or rubber is lowered, a point known as the glass-transition temperature is reached where polymeric materials undergo a marked change in properties. Below their glass-transition temperature, polymers have many of the properties associated with ordinary inorganic glasses including hardness, stiffness, brittleness, and transparency.

Above the glass-transition point, polymers are more elastic, are capable of deformation without breaking, and have lower modulus. The change in mechanical properties with respect to temperature may dictate the application of many materials in solar panel design. A continuing effort in the current program is to determine the actual mechanical properties (tensile strength, elongation, modulus, etc.) versus temperature. Glass transition temperatures (T_g) are shown in Table 53.

Brittleness Temperature

This test (ASTM D-746) establishes the temperature at which 50 percent of the plastic specimens exhibit brittle failure under specified impact conditions, and may be used to predict the behavior of materials in applications requiring low-temperature flexing.

The test procedure employs clamped specimens that are hit with a striking edge of preset dimensions, force, and speed. The percentage of failures occurring at different temperatures in freezing baths is then determined.

The results of brittleness temperature testing are shown in Table 54 and do not necessarily indicate minimum use temperature but serve as a guide to low-temperature performance.

Tensile Impact

This method - ASTM D-1822 - covers the determination of the energy required to rupture standard tension-impact specimens of plastic materials. The energy utilized in this method is delivered by a single swing of a calibrated pendulum of a standardized tension-impact machine. The energy to fracture by shock in tension is determined by the kinetic energy extracted from the pendulum of an impact machine in the process of breaking the specimen.

One end of the specimen is mounted in the pendulum. The other end of the specimen is gripped by a crosshead which travels with the pendulum until the instant of impact and instant of maximum pendulum kinetic energy, when the crosshead is arrested. In order to compensate for the minor differences in cross-sectional area of the specimens, the energy to break is normalized to units of kilojoules per square meter (or foot-pounds-force per square inch) of minimum cross-sectional area.

The tensile impact results for each material are given in ft-lb/in.^{2} and tabulated in Table 54. The highest impact strengths are found for the fluorocarbon polymers, the best being Tefzel 280 (439 ft-lb/in.^{2}). Only one nonfluorocarbon - Lexan 123 - demonstrated a similarly high resistance (269 ft-lb/in.^{2}). All other encapsulants had either very low impact strengths (Plexiglas DR-61K - 7 ft-lb/in.^{2}) or could not be tested, as in the case of the silicone rubbers.

Insulation Resistance

Encapsulants directly in contact with silicon solar cells, interconnects, or any other electrically active or conductive components of a solar panel must be insulators. Even very small short-circuit currents will serve to reduce the efficiency of power generation and may lead to system deterioration due to electrolytic effects.

Although each solar cell individually produces less than 2 volts, large arrays of multiple modules may be designed to reach several thousand volts to optimize power transmission over long distances. For these reasons it is generally desirable to have the insulation resistance as high as possible - consistent with acceptable mechanical, chemical, and heat-resisting properties. Since insulation resistance or conductance combines both volume and surface resistance or conductance, its measured value is most useful when the test specimen and electrodes have the same form as is required in actual use.

In this test procedure - ASTM D-257 - specimens were prepared using electrodes of the same dimensions as solar cells and encapsulant thicknesses found in current panel designs.

All materials tested show resistances sufficiently high to be acceptable for encapsulation (Table 54), the highest being Sylgard 184 at 875 x 10^{12} ohms. The lowest value was found for the dielectric gel material, Q3-6527, although it is still an excellent insulator. An additional feature of the gel is the manufacturer's claim that the material will "self-heal" in the event of electrical breakdown, leaving no conductive path for further breakdowns.

Changes in insulation resistance and electrical breakdown with respect to water absorption of polymers have not been studied but would be of importance in this program. Surface resistance or conductance changes rapidly with humidity, while volume resistance or conductance changes slowly, although the final change may eventually be greater.

Permeability

Permeation of water vapor into cell encapsulants could result in profound changes in performance. Possibilities include ion short circuits of cells, corrosion of interconnects, delamination of dissimilar materials, loss of optical coupling, and degradation of physical properties. All synthetic polymers are permeable, although permeation rates vary by about three orders of magnitude. Rates are generally higher for plasticized and low-modulus polymers and lower for crystalline, high-modulus and nonpolar materials.

Table 54 lists water vapor transmission rates derived from procedure ASTM E-96 in which the material to be tested is fastened over the mouth of a dish which contains a desiccant. The assembly is placed in an atmosphere of constant temperature and humidity, and the weight gain of the assembly is used to calculate the rate of water vapor movement through the sheet material under the conditions prescribed.

The fluorocarbons have the lowest permeation rates, the best being PFA 9705. The two acrylics (Plexiglas) and polycarbonates (C-4 and Lexan) had intermediate values and the silicone rubbers were found to be highly permeable.

The exclusion of atmospheric moisture from solar cell panels solely with plastics appears to be unfeasible and may necessitate designs incorporating moisture-resistant electrical and adhesive components.

Flammability

Two flammability tests were employed to determine the burning rates of the candidate polymers: ASTM D-635 - "Flammability of Rigid Plastics"; and ASTM D-568 - "Flammability of Flexible Plastics". The latter method was used on Tedlar, Sylgard, and TRV. Burning rates are expressed in terms of inches per minute (Table 54), and all but one of the materials tested were found to be flammable. Viton AHV fluoroelastomer fused without burning.

Low rates were found for the fluorocarbons and very high rates for the silicone rubbers at approximately 9 inches per minute for Sylgard 184 and 32 inches per minute for RTV 615. Tedlar film (2-mil) gave a test result of 13.1 inches per minute - probably a more realistic figure than the rates of the other materials because of the rapid oxidation that occurs in thin films. Most of the encapsulants - especially the fluorocarbons - will be used as thin films in actual practice.

Thermal Conductivity

Thermal conductivity is the rate at which a material transmits heat when exposed to a temperature differential and in this method - ASTM D-2214 - is expressed as Btu per foot thickness per square foot of area per hour per degree Farenheit temperature differential.

Specimens were sandwiched between metal plates having thermocouples mounted on the outer surfaces, and the difference was measured, according to the specification, after 7 minutes of heating on one side and cooling on the other. The average thermal conductivity, λ, of a flat slab of material was calculated from:

$$\lambda = qL/A(t_1 - t_2)$$

where

q	=	time rate of heat flow
L	=	specimen thickness
A	=	area of isothermal surface
t_1, t_2	=	temperature (K) of hot and cold surfaces, respectively

Variations between the resins were not large (Table 55) with the exception of Q3-6527 dielectric gel, which had two to three times less the conductivity of the other polymers.

Conduction of heat is a desirable property in an encapsulant because the power produced by silicon solar cells decreases with temperature. If the encapsulant functions as an efficient heat-transfer medium (transferring to a cooler substrate), higher operating efficiency should be maintained.

5. COST ANALYSIS

A basic cost analysis of the polymers under investigation and their application to a basic encapsulation model may be found in Table 57. Manufacturers of the resins (Table 1) were contacted for current (1977) price quotes on bulk purchases and also asked for the product density so that a cost per unit volume could be calculated. These figures appear in the first three columns of Table 56.

In order to generate some perspective on the cost-effectiveness of the encapsulant materials with respect to the LSSA project estimate of 80 cents per square foot, it was necessary to create a first-cut module design. The module is assumed to be a close square-packed arrangement of cells with diameters of 2.5 inches and a thickness of 0.015 inch (0.01 inch cell thickness and 0.005 inch adhesive layer).

Encapsulant is assumed to fill the space between the cells and additionally a layer 0.005 inch thick over the cells. Total encapsulant volume is then the volume of the layer covering the solar cells plus the volume of the space between them. The cover volume is calculated as 1 ft^2 = 144 $in.^2$ times 0.005 inch, which equals 0.72 $in.^3/ft^2$. The volume between the cells was calculated from the total panel volume (144 $in.^2$ x 0.015 in.) minus the volume of the cells contained in that area, and found to be 0.4644 $in.^3/ft^2$. Addition of intercellular and cover volumes gives a total encapsulant requirement of 1.184 $in.^3/ft^2$ for a representative square foot of solar panel surface. It must be noted that this model does not account for extra volumes that would occur for irregularities such as interconnect spacings or "wall" effects where the packing efficiency is reduced.

Protective cover films of 5-mil thickness were employed in most cases and the cost added to the calculated cost of the primary encapsulant, to give a total encapsulation cost for the system. The module systems described are those under actual construction at Springborn Laboratories for studies of indoor and outdoor weathering on complete panels.

It should be noted that the prices shown are for materials only and do not include substrates and fabrication costs.

The lowest cost of all the materials surveyed was found for Plexiglas V-811 at $0.56 per pound. Used as a primary encapsulant, covering the cells by a 0.005-inch layer, the material cost is found to be $0.028 per square foot of solar panel. The second most attractive material was Tenite 479 (CAB) at $0.046 per square foot.

We will later recommend that these two materials be investigated further (modified and more processable formulas) because of their low cost.

The experimental encapsulation studies were designed primarily to study materials performance and not economics; however, the silicone gel/Plexiglas V-811 system had an attractive cost of $0.172 per square foot.

6. UV UPGRADE STUDY

The deterioration of plastics in outdoor weathering is caused primarily by sunlight - especially ultraviolet - frequently combined with atmospheric oxygen and often involving atmospheric moisture, abrasion, and other factors as well. Sunlight reaching the earth is filtered through the atmosphere, removing shorter wavelengths up to 280-290 $m\mu$ before it reaches the surface of the earth. Thus ultraviolet effects on plastics result primarily from wavelengths of approximately 290-400 $m\mu$, which is approximately 5 percent of the total solar radiation reaching the earth.

Most polymers contain functional groups which absorb ultraviolet light. Most prominent and frequently mentioned is the carbonyl ($C=O$) group, whose ultraviolet absorptions have been observed at 270-360 $m\mu$ in different compounds (polyesters, acrylics). Aromatic rings (such as in polystyrene) absorb up to 350 $m\mu$; when combined with the $C=O$ chromophore, they absorb up to still higher wavelengths.

Ultraviolet light with wavelengths of 300-400 $m\mu$ corresponds to energy levels of 95-70 kcal. A $C=O$ group which absorbs at 280 $m\mu$ corresponds to an energy level of 100 kcal. Thus ultraviolet alone can cause breakdown of many polymers, as can be seen from the following tabulation listing ultraviolet wavelengths of maximum sensitivity for typical commercial polymers:

Polymer	Ultraviolet Wavelength of Maximum Sensitivity
Polyesters	325
Polystyrene	318
Polyethylene	300
Polypropylene	310
Polyvinyl chloride	310
Vinyl chloride/acetate	322-364
Polycarbonate	295
Polymethyl methacrylate	290-315
Polyformaldehyde	300-320

If a radical tends to form, the presence of unsaturation and especially aromatic resonance will stabilize it and thus favor the degradation reaction. Often atmospheric oxygen, and sometimes atmospheric moisture, also contribute to the reaction - either by lowering the energy level required for initial activation or by entering into the reaction sequence at a later stage.

In general, ultraviolet energy initiates breakdown by dissociating a covalent bond into a free radical. This initiates a free-radical chain reaction. In the presence of atmospheric oxygen, this usually becomes an oxidative chain reaction. Formation of degradation products like $C{=}O$ and $C{=}C$ double bonds, and hydroxyl $O{-}H$ and peroxide $O{-}O$ groups increases the number of groups which can absorb ultraviolet light and thus accelerates the degradation reaction.

When a polymer molecule absorbs ultraviolet light through such groups, this energy raises the structure to an unstable excited state. Such an excited state can then discharge this excess energy in a variety of ways:

1. It can transfer the excitation to another molecule, and thus restabilize itself.
2. It can return stepwise to its ground energy level, meanwhile reemitting the excess energy in longer wavelengths of lower, harmless energy levels such as visible light. This is known as fluorescence.
3. It can convert the excess energy directly into thermal vibrations as heat.
4. It can undergo a reversible molecular structural rearrangement or tautomeric shift, releasing the excess energy slowly as heat.
5. If the excited molecule cannot dispose of the excess energy in any of these ways, it will dissociate to open a bond and initiate breakdown. This is part of the process of degradation.

In general, when ultraviolet energy disassociates a polymer molecule to produce an initial free radical, this can lead to the following types of processes:

1. Cleavage into smaller fragments.

2. Elimination of small molecules.

3. Formation of residual unsaturation in the polymer molecule.

4. Depolymerization by elimination of monomer units from the radical end of the molecule, a simple unzipping or reversal of the original polymerization reaction.

5. Permanent rearrangement of the molecular structure.

6. Crosslinking between adjacent polymer molecules.

7. Oxidation of the polymer, especially at the surface exposed to atmospheric oxygen, and in the amorphous portions of the polymer through which oxygen can permeate.

8. Photohydrolysis of sensitive groups - mainly amides, esters, and urethanes.

The purpose of this study is to improve the optical and mechanical performance of marginally weatherable polymers selected from the current program and to determine the most feasible method of upgrading them. The materials selected were Lexan 123, Tenite 479 (cellulose acetate butyrate), C-4 polycarbonate, and the two acrylics - Plexiglas DR-61K and Plexiglas V-811. Two basic approaches were employed to increase the ultraviolet stability of these polymers: internal compounding and external coating.

Compounding was performed on a two-roll mill - permitting the incorporation of other substances into the polymer at its melt temperature. Generally, four types of stabilizers are usually added to maximize degradation resistance:

(1) Absorbers - compounds that absorb ultraviolet light strongly and preferentially, and convert the energy to harmless fluorescence or heat.

(2) Quenchers - compounds that interchange energies with excited polymer molecules and return them to ground state before bond scission occurs.

(3) Metal deactivators - chelati compounds that destroy the effect of trace metals that catalyze oxidation of the polymer molecule.

(4) Antioxidants - compounds that interrupt free-radical chain-reaction mechanisms or decompose peroxides that give rise to bond scissioning and depolymerization.

Each of the five materials previously mentioned was compounded with formulas A, B, and C - as follows:

Stabilizer	Function	Formula (phr)*		
		A	B	C
Cyasorb UV-531	Absorber	0.5	-	-
Cyasorb UV-1084	Quencher	0.3	0.3	-
Tinuvin P	Absorber	-	-	0.5
Uvinul N-539	Absorber	-	0.5	-
Pol gard	Metal deactivator	0.3	0.3	0.3
AM-105	Quencher	-	-	0.3
DSTDP	Antioxidant	0.3	0.3	0.3
Irganox 1010	Antioxidant	0.2	0.2	0.2

* phr = per hundred parts resin

In three cases already upgraded materials were obtained from the resin manufacturers and substituted for the formula above. Lexan 123 - Formula C - was replaced with Lexan 9030; Tenite 479 - Formula B - with Tenite 485; and Plexiglas V-811 - Formula B - was replaced with Grade UVA-5.

Two materials, Plexiglas V-811 and Tenite 479, were selected for further upgrading studies by coatings.

Since an ultraviolet absorber in the interior of the polymer may still permit some simultaneous attack on the polymer as well, it is sometimes worth while to apply a surface coating containing a high concentration of ultraviolet absorber - preferably in a stable binder such as polymethyl methacrylate - to keep the ultraviolet energy from ever reaching the sensitive polymeric substrate at all. Three approaches were used:

(a) Tedlar film - 100 BG30 UT (ultraviolet opaque)

(b) Acrylic coating: Acryloid B-82 containing 4 percent Cyasorb UV-1084 and 4 percent Cyasorb UV-531

(c) Photochemical rearrangement: solution of poly(resorcinyl isophthalate). Ultraviolet opacity is induced by UV, causing the polymer to undergc Fries rearrangement.

All upgraded materials are presently undergoing exposure to Weather-Ometer and RS-4 at 55°C accelerated aging conditions for periods of 120 and 240 days. Testing upon completion of exposure will comprise integrated optical transmittance and the four tensile properties previously reported.

The performance of these materials will be reported in a subsequent communication.

7. ADHESION STUDIES

The adhesion study is aimed at: (a) assessing the adhesive strength of an encapsulating resin molded or laminated to a silicon cell, and (b) selecting and evaluating adhesives and/or primers to improve this bond. Three general classes of materials - fluorocarbons, silicones, and acrylics - were used.

Since the cells are not self-supporting, the study also includes determinations of adhesive bond strengths to the substrate on which the cell is mounted. Three candidate substrates will be evaluated: aluminum, polyester board, and epoxy boad (NEMA G10, only with Sylgard 184).

Primers and adhesives have been selected to suit four general categories of resin: fluorocarbons, silicones, acrylics, and miscellaneous (primarily polycarbonate). Selection is based on the following factors:

- Potential bonding strength
- Processing parameters
- Hydrolytic stability
- UV stability
- Clarity
- Manufacturer's recommendations

Evaluation of adhesives and primers in the laboratory began with the construction of successful test units - prepared by cementing standard commercially available silicon solar cells to clean (vapor degreased) 6" x 3" steel plates using epoxy glue (Epon 828 with 10 percent triethylene tetramine). The cemented cells were then washed in toluene and methanol prior to final degreasing in toluene vapor.

Adhesives and primers were applied to the cell surfaces according to manufacturers' recommendations and usually required brushing on a thin film with subsequent air drying at a specified time and temperature. The thermoset polymers were bonded to the pretreated cells by curing in place directly on the cell surface. Thermoplastic polymers were applied as thin sheets (15-20 mils) and the sheet/cell assembly then placed in a heated platen press at moderate temperature and pressure. Silicon rubber pads (1 mm thickness) were placed on the platen surfaces to give uniform load distribution, although cell fracture still occurred in some instances.

Bond strengths were determined by slicing the resin across the surface of the cell into thin strips, using a razor blade, and then measuring the load required to peel a given strip back from the cell at constant angle. A simple apparatus in which the cell was attached to a conventional electronic laboratory balance was used for this determination and was excellent for screening purposes.

Peel strength (ASTM D-1876) and tensile shear (ASTM D-1002) will be the tests used for the final evaluation of the most promising adhesives. Adhesives, primers, and processes are outlined in Table 58. The peel strength results obtained so far are shown in Table 59 and are recorded for dry conditions and one-week water immersion.

Silicones Sylgard 184 and RTV 615 were the first resins to be investigated and were applied to treated/primed cells by casting and curing directly in place. A thin layer of cheesecloth was incorporated into the casting resin to improve the strength and manageability. Control cells with no primer or adhesive show peel strengths of 6.29 g/cm width (0.035 lb/in.) and are peeled easily. An application of DC Q36-060 prepolymer primer (3.5 percent solution) to the cell raised the peel strength to an excess of 357 g/cm (2 lb/in.) and exceeded the tensile strength of the resin. This treatment was found to be the most effective of the adhesives examined.

One week's immersion in water did not appear to affect the bond strength. This formulation was sufficiently successful that studies with Sylgard 184 were terminated and emphasis was shifted to the more challenging fluorocarbons.

FEP was obtained as both commercially treated (C-20 bondable) and untreated film. The treated film was much more amenable to adhesion than the untreated material, and an excellent bond strength of 4.3 lb/in. (768 g/cm) was obtained using Chemlok 607 primer. One week's immersion in water reduced the strength to 70 percent of control, however, indicating a sensitivity to hydrolysis.

Untreated FEP was found to be completely nonadherable, and no peel strengths were observed until surface oxidation occurred. Good bond strength was developed using Q36-060 primer on the cell, preceded by surface treatment of the film with heat and benzoyl peroxide.

Procedure 12 on Table 58 gives a method for the chemical etching of all fluorocarbon films that appears to be highly effective. The etchant ("Tetra-Etch") is believed to be a dispersion of sodium naphthalene and gives surfaces that bond well with Chemlok 607 primer and DC 282 silicone adhesive. Typical peel strengths range from 6 lb/in. to 14 lb/in. - both cell and substrate. DC 282 is additionally desirable because of its low modulus in the cured state and ability to absorb differences in expansion at the interface. Silicone adhesives also have high hydrolysis resistance.

Although fluorocarbon resins will not in themselves be recommended as primary encapsulants, they may prove to be useful as thin protective cover films and have provided useful information on their adhesive properties.

The acrylics - Plexiglas DR-61K and Plexiglas V-811 - gave the best response to systems 5 and 6 (Table 58). Both of these adhesives, Versilok 506 and Hughson B-1958, are two-part compositions requiring cure cycles at elevated temperatures. It is likely that the peroxide curing agents also crosslink with the acrylic polymer, giving chemically bonded structures. Bond strengths exceed the tensile strength of the resin in many cases. These two systems are also highly effective with Tenite 479 cellulosic resin and peel strength was again found to exceed tensile strength. C-4 polycarbonate had the best response to Hughson B-1958 (System 6).

With the exception of the silicone rubbers cured over Q36-060 primer, all other materials demonstrated the optimum adhesion with two-part (curing) systems such as Versilok 506, Hughson B-1958, and DC 282 - probably because of mutual crosslinking reactions.

Adhesives are being investigated for various other pairs of materials anticipated to be primary encapsulant/cover combinations. To date the most promising types of adhesives, generically, are the silicones - because of their high peel strengths, resistance to hydrolysis and ultraviolet irradiation, and their low modulus characteristics.

8. ENCAPSULATION/PROCESSING STUDY

This study provides for the actual encapsulation of cell systems with the materials under investigation and subsequent exposure to both artificial and outdoor (EMMAQUA)* weathering conditions prior to testing. It is expected that problems arising from material properties, fabrication, cell function, design, etc., will be revealed by real field experience with these modules.

Because the cells and interconnects are not self-supporting, a rigid structural component is required. Three substrates were selected for this purpose from a list of previously identified potential substrate materials. Polyester/fiberglass, aluminum, and epoxy-glass (NEMA G10) were used in the construction of all miniature cell modules. These test modules were prepared by Solar Power Corporation under subcontract and consist of two electrically active cells bonded to the substrate with an interconnect between them, and one at either end connected to the power line.

Power leads are soldered to either side of the cell fixture and come out through the underside of the substrate to permit electrical testing. A list of encapsulant systems selected for this task is shown in Table 60. The material combinations were chosen to optimize the amount of useful data obtainable while examining definite possibilities for feasible systems.

Completed cell modules are being exposed to Weather-Ometer and RS-4/55°C fluorescent sunlamp conditions for two time periods - 4 and 8 months.

The outdoor accelerated aging condition - EMMAQUA* - is also being used at the same exposures. This device simulates long-term weathering by concentrating natural sunlight about ten times on the specimen while spraying a fine stream of distilled water on the surface.

Testing of electrical characteristics (I/V curve) is performed before and after encapsulation to determine if cell or interconnect damage has occurred and again after the exposure times. It is hoped that the effects of moisture, delamination, corrosion, etc., will be observable in this study.

*Equatorially Mounted Mirror Accelerator, Phoenix, Arizona

The most expedient methods of fabricating the encapsulated systems are still being developed. In most cases the properties of the encapsulating resin dictate the processing methods which may be used.

In the easiest cases, the primary encapsulant is merely poured into place as a liquid and cured in an oven [Sylgard 184, RTV 615, and dielectric gel (Q3-6527)]. The three systems using silicone rubber were prepared in this manner with no difficulty. The two systems based on the dielectric gel as the primary encapsulant varied slightly. The cover materials were glued into place over constraining walls and the module was then filled with uncured gel using a hypodermic syringe inserted through a hole in the wall. The holes, one for filling and one for air exhaust, were sealed with RTV 732 adhesive and the gel permitted to cure at room temperature.

This technique might be well suited to automatic array assembly. Cells could be attached to the substrate, covers glued on, and the empty panels then filled with silicone through a "grease fitting" type of fixture.

Encapsulation with thermoplastic materials is a much more difficult task, the feasibility of which is still under investigation. The two major difficulties encountered are the high melting points of thermoplastics and the ease with which silicon cells fracture.

Compression molding is a conventional and usually simple technique but cannot be used with any material other than Tenite 479 (cellulose acetate butyrate). The reason for this is that all the other polymers of interest have "melting" points in excess of the solder and metalization melt temperature.

Compression molding is still not quite feasible with Tenite 479, however. Slight variations in molding pressure cause the fragile silicon cells to shatter. Very low molding pressures applied for long times reduce stress build-ups, but still produce a high percentage of failure.

Present experiments show that sintering is a feasible process - at least as a laboratory technique. In this procedure the cell module is covered with a layer of powdered resin and heated to flow temperature in an oven. As the resin fuses, the molten solder on the cell surfaces does not appear to migrate, and solidifies quite intact during the cooling cycle.

Temporary application of vacuum during fusion is found to produce good continuous, fairly bubble-free coatings as thick as 200 mils. This process appears to be a promising approach to the two systems using Tenite 479 and the single system with Plexiglas V-811 (see Table 61). Re-evaluation of adhesives to bond resin to cell and substrate was required for these temperatures (200^{o}C), however.

High-temperature epoxy formulations are beginning to work well - based on Epon 828 (Shell Chemical Company) and cured with an anhydride hardener rather than an amine. The hardener used was Ciba-Geigy 907, and the addition of small quantities of an antioxidant (1 percent by weight of Sandostab P-EPQ) gave clear, thermally stable and very adhesive coatings.

Attempts to fuse premolded sheets of polymer over the module were unsuccessful and trapped many air bubbles in addition to not flowing around the interconnects. Only powdered resin, approximately 50 mesh, has been effective. This method is not suitable for Resin 81, C-4 polycarbonate, or Viton AHV because of their high fusion temperatures.

An alternative method of encapsulation that may be employed is solution coating. A disadvantage of this process is that multiple coats have to be "built up" with drying between each coat in order to achieve the required thickness. Solvent emissions are also an undesirable aspect of this method.

The solution coating process has been successful with the Viton AHV fluoroelastomer, which does not appear to be usable by any other method. Correct solvent composition and drying cycles are the most important factors controlling uniform and bubble-free coatings.

The best results were achieved by applying 20-mil coatings of a 30 percent solution of Viton AHV in methyl isobutyl ketone and drying for 12 hours between coats. A silicone primer (DC Z-6020) treatment of both cell and substrate appeared to give adequate adhesion.

Encapsulation with C-4 polycarbonate (in progress) will also use a solvent casting process, but will additionally be baked on over an epoxy adhesive.

Although none of the aforementioned techniques will be recommended as commercially useful processes, they will aid in assessing material performance and design criteria.

Only one other process from those mentioned for encapsulation is being considered at this time. This is perhaps the only possible technique for use with Resin 81 (Kel-F 6060) and may be applicable to automatic array encapsulation with other thermoplastics. The technique is known as plasma spray and is a commercially available process. A plasma is generated by feeding a stream of inert gas (nitrogen) between two coaxial electrodes charged to voltage. Powdered resin is then fed into the ionized gas "flame" where it melts and may be sprayed upon a surface in the same manner as a paint from a spray gun.

The real advantage to this system is that high melting point polymers can be deposited on a cool cell/substrate without melting the solder. Springborn Laboratories is now working with another company having such facilities and will determine the feasibility of this process for Resin 81, C-4 polycarbonate, Plexiglas V-811, and Tenite 479. This process is claimed to be energy intensive and less expensive than other coating methods.

Investigations of the various encapsulation methods described have revealed a number of possible problem areas which are identified as:

- Metalization melt temperature low (350^{o}F). Encapsulant materials must be applied such that the solder joints and metalization do not melt.
- Cell fragility. Compression or injection molding techniques apply too much stress to the cell surface, causing fracture. This has been found to occur even when the cell is rigidly supported on its underside.
- Differential thermal expansion. Differences in thermal expansion have been found to cause delamination of high-modulus materials from the module, resulting in warping and cell fracture.
- Substrate outgassing. Polyester/fiberglass substrates contain volatile substances that outgas at elevated temperatures

(approximately 200°C) and result in bubbles in the coatings. No difficulties were noticed with the aluminum or NEMA epoxy substrates.

- Thermal decomposition of adhesives. Appropriate formulations should be used for the temperatures in use.
- Encapsulant outgassing. Materials such as Plexiglas V-811 and Tenite 479 absorb small quantities of water upon exposure to humid air and will bubble when fused. Vacuum drying is necessary before molding.
- Surface wetting. Multiple applications or the addition of wetting agents is sometimes required with adhes .ves and primers to give uniform coatings. Primary encapsulants will occasionally "pinhole" over areas inadequately primed.
- Oil films on aluminum substrates. Mill oil must be removed by vapor degreasing.
- Substrate chalking. This effect was noticed only in the case of polyester/fiberglass substrates.
- Entrapped air under cells. This gives rise to bubbles in both thermoplastic and ermoset materials and may cause cell fracture under vacuum operations.

9. CONCLUSIONS

1. For routine mechanical testing of polymers, ASTM D-1708 or ASTM D-638 (Instron) procedures appear to be satisfactory to determine the four basic properties of tensile strength, yield strength, elongation, and modulus.

2. Optical transmittance of transparent materials must be done with a spectrometer or photometer incorporating an integrating sphere so that wide-angle scattered light (as received by the cell) is also measured.

3. Data developed from materials exposed to Weather-Ometer and RS-4/55°C conditions has been given greater consideration because of the closer similarity to outdoor weathering. Actual correlations have not yet been made, however, and consequently the efficacy of the method is inconclusive.

4. A general conclusion of the aging data so far obtained is that there is no inherently weatherable low-cost transparent plastic. The fluorocarbons weather extremely well (e.g., Kel-F Resin 81) but can only be used as very thin films to provide cost effective protection.

5. The results of optical testing over the visible range after the 240-day exposure period indicate that all materials decrease in transmission from their control values. The most dramatic changes can be seen in the most severe conditions (Weather-Ometer, RS-4/100°C), and degradation to the point of disintegration was observed in Tedlar, C-4 polycarbonate, and Tenite 479. The worst decreases in transmission were found for Udel 1700 (polyaryl sulfone), Tedlar, Sylgard 184, and RTV 615 after Weather-Ometer exposure. The least affected were FA, CR-39, and both Plexiglas formulations.

6. Transmissions measured over the ultraviolet range (after 240 days of exposure) showed generally slowly decreasing values with no particular connection to the type of exposure condition. Uniform increases in ultraviolet transmissions were found for Kynar 460 and Tenite 479.

7. A comparison of optical losses versus humidity may be found in Table 15. The Weather-Ometer (incorporating water spray) was less severe than RS-4/55°C and 70 percent relative humidity. Sylgard 184 shows the most dramatic loss in transmission from combined ultraviolet and humidity exposures. RTV 615 was not nearly as much affected, indicating that silicone resins have varying stability (and chemistry).

8. The most optically stable (retaining high transmissions) materials were determined from "Material Transmission Indexes" (Table 14) and found to be PFA fluorocarbon, Q3-6527 silicone gel, and the two Plexiglas formulations.

9. Results of hardness (ASTM D-2240) evaluations demonstrate the tendency for all materials to decrease in surface hardness with time in all conditions. The only exceptions are the two silicone rubbers, Sylgard 184 and RTV 615, that steadily increase in hardness.

10. Mechanical properties determined by conventional Instron testing showed the following trends (based on Weather-Ometer and RS-4 55°C):

    (a) Tensile strength does not appear to change much with aging, with the exceptions of dramatic losses (30-50 percent) for Sylgard 184 and Plexiglas V-811.

    (b) Tensile modulus does not show great variations with aging for most materials studied.

    (c) Elongation at break appears to be the most sensitive indication of polymer degradation, showing the widest changes in values as aging proceeds. The most severely affected plastics were acrylics (Plexiglas), cellulosics (Tenite 479), and the polycarbonates (Lexan, C-4).

d) Fluorocarbon polymers demonstrate the least susceptibility to weathering.

11. In general, the most useful classes of materials are the fluorocarbons, silicones, and acrylics.

12. Soil accumulation specimens all lost a small percentage of original optical transmission (except for Udel 1700, which degraded) but retained relatively clean surfaces. RTV 615, Sylgard 184, and Viton AHV were the only materials that were severely affected and will have to be used outdoors with protective (high-modulus) coatings.

13. Fungus testing demonstrated that most of the resins supported only light growth and were generally unaffected. Only RTV 615, Sylgard 184, and Tenite 479 showed persistent splotches of fungus and surface attack. The use of bacteriocides may be necessary with these materials.

14. Cost effectiveness of encapsulant materials (Table 56) may be conveniently expressed in terms of cost per unit volume, $\$/in.^3$. The most attractive polymers are the acrylics, followed by cellulosic (Tenite 478) and the Q3-6527 dielectric gel. The cost effectiveness of acrylics is further reason to investigate this generic class more extensively.

15. The most significant conclusion to be drawn from processing and encapsulation studies is that no material - regardless of its transparency, stability, etc. - is useful unless it can be fabricated into solar cell modules.

Trial encapsulation studies have revealed two general observations:

(a) The encapsulant must be applied at low stress levels to avoid cell fracture.

(b) Encapsulant processing temperatures must be below the melting point of solder metalization or junctions (plasma spray may prove to be an exception, if successful).

10. RECOMMENDATIONS

1. For the evaluation of mechanical properties, ASTM D-1708 or ASTM D-638 (Instron testing) appears to be adequate. For evaluation of optical properties, a spectrometer or photometer utilizing an integrating sphere is recommended.

2. No specific type of accelerated weathering procedure can be recommended at this time because of incomplete correlation with natural weathering conditions (in progress).

3. Based on the difficulties encountered with the usage of materials in this program, we recommend that an extensive survey of low-cost polymers be investigated with the primary emphasis on processability. Acrylic copolymers are the most likely choice because of their stability, transparency, and cost.

4. Increased emphasis should be applied to the modification and stabilization of cellulosic polymers due to their high clarity, relative processing ease, low cost, and the fact that they are not petroleum derivations.

5. A study of the environmental effects on high-bond-strength, low-modulus adhesives would be valuable, as these materials serve as stress-relief regions between mechanically incompatible materials.

6. Of the materials and systems examined to date in this program, the most likely encapsulant systems for successful intermediate lifetime (5-10 years) are:

   (a) Silicone rubber with a thin fluorocarbon cover glued in place with a silicone adhesive.

   (b) Q3-6527 dielectric silicone gel with a glass cover.

7. The expanded metal type of interconnect between cells is recommended on the basis of the reduction in module profile and consequently lower encapsulant volume.

8. Due to the widespread use of silicone rubbers as encapsulant materials, it may be useful to find a chemically compatible fungicide or bacteriostat to decrease the possibility of fungus attack, which appears to occur readily.

9. Dielectric strength and/or insulation resistance should be determined for highly permeable polymers as a function of humidity (after equilibration). Moisture content could cause a serious failure of electrical properties in encapsulant materials.

10. Other investigators in the field of solar cell encapsulation have reported that thermal cycling causes cell fracture in encapsulants of high modulus. Cells should be embedded in materials having moduli ranging from high to low, with subsequent cycling and testing so that a failure rate versus modulus curve can be drawn. This experiment might determine an upper limit modulus value and consequently establish a useful material specification.

11. Although it is not appropriate to recommend any specific encapsulation method at this time, the most commercially attractive techniques would appear to be one of the following:

    (a) Spraying (plasma or nonsolvent based)
    (b) Dipping
    (c) LRM (liquid reaction molding)

11. FUTURE ACTIVITIES

1. The results of flexural testing of chemically strengthened glass (172 DRL) will be presented for the four exposure times in the five accelerated aging conditions.

2. Optical and mechanical test results for the three urethane encapsulant materials included late in the program will be tabulated.

3. Optical and mechanical properties of aged and unaged specimens of PVB resins behind glass will be reported.

4. All of the soil accumulation specimens will be cleaned according to a specified procedure and retested for optical transmittance to determine any change.

5. Evaluation of high-temperature epoxy primers and adhesives for the fusion and plasma spray methods of encapsulation will continue and be reported.

6. The results of attenuated total reflectance (ATR) in the infrared region of the spectrum will be presented as a function of material, exposure time, and exposure condition. An improved method of calculation will be used.

7. Optical transmittance attenuations of those polymers experiencing fungus attack will be reported.

8. Mechanical and optical property variations resulting from fixed-angle exposures of 6 and 12 months in Phoenix and Miami will be reported for thirteen materials selected from the present program. Attempts will be made to correlate the results with indoor artificial accelerated weathering conditions.

9. The results of mechanical and optical testing of materials exposed to EMMAQUA aging will be given for 4, 8, and 12 months of exposure. Correlations with indoor accelerated weather conditions will be made.

10. The effects of 4 and 8 months of EMMAQUA exposure of encapsulated cell modules will be reported, including I/V curves.

11. The mechanical and optical prop cies found for accelerated aging of polymers versus exposure times will be graphically presented The following relationships will be plotted in order to establish correlations and predictive methodology:

    - Linear - time versus property
    - Semi-log - log property versus time
    - Log-log - log property versus log time

    Projections will be made on the cost effectiveness of encapsulation techniques.

12. Final encapsulation methods and detailed techniques will be reported for all cell systems.

13. Mechanical and optical properties of those materials upgraded for UV stability will be reported after 120 and 240 days of exposure. The efficacy of UV stabilization methods will be determined and compared. Specific systems or goals will be recommended.

14. Temperature-modulus curves of selected polymers will be reported over the range of -40°C to +120°C.

15. A wide range of inexpensive processable materials will be surveyed under a recent contract extension and subsequently upgraded and used for trial encapsulation.

SECTION 12

TABLES

TABLE 1

Materials Selected and Molding Conditions
(Compression Molding)[1]

Section A - Thermoplastic Resins

Resin	Generic Type	Manufacturer	Temp. (°F)	Pre-heat (min.)	Mold (min.)	Cool (min.)
Kynar 460	Polyvinylidene fluoride	Pennwalt	370	3	2	2
Halar 500	Ethylene/chloro-trifluoroethylene	Allied	500	4	1	2
Tefzel 280	Ethylene/tetra-fluoroethylene	DuPont	550	3	1.5	2
FEP 100	Perfluoroethyl-ene propylene	DuPont	560	6	2	3
PFA 9705	Perfluoroalkoxy	DuPont	620	4	2	3
Viton AHV	Hexafluoropro-pylene vinylidene fluoride	DuPont	400	3	2	2
Resin 81	Chlorotrifluoro-ethylene	Minnesota Mining & Mfg.	480	3	2	3
Kel-F 800	Chlorotrifluoro-ethylene/vinyli-dene fluoride	Minnesota Mining & Mfg.	275	2.5	1	2
Udel 1700	Polyaryl sulfone	Union Carbide	460	3	1	2
Lexan 123-111	Polycarbonate	General Elec.	380	2	1	2
C-4	Polycarbonate	Union Carbide	500	3	2	2
Tenite 479	Cellulose ace-tate butyrate	Eastman	300	2	1.5	2
Plexiglas DR-100	Methyl methac-rylate copolym.	Rohm & Haas	370	2	1.5	2
Plexiglas V-811	Polymethyl methacrylate	Roym & Haas	350	3	2	2

(1) Preco Press, Model PA-7, 6" x 6" platens; and Service Physical Testers Press, Model HP-50T, 8" x 8" heated platens

. . . Continued

Table 1 (Continued - 2)

Section B - Thermoset Resins

Resin	Generic Type	Manufacturer	Molding Conditions
Sylgard 184	Silicone	Dow-Corning	Cast, cure for 1 hour at 100°C
Q3-6527	Silicone gel	Dow-Corning	Cast at ambient temperature into quartz cells
RTV 615	Silicone	General Electric	Cast, cure 1 hour at 100°C
Resin 650	Silicone "glass" resin	Owens-Illinois	Not fabricable
CR-39	Diethylene glycol diallyl carbonate	PPG Industries	Cast - prepared by mfr.
Tedlar 20	Polyvinyl fluoride	DuPont	Extruded - prepared at factory
Strengthened glass	Ceramic	Dow-Corning	Prepared at factory

TABLE 2

Materials Rejected

Generic Type	Brand Name(s)	Chemistry	Reason(s) for Rejection
ABS	Cycolac, Abson, Lustran	Acrylonitrile/Butadiene/Styrene	Low transmission; poor weatherability.
ASA	Luran-S	Acrylonitrile/Styrene/Acrylic	Low transmission; poor weatherability.
Acetal	Celcon, Delrin	Polyformaldehyde	Low transmission; chalks with UV; poor weatherability.
SB	Kraton, K-Resin	Styrene/Butadiene	Oxidizes rapidly; embrittles.
Furan	Polymeg, Duralon	Poly furfuryl alcohol	Opaque
Ionomer	Surlyn	Proprietary	UV unstable; poor weatherability.
Melamine	Cymel, Plaskon	Melamine/formaldehyde	Darkens with UV; embrittles.
Nylon(s)	Zytel, Trogamid, Grilon, Minlon	Polycaprolactam, Nylon 11, Nylon 12, Nylon 6, Nylon 6-6	Low transmission; hydrolytic instability; UV unstable.
Phenolic	Genal, Durez, Bakelite	Phenol/formaldehyde	Opaque
PPO	Noryl	Phenylene oxide	Opaque
Amide-imide	Torlon, Rhodeftal	Polyamide-imide	Low transmission; UV unstable.
Polyimide	Kapton, Vespel, Kinel, Kerimide	Polyimide	Low transmission; UV unstable.
Polyaryl ether	Arylon T	Polyaryl ether	UV unstable; oxidizes rapidly.

...Continued

Table 2 (Continued - 2)

Generic Type	Brand Name(s)	Chemistry	Reason(s) for Rejection
Polyester (Thermo-plastic)	Celanex, Mylar, PBT	Polyesters, mainly terephthalates.	Hydrolytic instability; crazes; UV unstable.
Unsaturated Polyester (Thermoset)	Hetron, Laminac, Dion, Atlac	Maleic acid esters and others	Hydrolytic instability; UV unstable; chalks.
Polyether sulfone	PES-200	Diphenyl ether sul-fone	UV unstable; crazes.
Polyethylene (and ethylene copolymers)	DYNH, Hi-Fax, Petrothene, Alka-thene, Alathon	Polyethylene	Low transmission
Polyolefin	TPR, TPX, Pro-fax, Tenite	Polybutene, poly-methyl pentene, poly-propylene	Crazes and oxidizes rapidly
Polyphenyl-ene Sulfide	Ryton	Polyphenylene sulfide	Opaque
Polystyrene	Bakelite, Lustrex	Polystyrene	Yellows; embrittles
SAN	Lustran, Tyril	Styrene/acrylonitrile	Yellows; crazes
Urea-formaldehyde	Avisco, Plaskon, Beetle	Urea-formaldehyde	Darkens; decomposes
PVC	VYHH, Pliovic, Geon, Tygon	Polyvinyl chloride	Darkens; degrades

TABLE 3

Baseline Optical Properties
(Visible Range)
Integrated Transmittance Over 350-800 nm

Resin	Generic Type	Manufacturer	Trans-mittance (%)
Kynar 460	Polyvinylidene fluoride	Pennwalt	59
Halar 500	Ethylene/Chlorotri-fluoroethylene	Allied Chemical	81
Tefzel 280	Ethylene/Tetrafluoro-ethylene	DuPont	71
FEP 100	Perfluoroethylene propylene	DuPont	84
PFA 9705	Perfluoroalkoxy	DuPont	88
Tedlar 20	Polyvinyl fluoride	DuPont	77
Viton AHV	Hexafluoropropylene vinylidene fluoride	DuPont	85
Resin 81 (Kel-F 6060)	Chlorotrifluoroethylene	Minnesota Mining & Mfg.	82
Kel-F 800	Chlorotrifluoroethylene/ Vinylidene fluoride	Minnesota Mining & Mfg.	85
Sylgard 184	Silicone	Dow-Corning	75
Q3-6527	Silicone gel	Dow-Corning	94
RTV 615	Silicone	General Electric	81
Udel 1700	Polyaryl sulfone	Union Carbide	86
Lexan 123-111	Polycarbonate	General Electric	88
C-4	Polycarbonate	Union Carbide	91
Tenite 479	Cellulose acetate butyrate	Eastman	91
CR-39	Diethylene glycol diallyl carbonate	PPG Industries	92
Plexiglas DR-61K	Methyl methacrylate copolymer	Rohm & Haas	90
Plexiglas V-811	Polymethyl methacryl-ate	Rohm & Haas	92

TABLE 4

Optical Transmission
30-Day Exposure — 350-800 nm
Visible Range

Resin	Control	Weather-Ometer 55°C		Air Oven				RS-4 Sunlamp			
				55°C		100°C		55°C		100°C	
	T %	T (%)	% Control	T %	% Control	T %	% Control	T %	% Control	T %	% Control
Kynar 460	58	56	96	58	100	55	95	56	96	57	98
Halar 500	81	80	99	82	101	80	99	82	101	78	96
Tefzel 280	71	71	100	70	99	72	101	74	104	73	103
FEP 100	84	80	95	84	100	82	98	82	98	82	98
PFA 9705	88	84	95	86	98	85	97	88	100	90	102
Tedlar 20	76	84	110	75	99	74	97	74	97	(a)	
Viton AHV	85	80	94	82	96	78	92	85	100	86	101
Resin 81 (Kel-F 6060)	82	82	100	84	102	85	104	86	105	84	102
Kel-F 800	85	82	96	82	96	(b)		86	101	86	101
Sylgard 184	76	78	102	78	102	80	105	80	105	82	108
Q3-6527	94	93	99	94	100	93	99	94	100	93	99
RTV 615	81	74	91	82	101	81	100	84	104	85	105
Udel 1700	86	45	52	86	100	86	100	71	82	64	74
Lexan 123-111	88	86	98	88	100	88	100	84	95	82	93
C-4	91	86	94	90	99	92	101	90	99	88	97
Tenite 479	92	85	92	92	100	92	100	88	96	(a)	
CR-39	92	93	101	92	100	92	100	92	100	92	100
Plexiglas DR-61K	90	88	98	90	100	90	100	89	99	89	99
Plexiglas V-811	92	89	97	91	99	92	100	90	98	90	98

(a) Degraded/Broken
(b) Melted/Flowed

TABLE 5

Optical Transmission
60-Day Exposure— 350-800 nm
Visible Range

Resin	Control T %	Weather-Ometer 55°C		Air Oven 55°C		Air Oven 100°C		RS-4 Sunlamp 55°C		RS-4 Sunlamp 100°C	
		T (%)	% Control	T (%)	% Control	T (%)	% Control	T (%)	% Control	T (%)	% Control
Kynar 460	58	29	50	32	55	46	79	29	50	34	58
Halar 500	81	68	83	70	86	88	109	74	91	81	100
Tefzel 280	71	50	70	50	70	54	76	50	70	54	76
FEP 100	84	56	66	65	77	88	105	68	80	76	90
PFA 9705	88	67	76	76	86	91	103	84	95	76	86
Tedlar 20	76	40	52	44	57	86	113	37	48	(a)	
Viton AHV	85	66	77	71	83	80	94	76	89	72	84
Resin 81 (Kel-F 6060)	82	58	70	76	92	88	107	74	90	68	82
Kel-F 800	85	59	69	72	84	(b)		86	101	(b)	
Sylgard 184	76	52	68	66	86	86	113	82	107	76	100
Q3-6527	94	94	100	94	100	88	94	94	100	92	98
RTV 615	81	42	51	48	59	66	81	70	86	78	96
Udel 1700	86	4	4	73	84	90	105	56	65	20	23
Lexan 123-111	88	75	85	76	86	90	102	74	84	72	81
C-4	91	54	60	86	94	94	103	90	98	(a)	
Tenite 479	92	80	86	87	94	94	102	84	91	(b)	
CR-39	92	90	97	92	100	88	96	90	91	86	93
Plexiglas DR-61K	90	76	84	82	91	92	102	82	91	82	91
Plexiglas V-811	92	80	86	88	95	89	96	87	94	(a)	

(a) Degraded/Broken
(b) Melted/Flowed

TABLE 6

Optical Transmission
120-Day Exposu - 350-800 nm
Visible Range

Resin	Control	Weather-Ometer 55°C		Air Oven				RS-4 Sunlamp			
				55°C		100°C		55°C		100°C	
	T (%)	T (%)	% Control	T(%)	% Control	% (%)	% Control	T (%)	% Control	T (%)	% Control
Kynar 460	58	29	50	30	52	27	46	30	52	29	50
Halar 500	81	68	84	69	85	69	85	73	90	72	89
Tefzel 280	71	56	79	52	73	51	72	55	77	35	49
FEP 100	84	70	83	68	81	77	92	67	80	68	81
PFA 9705	88	79	90	74	84	82	93	75	85	78	38
Tedlar 20	76	34	45	34	45	33	43	35	46	(a)	(a)
Viton AHV	85	35	41	67	79	57	67	71	83	76	89
Resin 81 (Kel-F 6060)	82	65	79	66	80	63	77	69	84	60	73
Kel-F 800	85	65	76	70	82	(b)	(b)	72	85	(b)	(b)
Sylgard 184	76	28	37	75	98	48	63	65	83	73	96
Q3-6527	94	93	99	93	99	91	97	93	99	91	97
RTV 615	81	26	32	64	79	75	92	70	86	68	84
Udel 1700	86	5	5.8	81	94	78	91	40	46	6	7
Lexan 123-111	88	53	60	78	88	78	88	73	83	59	67
C-4	91	66	72	84	92	82	90	77	85	(a)	(a)
Tenite 479	92	(a)	(a)	88	95	84	91	(a)	(a)	(a)	(a)
CR-39	92	91	99	91	99	68	74	90	98	85	92
Plexiglas DR-61K	90	80	89	84	93	79	88	80	89	76	84
Plexiglas V-811	92	79	86	88	96	87	95	84	91	89	97

(a) Degraded/Broken
(b) Melted/Flowed

TABLE 7

Optical Transmission

240-Day Exposure - 350-800 nm
Visible Range

Resin	Control T (%)	Weather-Ometer 55°C		Air Oven 55°C		Air Oven 100°C		RS-4 Sunlamp 55°C		RS-4 Sunlamp 100°C	
		T (%)	% Control	T (%)	% Control	T (%)	% Control	T (%)	% Control	T (%)	% Control
Kynar 460	58	28	48	NT	-	NT	-	NT	-	38	65
Halar 500	81	71	88	70	86	69	85	70	86	76	94
Tefzel 280	71	NT	-	NT	-	NT	-	NT	-	NT	-
FEP 100	84	78	93	63	75	72	86	68	81	71	84
PFA 9705	88	79	90	80	91	77	67	71	81	79	90
Tedlar 20	76	30	39	23	30	21	28	34	45	(a)	
Viton AHV	85	46	54	51	60	42	49	64	75	74	87
Resin 81(Kel-F 6060)	82	68	83	66	80	66	80	68	83	57	69
Kel-F 800	85	NT	-	NT	-	NT	-	NT	-	NT	-
Sylgard 184	76	26	34	51	67	50	66	64	84	64	84
Q3-6527 (c)	94	93	99	94	100	92	98	94	100	92	98
RTV 615	81	42	52	62	76	59	73	69	85	70	86
Udel 1700	86	NT	-	NT	-	NT	-	NT	-	NT	-
Lexan 123-111	88	38	43	NT	-	NT	-	NT	-	54	61
C-4	91	52	57	84	92	83	91	67	74	(a)	
Tenite 479	92	(b)	NT	87	94	75	81	(b)	(b)	(b)	
CR-39	92	NT	-	NT	-	NT	-	NT	-	NT	-
Plexiglas DR-61K	90	78	87	83	92	83	92	80	89	(a)	
Plexiglas V-811	92	81	88	87	94	85	92	76	82	(a)	(a)

NT = Not Tested (discontinued)
(a) Degraded/Broken
(b) Melted/Flowed
(c) Gel material in quartz cell; transmission reduced by formation of voids.

TABLE 8

UV-Optical Transmission
30-Day Exposure – 290-350 nm
Ultraviolet Range

Resin	Control	Weather-Ometer 55°C		Air Oven				RS-4 Sunlamp			
				55°C		100°C		55°C		100°C	
	T (%)	T (%)	% Control	T (%)	% Control	T (%)	% Control	T (%)	% Control	T (%)	% Control
Kynar 460	3	4	133	5	166	3	100	4	133	4	133
Halar 500	36	30	80	31	86	31	86	30	80	18	50
Tefzel 280	15	15	100	12	80	14	93	14	93	14	93
FEP 100	34	34	100	34	100	32	94	32	94	30	88
PFA 9705	42	51	121	47	111	45	107	51	121	49	116
Tedlar 20	13	16	123	16	138	11	85	15	115	0	-
Viton AHV	56	39	69	41	73	24	43	42	75	49	87
Resin 81 (Kel-F 6060)	24	33	137	32	133	35	146	36	150	26	108
Kel-F 800	60	45	75	31	51	(a)	(a)	53	88	(a)	(a)
Sylgard 184	32	23	72	29	91	34	106	28	87	29	91
Q3-6527	92	90	98	92	100	89	97	90	98	83	90
RTV 615	65	19	29	28	42	33	51	35	54	34	52
Udel 1700	21	0	-	22	104	20	95	0	-	0	-
Lexan 123-111	0	0	-	0	-	0	-	0	-	0	-
C-4	50	61	122	46	96	48	96	66	132	62	124
Tenite 479	44	2	4.5	61	138	59	134	0	-	(b)	(b)
CR-39	83	80	96	81	97	80	96	80	96	80	96
Plexiglas DR-61K	0	1	-	0	-	0	-	1	-	2	-
Plexiglas V-811	75	47	63	49	65	43	57	52	69	51	68

(a) Degraded/Broken

(b) Melted/Flowed

TABLE 9

UV-Optical Transmission

60-Day Exposure – 290-350 nm

Ultraviolet Range

Resin	Control	Weather-Ometer 55°C		Air Oven				RS-4 Sunlamp			
				55°C		100°C		55°C		100°C	
	T (%)	T (%)	% Control	T (%)	% Control	T (%)	% Control	T (%)	% Control	T (%)	% Control
Kynar 460	3	4	133	6	200	7	230	5	166	5	166
Halar 500	36	30	83	34	94	51	140	33	91	41	113
Tefzel 280	15	12	80	14	93	12	80	12	80	14	93
FEP 100	34	23	67	23	67	52	153	30	88	31	91
PFA 9705	42	36	85	46	109	70	167	52	123	44	104
Tedlar 20	13	14	107	22	169	49	377	8	61	(b)	(b)
Viton AHV	56	50	89	46	82	40	71	55	98	52	92
Resin 81 (Kel-F 6060)	24	19	79	38	158	48	200	32	133	28	116
Kel-F 800	60	36	60	26	43	(a)	(a)	56	93	(a)	(a)
Sylgard 184	32	36	112	53	165	79	247	68	212	72	225
Q3-6527	92	90	98	91	99	74(c)	80(c)	91	99	83(c)	90(c)
RTV 615	65	30	46	34	52	56	86	60	92	78	120
Udel 1700	21	0	0	19	90	26	124	0	0	0	0
Lexan 123-111	0	0	-	0	-	1	-	0	-	0	-
C-4	50	34	68	46	92	64	128	78	156	(b)	(b)
Tenite 479	44	2	4	51	115	60	136	6	13	(a)	(a)
CR-39	83	81	97	80	96	53	64	74	89	48	57
Plexiglas DR-61K	0	0	-	0	-	0	-	2	-	3	-
Plexiglas V-811	75	44	58	46	61	48	64	72	96	(b)	(b)

(a) Degraded/Broken
(b) Melted/Flowed
(c) Gel Material in Quartz Cell; Transmission Reduced By Formation of Small Voids

TABLE 10

Optical Transmission
120-Day Exposure - 290-350 nm
Ultraviolet Range

Resin	Control	Weather-Ometer 55°C		Air Oven				RS-4 Sunlamp			
				55°C		100°C		55°C		100°C	
	T (%)	T (%)	% Control	T (%)	% Control	T (%)	% Control	T (%)	% Control	T (%)	% Control
Kynar 460	3	4	133	4	133	3	100	3	100	7	233
Halar 500	36	31	86	26	72	24	67	31	86	32	89
Tefzel 280	15	14	93	12	80	12	80	15	100	6	40
FEP 100	34	29	85	29	85	32	94	26	76	24	70
PFA 9705	42	47	112	41	97	48	114	41	97	44	105
Tedlar 20	13	10	77	10	77	2	15	10	77	(a)	(a)
Viton AHV	56	21	37	39	69	20	36	53	95	58	103
Resin 81 (Kel-F 6060)	24	22	92	23	96	18	75	27	112	25	104
Kel-F 800	60	36	60	29	48	(b)	(b)	42	70	(b)	(b)
Sylgard 184	32	15	47	61	190	37	116	49	153	64	200
Q3-6527	92	88	96	90	98	(c)	-	90	98	74(c)	80
RTV 615	65	14	21	49	75	63	97	58	89	57	87
Udel 1700	21	0	-	20	95	18	86	0	-	0	-
Lexan 123-111	0	0	-	0	-	0	-	1	-	0	-
C-4	50	43	86	43	86	42	84	54	108	(a)	(a)
Tenite 479	44	(a)	[illegible]	53	120	44	100	(a)	(a)	(a)	(a)
CR-39	83	81	97	77	93	72	86	73	88	44	53
Plexiglas DR-61K	0	0	-	0	-	0	-	2	-	0	-
Plexiglas V-811	75	56	75	44	58	44	58	76	101	72	96

(a) Degraded/Broken
(b) Melted/Flowed
(c) Transmissions Reduced by Void Formation

TABLE 11

Optical Transmission

240-Day Exposure - 290-350 nm Ultraviolet Range

Re ı	Control	Weather-Ometer		Air Oven				RS-4 Sunlamp			
		55°C		55°C		100°C		55°C		100°C	
	T (%)	T (%)	% Control	T (%)	% Control	T (%)	% Control	T (%)	% Control	T (%)	% Control
Kynar 460	3	5	166	NT	-	NT	-	NT	-	7	233
Halar 500	36	34	94	24	67	24	67	29	80	39	108
Tefzel 280	15	NT	-	NT	-	NT	-	NT	-	NT	-
FEP 100	34	38	112	25	73	33	97	27	79	29	85
PFA 9705	42	45	107	43	102	43	102	38	90	46	109
Tedlar 20	13	2	15	3	23	0	-	7	54	(a)	
Viton AHV	56	32	57	24	43	10	18	49	87	49	87
Resin 81(Kel-F 6060)	4	25	104	22	92	25	104			17	71
Kel-F 800	60	NT	-	NT	-	NT	-	NT	-	NT	-
Sylgard 184	32	14	44	36	112	32	100	45	141	49	153
Q3-6527	92	89	97	90	98	0 (c)	-	89	97	0 (c)	-
RTV 615	65	28	43	46	71	45	69	54	83	57	88
Udel 1700	21	NT	-	NT	-	NT	-	NT	-	NT	-
Lexan 123-111	0	0	-	NT	-	NT	-	NT	-	1	-
C-4	50	22	44	44	88	42	84	42	84	(a)	
Tenite 479	44			43	98	13	30			(b)	
CR-39	83	NT	-	NT	-	NT	-	NT	-	NT	-
Plexiglas DR-61K	0	39	-	0	-	0	-	5	-	(b)	
Plexiglas V-811	75	78	104			78	104				

NT = Not Tested (discontinued)

(a) Degrao d/Broken

(b) Melted/Flowed

(c) Transmission reduced by void formation.

TABLE 12

Optical Transmission - RS-4 Sunlamp, 70% Relative Humidity

Resin	Percent Transmittance						
	Visible - 350-800 nm						
	Control	30-Day Exposure	% Control	60-Day Exposure	% Control	90-Day Exposure	% Control
Kynar 460	57	29	51	28	49	29	51
Halar 500	81	65	80	59	73	68	83
Tefzel 280	70	55	78	45	82	NT	-
FEP 100	84	51	61	57	68	54	64
PFA 9705	87	80	92	69	79	71	81
Tedlar 20	90	31	34	14	15	24	26
Vitcn AHV	83	53	64	46	55	58	69
Resin 81 (Kel-F 6060)	80	64	80	63	80	70	87
Kel-F 800	83	NT	-	NT	-	NT	-
Sylgard 184	78	15	19	15	19	13	16
Q3-6527	94	NT	-	NT	-	NT	-
RTV 615	82	27	33	23	28	33	40
Udel 1700	85	28	33	21	25	29	34
Lexan 123-111	88	51	58	41	46	42	47
C-4	91	56	61	52	57	44	48
Tenite 479	91	(a)	-	(a)	-	(a)	-
CR-39	92	89	97	47	51	NT	-
Plexiglas DR-61K	90	71	79	70	78	67	74
Plexiglas V-811	92	82	89	85	92	81	88

(a) - Melt/Flow
NT = Not Tested

TABLE 13

Optical Transmission - RS-4 Sunlamp, 70% Relative Humidity

Ultraviolet Range

Resin	Percent Transmittance						
		Ultraviolet - 280-350 nm					
	Control	30-Day Exposure	% Control	60-Day Exposure	% Control	90-Day Exposure	% Control
Kynar 460	3	4	133	5	166	5	166
Halar 500	36	24	66	24	66	26	72
Tefzel 280	15	3	87	10	66	(a)	-
FEP 100	34	19	56	22	65	19	56
PFA 9705	42	45	107	37	88	38	90
Tedlar 20	13	3	23	1	7	2	15
Viton AHV	56	15	27	19	34	31	55
Resin 81 (Kel-F 6060)	24	27	112	26	108	35	145
Kel-F 800	60	NT	-	NT	-	NT	-
Sylgard 184	32	7	22	7	22		-
Q3-6527	NT	NT	-	NT	-	NT	-
RTV 615	65	18	27	14	21	20	30
Udel 1700	21	0	0	0	0	0	0
Lexan 123-111	0	0	-	0	-	0	-
C-4	50	33	66	32	64	26	52
Tenite 479	44	(a)	-	(a)	-	(a)	-
CR-39	83	68	82	6	7	(a)	-
Plexiglas DR-61K	0	3	-	3	-	3	-
Plexiglas V-811	75	40	53	66	88	69	92

(a) - Melt/Flow

NT = Not Tested

TABLE 14

Material Transmission Index

Exposure: 30, 60, 120, and 240 Days

Resin	Baseline Control (Unaged) (%)	Baseline Transmittance (%) X Aged Transmittance (%)																			
		Weather-Ometer, 55°C				Air Oven, 55°C				Air Oven, 100°C				RS-4 Sunlamp, 55°C				RS-4 Sunlamp, 100°C			
		30	60	120	240	30	50	120	240	30	60	120	240	30	60	120	240	30	60	120	240
Kynar 460	58	32.5	16.8	16.8	16.2	33.6	18.5	17.4	NT	31.9	26.7	15.6	NT	32.5	16.8	17.4	NT	33.0	19.7	16.8	22.0
Halar 500	81	64.8	55.0	55.0	57.5	66.4	56.7	55.9	56.7	64.[illegible]	71.3	55.9	55.9	66.4	59.9	59.1	56.7	63.0	65.6	58.3	61.5
Tefzel 280	71	50.4	35.5	39.8	NT	49.7	35.5	36.9	NT	51.1	38.3	36.2	NT	52.5	35.5	39.0	NT	51.8	38.3	24.8	NT
FEP 100	84	67.2	47.0	58.8	66.5	70.5	54.6	57.1	52.9	68.9	73.9	64.7	60.4	68.9	57.1	56.3	57.1	68.9	63.8	57.1	59.6
PFA 9705	88	73.9	58.9	69.5	69.5	75.7	66.8	65.1	70.4	74.8	80.1	72.2	67.7	77.4	73.9	66.0	62.5	79.[illegible]	66.8	68.6	69.5
Tedlar 20	76	63.8	30.4	25.8	22.8	57.0	33.4	25.8	17.5	56.2	65.4	25.1	15.9	56.2	28.1	26.6	25.8	(a)	(a)	(a)	(a)
Viton AHV (c)	85	68.	56.1	29.7	39.1	69.7	60.3	56.9	43.3	66.3	68.0	48.4	35.7	72.2	64.6	60.3	54.4	73.1	61.2	64.6	62.9
Resin 81(Kel-F 6060)	82	67.2	47.5	53.3	55.7	68.8	62.3	54.1	54.1	69.7	72.2	51.6	54.1	70.5	60.7	56.6	55.7	68.8	55.7	49.2	46.7
Kel-F 800	85	69.7	50.1	55.2	NT	69.7	61.2	59.5	NT	(b)	(b)	(b)	NT	73.1	73.1	61.2	NT	73.1	(b)	(b)	NT
Sylgard 184	76	59.3	39.5	21.3	19.7	59.3	50.2	57.0	38.7	60.8	65.3	36.5	38.0	60.8	62.3	47.8	48.6	62.3	57.7	55.5	48.6
Q3-6527	94	87.4	88.3	87.4	87.4	88.3	88.3	87.4	88.3	87.4	82.7	85.5	86.5	88.3	88.3	87.4	88.3	87.4	86.5	85.5	86.5
RTV 615	81	59.9	34.0	21.1	34.0	66.4	38.9	51.8	50.2	65.6	53.5	60.7	47.8	68.0	66.7	56 7	55.9	68.8	63.2	55.1	56.7
Udel 1700	86	38.7	3.4	4.3	NT	73.9	72.2	69.6	NT	73.9	77.4	67.1	NT	61.0	48.2	34.4	NT	55.0	17.2	5.2	NT
Lexan 123-111	88	75.6	66.0	46.6	33.4	77.4	66.9	68.6	NT	77.4	79.2	68.6	NT	73.9	65.1	64.2	NT	72.2	63.3	51.9	47.5
C-4	91	78.2	49.1	60.1	47.3	81.9	78.3	76.4	76.4	83.7	85.5	74.6	75.5	81.9	81.9	70.1	60.9	80.1	(a)	(a)	(a)
Tenite 479	92	78.2	73.6	(b)	(b)	84.6	80.0	80.9	80.0	84.6	86.5	77.3	69.0	80.9	77.3	(b)	(b)	(b)	(b)	(b)	(b)
CR-39	92	85.5	82.8	83.7	NT	84.6	84.6	83.7	NT	84.6	80.9	62.6	NT	84.6	85.5	82.8	NT	84.6	79.1	78.2	NT
Plexiglas DR-61K	90	79.2	68.4	72.0	70.2	81.0	73.8	75.6	74.7	81.0	82.8	71.1	74.7	80.1	73.8	72.0	72.0	80.1	73.8	68.4	(a)
Plexiglas V-811	92	81.8	73.6	72.7	74.5	83.7	80.9	80.9	80.0	84.6	81.9	80.0	78.2	82.8	80.0	77.3	76.0	82.8	(a)	81.8	(a)

(a) Broken/Degraded (b) Melted/Flowed (c) Values are approximate where indicated; elongation exceeds machine capacity.

NT = Not tested (discontinued)

TABLE 15

Hydrolytic Sensitivity

Transmission Index for Selected Conditions

Resin	Control Value T (%)	Optical - 120 Days RS-4, 55°C	Optical - 120 Days Weather-Ometer	90 Days RS-4 55°C 70% RH
Kynar 460	58	17.4	16.8	16.5
Halar 500	81	59.1	55.0	55.0
Tefzel 280	71	39.0	39.8	(a)
FEP 100	84	56.3	58.8	45.4
PFA 9705	88	66.0	69.5	61.7
Tedlar 20	76	26.6	25.8	21.6
Viton AHV	85	60.3	29.7	48.1
Resin 81 (Kel-F 6060)	82	56.6	53.3	56.0
Kel-F 800	85	61.2	55.2	NT
Sylgard 184	76	47.8	21.3	10.1
Q3-6527	94	87.4	87.4	NT
RTV 615	81	56.7	21.1	27.0
Udel 1700	86	34.4	4.3	24.6
Lexan 123-111	88	64.2	46.6	36.9
C-4	91	70.1	60.1	40.0
Tenite 479	92	(b)	(b)	(b)
CR-39	92	82.8	83.7	(a)
Plexiglas DR-61K	90	72.0	72.0	60.3
Plexiglas V-811	92	77.3	72.7	74.5

NT = Not tested
(a) Discontinued Material
(b) Melted/Degraded

TABLE 16

Material Ranking

240-Day Optical Performance

Resin	Control Value T (%)	Optical - 240 Days (T% x % Control)(a)		Ranking Number
		Weather-Ometer	RS-4, 55°C	
Kynar 460	58	16	N.T.	-
Halar 500	81	58	57	6
Tefzel 280	71	N.T.	N.T.	-
FEP 100	84	66	57	5
PFA 9705	88	70	62	4
Tedlar 20	76	23	26	12
Viton AHV	85	39	54	9
Resin 81 (Kel-F 6060)	82	56	54	7
Kel-F 800	85	N.T.	N.T.	-
Sylgard 184	76	20	49	11
Q3-6527	94	93	94	1
RTV 615	81	34	56	10
Udel 1700	85	N.T.	N.T.	-
Lexan 123-111	88	33	N.T.	-
C-4	91	47	61	8
Tenite 479	92	(b)	(b)	-
CR-39	92	N.T.	N.T.	-
Plexiglas DR-61K	90	70	72	3
Plexiglas V-811	92	75	76	2

(a) Transmission index
(b) Specimens flowed too badly to be tested

N.T. = Not Tested

TABLE 17

Hardness - ASTM D-2240

Shore Readings at 1 Second and 15 Seconds

Control Results

Resin	Control, No Exposure
Kynar 460	D 75/73
Halar 500	D 72/70
Tefzel 280	D 62/62
FEP 100	D 57/55
PFA 9705	D 55/53
Tedlar 20	D 72/69
Viton AHV	A 54/46
Resin 81 (Kel-F 6060)	D 77/74
Kel F 800	D 51/38
Sylgard 184	A 35/35
Q3-6527	Gel
RTV 615	A 28/28
Udel 1700	D 83/82
Lexan 123-111	D 77/76
CR-39	D 88/86
C-4	D 69/68
Tenite 479	D 70/68
Plexiglas DR-61K	D 79/76
Plexiglas V-811	D 88/86

TABLE 18

Hardness - ASTM D-2240

Shore Readings at 1 Second and 15 Seconds

Materials Aged for 30 Days

Resin	Control, No Exposure	Aged - 30 Days				
		Air Oven		RS-4 Sunlamp		Weather-Ometer
		55°C	100°C	55°C	100°C	
Kynar 460	D 75/73	D 71/70	D 74/75	D 69/68	D 77/71	D 72/70
Halar 500	D 72/70	D 70/65	D 70/68	D 69/67	D 67/66	D 71/70
Tefzel 280	D 62/62	D 67/65	D 67/65	D 64/63	D 65/63	D 67/67
FEP 100	D 57/55	D 55/51	D 52/49	D 56/54	D 52/51	D 53/50
PFA 9705	D 55/53	D 53/51	D 52/50	D 53/52	D 50/5[illegible]	D 52/51
Tedlar 20	D 72/69	D 73/72	D 76/76	D 76/76	D 78/77	D 75/75
Viton AHV	A 54/46	D 56/53	A 58/57	A 57/55	A 56/54	A 56/55
Resin 81 (Kel-F 6060)	D 77/74	D 74/72	D 76/75	D 75/72	D 58/58	D 74/72
Kel F 800	D 51/38	D 60/57	(a)	D 59/54	(a)	A 59/54
Sylgard 184	A 35/35	A 46/43	A 66/65	A 35/35	D 56/55	A 43/43
Q3-6527	(b)	-	-	-	-	-
RTV 615	A 28/28	A 35/35	A 62/62	A 41/41	D 59/59	A 39/40
Udel 1700	D 83/82	D 78/77	D 79/7[illegible]	D 75/74	D 72/72	D 76/75
Lexan 123-111	D 77/76	D 80/79	D 80/79	D 80/79	D 76/75	D 77/77
CR-39	D 88/86	D 87/87	D 87/86	D 84/84	D 68/68	D 86/85
C-4	D 69/68	D 77/75	D 79/78	D 76/75	D 75/75	D 78/78
Tenite 479	D 70/68	D 68/65	D 74/66	D 68/66	(a)	D 68/65
Plexiglas DR-61K	D 79/76	D 80/77	D 80/78	D 59/58	D 80/80	D 78/75
Plexiglas V-811	D 88/86	D 55/54	D 63/62	D 76/75	D 72/71	D 73/73

(a) Flowed/Deformed - no test

(b) Gel - no measurable surface hardness

TABLE 19

Hardness

ASTM D-2240 - Shore A and D
Readings at 1 Second and 15 Seconds
Materials Aged for 60 Days

Resin	Control, No Exposure	Aged - 60 Days				
		Air Oven		RS-4 Sunlamp		Weather-Ometer
		55°C	100°C	55°C	100°C	
Kynar 460	D 75/73	D 63/62	D 66/65	D 65/64	D 68/67	D 61/61
Halar 500	D 72/70	D 59/58	D 57/56	D 53/52	D 59/59	D 62/61
Tefzel 280	D 62/62	D 54/53	D 58/57	D 53/53	(1)	D 57/57
FEP 100	D 57/55	D 51/50	D 47/47	D 46/46	D 40/40	D 46/45
PFA 9705	D 55/53	D 43/43	D 38/37	D 45/44	D 40/39	D 49/48
Tedlar 20	D 72/69	D 65/64	D 65/65	D 67/67	(1)	D 62/62
Viton AHV	A 54/46	A 57/56	A 57/56	A 54/53	A 52/51	A 58/58
Resin 81 (Kel-F 6060)	D 77/74	D 61/60	D 61/60	D 64/63	D 64/63	D 61/61
Kel-F 800	D 51/38	D 49/45	(2)	D 43/42	(2)	D 50/48
Sylgard 184	A 35/35	A 58/57	A 69/69	A 61/60	A 66/65	A 64/64
Q3-6527	(3)	-	-	-	-	-
RTV 615	A 28/28	A 56/56	A 63/63	A 56/56	A 65/65	A 61/61
Udel 1700	D 83/82	D 69/68	D 68/67	D 66/66	D 68/68	D 68/68
Lexan 123-111	D 77/76	D 66/66	D 69/69	D 71/71	D 68/68	D 66/65
C-4	D 67/66	D 67/66	D 67/66	D 67/66	(1)	D 64/64
Tenite 479	D 70/68	D 56/54	D 65/64	D 52/52	(2)	D 57/56
CR-39	D 88/86	D 68/67	D 45/45	D 68/67	D 38/38	D 52/51
Plexiglas DR-61K	D 79/76	D 65/63	D 65/63	D 73/72	D 66/64	D 64/63
Plexiglas V-811	D 88/86	D 76/75	D 69/67	D 76/75	(1)	D 73/72

(1) Too brittle to test, degraded
(2) Flowed/Deformed, no test
(3) Gel - no measurable surface hardness

TABLE 20

Hardness - ASTM D-2240
Shore A and D Readings at 1 Second and 15 Seconds

Materials Aged for 120 Days

Resin	Aged 120 Days				
	Weather-Ometer	Air Oven		RS-4 Sunlamp	
		55°C	100°C	55°C	100°C
Kynar 460	D 69/67	D 64/63	D 65/64	D 67/66	D 62/61
Halar 500	D 55/53	D 60/59	D 62/60	D 59/58	D 68/66
Tefzel 280	D 61/60	D 51/51	D 59/57	D 56/55	(1)
FEP 100	D 51/49	D 49/47	D 49/48	D 50/47	D 43/41
PFA 9705	D 50/49	D 45/44	D 48/46	D 52/51	D 38/37
Tedlar 20	D 74/73	D 64/64	D 70/70	D 68/68	(1)
Viton AHV	A 56/56	A 55/54	A 58/58	A 58/57	A 53/53
Resin 81 (Kel-F 6060)	D 66/63	D 61/60	D 68/66	D 67/64	
Kel-F 800	D 56/51	D 48/46	(2)	D 45/42	(2)
Sylgard 184	A 64/64	A 65/65	A 68/68	A 70/70	A 71/71
Q3-6527	(3)				
RTV 615	A 58/58	A 57/57	A 56/56	A 64/64	A 71/71
Udel 1700	D 71/71	D 71/71	D 71/70	D 71/70	D 69/69
Lexan 123-111	D 69/68	D 68/67	D 71/71	D 73/72	D 53/53
C-4	D 71/70	D 74/72	D 71/70	D 76/74	(1)
Tenite 479	D 61/59	D 58/56	(2)	(1)	(2)
CR-39	D 71/70	D 75/74	D 61/60	D 77/75	
Plexiglas DR-61K	D 66/64	D 67/65	D 71/69	D 78/75	(1)
Plexiglas V-811	D 76/75	D 77/76	D 72/71		

(1) Too brittle to test, degraded
(2) Flowed/Deformed; no test
(3) Gel - no measurable surface hardness

TABLE 21

Hardness - ASTM D-2240

Shore A and D Readings at 1 Second and 15 Seconds

Materials Aged for 240 Days

Resin	Aged 240 Days				
	Weather-Ometer	Air Oven		RS-4 Sunlamp	
		55°C	100°C	55°C	100°C
Kynar 460	Discontinued				
Halar 500	D 64/63	D 59/57	D 63/61	D 58/56	D 68/67
Tefzel 280	Discontinued				
FEP 100	D 49/47	D 50/47	D 47/46	D 51/49	D 50/48
PFA 9705	50/48	D 49/47	D 49/47	D 47/46	D 50/48
Tedlar 20	D 72/72	D 70/70	D 67/66	D 71/70	(1)
Viton AHV	A 56/54	A 60/59	A 60/58	A 57/57	A 56/54
Resin 81 (Kel-F 6060)	D 65/63	D 64/62	D 65/63	D 66/63	D 62/60
Kel-F 800	Discontinued				
Sylgard 184	A 68/68	A 60/60	A 65/65	A 63/63	A 74/74
Q3-6527	(3)	Gel - Not Tested			
RTV 615	A 59/59	A 60/59	A 58/58	A 58/58	A 66/66
Udel 1700	Discontinued				
Lexan 123-111	Discontinued				
C-4	D 75/74	D 69/67	D 75/74	D 65/64	(1)
Tenite 479	(2)	D 59/57	(1)	(1)	(2)
CR-39	Discontinued				
Plexiglas DR-61K	D 69/67	D 67/65	D 69/67	D 80/78	(2)
Plexiglas V-811	D 73/70	D 73/71	D 74/72	Brittle	(1)

(1) Too brittle to test; degraded.

(2) Flowed/Deformed; no test.

(3) Gel - no measurable surface hardness

TABLE 22

Elongation at Break Versus Accelerated Aging Conditions

Exposure: 30, 60, 120, and 240 Days

Resin	Control (Unaged) (%)	Average Change - Percent of Control Value Retained																			
		Weather-Ometer, 55°C				Air Oven, 55°C				Air Oven, 100°C				RS-4 Sunlamp, 55°C				RS-4 Sunlamp, 100°C			
		30	60	120	240	30	60	120	240	30	60	120	240	30	60	120	240	30	60	120	240
Kynar 460	50	370	340	300	NT	200	120	330	NT	100	60	70	NT	340	340	260	NT	50	60	60	NT
Halar 500	175	117	122	135	145	144	148	131	137	134	117	151	129	131	131	131	133	125	151	94	2
Tefzel 280	200	131	155	122	NT	116	125	105	NT	144	115	122	NT	120	127	145	NT	12	(a)	(a)	NT
FEP 100	220	129	113	147	142	113	145	108	140	141	129	129	104	131	140	129	120	150	134	134	144
PFA 9705	150	153	176	100	159	193	186	216	193	163	210	176	212	180	153	143	178	183	216	180	200
Tedlar 20	120	146	145	100	143	154	154	146	142	146	158	146	143	158	150	141	74	12	(a)	(a)	(a)
Viton AHV	2430	>131	121	>123	93	>121	~100	88	86	~100	66	56	57	~107	108	74	79	88	789	61	96
Resin 81 (Kel-F 6060)	130	146	123	130	127	126	115	135	131	96	115	131	116	120	134	134	118	124	100	42	35
Kel-F 800	200	13	40	34	NT	35	65	30	NT	(b)	(b)	(b)	NT	30	30	26	NT	(b)	(b)	(b)	NT
Sylgard 184	106	87	89	89	83	108	100	75	47	122	84	80	82	141	80	94	82	61	47	56	NT
Q3-6527	-	Gel - No Measurable Elongation																			
RTV 615	123	123	146	130	108	142	122	126	112	93	93	89	79.7	154	113	123	317	81	48	53	77
Udel 1700	16	25	25	6	NT	125	250	125	NT	62	125	62	NT	56	50	50	NT	37	37	25	NT
Lexan 123-111	104	31	11	21	NT	.25	62	96	NT	29	10	11	NT	115	11	16	NT	12	7	6	NT
C-4	49	173	16	61	43	183	[illegible]	204	141	114	102	112	92	82	51	32	29	2	(a)	(a)	(a)
Tenite 479	81	106	36	(a)	(b)	111	86	105	106	74	68	(a)	(a)	86	2	(a)	(a)	(b)	(b)	(a)	(b)
CR-39	4	100	100	37	NT	100	100	100	NT	25	25	25	NT	100	150	125	NT	50	50	50	NT
Plexiglas DR-61K	17	247	117	59	23	352	205	235	235	176	176	147	135	176	47	29	6	47	(a)	(a)	(b)
Plexiglas V-8	5	40	80	60	60	60	80	60	20	60	60	60	20	40	40	(a)	30	20	(a)	(a)	(a)

NT = Not tested (discontinued) (a) Broken/Degraded (b) Melted/Flowed

TABLE 23

Tensile Modulus Versus Accelerated Aging Conditions

Exposure: 30, 60, 120, and 240 Days

Resin	Control (Unaged) (x 10^5 psi)[(a)]	Average Change - Percent of Control Value Retained																			
		Weather-Ometer, 55°C				Air Oven, 55°C				Air Oven, 100°C				RS-4 Sunlamp, 55°C				RS-4 Sunlamp, 100°C			
		30	60	120	240	30	60	120	240	30	60	120	240	30	60	120	240	30	60	120	240
Kynar 460	1.99	107	123	133	NT	111	118	120	NT	113	120	128	NT	107	118	140	NT	117	119	109	NT
Halar 500	2.23	94	103	113	101	98	113	105	97	101	101	113	100	101	[illegible]	[illegible]	100	93	104	108	215
Tefzel 280	1.80	98	98	105	NT	127	123	96	NT	94	101	116	NT	98	115	122	NT	103	(b)	(b)	NT
FEP 100	0.704	100	149	127	105	104	104	100	94	145	115	113	117	110	112	123	[illegible]	142	48	120	119
PFA 9705	0.532	143	130	132	99	128	134	134	118	246	142	146	130	122	152	160	115	138	137	151	122
Tedlar 20	3.60	61	68	63	56	55	55	61	59	57	65	54	63	62	61	62	62	(b)	(b)	(b)	(b)
Viton AHV	(103 psi)	118	93	200	90	92	109	201	100	108	87	182	101	74	88	188	82	[illegible]	91	146	67
Resin 81 (Kel-F 6060)	1.72	113	113	138	116	119	126	121	105	116	122	121	NT	103	111	134	108	118	124	134	130
Kel-F 800	0.232	381	452	974	NT	279	512	461	NT	(c)	(c)	(c)	NT	668	452	629	NT	(c)	(c)	(c)	NT
Sylgard 184	(586 psi)	[illegible]	108	107	60	128	75	111	41	129	17	105	167	53	107	113	71	98	44	46	(b)
Q3-6527	-	Gel - Modulus Too Low To Be Tested																			
RTV 615	(389 psi)	71	76	56	91	41	57	54	70	71	117	[illegible]	129	[illegible]	87	98	89	132	129	49	108
Udel 1700	3.33	81	102	157	NT	101	109	115	NT	109	118	108	NT	109	109	122	NT	121	108	116	NT
Lexan 123-111	3.14	123	106	112	NT	110	111	116	NT	106	112	116	NT	109	114	122	NT	105	119	102	NT
C-4	1.67	71	138	143	146	125	142	133	129	126	144	134	123	169	144	151	144	133	(b)	(c)	(c)
Tenite 479	1.54	129	116	(b)	(b)	113	114	126	109	134	135	(c)	(c)	104	113	(b)	(b)	(c)	(c)	(c)	(c)
CR-39	2.67	119	120	143	NT	78	115	128	NT	116	75	55	NT	124	93	141	NT	113	123	119	NT
Plexiglas DR-61K	2.20	102	111	116	112	109	110	112	108	105	107	102	103	112	108	121	95	110	(b)	(b)	(b)
Plexiglas V-811	4.18	111	115	102	109	108	111	104	100	104	106	105	98	109	115	109	78	104	(b)	(b)	(b)

NT = Not Tested (discontinued)

(a) Modulus x 10^5 psi except where otherwise indicated.

(b) Broken/Degraded

(c) Melted/Flowed

TABLE 24

Tensile Strength at Break Versus Accelerated Aging Conditions

Exposure: 30, 60, 120, and 240 Days

Resin	Control (Unaged) (psi)	Average Change - Percent of Control Value Retained																			
		Weather-Ometer, 55°C				Air Oven, 55°C				Air Oven, 100°C				RS-4 Sunlamp, 55°C				RS-4 Sunlamp, 100°C			
		30	60	120	240	30	60	120	240	30	60	120	240	30	60	120	240	30	60	120	240
Kynar 460	4750	110	114	110	NT	104	103	114	NT	104	[illegible]	105	NT	112	116	126	NT	122	84	130	NT
Halar 500	6090	111	99	111	113	112	120	115	113	105	99	125	108	97	105	104	109	95	97	70	61
Tefzel 280	5380	118	124	110	NT	106	104	102	NT	115	107	119	NT	109	113	127	NT	86	(a)	(a)	NT
FEP	2800	90	101	107	96	93	109	81	106	102	102	95	103	98	105	109	89	109	105	101	110
PFA 9705	2980	99	100	89	96	111	112	130	112	94	131	111	128	71	95	95	102	116	132	107	121
Tedlar 20	12,100	91	[illegible]	214	84	87	98	85	95	88	102	90	87	92	85	78	59	20	(a)	(a)	(a)
Viton AHV	39.5	(c)	(c)	(c)	235	(c)	174	615	104	3334	1650	(d)	252	95	69	918	232	164	673	1711	268
Resin 81 (Kel-F 6060)	5680	102	91	97	96	97	110	104	98	86	95	96	96	97	95	98	101	96	93	91	91
Kel-F 800	1920	64	80	66	NT	83	93	68	NT	(b)	(b)	(b)	NT	87	82	106	NT	(b)	(b)	(b)	NT
Sylgard 184	930	46	62	60	50	97	56	49	16	119	49	56	69	89	57	71	60	40	32	51	NT
Q3-6527		Gel - No Measurable Tensile Strength																			
RTV 615	520	88	124	98	108	81	102	94	91	67	113	132	91	117	105	143	120	35	58	64	103
Udel 1700	7860	101	67	44	NT	94	88	102	NT	102	104	101	NT	101	106	125	NT	128	120	94	NT
Lexan 123-111	[illegible]160	91	88	88	NT	103	98	102	NT	96	124	106	NT	99	97	92	NT	117	122	103	NT
C-4	5570	103	104	92	91	102	104	109	99	98	100	99	98	92	90	89	58	13	(a)	(a)	(a)
Tenite 479	4400	62	73	(b)	(b)	93	87	105	94	127	130	(b)	(a)	86	53	(b)	(a)	(b)	(b)	(b)	(b)
CR-39	4940	114	107	82	NT	115	116	86	NT	21	19	17	NT	124	111	92	NT	78	52	58	NT
Plexiglas DR-61K	5380	100	98	100	60	103	98	101	102	101	103	100	105	107	104	84	28	92	(a)	(a)	(b)
Plexiglas V-811	9030	57	83	68	80	101	93	93	92	92	86	85	86	88	67	67	33	35	(a)	(a)	(a)

NT = Not tested (discontinued)
(a) Broken/Degraded
(b) Melted/Flowed
(c) No break; elongation exceeds machine capacity.

TABLE 25

Baseline Mechanical Properties

Controls - Unaged

Test Specification ASTM D-1708

Apparatus: Instron TM with Extensometer, 200:1

Material	Yield Strength (psi)	Modulus ($x 10^5$ psi)	Elongation at Break (%)	Tensile Strength at Break (psi)
Kynar 460	6810	1.99	50	4750
Halar 500	5030	2.23	175	6090
Tefzel 280	4270 (a)	1.80	200	5380
FEP 100	2130 (a)	0.704	220	2800
PFA 9705	2000 (a)	0.532	150	2980
Tedlar 20	5820 (a)	3.60	120	12,100
Viton AHV	340	103 psi(200%)(c)	2430	39.5
Resin 81 (Kel-F 6060)	5690	1.72	130	5680
Kel-F 800	1260	0.232	200	1920
Sylgard 184	(b)	586 psi(100%)(c)	106	930
Q3-6527	Gel - Requires special testing			
RTV 615	(b)	389 psi(100%)(c)	123	520
Udel 1700	10,000	3.33	16	7860
Lexan 123-111	8500	3.14	104	8160
C-4	5320	1.67	49	5570
Tenite 479	3470	1.54	81	4400
CR-39	(b)	2.67	4	4940
Plexiglas DR-61K	5630	2.20	17	5380
Plexiglas V-811	9030	4.18	5	9030

(a) Pseudo yield point; approximation

(b) No observable yield point

(c) Apparent Modulus -- at indicated elongation

TABLE 26

Mechanical Properties
Test Conditions: Weather-Ometer - 55°C - 30 Days

Test Specification ASTM D-1708
Apparatus: Instron TM with Extensometer, 200:1

Material	Yield Strength (psi)	Modulus (x 10^5 psi)	Elongation at Break %	Tensile Strength at Break (psi)
Kynar 460	6970	2.14	185	5260
Halar 500	5030	2.10	205	6760
Tefzel 280	4530 (a)	1.77	263	6370
FEP 100	2030 (a)	0.707	285	2520
PFA 9705	1940 (a)	0.762	230	2960
Tedlar 20	5860 (a)	2.22	175	11,050
Viton AHV	480	122 psi(200%)(c)	>3,200	no break
Resin 81 (Kel-F 6060)	5600	1.95	190	5,795
Kel-F 800	2370	0.884	26	1240
Sylgard 184	(b)	462 psi(93%)(c)	93	430
Q3-6527	Gel - Requires special testing			
RTV 615	(b)	277 psi(100%)(c)	152	460
Udel 1700	(b)	3.41	4	8000
Lexan 123-111	8920	3.88	32	7450
C-4	5480	2.43	85	5770
Tenite 479	3770	1.99	86	2760
CR-39	(b)	3.19	4	5630
Plexiglas DR-61K	5600	2.25	42	5410
Plexiglas V-811	(b)	4.66	2	5170

(a) Pseudo yield point; approximation
(b) No observable yield point
(c) Apparent Modulus -- at indicated elongation

TABLE 27

Mechanical Properties
Test Conditions: Air Oven - 55^{o}C - 30 Days

Test Specification ASTM D-1708
Apparatus: Instron TM with Extensometer, 200:1

Material	Yield Strength (psi)	Modulus (x 10^5 psi)	Elongation at Break (%)	Tensile Strength at Break (psi)
Kynar 460	7410	2.21	100	4940
Halar 500	5037	2.18	253	6840
Tefzel 280	4220 (a)	2.29	232	5740
FEP 100	2080 (a)	0.733	250	2600
PFA 9705	1760 (a)	0.68	290	3320
Tedlar 20	5540 (a)	1.98	185	10,600
Viton AHV	314	94.5 psi(200%)(c)	>2,950	no break
Resin 81 (Kel-F 6060)	5800	2.05	165	5520
Kel-F 800	2420	0.649	70	1600
Sylgard 184	(b)	753 psi(100%)(c)	115	903
Q3-6527	Gel - Requires special testing			
RTV 615	(b)	160 psi(100%)(c)	175	424
Udel 1700	9890	3.35	20	7370
Lexan 123-111	9030	3.45	130	8410
C-4	5380	2.09	90	5680
Tenite 479	3730	1.74	90	4110
CR-39	5380	2.09	4	5680
Plexiglas DR-61K	5790	2.41	60	5560
Plexiglas V-811	(b)	4.50	3	9130

(a) Pseudo yield point; approximation
(b) No observable yield point
(c) Apparent Modulus -- at indicated elongation

TABLE 28

Mechanical Properties
Test Conditions: Air Oven - 100°C - 30 Days

Test Specification ASTM D-1708
Apparatus: Instron TM with Extensometer, 200:1

Material	Yield Strength (psi)	Modulus ($\times 10^5$ psi)	Elongation at Break (%)	Tensile Strength at Break (psi)
Kynar 460	7240	2.25	50	4940
Halar 500	4720	2.25	235	6400
Tefzel 280	4270 (a)	1.70	288	6180
FEP 100	2080 (a)	1.02	310	2860
PFA 9705	1572	1.31	245	2813
Tedlar 20	5420 (a)	2.07	175	10,700
Viton AHV	557	112 psi (200%)(c)	>2,440	1317
Resin 81 (Kel-F 6060)	5240	1.99	125	4900
Kel-F 800	Flowed - no test			
Sylgard 184	(b)	758 psi (100%)(c)	130	1110
Q3-6527	Gel - Requires special testing			
RTV 615	(b)	248 psi (100%)(c)	115	348
Udel 1700	10,800	3.65	10	7990
Lexan 123-111	[illegible],400	3.32	30	7830
C-4	5920	2.11	55	5450
Tenite 479	5420	2.06	60	5590
CR-39	(b)	3.10	1	1050
Plexiglas DR-61K	5600	2.32	30	5420
Plexiglas V-811	(b)	4.35	3	8330

(a) Pseudo yield point; approximation
(b) No observable yield point
(c) Apparent Modulus -- at indicated elongation

TABLE 29

Mechanical Properties
Test Conditions: RS-4 - $55^{o}C$ - 30 Days

Test Specification ASTM D-1708
Apparatus: Instron TM with Extensometer, 200:1

Material	Yield Strength (psi)	Modulus ($\times 10^5$ psi)	Elongation at Break (%)	Tensile Strength at Break (psi)
Kynar 460	7130	2.13	170	5310
Halar 500	5170	2.26	230	5920
Tefzel 280	4740 (a)	1.76	240	5900
FEP 100	2100 (a)	0.774	290	2750
PFA 9705	1850 (a)	0.650	270	2110
Tedlar 20	5850 (a)	2.23	190	11,130
Viton AHV	350	76 psi(200%)(c)	>2,610	37.6
Resin 81 (Kel-F 6060)	5660	1.77	157	5500
Kel-F 800	2680	1.55	60	1680
Sylgard 184	(b)	311 psi(100%)(c)	150	832
Q3-6527	Gel - Requires special testing			
RTV 615	(b)	202 psi(100%)(c)	190	610
Udel 1700	7510	3.62	9	7937
Lexan 123-111	9460	3.44	120	8070
C-4	5600	2.83	40	5150
Tenite 479	3560	1.60	70	3780
CR-39	(b)	3.31	4	6120
Plexiglas DR-61K	6090	2.47	30	5760
Plexiglas V-811	(b)	4.57	2	7960

(a) Pseudo yield point; approximation
(b) No observable yield point
(c) Apparent Modulus -- at indicated elongation

TABLE 30

Mechanical Properties
Test Conditions: RS-4, - 100°C - 30 days

Test Specification ASTM D-1708
Apparatus: Instron TM with Extensometer, 200:1

Material	Yield Strength (psi)	Modulus (x 10^5 psi)	Elongation at Break (%)	Tensile Strength at Break (psi)
Kynar 460	7170	2.34	25	5800
Halar 500	4990	2.07	220	5780
Tefzel 380	4820 (a)	1.85	25	4650
FEP 100	2160 (a)	1.00	330	3060
PFA 9705	1950 (a)	0.737	275	3460
Tedlar 20	(b)	Broken	15	2380
Viton AHV	460	83.5 psi(200%)(c)	2160	65
Resin 81 (Kel-F 6060)	6010	2.03	162	5440
Kel-F 800	Flowed - no test			
Sylgard 184	(b)	575 psi(65%)(c)	65	374
Q3-6527	Gel - Requires special Testing			
RTV 615	(b)	514 psi(100%)(c)	100	494
Udel 1700	(b)	4.02	6	10,100
Lexan 123-111	10,600	3.31	12	9550
C-4	(b)	2.22 psi(200%)(c)	< 1	727
Tenite 479	Flowed - no test			
CR-39	(b)	3.02	2	3880
Plexiglas DR-61K	5800	2.42	8	4960
Plexiglas V-811	(b)	4.37	1	3180

(a) Pseudo yield point; approximation
(b) No observable yield point
(c) Apparent Modulus -- at indicated elongation

TABLE 31

Mechanical Properties
Test Conditions: Weather-Ometer - 55°C - 60 Days

Test Specification ASTM D-1708
Apparatus: Instron TM with Extensometer, 200:1

Material	Yield Strength (psi)	Modulus (x 10^5 psi)	Elongation at Break (%)	Tensile Strength at Break (psi)
Kynar 460	7210	2.45	170	5460
Halar 500	4960	2.29	215	6060
Tefzel 280	4230 (a)	1.77	310	6660
FEP 100	2020 (a)	1.05	250	2340
PFA 9705	1850 (a)	0.691	265	2980
Tedlar 20	5710 (a)	2.48	175	10,500
Viton AHV	433	96 psi (200%)[c]	>2950	no break
Resin 81 (Kel-F 6060)	5490	1.95	1[illegible]0	5200
Kel-F 800	2610	1.05	80	1540
Sylgard 184	(b)	638psi(100%)[c]	95	576
Q3-6527	Gel - Requires special testing			
RTV 615	(b)	295 psi (100)[c]	180	647
Udel 1700	(b)	3.40	4	5300
Lexan 123-111	8680	3.33	12	7160
C-4	5620	2.31	80	5800
Tenite 479)	3770	1.79	25	3200
CR-39	(b)	3.22	4	5315
Plexiglas DR-61K	5710	2.45	20	5260
Plexiglas V-811	(b)	4.81	4	7480

(a) Pseudo yield point; approximation
(b) No observable yield point
(c) Apparent Modulus -- at indicated elongation

TABLE 32

Mechanical Properties

Test Conditions: Air Oven - 55°C - 60 Days

Test Specification ASTM D-1708
Apparatus: Instron TM with Extensometer, 200:1

	Yield Strength (psi)	Modulus ($\times 10^5$ psi)	Elongation at Break (%)	Tensile Strength at Break (psi)
Kynar 460	7350	2.36	60	4900
Halar 500	5280	2.53	260	7290
Tefzel 2[illegible]0	4450 (a)	2.21	250	5620
FEP 100	000 (a)	0.730	320	3060
PFA 9705	1880 (a)	0.713	280	3350
Tedlar 20	[illegible]140 (a)	1.97	185	11,900
Viton AHV	415	112 psi (200%)(c)	>2295	68.9
Resin 81 (Kel-F 6060)	6210	2.17	150	6250
Kel-F-800	2450	1.19	130	1790
Sylgard 184	(b)	441 psi (100%)(c)	105	517
Q3-6527	Gel - Requires special testing			
RTV 615	(b)	224 psi (100%)(c)	150	532
Udel 1700	10,400	3.65	40	6910
Lexan 123-111	9460	3.50	6[illegible]	8040
C-4	5680	2.37	80	5790
Tenite 479	3960	1.75	70	3840
CR-39	(b)	3.08	4	5740
Plexiglas DR-61K	5630	2.43	35	5310
Plexiglas V-811	(b)	4.66	4	8420

(a) Pseudo yield point; approximation
(b) No observable yield point
(c) Apparent Modulus -- at indicated elongation

TABLE 33

Mechanical Properties
Test Conditions: Air Oven - 100°C - 60 Days

Test Specification ASTM D-1708
Apparatus: Instron TM with Extensometer, 200:1

Material	Yield Strength (psi)	Modulus ($x 10^5$ psi)	Elongation at Break (%)	Tensile Strength at Break (psi)
Kynar 460	7507	2.23	30	4873
Halar 500	4900	2.26	205	6020
Tefzel 280	4520 (a)	1.83	230	5770
FEP 100	2100 (a)	0.808	285	2360
PFA 9705	2030 (a)	0.757	315	3920
Tedlar 20	6440 (a)	2.36	190	12,300
Viton AHV	761	90 psi (200%)(c)	1605	652
Resin 81 (Kel-F 6060)	5720	2.11	150	5430
Kel-F 800	Flowed - no test			
Sylgard	(b)	101 psi (100%)(c)	90	456
Q3-6527	Gel - Requires special testing			
RTV 615	(b)	458 psi (100%)(c)	115	590
Udel 1700	11,300	3.94	20	8220
Lexan 123-111	10,900	3.53	10	10,177
C-4	6230	2.41	50	5590
Tenite 479	5600	2.08	55	5760
CR-39	(b)	1.99	1	971
Plexiglas DR-61K	5790	2.36	30	5540
Plexiglas V-811	(b)	4.44	3	7810

(a) Pseudo yield point; approximation
(b) No observable yield point
(c) Apparent Modulus -- at indicated elongation

TABLE 34

Mechanical Properties

Test Conditions: RS-4 - 55°C - 60 Days

Test Specification ASTM D-1708

Apparatus: Instron TM with Extensometer, 200:1

Material	Yield Strength (psi)	Modulus (x 10^5 psi)	Elongation at Break (%)	Tensile Strength at Break (psi)
Kynar 460	7320	2.36	170	5500
Halar 500	5060	2.33	230	6390
Tefzel 280	4460 (a)	2.07	255	6070
FEP 100	2080 (a)	0.791	310	2960
PFA 9705	1920 (a)	0.81	230	2850
Tedlar 20	6000 (a)	2.21	180	10,300
Viton AHV	392	91 psi (200%)(c)	> 2640	27.5
Resin 81 (Kel-F 6060)	5380	1.92	175	5420
Kel-F 800	2440	1.05	60	1580
Sylgard 184	(b)	628 psi (85%)(c)	85	534
Q3-6527	Gel - Requires special testing			
RTV 615	(b)	339 psi (100%)(c)	140	549
Udel 1700	10,100	3.63	8	8370
Lexan 123-111	9570	3.60	12	7960
C-4	5720	2.41	25	5000
Tenite 479	(b)	1.75	2	2350
CR-39	(b)	2.49	5	5500
Plexiglas DR-61K	5700	2.38	8	5630
Plexiglas V-811	(b)	4.81	[illegible]	6040

(a) Pseudo yield point; approximation

(b) No observable yield point

(c) Apparent Modulus -- at indicated elongation

TABLE 35

Mechanical Properties
Test Conditions: RS-4 - 100°C - 60 Days

Test Specification ASTM D-1708
Apparatus: Instron TM with Extensometer, 200:1

	Yield Strength (psi)	Modulus ($x\ 10^5$ psi)	Elongation at Break (%)	Tensile Strength at Break (psi)
Kynar 460	7600	2.38	30	4000
Halar 500	5100	2.33	265	5920
Tefzel 280	Broke			
FEP 100	2130 (a)	0.861	295	2950
PFA 9705	2050 (a)	0.730	325	3950
Tedlar 20	Broke			
Viton AHV	532	94 psi (200%) (c)	>2180	266
Resin 81 (Kel-F 6060)	6060	2.14	130	5310
Kel-F 800	Flowed - no test			
Sylgard 184	(b)	257 psi (100%) (c)	50	298
Q3-6527	Gel - Requires special testing			
RTV 615	(b)	502 psi (100%) (c)	60	301
Udel 1700	(b)	3.61	6	9430
Lexan 123-111	9950	3.74	7	9950
C-4	Broke			
Tenite 479	Melted/Degraded			
CR-39	(b)	3.30	2	2560
Plexiglas DR-61K	Degraded			
Plexiglas V-811	Degraded			

(a) Pseudo yield point; approximation
(b) No observable yield point
(c) Apparent Modulus -- at indicated elongation

TABLE 36

Mechanical Properties
Test Conditions: Weather-Ometer - 55°C, 120 Days
Test Specification ASTM D-1708
Apparatus: Instron TM With Extensometer, 200:1

Resin	Yield Strength (psi)	Modulus (x 10^5 psi)	Elongation at Break (%)	Tensile Strength at Break (psi)
Kynar 460	7380	2.65	150	5250
Halar 500	5100	2.53	235	6790
Tefzel 280	4260 (a)	1.89	245	5920
FEP 100	2030 (a)	0.896	325	3000
PFA 9705	1860 (a)	0.704	215	2660
Tedlar 20	6952 (a)	2.20	175	10,300
Viton AHV	560	207 psi (200%) (c)	>3000	no break
Resin 81 (Kel-F 6060)	5780	2.[illegible]7	170	5540
Kel-F 800	2040	2.[illegible]6	68	1280
Sylgard 184	(b)	630 psi (100%) (c)	95	557
Q3-6527	Gel - Requires special testing			
RTV 615	(b)	220 psi (160%) (c)	160	511
Udel 1700	(b)	5.22	1	3440
Lexan 123-111	8950	3.53	22	722[illegible]
C-4	5560	2.40	40	5120
Tenite 479	Melted/Degraded			
CR-39	(b)	3.82	1.5	4040
Plexiglas DR-61K	5690	2.56	10	5400
Plexiglas V-811	(b)	4.26	3	6190

(a) Pseudo yield point; approximation
(b) No observable yield point
(c) Apparent Modulus -- at indicated elongation

TABLE 37

Mechanical Properties
Test Conditions: Air Oven - 55°C, 120 Days
Test Specification ASTM D-1708
Apparatus: Instron TM With Extensometer, 200:1

Resin	Yield Strength (psi)	Modulus (x 10^5 psi)	Elongation at Break (%)	Tensile Strength at Break (psi)
Kynar 460	7790	2.40	165	5410
Halar 500	5480	2.34	230	6990
Tefzel 280	4220 (a)	1.72	210	5480
FEP 100	1860 (a)	0.705	237	2297
PFA 9705	1870 (a)	0.715	325	3890
Tedlar 20	6080 (a)	2.19	175	11,700
Viton AHV	574	209 psi (200%) (c)	2140	243
Resin 81 (Kel-F 6060)	5980	2.09	175	5940
Kel-F 800	2220	1.07	60	1320
Sylgard 184	(b)	650 psi (100%) (c)	80	457
Q3-6527	Gel - Requires special testing			
RTV 615	(b)	211 psi (100%) (c)	155	491
Udel 1700	10,900	3.83	20	8090
Lexan 123-111	9290	3.67	100	8350
C-4	5510	2.23	100	6080
Tenite 479	4280	1.95	85	4610
CR-39	(b)	3.42	4	5750
Plexiglas DR-61K	5800	2.48	40	5430
Plexiglas V-811	(b)	4.35	3	8400

(a) Pseudo yield point; approximation
(b) No observable yield point
(c) Apparent Modulus -- at indicated elongation

TABLE 38

Mechanical Properties
Test Conditions: Air Oven - 100°C, 120 Days
Test Specification ASTM D-1708
Apparatus: Instron TM With Extensometer, 200:1

Resin	Yield Strength (psi)	Modulus ($\times 10^5$ psi)	Elongation at Break (%)	Tensile Strength at Break (psi)
Kynar 460	7150	2.55	35	4980
Halar 500	5360	2.53	265	7660
Tefzel 280	4810 (a)	2.09	245	6420
FEP 100	1990 (a)	0.800	285	2660
PFA 9705	1980 (a)	0.781	265	3310
Tedlar 20	6010 (a)	1.96	175	11,000
Viton AHV	8370	188 psi (200%) (c)	1370	8400
Resin 81 (Kel-F 6060)	5740	2.08	170	5460
Kel-F 800	Flowed - no test			
Sylgard 184	(b)	619 psi (100%) (c)	85	527
Q3-6527	Gel - Requires special testing			
RTV 615	(b)	642 psi (100%) (c)	110	688
Udel 1700	10,300	3.60	10	8720
Lexan 123-111	10,400	3.64	12	8720
C-4	6150	2.25	55	5550
Tenite 479	Melted/Degraded			
CR-39	(b)	1.46	1	868
Plexiglas DR-61K	5630	2.26	25	5370
Plexiglas V-811	(b)	4.42	3	7730

(a) Pseudo yield point; approximation
(b) No observable yield point
(c) Apparent modulus -- at indicated elongation

TABLE 39

Mechanical Properties
Test Conditions: RS-4 - 55°C, 120 Days
Test Specification ASTM D-1708
Apparatus: Instron TM With Extensometer, 200:1

Resin	Yield Strength (psi)	Modulus (x 10^5 psi)	Elongation at Break (%)	Tensile Strength at Break (psi)
Kynar 460	7350	2.80	130	6000
Halar 500	4920	2.37	230	6320
Tefzel 280	4700 (a)	2.19	290	6860
FEP 100	2210 (a)	0.867	285	3050
PFA 9705	2050 (a)	0.855	215	2850
Tedlar 20	6070 (a)	2.22	170	9420
Viton AHV	649	194 psi (200%) (c)	1800	363
Resin 81 (Kel-F 6060)	5760	2.31	175	5610
Kel-F 800	2750	1.46	52	2040
Sylgard 184	(b)	663 psi (100%) (c)	100	663
Q3-6527	Gel - requires special testing			
RTV 615	(b)	388 psi (100%) (c)	152	746
Udel 1700	9950	4.06	8	9850
Lexan 123-111	9570	3.84	17	7540
C-4	5830	2.52	16	5000
Tenite 479	Melted/Degraded			
CR-39	(b)	3.77	5	6880
Plexiglas DR-61K	(b)	2.66	5	4530
Plexiglas V-811	(b)	4.57	2	6040

(a) Pseudo yield point; approximation
(b) No observable yield point
(c) Apparent Modulus -- at indicated elongation

TABLE 40

Mechanical Properties
Test Conditions: RS-4 - 100°C, 120 Days
Test Specification ASTM D-1708
Apparatus: Instron TM With Extensometer, 200:1

Resin	Yield Strength (psi)	Modulus (x 10^5 psi)	Elongation at Break (%)	Tensile Strength at Break (psi)
Kynar 460	7110	2.17	30	6190
Halar 500	5200	2.41	165	4260
Tefzel 280	(e)	(e)	(e)	(e)
FEP 100	2080 (a)	0.85	295	2820
PFA 9705	1990 (a)	0.803	270	3190
Tedlar 20	Broken			
Viton AHV	716	151 psi (200%) (c)	1500	676
Resin 81 (Kel-F 6060)	6220	2.31	55	
Kel-F 800	Flowed -- no test			
Sylgard 184	(b)	272 psi (50%) (c)	60	478
Q3-6527	Gel -- requires special testing			
RTV 615	(b)	192 psi (50%) (c)	65	335
Udel 1700	(b)	3.87	4	7370
Lexan 123-111	8510	3.23	6	8470
C-4	Degraded			
Tenite 479	Degraded			
CR-39	(b)	3.18	2	28.70
Plexiglas DR-61K	Degraded			
Plexiglas V-811	Degraded			

(a) Pseudo yield point; approximation
(b) No observable yield point
(c) Apparant Modulus -- at indicated elongation

TABLE 41

Mechanical Properties

Test Conditions: Weather-Ometer - 55°C, 240 Days
Test Specification ASTM D-1708
Apparatus: Instron TM with Extensometer, 200:1

Resin	Yield Strength (psi)	Modulus (x 10^5 psi)	Elongation at Break (%)	Tensile Strength at Break (psi)
Kynar 460	Discontinued			
Halar 500	5140	2.27	255	6900
Tefzel 280	Discontinued			
FEP 100	1883	0.739	312	2700
PFA 9705	1888 (a)	0.525	238	2855
Tedlar 20	5821 (a)	2.01	172	10,150
Viton AHV	397	93 psi at (c) 200% E	2267	93
Resin 81(Kel-F 6060)	5675	2.0	165	5480
Kel-F 800	Discontinued			
Sylgard 184	(b)	(c) 352 psi at 50% E	88	468
Q3-6527	Gel - Requires Special Testing			
RTV 615	(b)	(c) 355 psi at 100% E	133	560
Udel 1700	Discontinued			
Lexan 123-111	Discontinued			
C-4	5636	2.45	2[illegible]	5064
Tenite 479	Discontinued			
CR-39	Discontinued			
Plexiglas DR-61K	(b)	2.47	4	3208
Plexiglas V-811	(b)	4.57	2	7200

(a) Pseudo yield point; approximation
(b) No observable yield point
(c) Apparent modulus at indicated elongation

TABLE 42

Mechanical Properties

Test Conditions: Air Oven - 55°C, 240 Days
Test Specification ASTM D-1708
Apparatus: Instron TM with Extensometer, 200:1

Resin	Yield Strength (psi)	Modulus (x 10^5 psi)	Elongation at Break (%)	Tensile Strength at Break (psi)
Kynar 460	Discontinued			
Halar 500	5322	2.16	241	6879
Tefzel 380	Discontinued			
FEP 100	2036 (a)	0.66	308	2972
PFA 9705	1889 (a)	0.63	290	3330
Tedlar 20	6038 (a)	2.12	171	11,515
Viton AHV	467	(c) 104 psi at 200% E	2085	41.1
Resin 81(Kel-F 6060)	5658	1.81	170	5588
Kel-F 800	Discontinued			
Sylgard 184	(b)	(c) 241 psi at 50% E	50	148
Q3-6527	Gel - Requires Special Testing			
RTV 615	(b)	(c) 272 psi at 100% E	138	474
Udel 1700	Discontinued			
Lexan 123-111	Discontinued			
C-4	5473	2.16	69	5535
Tenite 479	4069	1.69	86	4155
CR-39	Discontinued			
Plexiglas DR-61K	5943	[illegible] 38	40	5496
Plexiglas V-811	(b)	4.18	1	8309

(a) Pseudo yield point; approximation
(b) No observable yield point
(c) Apparent modulus at indicated elongation

TABLE 43

Mechanical Properties

Test Conditions: Air Oven - 100°C, 240 Days
Test Specification ASTM D-1708
Apparatus: Instron TM with Extensometer, 200:1

Resin	Yield Strength (psi)	Modulus ($x 10^5$ psi)	Elongation at Break (%)	Tensile Strength at Break (psi)
Kynar 460	Discontinued			
Halar 500	4957	2.25	225	6603
Tefzel 380	Discontinued			
FEP 100	2138 (a)	0.83	229	2892
PFA 9705	1980 (a)	0.69	318	3810
Tedlar 20	6303 (a)	2.26	171	10,475
Viton AHV	1074	105 psi at 200% E (c)	1368	998
Resin 81(Kel-F 6060)	5650	1.78	151	5459
Kel-F 800	Discontinued			
Sylgard 184	(b)	397 psi at 50% E (c)	87	643
Q3-6527	Gel - Requires Special Testing			
RTV 615	(b)	505 psi at 100% E (c)	98	475
Udel 1700	Discontinued			
Lexan 123-111	Discontinued			
C-4	6070	2.06	45	5459
Tenite 479	Broken/Degraded			
CR-39	Discontinued			
Plexiglas DR-61K	5953	2.28	23	5661
Plexiglas V-811	(b)	4.11	1	7779

(a) Pseudo yield point; approximation
(b) No observable yield point
(c) Apparent modulus at indicated elongation

TABLE 44

Mechanical Properties

Test Conditions: RS-4 Sunlamp - 55°C, 240 Days
Test Specification ASTM D-1708
Apparatus: Instron TM with Extensometer, 200:1

Resin	Yield Strength (psi)	Modulus (x 10^5 psi)	Elongation at Break (%)	Tensile Strength at Break (psi)
Kynar 460	Discontinued			
Halar 500	5233	2.23	234	6653
Tefzel 380	Discontinued			
FEP 100	2060 (a)	0.71	265	2510
PFA 9705	1892 (a)	0.61	268	3053
Tedlar 20	6108 (a)	2.23	89	7149
Viton AHV	548	85 psi at 200% E (c)	1940	92
Resin 81(Kel-F 6060)	6164	1.87	154	5763
Kel-F 800	Discontinued			
Sylgard 184	(b)	415 psi at 50% E (c)	87	554
Q3-6527	Gel - Requires Special Testing			
RTV 615	(b)	348 psi at 100% E (c)	390	627
Udel 1700	Discontinued			
Lexan 123-111	Discontinued			
C-4	5763	2.4	14	3228
Tenite 479	Broken/Degraded			
CR-39	Discontinued			
Plexiglas DR-61K	(b)	2.09	1	1525
Plexiglas V-811	(b)	3.26	1.5	2961

(a) Pseudo yield point; approximation
(b) No observable yield point
(c) Apparent modulus at indicated elongation

TABLE 45

Mechanical Properties

Test Conditions: RS-4 Sunlamp - 100°C, 240 Days
Test Specification ASTM D-1708
Apparatus: Instron TM with Extensometer, 200:1

Resin	Yield Strength (psi)	Modulus (x 10^5 psi)	Elongation at Break (%)	Tensile Strength at Break (psi)
Kynar 460	Discontinued			
Halar 500	(b)	4.8	3	3730
Tefzel 280	Discontinued			
FEP 100	2070 (a)	0.84	318	3089
PFA 9705	2035 (a)	0.65	301	3608
Tedlar 20	Broken/Degraded			
Viton AHV	244	69 psi at 200% E (c)	2342	106
Resin 81(Kel-F 6060)	6446	2.25	45	5188
Kel-F 800	Discontinued			
Sylgard 184	Degraded			
Q3-6527	Gel - Requires Special Testing			
RTV 615	(b)	421 psi at 50% E (c)	95	540
Udel 1700	Discontinued			
Lexan 123-111	Discontinued			
C-4	Broken/Degraded			
Tenite 479	Melted/Degraded			
CR-39	Discontinued			
Plexiglas DR-61K	Melted/Degraded			
Plexiglas V-811	Broken/Degraded			

(a) Pseudo yield point; approximation
(b) No observable yield point
(c) Apparent modulus at indicated longation

TABLE 46

Mechanical Properties
Test Conditions: RS-4 - 55°C, 30 Days, 70% Humidity
Test Specification ASTM D-1708
Apparatus: Instron TM With Extensometer, 200:1

Resin	Yield Strength (psi)	Modulus ($\times 10^5$ psi)	Elongation at Break (%)	Tensile Strength at Break (psi)
Kynar 460	7680	2.59	25	3950
Halar 500	5490	2.55	210	6210
Tefzel 280	4660 (a)	1.92	265	6710
FEP 100	2260 (a)	0.873	320	3270
PFA 9705	2100 (a)	0.721	275	3450
Tedlar 20	6760 (a)	None	125	7540
Viton AHV	(b)	188 psi at 200%	>3000	No break
Resin 81 (Kel-F 6060)	6080	2.22	85	5450
Kel-F 800	(d)	(d)	(d)	(d)
Sylgard 184	(b)	33.7 psi at 100%	110	134
Q3-6527	Gel - Requires special testing			
RTV 615	(b)	162 psi at 100%	150	427
Udel 1700	(b)	3.48	7	10,700
Lexan 123-111	(b)	3.60	7	10,000
C-4	5730	2.42	15	4990
Tenite 479	(c)	(c)	(c)	(c)
CR-39	(b)	3.40	< 1	1530
Plexiglas DR-61K	(b)	2.42	< 1	1810
Plexiglas V-811	(b)	4.12	2	4770

(a) Pseudo yield point; approximation
(b) No observable yield point
(c) Specimen broke/degraded
(d) Specimen melted/flowed

TABLE 4[illegible]

Mechanical Properti[illegible]

Condition: RS-4 70% RH Temp.: 55°C Time: 90 days

Test Specification ASTM D-1708
Apparatus: Instron TM With Extensometer, 200:1

Resin	Yield Strength (psi)	Modulus ($\times 10^5$ psi)	Elongation at Break (%)	Tensile Strength at Break (psi)	Hardness ASTM-D2240
Kynar 460	7750	2.56	35	4425	D62/60
Halar 500	5320	2.27	230	6260	D67/65
Tefzel 280	-	Discontinued		-	-
FEP 100	2150 (a)	0.892	320	3460	D52/49
FPA 9705	1950 (a)	0.786	280	3150	D51/49
Tedlar 20	-	Broken		-	-
Viton AHV	490	170 psi 100%	>2800	no break	A61/61
Resin 81 (Kel-F 6060)	5680	1.97	150	5180	D69/67
Kel-F 800	-	Melt/Flowed		-	-
Sylgard 184	(b)	57 psi 100%	160	170	A[illegible]4/54
Q3-6527	-	Untestable		-	-
RTV 6[illegible]5	(b)	315 psi 100%	150	670	A60/60
Udel 1700	(b)	3.88	6	9900	D77/76
Lexan 123-111	(b)	3.40	6	9380	D71/70
C-4	5950	2.68	12	4770	D76/75
Tenite 479	-	Melt/Flowed		-	-
CR-39	(b)	3.32	1	1680	D89/88
Plexiglas DR-61K	-	- Broken		-	-
Plexiglas V-811	(b)	3.26	2	5030	D67/65

(a) Pseudoyield Point (b) No observable yield

TABLE 48

Visual and Microscopic Examination

Exposure: 30, 60, 120, and 240 Days

Resin	Weather-Ometer, 55°C				Air Oven, 55°C				Air Oven, 100°C				RS-4 Sunlamp, 55°C				RS-4 Sunlamp, 100°C			
	30	60	120	240	30	60	120	240	30	60	120	240	30	60	120	240	30	60	120	240
Kynar 460	1	1	1	1	1	1	1	1	1	2,5	2,5	2,5	1	1	1	1	2,5	2,5	3	5
Halar 500	1	1	1	1	1	1	1	1	1	1	2	3,10	1	2	2	2	2	2	2	2
Tefzel 280	1	1	1	13	1	1	1	13	1	1	1	13	1	1	1	13	1	2,5	2,5,7	13
FEP 100	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1
PFA 9705	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Tedlar 20	1	1	1	1	1	1	1	1	1	1	2	3,10	1	1	1	1	1	1	7	7
Viston AHV	1	1	1	1	1	1	1	1	1	1	4,10	4,10	1	1	1	1	2	2	2,9	2,9
Resin 81 (Kel-F 6060)	2	2	2	2	1	1	2	2	1	1	2	2	2	2	2	2	2	2	2	2,5
Kel-F 800	1	1	5	13	1	1	1	13	9	9	9	13	1	1	1	13	9	9	9	13
Sylgard 184	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Q36527	1	1	1	2	1	1	1	2	2	2	3	4,7	2	2	2	2	3	3	4	4,7,10
RTV 615	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	7
Udel 1700	3,5	3,5	4,5 10,12	13	1	1	1	13	1	1	1	13	4	4,5	4,5,7 10	13	4,5	4,5	4,5 10	13
Lexan 123-111	2	2	3,10	3,10	1	1	1	1	1	1	1	1	1	2	3,10	3,10	3	4	4,10	4,10
C-4	5	5	5	5	1	1	1	1	1	1	1	1	1	1	1	1	1	1,7	7	7
Tenite 479	1	2	5,6 9	9	1	1	1	2	1	1	3,7 9,10	4,7 9,10	1	1	2,7 10,11	3,7 10,11	4,9	4,9	9	9
CR-39	1	1	1	13	1	1	1	13	3	3,6	4,7,8	13	2,6	3,6	3,8	13	4	4,7	4,6 10	13
Plexiglas DR-61K	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	3	4	4,7 10	9
Plexiglas V-811	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	3	7	7

CODE:
- (1) No observable change
- (2) Very slight color formation
- (3) Noticeable color formation
- (4) Strong color formation
- (5) Haze formation
- (6) Micro fractures (crazing)
- (7) Large fractures (cracks) or voids
- (8) Surface effect (color formation)
- (9) Melted/flowed
- (10) Bulk effect (color formation)
- (11) Specimen decomposed
- (12) Chalking (surface degradation)
- (13) Discontinued

TABLE 49

Fungus Attack According to ASTM G-21
21-Day Exposure

Resin	G-21[a] Rating
Kynar 460	2
Halar 500	2
Tefzel 280	2
FEP 100	1
PFA 9705	2
Tedlar 20	2
Viton AHV	2
Resin 81 (Kel-F 6060)	2
Kel-F 800	2
Sylgard 184	2
Q3-6527	2
RTV 615	4
Udel 1700	3
Lexan 123-111	2
C-4	1
Tenite 479	4
CR-39	2
Plexiglas DR-61K	2
Plexiglas V-811	2

(a) Observed Growth on Specimens:

Observed Growth on Specimens	Rating
None	0
Trace of growth (less than 10%)	1
Light growth (10-30%)	2
Medium growth (30-60%)	3
Heavy growth (60% to complete coverage)	4

TABLE 50

Soil Accumulation Study

Severely Affected Materials

45° South Mounting - Enfield, Connecticut

Reference	Transmittance, Percent (350-800 nm)		
	Viton AHV	Sylgard 184	RTV 615
Control (total transmittance)	83	78	82
Two-month percent of control	86	84	78
Four-month percent of control	83	39	62
Six-month percent of control	80	81	58

TABLE 51

Soil Accumulation Test
6-Month Outdoor Exposure

Resin	Optical Transmission(2)	
	Transmission %	% of Control Value
Kynar 460	48	84
Halar 500	79	97
Tefzel 280	79	112
FEP 100	79	94
PFA 9705	83	95
Tedlar 20	66	73
Viton AHV	67	81
Resin 81 (Kel-F 6060)	79	99
Kel-F 800	88	106
Sylgard 184	63	81
Q3-6527	no test	
RTV 615	47	58
Udel 1700	57	67
Lexan 123-111	86	98
C-4	90	99
Tenite 479	87	96
CR-39	92	100
Plexiglas DR-61K	88	96
Plexiglas V-811	89	97

(a) 350-800 nm integrated transmittance normalized to solar spectrum

TABLE 52

Abrasion Resistance
ASTM Method D673[c]
"Mar Resistance of Plastics"

This method uses a falling stream of 80 mesh silicon carbide grit to abrade the test specimen mounted at 45°. The effects are measured with a Gardner Glossmeter and a Bausch & Lomb 505 visible spectrophotometer.

Material	Glossmeter Readings % Reflectance			Optical Transmission (% Transmittance: 350-800 nm)		
	Grams of Abrasive[c] 200	1000	2000	Control	After Final Abrasion	% of Control
Kynar 460	95	91	80	57	40	70
Halar 500	90	63	53	81	46	56
Tefzel 280	92	86	79	70	48	68
FEP 100	87	79	72	84	52	61
PFA 9705	82	74	72	87	73	83
Tedlar 20	94	89	75	90	70	77
Viton AHV	(a)	(a)	(a)	83	(a)	(a)
Resin 81 (Kel-F 606[illegible])	84	66	44	80	68	85
Kel-F 800	76	51	44	83	70	84
Sylgard 184	(a)	(a)	(a)	78	(a)	(a)
Q3-6527	(b)	(b)	(b)	(b)	(b)	(b)
RTV 615	(a)	(a)	(a)	82	(a)	(a)
Udel 1700	68	54	43	85	57	67
Lexan 12[illegible] 111	84	61	52	88	75	85
C-4	90	79	71	91	74	81
Tenite 479	79	63	52	91	67	73
CR-39	93	84	79	92	90	97
Plexiglas DL-61K	90	72	62	90	64	71
Plexiglas V-811	94	7[illegible]	64	92	87	94

(a) Abrasive grit adheres to surface; no measurement
(b) Gel - not amenable to testing; no resistance
(c) Eighty-mesh silicon carbide grit

TABLE 53

Refractive Index

(Based on Sodium D Line)

Glass Transition Temperature (Tg)

Resin	n_d^{20}	Tg (^oC)	Reference
Kynar 460	1.42	- 39	(a)
Halar 500	1.447	- 64	(b)
Tefzel 280	1.40	- 51	(b)
FEP 100	1.34	+ 90	(c)
PFA 9705	1.35	+ 85	(c)
Tedlar 20	1.46	- 20	(a)
Viton AHV	1.370	- 14	(b)
Resin 81 (Kel-F 6060)	1.435	+ 52	(a)
Kei-F 800	1.435	- 10	(c)
Sylgard 184	1.43	-123	(a)
Q3-6527	1.435	-123	(a)
RTV 615	1.43	-123	(a)
Udel 1700	1.63	+190	(c)
Lexan 123-111	1.586	+150	(c)
C-4	1.46	+125	(c)
Tenite 479	1.48	+138	(a)
CR-39	1.50	+130	(c)
Plexiglas DR-61K	1.54	+100	(c)
Plexiglas V-811	1.50	+114	(a)

(a) Physical Constants of Linear Homopolymers - O. Griffin Lewis Springer-Verlag New York Inc. C 1968

(b) Calculated from individual monomer Tg values

(c) Supplier's information

TABLE 54

Miscellaneous Tests - Unaged Specimens

Resin	Brittleness Temperature ASTM D-746	Tensile Impact (ft-lb/in.^{2}) ASTM D-1822	Insulation Resistance (ohms x 10^{12}) ASTM D-257	Permeability, (g-mil/100 in.^{2} x 24 hr) ASTM E-96	Flammability	
					Avg. Burning Rate (in./min.)	ASTM Method
Kynar 460	-3	41	NT (a)	0.235	NT	-
Halar 500	< -76 (b)	258	261.5	0.102	0.26	D-635
Tefzel 280	< -76 (b)	439	NT	0.469	NT	-
FEP 100	-65	354	135.9	0.038	0.25	D-635
PFA 9705	< -76 (b)	295	103.2	0.018	0.29	D-635
Tedlar 20	< -76 (b)	259	200.0	0.308	13.1	D-568
Viton AHV	-45	299	12.9	0.720	Fuses - Nonburning	
Resin 81 (Kel-F 6060)	< 16	18	512.5	0.058	0.26	D-635
Kel-F 800	-	73	NT	NT	NT	-
Sylgard 184	< -76 (b)	(c)	875.0	50.598	9.70	D-568
Q3-6527	< -76 (b)	(d)	0.065	NT	NT	-
RTV 615	< -76 (b)	(c)	650.0	51.527	32	D-568
Udel 1700	-65	50	NT	NT	NT	-
Lexan 123-111	< -76 (b)	269	NT	2.535	NT	-
C-4	-70	39		7.537	1.35	D-635
Tenite 479	+22	35	9.1	34.489	0.96	D-635
CR-39	-	4	NT	NT	NT	-
Plexiglas DR-61K	+20	7	18.4	3.721	0.79	D-635
Plexiglas V-811	+25	19	81.5	1.428	1.27	D-635

(a) NT = Not Tested (b) Material embrittles below -76°C (methanol-dry ice bath)
(c) Jaw failures - broke while clamping (d) Not amenable to impact testing - gel

TABLE 55

Thermal Conductivity

ASTM D-2214

Resin	K_7 [a]
Kynar 460	0.65
Halar 500	0.57
Tefzel 280	0.63
FEP 100	0.74
PFA 9705	0.73
Tedlar 20	0.96
Viton AHV	0.40
Resin 81 (Kel-F 6060)	0.53
Kel-F 800	0.67
Sylgard 184	0.41
Q3-6527	0.13
RTV 615	0.75
Udel 1700	0.51
Lexan 123-111	0.87
C-4	0.33
Tenite 479	0.71
CR-39	0.36
Plexiglas DR-61K	0.75
Plexiglas V-811	0.47

(a) Thermal Conductivity; measured 7 minutes into test. BTU-Ft/Ft^2/hr/^oF

TABLE 56

Materials Cost Analysis

Resin	Current Cost $/lb.	Density lb./in.^{3}	Cost Per Volume $/in.^{3}	Cost As Film (5 mil) $/ft.^{2}
Kynar 460	5.50	0.0636	0.3496	0.251
Halar 500	7.90	0.0606	0.4795	0.345
Tefzel 280	8.50	0.0614	0.5221	0.376
FEP 100	16.70	0.0773	0.8503	0.612
PFA 9705	11.00	0.0776	0.8536	0.615
Tedlar 20	5.90	0.0531	0.3134	0.168[a]
Vilton AHV	11.00	0.0657	0.7234	0.521
Resin 91 (Kel-F 6060)	22.50	0.0773	1.7399	1.253
Kel-F 800	22.00	0.0668	1.4704	1.058
Sylgard 184	9.02	0.0379	0.3422	0.246
Q3-6527	3.75	0.0350	0.1314	0.095
RTV 615	8.84	0.0368	0.3257	0.234
Udel 1700	2.95	0.0448	0.1322	0.095
Lexan 123-111	1.14	0.0433	0.04941	0.035
C-4	Not Available			
Tenite 479	0.91	0.0430	0.0391	0.028
CR-39	1.50	0.0477	0.0715	0.051
Plexiglas DR-61K	0.83	0.0415	0.0344	0.025
Plexiglas V-811	0.56	0.0430	0.0240	0.017
Polyvinyl Butyral (PVB)	(c)	0.0390	0.1805	0.129
Soda Lime Glass [b]	-	-	-	.30

(a) - 4.0 Mil Film
(b) - 0.08 in Thickness
(c) - Obtained as film - Saflex PT-10.

TABLE 57

Cell Encapsulation
System Costs

Primary Encapsulant Material	Film Cover Material	Primary(a) Encapsulant Cost \$/ft.^{2}	Cover Film Cost \$/ft.^{2}	Total(b) Encapsulation Cost \$/ft.^{2}
Polyester Substrate				
Resin 81		5 mil Coating (c) →	1.253	1.253
Tenite 479	Kynar 460	0.046	0.251	0.297
C-4	Tedlar 20	Not Available	0.168	-
Plexiglas V-811	Halar 500	0.028	0.345	0.373
RTV 615	Halar 500	0.385	0.345	0.73
Sylgard 184	PFA 9705	0.405	0.615	1.02
Viton A-HV	Plexiglas DR-61K	0.856	0.025	0.881
Gel	Plexiglas V-811	0.155	0.017	0.172
Aluminum Substrate				
Tenite 479	FEP 100	0.046	0.612	0.658
C-4	-	5 mil Coating (c) →	Not Available	
PVB	Soda-lime(d) glass	0.213	0.30	0.513
Gel	Soda-lime(d) glass	0.155	0.30	0.455
Nema G10 Substrate				
Sylgard 184	Tedlar 20	0.405	0.168	0.573

(a) Based on 1.184 in.^{3}/ft.^{2} required for close square-packed cells. See text.
(b) Does not include substrate cost.
(c) Only primary encapsulant used.
(d) Thickness of 0.08 inch.

TABLE 58

Trial Adhesive Systems

Adhesive System	Steps
1. Du Pont Cavalon 3100S	Put on thin film of Catalyst 3300S Squeeze out some 3100S adhesive Press films together Permit to cure at room temperature for approximately 5 hours
2. Flame Treatment (Polyester Board)	Use "Burnzomatic Torch" - tip of flame Brush back and forth at approximately 3 inches Continue until slight yellow color appears
3. Monsanto Gelva RA-1159 (35 percent solids)	Coat clean panel, approximately 4 mils (both) Bake for 2 hours at 75°C Laminate/press for 15 minutes at 120°C and 25 psi
4. Rohm & Haas Acryloid B-7 (20 percent solids)	Coat both surfaces, approximately 4 mils Bake for 2 hours at 75°C Laminate/press for 15 minutes at 120°C and 25 psi
5. Hughson Versilok 506	Swab thin layer of Accelerator 4 on both surfaces Brush on layer of VErsilok 506 Press/rub both surfaces together Put in press at room temperature for 5-10 minutes (within 5 minutes) Postcure at room temperature for several hours

...Continued

Table 58 (Continued - 2)

Adhesive Systems	Steps
6. Hughson B1958-46	Prepare adhesive: **Grams** B-1959-46 5.0 RD-2801-65 0.25 Coat both surfaces - approximately 4 mils Air-dry for 10 minutes, oven-dry at 70°C for 5 minutes Press for 5 minutes at 120°C and 25 psi
7. Dow Corning Q36-060	Swab both surfaces with DC Q36-060 Air-dry for 2 hours at 30°C Press/laminate for 15 minutes at 120°C and 25 psi
8. Dow Corning DC 282	Prepare catalyst solution: 10% BPO in toluene Mix 3% catalyst with DC 282 Coat both pieces of material Bake for 5 minutes at 80°C; 8 minutes at 150°C Press 5 minutes at 150°C and 25 psi
9. Hughson Chemlok 607	Swab both sides with Chemlok 607 Air-dry for 15 minutes Press for 15 minutes at 150°C and 25 psi
10. Kenrich Ken-React TSM 2-7	Prepare the following: **Grams** Isopropanol 79.0 TSM 2-7 1.0 MMA 20.0 BPO 0.2 Swab onto both surfaces; laminate Press for 10 minutes at 150°C and 25 psi

...Continued

Table 58 (Continued - 3)

Adhesive Systems	Steps	
11. Epoxy for Gluing Cells	Prepare:	Grams
	Versamid 125	7
	Epon 828	3
	Spread on one surface	
	Laminate/press	
	Cure at 75°C for 1 hour	
12. Fluorocarbon Treatment	Shake can of "Tetra Etch"	
	Swab on liberal quantity	
	Allow to react for:	Seconds
	PFA	20
	Kynar	60
	Halar	60
	Wash: acetone, water, acetone	
13. Epoxy for High-Modulus Encapsulants		Grams
	Epon 828	2.5
	HHPA (Hardener)	1.0
	Benzyl dimethyl amine	0.023
	DC-21 (leveling additive)	0.14
	Sandostab P-EPQ (antioxidant)	0.035

TABLE 59

Adhesion Study

ID Number	Resin	Substrate	Adhesive/Primer System (a)		Peel Strength (lb/in.)	
			Resin	Substrate	Dry	Immersed in Water, 1 Week
5204-1	FEP C-20	Cell	9	9	4.4	3.3
5205-2	FEP C-20	Cell	Z6020	-	1.3-1.9	0.4-1.1
5206-3	FEP C-20	Cell	8	8	1.1-3.3	1.5-3.1
5207-4	FEP C-20	Cell	177°C	-	1.25	0
5210-7	FEP C-20	Cell	9	9	0	0
5212-8	FEP C-20	Cell	Z6020	-	0	0
5213-9	FEP C-20	Cell	8	8	2.8-3.6	2.8-3.6
5214-10	FEP C-20	Cell	KR-TTS	KR-TTS	0	0
5215-11	FEP C-20	PSTR	8	8	1.3-3.9	1.7-2.2
5216-12	FEP C-20	PSTR	9	9	3.3-4.4	2.8-3.0
5219-15	FEP 100	PSTR	8	8	1.9-3.5	3.3-4.6
5219-16	Cell	Steel	11	11	-	-
5208-5	DC 184	Cell	9	9	0.13	0
5206-6	DC 184	PLX-DR	7	7	0.66-0.88	1.3
5217-13	DC 184	PSTR	7	7	0	0.44
5217-14	DC 184	PSTR	7	7	~	0.84
5224-21	DC 184	Glass	7	7	~	0.19
5225-22	PLX-DR	PSTR	4	4	0.9	0
5225-23	PLX-DR	PSTR	3	3	6.8-9.0	7.0
5225-24	PLX-DR	PSTR	10	10	0	0
5225-25	PLX-DR	PSTR	5	5	3.5	2.1

(a) Refer to Table 58

...Continued

Table 59 (Continued - 2)

ID Number	Resin	Substrate	Adhesive/Primer System		Peel Strength (lb/in.)	
			Resin	Substrate	Dry	Immersed in Water, 1 Week
5225-26	PLX-DR	PSTR	6	6	> Tensile	3.5-6.0
5225-29	PLX-DR	PSTR	5	5	> Tensile	> Tensile
5225-30	PLX-DR	PSTR	7	7	3.5	2.9
5225-31	PLX-811	PSTR	3	3	3.5	1.5
5221-17	TED-20	PSTR	7	7	10.0	4.8
5221-18	FEP-100	PSTR	7	7	5.4	5.4-8.5
5221-19	AHV	PSTR	7	7	1.4	1.5-2.0
5221-20	HLR	PSTR	8	8	6.7-7.0	8.0-12.0
5221-27	HLR	PSTR	8	8	9.5-14.0	3.0-4.5
5221-23	TED 20	PSTR	9	9	7.0-8.0	0.46
B11A	FEP C-20	AHV	9	9	2.0-2.4	0.3
B11B	FEP C-20	AHV	8	7,8	1.68	3.3
B13A	TED 20	DC 184	9	9	1.12	0.5
B13B	TED 20	DC 184	7,8	8	1.4	2.75
A5239-1	TEN 479	PSTR	3	3	3.37	3.2
A5239-2	TEN 479	PSTR	5	5	> Tensile	~
2DA	TEN 479	PSTR	1	1	3.37	0.5
A5240-2	PLX 811	PSTR	5	5	> Tensile	~
A5240-3	PLX 811	PSTR	6	-	Above Tension	1.0
B13C	TED 20	DC 184	9,8	9,8	1	-
B11C	FEP C-20	AHV	9,8	9,8	[illegible]	0.5
B6C	PFA	DC 184	12,9,8	9,[illegible]	[illegible]	0.5

...Continued

Table 59 (Continued - 3)

ID Number	Resin	Substrate	Adhesive/Primer System		Peel Strength (lb/in.)	
			Resin	Substrate	Dry	Immersed in Water, 1 Week
B5C	HLR	RTV 615	12,9,8	9,8	5.6	~
B7A	PLX-DR	AHV	6	6	3.93	> Tensile
7A	AHV	PSTR	7	7	0	0
5238-2	C-4	PSTR	5	5	2.2	0.5
10B	C-4	AL	1	1	5.3	4.8
3D	C-4	PSTR	1	1	0	0
11	AHV	AL	5	5	0	0
1A	KF	PSTR	1	1	-	0
A5238-1	C-4	PSTR	3	3	2.79	2.2
10A	C-4	AL	5	5	0.56	~
A5238-3	C-4	PSTR	6	6	>Tensile	> Tensile
4D	PLX 811	PSTR	1	1	0	-
A5237-3	KF	PSTR	12,9	9	0	0
A5237-2	KF	PSTR	12	-	0	0
5A	RTV 615	PSTR	7	7	>Tensile	> Tensile
6A	DC 184	PSTR	7	7	>Tensile	> Tensile
5240-1	PLX 811	PSTR	3	3	>Tensile	> Tensile
5240-2	PLX 811	PSTR	5	5	> Tensile	> Tensile
5239-3	TEN 479	PSTR	6	6	> Tensile	> Tensile
B2A	Kynar	TEN 479	9	9	~	~
B3A	TED 20	C-4	9	9	1.12	~
B38	TED 20	C-4	8	8	3.37	4.5

...Continued

Table 59 (Continued - 4)

ID Number	Resin	Substrate	Adhesive/Primer System		Peel Strength (lb/in.)	
			Resin	Substrate	Dry	Immersed in Water, 1 Week
B4A	Halar	PLX 811	12,9	9	0	0
B4B	HLR	PLX 811	7,8	7,8	4.49	3.8
B5B	HLR	RTV	7,8	7,8	1.4	3.8
B6A	PFA	DC 184	12,9	9	0.56	0.7
B6B	PFA	DC 184	7,8	8	1.1	2.2
B9A	FEP	TEN 479	9	9	~	0
B9B	FEP	TEN 479	7,8	8	3.37	1.0
5241A-8	KF	PSTR	12,7,8	2,7,8	>Tensile	7.27
5241C-8	184	G10	8	2,8	7.3	5.5
C1A	KF	Cell	12,7,9	7,9	0	0
C4A	PLX 811	Cell	7,6	7,6	>Tensile	>Tensile
C3A	C4	Cell	7,6	7,6	12.0	12.0
C7A	AHV	Cell	7,9	7,9	>Tensile	0
5241 B1-9	AHV	PSTR	9	9	3.65	~
5241 B2-5	AHV	PSTR	5	2,5	>Tensile	~
5241 6B-3	AHV	PSTR	6	12,6	>Tensile	>Tensile
C2B	TEN 479	Cell	6	7,6	6.74	4.4
C2A	TEN 479	Cell	Comp. Mold	7	0	0

TABLE 60

Cell Encapsulation Systems

Substrate Systems: Polyester/Fiberglas, Aluminum, and NEMA G10

Primary Encapsulant		Secondary Cover Film Over Primary Encapsulant			
Material	Cost	Needed	Reason	Material	Rationale for Use
Polyester/Fiberglas					
Resin 81	High	No	-	-	-
Tenite 479	Low	Yes	Mech. deg.	Kynar 460	Gives maximum protection; absorbs UV.
C-4	Med.	Yes	Mech. deg.	Tedlar 20	Has lowest UV trans. of four best secondary films.
Plexiglas V-811	Low	Yes	Mech. deg.	Halar 500	Halar should be used on at least one high-modulus primary vs. use on low-modulus RTV 615.
RTV 615	High	Yes	Soil	Halar 500	High-modulus film vs. low-modulus film on Sylgard 184.
Sylgard 184	High	Yes	Soil	PFA 9705	Higher ranking 120-day optical, vs. Tedlar 20, which is used with Nema G10.
Viton AHV	High	Yes	Soil	Plexiglass DR 61K	1. Rigid sheet needed. 2. Compare vs. Plexiglass V-811 below.
Gel	Low	Yes	Soil	Plexiglass V-811	1. Rigid sheet needed. 2. Compare vs. DR 61K above.
Aluminum					
Tenite 479	Low	Yes	Mech. deg.	FEP 100	1. Practical system. 2. Over high modulus primary vs. over low modulus primary below.

...Continued

Table 60 (Continued - 2)

Primary Encapsulant		Secondary Cover Film Over Primary Encapsulant			
Material	Cost	Needed	Reason	Material	Rationale for Use
C-4	Med.	Yes, but will not use.	Mech. deg.	-	1. Need understanding of effect of UV on cell properties using unstable primary. This primary used because it is not yet a fully commercial material.
PVB	High	Yes	Soil	Soda Lime Glass	1. History of experience. 2. Known technology.
Gel	Low	Yes	Soil	Soda Lime Glass	1. Need rigid material. 2. Glass is a significant possibility.
NEMA G10 Sylgard 184	High	Yes	Soil	Tedlar 20	Lowest ranking optical of four secondary films.

TABLE 61

Tentative Cell Encapsulation Methods

Primary Encapsulant Material	Film Cover Material	Primary Process	Cover Process
Polyester Substrate			
Resin 81	—	Plasma spray.	None
Tenite 479	Kynar 460	Electrostatic or plasma spray over Gelva RA-1159 adhesive	Glue-etched film on with Q36-060 primer and DC 282 adhesive
C-4	Tedlar 20	Electrostatic or plasma spray over Gelva RA-1159 adhesive	Glue on with DC 282 adhesive
Plexiglas V-811	Halar 500	Electrostatic or plasma spray over Gelva RA-1159 adhesive	Glue-etched film on with Q36-060 primer and DC 282 adhesive
RTV 615	Halar 500	Pour in place with constraining walls; Q36-060 primer	Glue-etched film on with Chemlok 607 primer and DC 282 adhes.
Sylgard 184	PFA 9705	Pour in place with constraining walls; Q36-060 primer	Glue-etched film on with Chemlok 607 primer and DC 282 adhes.
Viton AHV	Plexiglas DR 61K	Solution-cast over Hughson B1958 adhesive	Glue on with Hughson B1958 adhesive
Gel	Plexiglas V-811	Pour in place with constraining walls	Place over gel, seal edges with RTV 732
Aluminum Substrate			
Tenite 479	FEP 100	Electrostatic or plasma spray over Hughson B1958 or Gelva RA-1159 adhesive	Glue on with Q36-060 primer and DC 282 adhesive
C-4	—	Plasma spray or electrostatic coat over RA-1159 adhesive	None
PVB	Soda lime glass	Solution-cast or compression laminate	Compression laminate
Gel	Soda lime glass	Pour in place with constraining walls	Glue on with RTV 732 adhesive/sealant
NEMA G10 Substrate			
Sylgard 184	Tedlar 20	Pour in place with constraining walls and DC Q36-060 primer	Glue on with Q36-060 primer and DC 282 adhesive

APPENDIX A

DRAFT OF RECOMMENDED TEST STANDARDS

JPL Contract 954527

DRAFT OF RECOMMENDED TEST STANDARDS

This constitutes a survey of standard test methods for the evaluation of potential encapsulant materials for photo-voltaic arrays. For convenience and to make possible brief comparison, each of the tests has been listed in the following tabulation, showing test number, method, and suitability.

Teses for candidate solar array encapsulants were selected and recommended on the basis of the following criteria:

- Applicability to the property being evaluated
- Conformity to standardized or well-known test methods (where available)
- Accuracy of measurements
- Reproducibility

The various information sources surveyed for tests and specifications relevant to coated/encapsulated products, especially under outdoor weathering, are: The ASTM (American Society for Testing Materials), Federal Test Methods, MIL Specs, ANSI (American National Standards Institute), ISO (International Standards Organization), NEMA (National Electrical Manufacturers Association), UL (Underwriters' Laboratories), and other smaller organizations that may have published test standards.

Discussion of test methods and the rationale for selecting each follow under the general headings of the property being determined.

Optical Properties

The most important property to be measured in the testing program is optical clarity or luminous transmittance. Various test methods have been examined and compared in order to determine the most efficient test. Briefly, the deficiencies in test methods ASTM D-1746 (Transparency of Plastic Sheeting) and ASTM D-1004 (Haze and Luminous

Transmittance), are lack of compensation for beam dispersion, frequency limitation, and multiple testing required to obtain total light transmittance as would be seen by the silicon cell. A Beckman 505 spectrometer has been modified to provide rapid and accurate assessment of luminous transmittance from 350 nm to 820 nm. The light beam passes through the sample and enters an integrating sphere prior to measurement by a photomultiplier tube. Total light transmitted is then calculated as a function of wavelength - independent of scattering angle. A Monroe 1860 programable calculator is then used to record the percent of transmittance every 50 nm throughout the range and integrate the results to give total percent transmittance. The function is normalized based on 100% transmittance.

At Springborn Laboratories (formerly DeBell & Richardson, Inc.) the testing program also involves percent transmittance measurements in the 210 nm - 350 nm ultraviolet range. Although these wavelengths do not significantly contribute to the power output of silicon solar cells, they are responsible for many polymer degradation mechanisms. The degree of "screening" protection provided by some materials and additives may be assessed in this range. This test method is the only nonstandardized procedure used in the Springborn Labs encapsulant evaluation program and has no exact literature reference; however, it bears the most resemblance to ASTM E-424.

Abrasion

Plastics which lose excessive amounts of light transmission as a result of the surface scratching and marring effect of wind-blown dust, sand, branches, etc., would not be of interest.

It would appear that most of the abrasion tests are too severe to evaluate performance in the end use anticipated. Test method MIL-810B-510 should be suitable but is limited to very fine sand grit (the primary interest of this test is penetration of fine grit into moving parts). This method enables the retention of fine grit superficially embedded in the surface at 63°C, which may not be realistic. The embedded grit would, of course, adversely affect light transmission.

Test Method ASTM D-673 is a simpler test using a mixture (in effect) of fine and coarser grit which more closely duplicates the anticipated use conditions than does the MIL 810B-510 finest airborne grit only.

Resistance to Fungus

Fungus growth can survive on plastic surfaces – especially if the surface is etched and dirty, and high humidity conditions prevail. The growths can not only shut off sunlight but can sometimes digest the plastic surface as well.

Published test methods for resistance to fungus include:

- ASTM D-1413 – for fungus attack on wood
- ASTM D-2017 – for fungus attack on wood
- South African Bureau of Standards M472 - fungal attack by Aspergillus Niger
- South African Bureau of Standards M277 - fungal attack by Chaetomium Globosum
- International Standard ISO R846 - similar to the G-21 test method discussed below, except that Paecilomyces Varioti is used instead of Pullalaria Pullulans
- SAA (Australian) Int-88 RPKL41-504 - similar to G-21, using some different fungi
- MSZ (Hungarian) - similar to G-21
- GOST (Russian) 13410-67 - similar to G-21
- Japanese Ind. Std. Z2911 – Not available at SL
- British Standard BSI 1982 – Not available at SL
- MIL D 7850 – Not available at SL
- MIL V 173 – Not available at SL

There are no great differences in these procedures. Foreigh tests (South African, Australian, Hungarian, Russian, etc.) are similar to Method G-21. The G-21 test offers a choice between a broth or a system of sample resting on soil. The broth is our best course of action. There is no reason to believe that the G-21 method will not be adequate. One problem with any of these tests is that the general-purpose fungi used may not attack the plastic being tested while a foreign fungus found in the field may show some activity.

Salt Spray

Salt spray tests are usually employed to evaluate the ability of a coating to resist salt water penetration between coating and substrate. In our application, salt penetration between wiring or cell and the plastic encapsulant would cause failure. Some adhesive systems fail with continuous humidity exposure.

Test Method ASTM B-117 is a most generally used and widely accepted test and should be adequate for our purposes. Other tests which are similar but offer no particular advantage over B-117 are:

- ASTM B-287 - similar to B-117 but with pH 3.1-3.3, adjusted with acetic acid
- ASTM B-368 - similar to B-287 but with 1 gram $CuCl_2 \cdot 2H_2O$ per gallon
- Federal Test 406-6071 - similar to B-117
- BSI (British Standards) AV 148-2

Teses B-287 and B-368 accelerate the undercutting or corrosion of some alloys, but are more specialized. In solar cell applications, temperature cycling before, or in conjunction with, salt spray cycles may be more efficacious in spotting marginal systems than simple salt spray only.

Impact Resistance

It is important that the plastic encapsulant have the ability to protect the solar cell from falling objects - resist cracking, impact whitening, or other failure resulting from falling objects.

The main categories of impact testing are Izod impact, the Charpy procedure or tensile impact, and falling ball. The Tensile-Charpy and Izod impact utilize a constant velocity and measure energy absorption. The drop-ball tests usually employ increasing velocity to eventually effect a crack or even shatter the plaque, although some tests utilize increasing weight at constant height. Thickness of specimen can affect the results in all of the tests. All of the tests are effective, and a series of, say, three polymers with increasing impact properties of reasonable property spacing would usually rate in the same order, regardless of test procedure selected.

Although the drop-dart impact resembles the envisioned end use, there are a number of drawbacks:

1. The method is not suitable for rubbery materials - e.g., FEP, PFA, silicone.

2. For variable drop distance tests, the velocity increases geometrically with distance of drop, thereby decreasing accuracy at high impact loadings.

3. The drop height for plaque crack-through is generally more variable than Izod, etc., numbers.

4. The plaques have to be fairly thick (0.125 inch or more) unless a film impact test is used. Thicker plaques are hard to degrade in accelerated weathering tests.

The Izod and Charpy tests are also useless for rubbery materials (FEP, PFA, silicone). This leaves only the tensile impact test, which would be a good choice in any case since it can yield numbers for a rubbery material - numbers that will decline if the rubbery material degrades on aging.

Low-Temperature Brittleness

Envisioned use of the solar cell arrays includes impacting in Arctic or winter environments. The question arises as to minimum use temperature, and this is best set by empirical brittle temperature testing rather than by T_g ratings; especially if weathering or heating cause embrittlement is empirical testing required.

The ASTM 758 test utilizes an Izod impactor in a low-temperature chamber. This test is useful but probably should not be put to use if ASTM has abandoned it. This leaves the ASTM D-746 test (or similar ISO or Federal Standard tests).

Temperature/Modulus Curve

Design of the cell array encapsulant system for a given environment requires knowledge of the maximum use temperature of load-bearing parts (sag) and low-temperature stiffness properties. A temperature/modulus curve generally indicates the range over which a material is useful.

ASTM D-1043 or D-1053 apparatus and procedures are suitable to our purposes.

Thermal Conductivity

The silicon cell operates more efficiently at lower temperatures. Ability of the plastic to conduct away the heat buildup in the array is important in maintaining optimum output.

Laboratory devices are available to measure thermal conductance, average, C, of a body between two definite surfaces – the time rate of heat flow between these surfaces, under steady-state conditions, divided by the difference of their average temperatures and by the area of one of the surfaces. The average temperature is one which adequately approximates that obtained by integrating the temperature of the entire surface. The thermal conductance of a flat slab is calculated as follows:

$$C = q / [A(t_1 - t_2)] = \lambda / L$$

Thermal conductivity is usually reported in calories per square centimeter per cm thickness per second at 1°C differential. The ASTM D-2214 Cenco-Fitch apparatus provides an easy test method, but ASTM C-177 gives higher accuracy and is generally more applicable

Coefficient of Thermal Expansion

The design of high surface area arrays having a composite silicon/rubbery material/rigid surface structure requires a knowledge of the coefficient of thermal expansion of the various materials to avoid undue stress buildup in the design.

The test in widespread use is D-696. The D-696 method works well for rigid materials and is based on expansion of a standard sample against a spring micrometer. Low-modulus materials cannot expand readily against the dial micrometer spring, however, and it may be necessary to run ASTM D-864 on soft materials. D-864 (cubical expansion) is performed by immersing the sample in mercury and determining volume of expansion versus temperature. The cube root of the corrected reading gives the linear coefficient of thermal expansion.

Mechanical Properties - Tensile Properties

A large number of excellent tensile test methods exist, but all are variations of a general method employing similarities in specimen shapes and loading rates (as a function of size and stiffness). The general test method includes a procedure for determining elongation at yield, load at yield, breaking load, ultimate elongation.

Test specimens vary from 1.3 inches (D-412; Fed. 601-4111) to 12 inches (D-638) in length and from 0.125 inch in width (D-412; Fed. 601-4111) to 1.5 inches (D-638). Most of the tests utilize dogbone shapes, but D-882 utilizes strips.

Although many tests are available to choose from, we are utilizing ASTM D-1708. The D-1708 specimens are small and provision is made for high packing density in artificial weathering chambers. In this test a strain gage extensiometer is used to increase the resolution of the stress/strain curve and to enable accurate modulus data to be determined (modulus is commonly run with D-882 strips without reservation). The D-412 method also offers smaller dogbone sizes than the D-1708 test, but the D-412 test is presently recommended only for rubbery materials.

Hardness

Hardness is generally used to characterize materials - especially with respect to their scratch resistance. To resist minor vandalism or handling scratches, the outer surface should preferably exceed a Shore D of 70.

The ASTM D-2240 durometer (penetration depth) and D-785 (Rockwell Hardness - indentation hardness) procedures are in most widespread use.

Flammability

A self-extinguishing or nonburning plastic array would have certain advantages. A distant forest fire would be less likely to ignite the array by radiation or falling embers. On structures (roofs, etc.), resistance to flaming as a result of shorts or nearby fires, etc., is certainly desirable.

Certainly there are at this point numerous tests to evaluate flammability. In recent years it was found that "nonburning" materials by a bar burning test frequently yield less favorable results in a burning building. In a structure, burning drips can propagate the fire. Intense heat can decompose the plastic, enabling evolution of flammable gases. There is a trend, for indoor fire potential, to use tunnel ovens (E-84, E-286), flame spread tests (E-84, E-286, E-162), or to construct corners of buildings or entire buildings for tests (E-119, E-152, E-163). Smoke tests (NBS, D-2843) are of more concern in indoor applications. Oxygen index (D-2863) correlates with heat of combustion, ASTM D-635, and UL-94 ratings to a reasonable extent. It is no substitute for the more empirical testing, however.

For our purposes, many tests are suitable and in common use - e.g., D-568, D-1692, D-635, E-162, UL-94. We have specified UL-94 because it appears to be the test in most widespread use for small samples, presently, and is concerned with burning drips and burning time. The UL-94 test is also a vertical test (more severe than horizontal tests).

Insulation Resistance - Volume Resistivity

A high resistance to electric current leakage is essential - especially if high voltage (series) arrays are employed. Since humidity can lower the insulation resistance, it is desirable to have the testing carried out at high humidity.

The insulation resistance section of D-257 is closest to simulating actual use conditions and can readily be carried out at 90% relative humidity. The test measures surface and volume resistivity.

Permeability - Moisture

Although tight adhesion to the silicon solar cell can reduce the moisture at the silicon surface to almost zero, this cannot or should not be totally relied upon. Materials of construction with a low moisture permeability have an inherent advantage, other factors being equal.

The pertinent tests are all very similar in principle, differing in details of apparatus construction only. We have run E-96 and D-1653 with no difficulties for many years and recommend this method of testing.

In summation, we feel that the following test methods will be adequate for initial determinations of solar cell encapsulant materials.

Test	Method
• Clarity	
Haze and luminous transmittance	D&R
Abrasion	ASTM D-673 or MIL STD 810B, Method 50
Resistance to fungus	ASTM G-21
Salt spray	ASTM B-117
• Toughness	
Tensile impact	ASTM D-1822
Low-temperature brittleness	ASTM D-746
• Heat Resistance	
Temperature modulus curve	ASTM D-1053
Thermal conductivity	ASTM C-177
Coefficient of thermal expansion	ASTM D-696
• Mechanical Properties	
Tensile strength Ultimate elongation Tensile yield strength Yield elongation Tensile modulus	ASTM D-1708 or ASTM D-638
Hardness	ASTM D-2240
• Miscellaneous	
Flammability	UL-94
Insulation resistance (run at 90% RH)	ASTM D-257
Permeability - water vapor only	ASTM E-96

An outline of methods surveyed follows:

TEST METHOD COMPARISON

Test Name and Number	Applicability	Description
OPTICAL PROPERTIES - Haze and Light Transmittance		
ASTM D-1003	Marginal	The test described includes a haze meter section and an integrating sphere recording photometer. The integrating sphere is an advantage, but the narrow light beam (2.5°) measured is not suitable for this application (see also Federal Standard 406-3022 following).
Federal Standard 406-3022	Marginal	Similar to the Fig. 1 and Fig. 2 Hazemeter section of ASTM D-1003 above. Haze does not indicate poor light transmission if the solar cell is close to the plastic-air interface.
ASTM D-1746	Marginal	This test measures narrow beam (0.1°) transmittance; it ignores scattered light.
ASTM E-424	Yes	Measures wide beam spectrophotometer transmittance over the visible wavelengths.
MIL C-7989	No	Covers general specs for light transmitting aeronautical lights.
Federal Standard 406-3031	Marginal	Measures narrow beam light reflectance and transmittance versus angle of light beam impinging.
Federal Standard 406-3032	Marginal	Measures narrow beam perpendicular light transmittance.

...Continued

Continued - Test Method Comparison

Test Name and Number	Applicability	Description
ABRASION RESISTANCE		
ASTM D-673	Yes	This test uses falling abrasive (from 25-inch height). No. 80 carborundum is recommended.
ASTM D-1242	Too severe	Test uses a weighted test specimen, with abrasive being fed to a turntable. Alternatively, the (flat) specimens are mounted on a belt and travel continuously past a point of contact with an abrasive belt.
ASTM D-1630	Too severe	Specimen is held against an abrasive-covered drum. Revolutions to abrade 0.1 inch are counted.
ASTM D-2228	Too severe	Tungsten carbide knives are rotated against the test specimen.
ASTM D-658	Limited to coatings	Abrasive is run against a coated metal panel until bare metal shows through. The weight of abrasive required per coating thickness is reported.
ASTM D-968	Limited to coatings	Similar to D-673 but uses falling sand from a 36-inch drop height.
ASTM D-1395	No	Uses D-968 or D-658 methods for floor coatings.
ASTM D-1044	Too severe	Uses the Taber Abraser. The abraser consists of two weighted abrasive wheels rubbing on a plastic-faced turntable. The weight loss of plastic versus, e.g., 500 cycles is reported. This method is also used in conjunction with haze and luminous transmittance measurements for abrasion of clear plastics.

...Continued

Continued - Test Method Comparison

Test Name and Number	Applicability	Description
Fed. Std. 406-1091	Too severe	Similar to ASTM D-1044 above.
Fed. Std. 406-1092	Too severe	Similar to Fed. Std. 406-1091 above, but with gloss meter evaluation.
Fed. Std. 406-1093	Yes	Similar to ASTM D-673.
Fed. Std. 601-14111	Too severe	Similar to D-1630 (ASTM).
American National Standards Institute J2.26 - 1971	Too severe	Similar to D-1630 (ASTM).
AATCC 93	No	For fabric abrasion by tumbling.
MIL-STD 810B-510	Yes	Uses fine silica, 75% through 325 mesh, circulated through a chamber at a velocity of 1750 feet per minute with the plastic sheet or other object to be evaluated.
FUNGUS RESISTANCE		
ASTM G-21	Yes	This test is very widely used for plastics and coatings. Five fungus growths which show affinity for plastics are cultured on the surface and at the completion of the test the plastic is rated for ability to retard growth; also, the plastic surface is cleaned and examined for corrosive effects of fungus activity.
ASTM D-1924	(No)	Superseded by G-21.

...Continued

Continued - Test Method Comparison

Test Name and Number	Applicability	Description
ASTM D-1413	No	Test is for fungus attack on wood.
ASTM D-2017	No	Test is for fungus attack on wood.
International Standards ISO R-846	Yes	Similar to ASTM G-21
Fed. Std. 141a-6271.1	Yes	G-21 fungus testing.
MIL-STD 810B-508	Yes	Similar to G-21.
SALT SPRAY RESISTANCE		
ASTM B-117	Yes	The procedure describes the standard test in a pressurized salt chamber with 5% sodium chloride/95 water mist-fog at 95°F/35°C.
ASTM B-287	No	Similar to B-117, but with pH 3.1-3.3 adjusted with acetic acid.
ASTM B-368	No	Similar to B-287, but with 1 gram $CuCl_2 \cdot 2H_2O$/gallon.
Fed. Std. 406-6071	Yes	Similar to ASTM B-117.
MIL-STD 810B-509	Yes	Similar to ASTM B-117.

...Continued

Continued - Test Method Comparison

Test Name and Number	Applicability	Description
IMPACT RESISTANCE		
ASTM D-1822	Yes	Tensile Impact. Measures the kinetic energy extracted from the test pendulum in the course of (tensile) breaking of a 0.25 inch wide (dumbell) specimen. Impact is at 11.3 feet per second.
ASTM D-256 A. Izod B. Charpy	 Yes (rigids) Yes (rigids)	Measures the kinetic energy extracted from the test pendulum in the course of breaking a notched or unnotched 1/8-1/2 inch thick bar.
International Standards ISO R-179 - Charpy	Yes (rigids)	Similar to D-256. Notching, specimen size somewhat different.
ISO R-180 - Izod	Yes (rigids)	Similar to D-256; notching angle is wider.
Fed. Std. 406-1071	Yes (rigids)	Similar to D-256, Izod.
Fed. Std. 601-11221	Yes (rigids)	Similar to D-256, Izod.
Fed. Std. 601-11231	Yes (rigids)	Similar to D-256, Charpy.
ASTM D-1054	No	Measures pendulum rebound; limited to rubbers (impact resilience).
ASTM D-2632	No	Measures plunger rebound; limited to rubbers (impact resilience).
ASTM D-2463	No	For polyethylene blow-molded containers.

... Continued

Continued -- Test Method Comparison

Test Name and Number	Applicability	Description
ASTM G-14, G-13	No	Impact resistance of pipe line coatings.
ASTM D-1709	No	Falling-dart impact on clamped, unsupported polyethylene film; weights are varied at fixed height.
ASTM D-3029	Yes (rigids)	Weights are dropped froma fixed height onto plastic plaque. Weight causing 50% failure is reported.
ASTM D-2444	Yes (rigids)	Rounded-end weights, 6-30 pounds, are dropped from varying height to shatter object. Rounded-end radius of 0.25, 0.5, or 2 inches used as specified.
Fed. Std. 601-11241	Yes (rigids)	Weights (steel balls) are dropped 12-36 inches onto a notched bar.
Fed. Std. 601-11251	Yes (rigids)	A 2.3-pound steel ball is dropped onto a 4" x 2" plaque from increasing height until breakage occurs.
Fed. Std. 601-11261	Yes (rigids)	A 3-pound steel ball is dropped onto a 12" x 12" plaque from increasing height until breakage occurs.
Fed. Std. 406-1073	Yes (rigids)	Similar to 601-11261 above, using a 2-pound ball.
Fed. Std. 406-1074	Yes (rigids)	A 0.5 pound ball is dropped onto a 12" x 12" plaque from increasing heights.
Fed. Std. 601-11211	Yes (rigids)	Merely describes Izod and falling-ball tests.
Fed. Std. 406-1075	Yes (rigids)	Similar to 406-1074 but utilizes a 2.5-4.5 inch diameter disc.
HEW XYZ3	Yes (rigids)	Impact-resistant eyeglass lens.

...Continued

Continued - Test Method Comparison

Test Name and Number	Applicability	Description
Fed. Std. 406-1072	Yes (rigids)	Izod-type hammer blow of 250-2000 ft-lb is directed against a 4-1/2 inch diameter meter case windcw.
ASTM D-3099	Yes	Steel ball, 8.35 grams, is fired upward, 50-300 ft/sec, at a plastic sheet.
MIL P-8045 Paragraph 4.6.5	Some	Tensile impact; tank backing material.
MIL B-131	Some	Impact puncture resistance of film and barrier.
MIL F-22191	Some	Impact puncture resistance of film and barrier.
MIL F-23712	Some	Impact puncture resistance of film and barr.er.
Fed. Std. 101 - Method 313	Some	Impact puncture resistance of film and barrier.
Natl. Electrical Mfrs. Assn. (NEMA) LD-1, Paragraph 2.15	(Yes)	Similar to ASTM D-256.
Society of Plastics Industry (SPI) ERF-23-66	(Yes)	Falling-ball impact.
ASTM 2794	Yes (rigids)	Gardner Impact. The Gardner device is widely used to evaluate coatings on metal but has been used increasingly as a drop-impacting device for plastic sheet using procedures similar to those of D-2444.

...Continued

Continued - Test Method Comparison

Test Name and Number	Applicability	Description
LOW TEMPERATURE BRITTLENESS		
ASTM D-746	Yes	Strips of the polymer are cooled to various temperatures and subjected to 90° impact bending. The temperature for 50% breakage is determined or interpolated.
ASTM D-1790	Yes	Similar to ASTM D-746, but for 10 mils or less thickness.
ASTM D-2137	No	For coated fabric.
International Standards ISO R 974	Yes	Similar to ASTM D-746.
Fed. Std. 601-5311	Yes	Similar to ASTM D-746.
Fed. Std. 601-5321	Yes	Similar to 601-5311 but uses a solenoid-activated impactor.
TEMPERATURE/MODULUS CURVE		
ASTM D-797	Yes (for rubbers only)	Measures Young's modulus in flexure by deflection under load while in a variable temperature chamber.
ASTM D-1043	Yes	Measures modulus of rigidity in a variable temperature chamber by torque and deflection angle measurement.
ASTM D-1053	Yes	Measures modulus of rigidity in a variable temperature chamber by angle of twist and wire constant measurement. Somewhat similar apparatus to that in ASTM D-1043.
ISO R 458	(Yes)	Same as ASTM D-1043.

...Continued

Continued - Test Method Comparison

Test Name and Number	Applicability	Description
Fed. Std. 601-5611	(Yes)	Same as ASTM D-1053.
American National Standards (ANSI) J2.2 - 1971	Yes	Same as ASTM D-1053.
ISO R 537	Yes	Device records oscillations of 30-gram disc suspended under sample. Measurements enable shear modulus, damping, and mechanical loss factor to be calculated.
THERMAL CONDUCTIVITY		
ASTM C-177	Yes	Guarded Hot Plate. The metal surfaced, guarded hot hot plate is used. The stack consists of cold plate/plastic/hot plate/plastic/cold plate. Conductivity is calculated from the temperature differential across the plastic.
ASTM D-2214	Yes	Cenco-Fitch. Apparatus utilizes a 100°C source and measures plastic, rubber, leather, etc., temperature on cold side to calculate conductivity.
ASTM C-745	Yes	Heat flux is determined through evacuated insulations using a guarded flat plate boil-off calorimeter.
ASTM C-236	Yes	Guarded Hot Box. Apparatus uses insulator to be measured between hot and cold circulating air chambers.
ASTM D-2326	No	For foams.

...Continued

Continued - Test Method Comparison

Test Name and Number	Applicability	Description
ASTM D-2717	No	For liquids.
ASTM D-1518	No	For fabrics; uses a guarded hot plate - textile - cool air chamber.
ASTM C-518	Yes	Similar to ASTM C-177.
COEFFICIENT OF THERMAL EXPANSION		
ASTM D-696	Yes, except for soft rubbers	Linear Thermal Expansion. A length of plastic is confined within a quartz tube. Any expansion on heating in a bath is picked up by a dial micrometer bearing on plastic through a quartz rod.
ASTM B-95	(Yes)	Similar to ASTM D-696, but for metals.
ASTM D-864	Yes	Cubical Thermal Expansion. Plastic specimen is sealed into thermometer bulb type quartz tube and tube is filled with mercury (vacuum). The mercury expansion into a capillary is recorded and the coefficient of expansion is calculated.
ASTM D-1903	No	For petroleum liquids. Does not give procedure.
ASTM C-531	No	For mortar.
SDC Plastics Ind. EMM 117-68 ERF 11-63	(Yes)	Same as ASTM D-696.

...Continued

Continued - Test Method Comparison

Test Name and Number	Applicability	Description
Fed. Std. 406-2031	(Yes)	Same as ASTM D-696.
Fed. Std. 406-2032	Yes (marginal for rubbers)	Linear Thermal Expansion. Dried 6-inch strips are placed in 0-50°C chambers and remeasured.

MECHANICAL PROPERTIES - Tensile Strength, Tensile Yield, Ultimate Elongation, Tensile Modulus

ASTM D-638	Yes	This test is widely used for plastics testing. Utilizes a "dogbone" specimen 8.5-12 inches long, 0.75-1.5 inches at the narrow width. Specimens are usually injection molded but rigid materials can be machined from sheet to achieve fairly scratch-free sides. Crosshead speed can vary from 0.05 inch/minute (rigid thermoset) to 20 inches/minute (rubbery). Modulus is determined by extending the initial linear portion of the load-extension curve.
ASTM D-412	Yes	This test is used for rubber sheet. Specimens 1.3-?.3 inches long and 0.125-0.5 inch at the narrow width are cut from the sheet with cookie-cutter type die cutters (six die sizes). The unstressed cross section is used in the calculations.
ASTM D-882	Yes	This test is frequently used for less than 40-mil thick sheet. Strips 0.2-1 inch in width are tested. Strain rate is 0.1-10 inches/inch of length per minute. Modulus determination is carried out at 0.1 inch/inch/minute.
ASTM D-1923	Yes	Utilizes D-882 specimens and the inclined plane test.

...Continued

Continued - Test Method Comparison

Test Name and Number	Applicability	Description
ASTM D-1708	Yes	This test utilizes a 1.5 inch long dogbone specimen, 0.187 inch in width at the narrow portion. Results are generally equivalent to D-638 or D-882, but extra care has to be taken in the preparation of brittle or notch-sensitive materials. Test speeds are one-fourth those of D-638. Ordinarily modulus is not determined by this test.
ASTM D-2289	No	Utilizes high-speed testing.
ASTM D-651	No	This test is primarily for electrical materials and uses a special dogbone specimen having reduced thickness at the center area.
ASTM D-3196	Yes (rubber only)	Utilizes a punched-out ring specimen.
Fed. Std. 601-4111	(Yes)	Similar to ASTM D412.
Fed. Std. 601-11011	Yes	For hard rubber tensile and uses a 1/2 inch width, 6 inch long dogbone - triplicate specimens.
Fed. Std. 601-10021	Yes	Similar to 601-11011 but concerns elongation measurement.
Fed. Std. 601-11051	Yes	As above - measures deflection.
Fed. Std. 601-13021	(Yes)	Measures tensile strength of insulating tape; similar to ASTM D-412.
Fed. Std. 601-13031	(Yes)	Measures elongation of insulating tape.
Fed. Std. 601-4131	(Yes)	Measures tensile strength of soft rubber; similar to D-412.

...Continued

Test Name and Number	Applicability	Description
Fed. Std. 601-4141	(Yes)	Measures strain of soft rubber.
Fed. Std. 406-1011	(Yes)	Similar to ASTM D-638.
Fed. Std. 406-1012	Yes	For tensile, electrical insulation.
Fed. Std. 406-1013	(Yes)	Similar to ASTM D-882 – 0.1875-1 inch wide strips.
Am. National Standards Institute (ANSI) J2.1 - 1969	(Yes)	Similar to ASTM D-412.
ISO R 1184	(Yes)	Similar to ASTM D-882.
ISO R 527	(Yes)	Similar to ASTM D-638 and D-1708; offers three types and sizes of dogbone.
ISO R 37	-	Abandoned
Underwriters' Lab UL 62 - Flexicord	No	Establishes minimum tensile and elongation for Class 1, 2, etc., wire covering, oven-aged and unaged.
ANSI C33.1	No	Same as above.
HARDNESS		
ASTM D-2240	Yes	Shore A and Shore D durometer tests.
ASTM D-1706	(Yes)	Similar to ASTM D-2240 but discontinued (revised).

... Continued

Continued - Test Method Comparison

Test Name and Number	Applicability	Description
Fed. Std. 406-1802	(Yes)	Similar to ASTM D-1706 – for rubbery materials.
Fed. Std. 406-1803	(Yes)	Similar to ASTM D-1706 – for rigid plastics.
Fed. Std. 601-3021	(Yes)	Similar to ASTM D-1706 – for rubbery materials.
ASTM D-531	Yes (for rubber only)	Pusey & Jones Durometer apparatus (Plastometer).
Fed. Std. 601-3031	Yes (for rubber only)	Same as above.
ISO R 868	(Yes)	Similar to ASTM D-2240.
ASTM D-1415	Yes (for rubber only)	International Rubber Hardness. Similar to Durometer but with ball point. One International rubber hardness degree represents approximately the same proportionate difference in Young's modulus.
MIL T4566	(Yes)	Similar to ASTM D-2240.
ASTM D-2583	Yes (for hard plastics)	Barcol Hardness. Barcol durometer.
ASTM D-785	Yes	Rockwell Hardness. Uses the Rockwell durometer type round-end impressor apparatus. The procedure entails impressing a minor load, a major load, then reading penetration under minor loads.
Fed. Std. 406-1081	(Yes)	Similar to ASTM D-785.

...Continued

Continued - Test Method Comparison

Test Name and Number	Applicability	Description
Fed. Std. 601-3041	Yes	So-called ASTM hardness number. Apparatus appears to be durometer type.
Fed. Std. 601-3051	Yes (rubber only)	"Indentometer" with 0.125 inch round end and 90 g (minor) and 1000 g (major) load. Penetration is measured with dial gage.
Fed. Std. 601-3111	No	Measures penetration of the impresser over a period of time.
ASTM D-1526		Discontinued
ASTM E-18	No	Rockwell – for metals.
ASTM E-10	No	Brinell. For metals.
ASTM D-1474		
A. Knoop	No	Microscope, diamond-point indenter (for coatings).
B. Pfund	No	Microscope, quartz or saphire indenter (for coatings).
ASTM B-347	No	For metals.
ASTM B-294	No	For carbides.
ASTM B-578	No	For electroplated metals.
ASTM E-92	No	For metals.
ASTM E-384	No	Microhardness

...Continued

Continued - Test Method Comparison

Test Name and Number	Applicability	Description
ASTM D-617	No	Uses hot and room-temperature Rockwell to correlate with punchout qualities.
ASTM D-143	No	Special tensile bar and procedure for wood tensile.
ASTM D-2134	(Yes)	Rocker Hardness. Can be used for smooth surfaces, although its use is almost entirely confined to coatings. Softer materials damp the number of ocillations per minute. The test is really not as accurate as indenter tests.
Fed. Std. 601-5511	No	Uses 601-3021 methods at low temperature (for rubber).
Fed. Std. 601-5521	No	Uses 601-3051 methods at low temperature (for rubber).
Fed. Std. 601-5531	No	Uses 601-3031 methods at low temperature (for rubber).
SPI VDT4	-	For fused vinyl dispersion.
SPI ERF9	-	For cured epoxy.
TAPPI (Tech. Assn. of the Pulp & Paper Ind.) T640SM	No	Hardness of rubber-covered rolls (Plastometer test) (1953).
ASTM D-314	-	Discontinued
Fed. Std. 501a-3511	(Yes)	Durometer hardness.
Fed. Std. 501a-3531	(Yes - for rubber only)	Similar to ASTM D-1415.

...Continued

Test Name and Number	Applicability	Description
FLAMMABILITY		
ASTM D-2843-70	No	Smoke Density - measurement of smoke density by this test would be of greater interest for indoor construction.
ASTM D-1433-58	No	For thin plastic sheet only – 45° angle.
ASTM D-568-61	Yes	Vertical slab is ignited and burning extent and rate are noted. Especially designed for flexible plastics less than 0.05 inch thick.
ASTM D-1692-59	Yes	Horizontal slab on coarse gauze is ignited for 1 minute (to gage mark) and burning extent and rate are noted thereafter. Especially designed for sheet and foam.
ASTM D-635-63	Yes (for rigids)	For rigid slabs or bars over 0.05 inch thick. Bar is clamped horizontally at 45° angle of twist 3/8 inch over 20-mesh wire gauze and ignited for 30-60 seconds to first gage mark. Burning extent and rate are noted.
ASTM D-757-49	Yes	Globar. For rigid 1/8 inch thick plastics found self-extinguishing by ASTM D-635-63. A 950°C "Globar" is used to ignite a horizontal plastic bar.
ASTM D-777	No	For treated paper and paperboard.
ASTM D-2633	No	Vertical burning test for plastic-coated wire.
ASTM D-876	No	Vertical burning test for plastic-coated wire.
ASTM D-470	No	Horizontal burning test for plastic-coated wire.

...Continued

Continued - Test Method Comparison

Test Name and Number	Applicability	Description
ASTM D-350, Sec. 21	No	Vertical test for wire.
ISO R '326	No	Vertical test for films.
Fed. Std. 191-5900, 191-5907, 191-5910, 191-5908, 191-5904, 191-5903	No	For cloth.
Fed. Std. 406-2023	Yes	Vertical 5" x 0.5" x 0.5" sample is ignited 30-600 seconds with hot resistance wire. Time to ignite, burning time, and flame travel are reported.
Fed. Std. 406-2021	Yes	Similar to ASTM D-635.
Fed. Std. 406-2022	Yes	Similar to ASTM D-568.
Fed. Std. 501a-6421	Yes	Flame spread test.
ASTM D-1361	No	For coatings.
ASTM D-1360	No	For coatings.
ASTM E-160	No	For treated wood.
ASTM E-69	No	For treated wood.
ASTM D-1230	No	For textiles.

...Continued

Continued - Test Method Comparison

Test Name and Number	Applicability	Description
ASTM E-84-70	Yes	Flame spread tunnel oven. Constructions are burned in a furnace fitted with gas burners, and evaluated.
ASTM E-119-71	No	Describes the techniques for constructing, fitting thermocouples, and burning large structures.
ASTM E-152-72	No (?)	Describes test on full-size door assemblies.
ASTM E-163-65	No (?)	Describes test on full-size window assemblies.
ASTM C-209 Sections 32-36	Yes (?)	Test reports area of char from the burning of 1 ml ethanol (test was designed for insulating board from vegetable fibers).
ASTM E-286-69	Yes	Flame spread by means of an 8-foot tunnel furnace. Flame travel, smoke index, etc., are also reported.
ASTM E-162-67	Yes	Radiant Panel Flame Spread. Surface flammability via ignition of an inclined 6" x 18" specimen by means of a radiant energy source.
Underwriters' Lab UL-94	Yes	A vertical bar is ignited twice (multiple tests). Excessive burning time (over 10 seconds), or flaming drips capable of igniting cotton 1 foot below, downgrades the rating. The test is repeated with 70°C-aged samples.
SPI ERF7-1962	(Yes - for rigids)	Similar to ASTM D-635.
SPI VDT11-1962	No (?)	For foams and sheeting.

...Continued

Continued - Test Method Comparison

Test Name and Number	Applicability	Description
ISO R871	No (?)	Determines temperature at which appreciable decomposition occurs.
ISO R 1210	Yes	Horizontal specimen is ignited for 60 seconds and burning time is reported: Rating "1", nonburning after removal; "2", burns less than 15 seconds; etc.
ASTM D-2863-70	No. (?)	Oxygen Index. The gas phase oxygen content required for a strip of plastic to burn for 3 minutes or 50 mm is determined.
U.S. Dept. of Commerce, NBS USC FF2	Yes (?)	Similar to ASTM D-2859.
Pressure-Sensitive Tape Council (PST) 57	For flexibles	Pressure-sensitive tape flammability.
Underwriters' Lab UL 62 - Par. 130	No	Vertical wire burning test.
NBS Smoke Test	No	Measures the amount of smoke eminating from the burning plastic. Usually toxic gases are also identified and measured. Smoke test is similar to D-2843.
ASTM D-1929-68	No	Apparatus and procedure to determine flash ignition temperature and self-ignition temperature of plastic.

...Continued

Continued - Test Method Comparison

Test Name and Number	Applicability	Description
MOISTURE PERMEABILITY		
ASTM E-96	Yes	The material to be tested is sealed (wax) over the mount of a dish containing desiccant or water. The weight gain or loss is determined after exposure to desired temperature and humidity. For 1/8 inch or less sheet materials.
ASTM D-1653	Yes	Similar to ASTM E-96; gasket sealed cup (Gardner-Park). (Better than wax-sealed for higher temperatures.) Similar to above tests but uses larger dish for thicker (over 1/8 inch) sheets.
ASTM E-998	No	Penetration of liquids into submerged containers.
ASTM D-1276	No	Test for moisture permeability of packages by cycling methods.
ASTM D-1251	No	Test for moisture permeability of packages by cycling methods.
ASTM D-895	No	Permeability of packages to moisture.
ASTM D-3079	No	Moisture Vapor Transmission (MVT) of heat-sealed packages.
ASTM D-1008	No	Moisture vapor transmission of shipping containers.
ASTM D-461	No	Moisture vapor transmission of felt.
ASTM D-2684	No	Permeability through (sealed) molded bottle or other container.

...Continued

Continued - Test Method Comparison

Test Name and Number	Applicability	Description
ASTM D-814	Marginal	Rubber diaphragm to be tested is sealed to jar and jar inverted. Weight loss is checked.
ASTM E-398	(Yes)	Special test cell (Honeywell Rapid WVTR) with sensor to determine relative humidity above the plastic film or sheet.
ISO R 1195	Yes	Apparatus consists of a wax-sealed film onto a dish containing desiccant. Moisture transpiration is calculated from weight gain and film area/thickness. Curing is at 90% relative humidity and 25 or 38°C (similar to E-96).
Fed. Std. 406-7032	(Yes)	Similar to E-96.
Fed. Std. 191-5516	No	For textiles.

Property	Test Name and Number	Applicability	Description
ELECTRICAL PROPERTIES			
Volume Resistivity	ASTM D-257	Yes	Wheatstone Bridge resistance through a disc of plastic.
Insulation Resistance (90% RH)	ASTM D-257	Yes	Wheatstone Bridge resistance between 1-inch gaps in metal clamps on 6" x 1" sheet.
Volume Resistivity	ASTM C-657	No	For glass.
	ASTM D-116	No	For vitrified ceramic.
	ASTM F-150	No	For conductive resilient flooring.

...Continued

Continued - Test Method Comparison

Property	Test Name and Number	Applicability	Description
Volume Resistivity	ASTM D-1169	No	For liquids
	ASTM B-421	No	For tungsten carbide
	ASTM F-43	No	For semiconductors
Resistivity	ASTM C-611	No	For graphite articles
Resistivity	ASTM D-2739	No	For resin bonded conductive adhesives
Insulation Resistance	ASTM D-470	No	For coated wire
	ASTM D-991	No	For electrically conductive elastomers
	UL 62 - Par. 138	No	For coated wire
	ANSI C 33.1	No	For coated wire
Electrical Resistivity	AATCC ATC 76	No	For fabrics
Electrical Resistivity	AATCC ATC 84	No	For yarns
Volume Resistivity	Fed. Std. 601-9111	Yes	Measures volume resistivity using special jig.
Resistivity	Fed. Std. 601-9211	No	Measures the resistance of conductive casters.

...Continued

Continued - Test Method Comparison

Property	Test Name and Number	Applicability	Description
Volume Resistivity and Insulation Resist.	Fed. Std. 406-4041	(Yes)	Similar to ASTM D-257
Volume Resistivity	Fed. Std. 406-4042	Yes (for cast polymers)	Electrodes are cast in and volume resistivity measured.
Insulation Resistance	Fed. Std. 406-5011	Yes	Similar to ASTM D-257, insulation resistance section.

9-2-76