NBS TECHNICAL NOTE 972

U. S. DEPARTMENT OF COMMERCE/National Bureau of Standards

Elastomeric Roofing: A Survey

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+ NBS Technical Note

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by

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Abstract

In recent years the use of elastomeric roofing systems in the United States has been increasing. A survey was conducted to ascertain the current state-of-the-art of these roofing systems. The information obtained in the survey was gathered from a literature search complemented by the opinions of people knowledgeable in the field including researchers, contractors, manufacturers and users. A listing of the current elastomeric roofing materials was compiled, along with test methods for determining the properties of membranes fabricated with these materials. The principal materials, available in either liquid or sheet applied systems, included acrylic, butyl, chlorosulphonated polyethylene, EPDM (ethylene propylene diene terpolymer), neoprene, polyvinyl choloride (PVC) and vinyl, silicone and urethane. In addition to these materials some composite membranes were also available.

Factors affecting the performance of the membranes were identified including durability, design of the roofing system, substrate condition at the time of application, attachment of the membrane to the substrate, and workmanship during application. The performance of elastomeric roofing was discussed based on its advantages, disadvantages and limitations. Guidelines to assist the user in the selection and use of elastomeric roofing were prepared for both new and remedial roofing applications.

Criteria were not available to evaluate or predict the performance of elastomeric roofing. As a first step in the development of criteria, preliminary performance characteristics were suggested.

Keywords: Application guidelines; elastomeric; materials; membranes; performance factors; review; roofing.

1. INTRODUCTION

1.1 Background

In the United States today, it may be estimated that most low-sloped industrial and commercial buildings are roofed with conventional bituminous built-up roofing membranes. More than fifty years of experience have shown that a built-up roofing system, properly designed, specified, applied and maintained, will function adequately, keeping the roof watertight for 15 to 20 years or more. In addition to functioning acceptably, an important reason for the continued usage of built-up roofing has been its low construction cost in comparison to other types of roofing systems for industrial and commercial buildings.

An alternative to bituminous built-up roofing is elastomeric roofing. An elastomer has been defined by the American Society for Testing and Materials (ASTM) as a macromolecular material that at room temperature returns rapidly to approximately its initial dimensions and shape after substantial deformation by a weak stress and release of the stress [1]*. Elastomeric roofing membranes are in general single-ply, synthetic polymer materials with rubberlike (elastic) properties applied to substrates on roofs to protect buildings and their occupants from the weather. Since the membranes are elastomeric, they should be capable of accommodating some movement of the substrate without failure. Elastomeric roofing membranes are available as either sheet or liquid applied materials.

In comparison with the long history of built-up roofing membranes, experience with the elastomeric membranes is short. Even though elastomeric roofing is not new and has been used in the United States for over two decades, its usage has been slight. Elastomeric membranes were introduced into roofing in an attempt to provide improved roofing membrane performance, to simplify application procedures and to overcome some of the deficiencies of conventional built-up roofing such as low temperature brittleness and inability to accommodate substrate movement. In addition, modern architecture and technology led to the design and construction of buildings with non-conventional roof shapes, such as domes, folded plates, and hyperbolic paraboloids which could more readily be roofed with elastomeric than built-up roofing. The early elastomeric roofing systems were expensive, especially in comparison to built-up roofing. For conventional low-sloped application there was no great need for elastomeric membranes if they did not perform better than built-up membranes.

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* Figures in brackets indicate references listed in Section 8.

In the early 1960's many manufacturers, including producers of built-up roofing materials attempted to enter the elastomeric roofing field. The roofing trade journals hinted quite optimistically at a prolonged growth and prosperity for elastomeric roofing. The performance of some of the earlier elastomeric systems was reported by Cullen in 1962 [2]. He concluded from short-term field observations that their performance was satisfactory and recommended that they be used only in special applications where conventional roofing was not practicable. Interestingly, many of the systems reported on by Cullen do not exist today. Moreover, most of the major producers of built-up roofing materials who entered the elastomeric field discontinued production. The prosperity predicted for elastomeric roofing did not occur. In the late 1960's elastomeric roofing was in general limited to buildings where conventional roofing was not practicable.

The reasons why the prosperity never occurred have not been well-documented. High cost and in some instances poor performance of the membranes were mostly responsible. Specific reasons for the poor performance have not been reported. It has been suggested that much of the earlier poor performance was linked with poor application of the membranes. The applicators of the earlier systems were not fully aware of the significance of good application procedures and workmanship on the performance of the membranes. It has also been suggested that the technology for the use of the earlier elastomeric materials as roofing systems was insufficiently developed.

Some elastomeric roofs applied over 15 years ago have performed excellently and are still in existence today. In many of these cases, conventional bituminous roofing may not have performed satisfactorily. A notable example is the Terminal Building at Dulles International Airport outside Washington, D.C. The roof consists of a suspended cable concrete deck covered with a sheet neoprene membrane coated with liquid applied chlorosulfonated polyethylene. The membrane has functioned without problems since its fabrication in the early 1960's, easily accommodating the movement of the suspended cable deck. The chlorosulfonated polyethylene coating has weathered, but recently, another coating was applied.

In the last few years, there have been indications that elastomeric roofing may again become a competitor for low-sloped industrial roofing. A number of manufacturers of new materials and systems has entered the field. The major reason for the renewed interest in elastomeric roofing is economic. Whereas in the early 1960's elastomeric roofing was high in cost in comparison to built-up roofing, it is now economically competitive with built-up roofing in some areas of the United States. The cost of elastomeric materials is high, but their installation cost is low, since a one ply membrane is normally installed. Conversely, the cost of bituminous roofing materials is low, but their installation cost is high, since a three or four ply membrane is normally installed. In addition to cost, performance should also be considered. Modern chemistry and technology can produce some elastomeric materials which are more durable and may perform better than some of the materials produced 20 years ago. In an age of materials shortages and emphasis on conservation, elastomeric roofing may offer an acceptable alternative to conventional types of roof construction.

1.2 Objectives

Because of the renewed interest in elastomeric roofing and because of the potential cost and performance benefits to be gained through its use in certain roofing applications, the Tri-Services requested the National Bureau of Standards to survey the current state-of-the-art of elastomeric roofing technology. Information and data obtained in the survey would assist military construction personnel in the design, construction, and maintenance of elastomeric roofing. This report describes the results of the survey. The objectives of the report are to compile generically a list of elastomeric roofing membranes and test methods for evaluating their properties; to identify factors affecting performance; to provide guidelines for the application of elastomeric roofing; and to suggest preliminary performance characteristics for elastomeric roofing systems.

1.3 Scope of the Project

Data and information presented in this report were obtained from existing sources including the literature and opinions of those knowledgeable in the field. No laboratory research was performed during the course of the survey. Discussions were held with researchers, contractors, manufacturers and users to determine their views of elastomeric roofing systems. Topics of discussion included comparisons of the various available systems, properties and test methods for elastomeric roofing materials, methods of application, and advantages, disadvantages and problems involved with using elastomeric roofing. A limited number of roofs were inspected to assess their performance. The laboratory facilities of some manufacturers were visited to become acquainted with the test methods for evaluating elastomeric roofing materials. These discussions and field inspections complemented the information obtained from an extensive survey of the literature.

1.4 The Literature

During the past twenty years, many articles have been written concerning elastomeric roofing. Most of the articles have been qualitative or descriptive in nature. Little quantitative data for evaluating the performance of elastomeric roofing have been published. In general, the performance of elastomeric roofing systems has been determined by in-use experience and not laboratory research. A brief summary of selected references [3-13] is given in the Appendix.

In some European countries standards and certificates have been prepared that describe the properties, assess performance and provide design data and limited application guidelines for specific elastomeric membranes [14-17]. These standards and certificates facilitate the use of these membranes in the countries where the documents are applicable.

2. TYPES OF ELASTOMERIC ROOFING

Elastomeric roofing is available as two types, liquid applied and preformed sheet systems. The liquid applied systems are available as either single component or two component materials. The liquid materials are applied to substrates by brush, roller, squeegee, trowel or spraying where they adhere and solidify to seamless waterproofing membranes. The single component materials solidify either by evaporation of a solvent or water, or chemical curing. The two component materials solidify through chemical curing which begins as soon as the two components are mixed together. The rates of curing of both one and two component systems are dependent on temperature. However, the rates of curing of two component systems are in general less dependent upon atmospheric conditions and more on formulation than the rates of curing of single component systems. Depending upon the amount of elastomer within the liquid solution, the system is usually described as having a low solids or high solids content. The thickness of the membrane is controlled by the amount of liquid applied to the substrate. The uniformity of the thickness throughout the membrane is controlled by the quality of the workmanship during application and the surface roughness of the substrate.

The elastomeric sheet systems are available in roll form as thermosetting and thermoplastic* materials. They are preformed in the factory where the thickness and uniformity of the sheet can be controlled. Application of a sheet membrane is accomplished by unrolling individual sheets on the roof and sealing them together to form seams, normally by overlapping. The ability of the membrane to keep the roof watertight is dependent upon the integrity of the seams. For thermosetting sheet materials, adhesives are generally used to seal the lapped seams. For thermoplastic sheets, the seal of the seams may be achieved by use of a solvent cement or heat welding. Sheet membranes may be fully or partially bonded to the substrate or loose laid (non-bonded) on the substrate. Loose-laid membranes are only bonded at the perimeter of the roof and at roof penetrations. They are held in place with a ballast of gravel or concrete pavers.

2.1 Elastomeric Roofing Materials

A wide variety of elastomeric roofing materials is currently available. These materials are in general proprietary and their compositions are not usually reported in the literature. Some have been used for over 20 years, others are relatively new. Many of these materials can be used in a variety of applications, while others are intended for specific applications. Gumpertz prepared a list of some liquid applied products in a recent paper in which he discussed the performance of both liquid applied and sheet materials [3].

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* Although thermoplastic materials are not truly elastomeric materials, some are used for roofing and therefore included in this report.

Elastomeric roofing systems, particularly the sheet applied, are in some cases custom designed and engineered by the materials manufacturer for specific buildings. Because of today's economic situation, some systems which were long known and used in other areas of waterproofing (e.g., below grade waterproofing and pond liners) are now being marketed as roofing membranes. Those materials most commonly used for elastomeric waterproofing in the United States are described below. The materials are also listed in table 1 along with the types of substrates to which the materials are commonly applied and the membrane thicknesses recommended by manufacturers.

2.1.1 Acrylic

Acrylic refers to those polymers synthesized from acrylic or methacrylic esters. Acrylic polymers have good resistance to ultraviolet light and weathering. Acrylic elastomeric roofing materials are available as one component liquid systems. Unlike many elastomeric roofing membranes, they may be obtained in a variety of colors.

2.1.2 Butyl

Butyl rubber is an elastomer synthesized by copolymerizing isobutylene with a small amount of isoprene or butadiene. It is resistant to ozone and weathering and has extremely low water vapor and gas permeability. It has good resistance to corrosive chemicals, dilute mineral acids and vegetable oils but has poor resistance to petroleum oils and gasoline. Butyl elastomeric roofing is available as both sheet and two-component liquid applied systems. The sheet systems have been used for over 15 years in the United States but have limited use today. Reported problems with adhesion of the lap seams has limited its use to applications where a specific property of the membrane (e.g., low water vapor permeability) is required. A bulletin has been published by the National Building Research Institute of South Africa describing the properties and uses of butyl rubber sheet roofing [18].

2.1.3 Chlorosulfonated Polyethylene

Chlorosulfonated polyethylene is a chlorinated polyethylene containing a small number of chlorosulphonyl groups produced by the simultaneous chlorination and sulfonation of high molecular weight, low density polyethylene. The cured material has outstanding resistance to ozone, heat and weathering. It has good resistance to mineral oils and general chemical attack but will swell in aromatic and chlorinated solvents. In addition, it shows good color stability and may be formulated in a wide variety of colors. Chlorosulfonated polyethylene elastomeric roofing is available as both sheet and liquid applied systems. The sheet material generally contains an asbestos backing which facilitates handling and application. The major market in the United States for this sheet applied system is in industrialized or modular construction. It has been used considerably in Europe in conventional roof construction and an Agrément Certificate has been issued in the United Kingdom [14]. The liquid applied system is a one component elastomer used on sprayed-in-place polyurethane foam insulation or often as a weather resistant, colored coating for other elastomeric membranes such as neoprene. The properties of chlorosulphonated polyethylene roofing have been described in a bulletin by the National Building Research Institute of South Africa [19].

Table 1. Elastomeric Roofing Membranes, Listed Generically, as well as the Substrates to Which the Membranes are Applied and the Approximate Thicknesses of Application(1)

Type of Membrane	Membrane	Substrates	Thickness mils(2)	Thickness mm
Liquid applied(3)	Acrylic	concrete, plywood, spray-in-place urethane foam, remedial roofing	20	0.5
	Butyl	concrete, spray-in-place urethane foam, remedial roofing	15-30	0.4-0.8
	Chlorosulphonated polyethylene	spray-in-place urethane foam, weatherproof coating for elastomeric membranes	20-45	0.5-1.1
	Neoprene/chlorosulphonated polyethylene	concrete, plywood, spray-in-place urethane foam	20	0.5
	Polyvinyl chloride (PVC) and vinyl	concrete, plywood, spray-in-place urethane foam	15-30	0.4-0.8
	Rubberized asphalt	concrete	150-180	3.8-4.6
	Silicone	spray-in-place urethane foam	20	0.5
	Urethane(4)	concrete, plywood, spray-in-place urethane foam, remedial roofing	20-60	0.5-1.5
Preformed sheets(5)	Chlorosulphonated polyethylene/ asbestos backed	plywood decks on industrialized or modular construction	35	0.9
	EPDM (Ethylene propylene diene terpolymer)	concrete, plywood, insulation board, remedial roofing	45	1.1
	Neoprene	concrete, plywood, insulation board	63	1.6
	Polyvinyl chloride (PVC)	concrete, plywood, insulation board, remedial roofing	48	1.2
Composite preformed sheets	Nylon reinforced PVC backed with neoprene or butyl	concrete, plywood, insulation board, remedial roofing	30	0.8
	Non-woven glass reinforced PVC	concrete, plywood, insulation board	47	1.2
	Modified asphalt/polyethylene sheet	spray-in-place urethane foam, remedial roofing	68	1.7

(1) The information presented in this table has been assembled from the literature of various manufacturers. It is presented for purposes of comparison to give the reader an overview of the materials available and the substrates to which they may be applied. Individual products should be applied to substrates and in thicknesses recommended by the manufacturers.

(2) 1 mil = 0.001 inch.

(3) Liquid membranes are commonly applied by a number of techniques including brush, roller, squeegee, trowel and conventional and airless spraying.

(4) A number of widely varying membrane systems are classified under the title urethane including asphalt and coal-tar modified urethanes.

(5) Sheet membranes are applied bonded to or loose-laid on the substrate.

2.1.4 EPDM (Ethylene propylene diene terpolymer)

EPDM is an elastomer synthesized from ethylene, propylene and a small proportion of a diene monomer. The properties of EPDM are similar to those of butyl rubber, except EPDM exhibits better resistance to weathering and ozone. As in the case with butyl, EPDM is not resistant to petroleum oils and gasoline. EPDM elastomeric roofing is available in sheet form, normally black in color, although a white sheet may be obtained.

2.1.5 Neoprene

Neoprene is the generic name of polymers and copolymers of chloroprene (2-chloro-1,3-butadiene). It was the first commercially produced synthetic rubber and has been used for over 20 years in elastomeric roofing. Properly formulated, it exhibits good resistance to petroleum oils, solvents, heat and weathering. Neoprene elastomeric roofing is available in both sheet and liquid applied systems. The sheet materials are available in weathering and non-weathering grades. The weathering grade is black whereas the non-weathering grade is light colored. The non-weathering grade must be protected from sunlight, normally through application of a coating. The properties of neoprene sheet roofing have been described in a bulletin published by the National Building Research Institute of South Africa [20]. Liquid applied neoprene is a one component elastomer which is also coated for protection against degradation from solar radiation. The protective coating most commonly used for both the liquid and sheet neoprene systems is chlorosulphonated polyethylene. A tentative ASTM standard specification has been prepared for liquid applied neoprene/chlorosulphonated polyethylene roofing membranes [21].

2.1.6 Polyvinyl Chloride (PVC) and Vinyl

Polyvinyl chloride (PVC) is a thermoplastic polymer synthesized from vinyl chloride. PVC is a member of a larger group of polymers designated as "vinyls." In a strict chemical sense, the word vinyl refers to the chemical group, CH =CH-, from which vinyl polymers are synthesized. Now through common usage, vinyl frequently means a homopolymer or copolymer of polyvinyl chloride. PVC polymers and copolymers are rigid materials. However, through plasticizing and proper formulation, PVC materials can be obtained which show elastomeric properties and resistance to weathering. Data are not available on the permanency of the plasticizer in PVC roofing membranes subjected to various exposures. The loss of plasticizer as a result of aging, solar exposure or other factors will cause embrittlement and may also result in shrinkage. An important property of PVC is its resistance to acids, alkalies and many chemicals. It is soluble in certain solvents, such as tetrahydrofuran which is the common solvent in PVC solvent-cements. Elastomeric PVC roofing is available as sheet and liquid applied systems. Sheet membranes are normally applied loose-laid (non-bonded) over the substrate. The liquid applied membranes are one component systems normally applied by spraying.

PVC sheet roofing membranes have been used considerably more in Europe than in the United States. Consequently, a German materials standard has been developed [15] and Agrément Certificates for a proprietary product have been issued in the United Kingdom [16] and France [17].

2.1.7 Rubberized Asphalt

The principal use of rubberized asphalt has been for waterproofing concrete structures such as plaza decks, foundation walls and tunnels. A recent application has been elastomeric roofing. Rubberized asphalt embrittles at temperatures lower than asphalt, reportedly retaining its flexibility as low as -15 °F (-26 °C). It can be applied hot, or cold as a cutback or an emulsion. Rubberized asphalt should not be used in exposed applications. When used as a roofing material, it must be protected from degradation by solar radiation. This is normally accomplished by mineral aggregate surfacing or by the insulation in a protected membrane roofing system. Hot applied rubberized asphalt membranes are generally thicker than other elastomeric roofing membranes.

2.1.8 Silicone

Silicones are semi-organic polymers, whose chains are comprised of alternating silicon and oxygen atoms and modified with various organic groups attached to the silicon atoms. Silicones are resistant to high temperatures and are flexible at low temperatures. They also offer good resistance to oxidation, ozone and weathering, and possess a higher water vapor permeability than most other elastomers used for roofing. Silicone elastomeric roofing is available as single component or two component liquid systems and is used for protecting spray-in-place polyurethane foam. Silicone membranes tend to retain dirt and may darken with time of exposure.

2.1.9 Urethane

Urethane (polyurethanes) refers to that class of synthetic polymers produced from the reaction of a di-isocyanate and a poly-ol in the presence of a catalyst. Because of the wide variety of reactants which may possibly be selected, urethanes may be synthesized with widely varying properties including the ability to be colored. With proper formulation, urethanes have good resistance to petroleum oils, solvents, oxidation, ozone and weather. Urethane elastomeric roofing is available as single and two component systems. The single component system cures in the presence of moisture.

Both single component and two component, bitumen-modified urethane systems are used for elastomeric roofing. These systems containing either asphalt or coal tar pitch are available in both weathering and non-weathering grades.

2.1.10 Composite Membranes

During the course of this survey, information was obtained on three composite membrane systems. One system consisted of a nylon reinforced polyvinyl chloride sheet backed with either neoprene or butyl sheeting. After installation, this sheet is covered with a weather resistant coating. The second composite system consisted of a non-woven glass reinforced polyvinyl chloride sheet.

The third composite system consisted of a rubber-modified bitumen sheet to which a polyethylene film was laminated. This composite was self-adhering and bonds to the substrate upon application of pressure. The membrane is protected from weathering by coating or surfacing with a mastic and embedded gravel.

2.2 Properties and Test Methods

Little data describing the properties and performance of elastomeric membranes were found in the literature other than those distributed by manufacturers. Elastomeric roofing membranes possess a wide range of mechanical, chemical and physical properties. There are two major reasons which account for the wide range. First, a variety of different systems is available and properties may vary greatly between systems. Secondly, the properties of the membrane for a specific type of system may vary between producers because of differences in formulation and manufacture. It is, therefore, not possible at this time, based on available information, to determine minimum materials properties required for acceptable performance of elastomeric membranes. Comprehensive performance criteria and performance tests are not available for evaluating elastomeric roofing systems. To illustrate the variability in properties of the different types of membranes, typical values of the tensile strengths, ultimate elongations and service temperature ranges taken from manufacturers' literature are given in table 2.

Elastomeric roofing is an outgrowth of the rubber and plastics industries. Thus, many test methods, originally developed for evaluating rubbers and plastics, are available for evaluating or specifying the properties of elastomeric roofing membranes. The ASTM has assembled a standard index of methods for testing elastomeric roofing [22] from the numerous ASTM test methods available for measuring the properties of rubbers and plastics. Properties of membranes determined from many of these tests are reported in manufacturers' literature, the most commonly described properties include the following:

- Tensile strength -- The maximum force, per unit of cross section area, which the membrane can sustain when it elongates to rupture. This property may be a measure of the membrane to withstand normal movements in the substrate without rupture. Preformed sheets should have sufficient strength for handling and installing without causing damage. Tensile strength is usually measured according to ASTM D 412.
- Ultimate elongation -- The maximum extension of the membrane at the moment of rupture. This property may be a measure of the membrane to expand enough to accommodate normal movements in the substrate. The change in ultimate elongation on aging may be an indication of the durability of the elastomeric material. Ultimate elongation is usually measured according to ASTM D 412.
- Water vapor permeability -- The ability of the membrane to retard the flow of water vapor. It is usually measured according to ASTM E 96.
- Water absorption -- Resistance to penetration of liquid water into the membrane. Absorbed water may alter the properties of the membrane. It is measured according to ASTM D 471 and ASTM D 570.
- Hardness -- Resistance of the elastomeric membrane to indentation under test conditions which do not cause rupture. It is usually measured according to ASTM D 2240 or D 1415.
- Tear resistance -- A measure of the stress needed to continue rupturing the elastomeric sheet, usually after a cut has been initiated in the sheet. It is usually measured acccording to ASTM D 624.

Table 2. Tensile Strengths, Ultimate Elongations and Service Temperature Ranges of Elastomeric Membranes[1]

Type of Membrane	Membrane	Property[2]				
		Tensile Strength[3]		Ultimate Elongation[3]	Service Temperature	
		lbf/in^2	MPa	%	°F	°C
Liquid applied	Acrylic	180	1.2	200-300	-70 to 180	-57 to 82
	Butyl	600	4.1	250	-55 to 180	-48 to 82
	Chlorosulphonated polyethylene	800	5.5	400	-50 to 250	-45 to 121
	Neoprene	700	4.8	600	-50 to 180	-45 to 82
	Polyvinyl chloride (PVC) and vinyl	1200	8.3	150-200	-30 to 160	-35 to 71
	Rubberized asphalt	NA[4]	-	NA[4]	-40 to 180	-40 to 82
	Silicone	400-600	2.8-4.1	100-150	-70 to 350	-57 to 177
	Urethane	100-3000	0.7-2.1	300-800	-60 to 200	-51 to 93
	Urethane (bitumen modified)	50-500	0.3-3.4	400-500	-40 to 175	-40 to 81
Preformed sheets	Chlorosulphonated polyethylene asbestos backed	1000	6.9	350	-50 to 250	-45 to 121
	EPDM (ethylene propylene diene terpolymer)	1400	9.7	300	-65 to 300	-54 to 149
	Neoprene	1400-1800	9.7-12.4	450 - 700	-40 to 200	-40 to 93
	Polyvinyl chloride (PVC)	2800	19	250	-30 to 160	-35 to 71
Composite sheets	Nylon reinforced PVC backed with neoprene or butyl	2500	17	330	-20 to 160	-29 to 71
	Non-woven glass reinforced PVC	1420	9.8	250 - 300	-40 to 150	-40 to 66
	Modified asphalt/polyethylene sheet[5]	4000	28	400	-25 to 180	-32 to 82

(1) The information presented in the table has been assembled from the literature of various manufacturers. It is presented for the information of the reader to show the variability in tensile strength and ultimate elongation that exists among the various membranes. In addition the properties of a specific type of system vary between manufacturers because of differences in formulation and production.

(2) The numerical values listed in the table should not be considered absolute. Values of properties may change as formulations of the membrane change. No direct comparison between membranes should be made since the test conditions may have varied and were not specified.

(3) This property is normally determined according to ASTM D 412.

(4) NA = not available from literature.

(5) Tensile strength and ultimate elongation depend on the properties of the polyethylene sheet.

- Heat aging -- The ability of the membrane to retain its physical properties after continued exposure to heating. It is usually measured according to ASTM D 573 or D 865.
- Ozone resistance -- The ability of the membrane to resist long-term exposure to ozone. Ozone rapidly degrades many rubber materials, especially if they are stressed. It is measured according to ASTM D 1149.
- Low temperature brittleness -- The ability of the membrane to remain flexible and not embrittle at low temperatures. It is usually measured according to ASTM D 746 or D 2137.
- Weatherability -- The ability of the membrane to resist weathering, i.e., degradation due to sun, rain, wind, etc. Membrane properties change upon exposure to weathering. Weathering resistance is determined by either outdoor exposure or accelerated weathering. In the case of elastomeric membranes, many manufacturers do not conduct accelerated weathering tests, possibly due to the uncertainty of the results of such tests. More often manufacturers depend on the performance of test roofs exposed to various climates.
- Flammability -- The ability of the membrane to resist combustion and spreading of the flame. This property has been measured by both ASTM E 162 and E 108 (which is similar to UL 790).

In addition to these properties, there are others which are not generally measured but may be important for evaluating performance and should be considered. These include:

- Impact resistance -- The ability of the membrane to resist hail and falling objects without puncturing. A field test is needed to determine the impact resistance of spray-in-place polyurethane foam systems including the membrane.
- Abrasion resistance -- The ability of the membrane to resist mechanical action such as foot traffic and wind blown particles which tend progressively to remove materials from its surface.
- Adhesion -- The ability of the membrane to remain adhered during its service life to the substrate (if the system requires substrate adhesion) or to itself (e.g., lap seams in sheet systems).
- Tensile fatigue resistance -- The ability of the membrane to resist cyclic induced internal and external tensile forces, particularly at joints in the substrate.
- Compatibility with other materials -- The ability of the membrane to interact with other materials of the roofing system without loss of performance properties. When used in conjunction with materials such as bitumens and solvents elastomeric membranes should be compatible with them.
- Punching shear resistance -- The ability of the membrane to resist normally expected concentrated forces such as foot traffic and wheel loads. These forces applied directly to the membrane or to gravel and other objects should not puncture the membrane.
- Color stability and reflectivity -- The ability of the membrane to retain its original color and reflectivity. An elastometric roofing system may be chosen for its architectural attractiveness or its ability to reflect solar radiation. In these cases, the membrane should not change color or retain dirt on its surface.

- o Crystallization -- The arrangement of previously disordered polymer segments of repeating patterns into geometric symmetry, usually occurring at moderately low temperatures. Upon crystallization, elastomers generally become hard and the ultimate elongation decreases. The process is reversible as the temperature is raised.

3. FACTORS AFFECTING PERFORMANCE

During the survey factors which affect the performance of elastomeric roofing systems were identified. These factors are discussed in this section and include:

- o Mechanical, chemical and physical properties of the membrane and changes in these properties caused by weathering
- o Design of the roofing system
- o Slope of the roof
- o Substrate condition at the time of application and movement in the substrate
- o Attachment of the membrane to the substrate
- o Seams in the membrane
- o Workmanship during application.

3.1 Mechanical, Chemical and Physical Properties of the Membrane and Changes in These Properties Caused by Weathering

As previously mentioned, many properties of elastomeric membranes can be routinely measured in the laboratory, but criteria relating materials properties to performance are not generally available. Moreover, little data exist which describe changes in membrane properties caused by weathering or aging. The durability of an elastomeric membrane is of prime importance when considering performance and is difficult to evaluate.

Durability is generally assessed through in-service performance. In-service performance provides a means for evaluating the durability of elastomeric roofing membranes which have been in use for many years; however, in-service performance may not be adequate to evaluate new materials and systems which have been available for only a short period of time. Some manufacturers of new materials conduct field testing of their systems before introducing them to the market for general use. This is desirable since field testing of new and untried systems may reveal problems which may be corrected before marketing. It has been suggested in the literature that a user of elastomeric roofing check the past performance of the system [7]. This suggestion is emphasized herein since experience has shown that some elastomeric roofing systems have been taken off the market due to unsatisfactory performance which was not anticipated.

The mechanical properties of elastomeric roofing membranes are generally measured at room temperature. Data obtained at low temperatures would be more meaningful in assessing membrane performance. As the temperature is lowered in the subfreezing range, the ultimate elongation of elastomeric roofing materials may be significantly reduced. In addition, the ultimate elongation of weathered or aged elastomeric membranes may be significantly lower than that for new materials. The combined effects of low temperature and aging on the ultimate elongation may result in poor performance in cold climates.

3.2 Design of the Roofing System

Adequate performance of any type of roof membrane including elastomeric depends on the proper design of the roof system. In the design of the system consideration should be given to factors such as materials compatibility, materials properties, environmental conditions and imposed internal and external stresses. Attention should also be directed to design details such as flashings and expansion joints. For example, although an elastomeric membrane may be capable of accommodating some movement of the substrate, it should not be intended as a replacement for an expansion joint.

3.3 Slope of the Roof

Experience over the years has shown that roofs perform better when water is drained from their surfaces. Ponding of water generally results in more rapid deterioration of membranes than would be expected if they were adequately drained. A roof slope of at least 1/4 inch per foot (20 mm/m), 2 percent, is generally recommended for bituminous roofing to achieve adequate drainage. This recommendation should be extended to elastomeric roofing systems. There are specific cases where ponded water has lead to a decrease in the anticipated service life of elastomeric membranes. There have been cases where flat concrete plaza decks have been waterproofed with liquid applied membranes and have performed satisfactorily since installed eight years ago. These membranes have not been exposed to weathering but were covered with protection boards and concrete or other traffic bearing surfaces.

During the course of this survey, it was pointed out by some producers of elastomeric materials that some sheet membranes have performed adequately for long periods of time as tank, canal and pond liners. It was therefore suggested that these membranes would also function adequately on roofs having no slope where water may pond. However, data are not available which support or refute this suggestion. Performance requirements for roofs differ somewhat from these other applications. Until data applicable to roof performance become available, it is recommended that elastomeric roofing be provided with adequate slope. Roofs are exposed to thermal and structural stresses to which tanks, canals and ponds may not be subjected. Although a membrane may resist degradation from water alone, ponded water may increase thermal and structural stresses and thus enhance more rapid degradation of the membrane. In addition, if a leak occurs in a membrane in a location where water is ponded, the risk of water damage to the building and its contents will be greater. Finally, ponded water can collect dirt which may impair the architectural attractiveness of the roof, reduce its reflectivity or in extreme cases may lead to harmful plant growth.

3.4 Substrate Condition at the Time of Application and Movement in the Substrate

The performance of elastomeric membranes can be directly linked to the condition of the substrate at the time of application. A poorly prepared substrate will probably result in inadequate performance of the membrane. Most elastomeric membranes are bonded either totally or partially to the substrate. Good adhesion requires that the surface of the substrate be clean, smooth, dry, and free from oil, wax, grease, dust, dirt and other loose particles such as spalling concrete or rust. It is difficult to apply a liquid system to a rough surfaced substrate. Pin-holes in the membrane and an uneven application of the membrane may result. In addition, a soft substrate or one having a rough surface may result in the membrane being punctured when exposed to foot traffic.

Elastomeric membranes have been applied to most types of roofing substrates including concrete, plywood, insulation boards, spray-in-place polyurethane foam insulation and weathered bituminous built-up roofing. In general, the more dimensionally stable the substrate and less joints in the substrate, the better the membrane is expected to perform. This is especially true for liquid applied and bonded sheet membranes which are less capable of bridging cracks and joints than partially bonded or loose laid sheets. The application of liquid applied and bonded sheet membranes can be designed by including a bond breaker to allow the membrane to float free (not bonded) over cracks and joints which may be susceptible to moderate movement. Since the use of bond breakers with liquid applied systems has not always been satisfactory, liquid applied membranes should be reinforced at cracks and joints.

Structural concrete and plywood have been the most common substrates for elastomeric membranes. Structural concrete decks should be smooth and dry and adequate preparation of joints and cracks should be completed before the membrane is applied so that it will resist movement at these locations. For liquid systems, cracks are commonly prepared by removing loose particles and applying a thick coating, about 60 mil (1.5 mm), of the liquid membrane material over the crack before the membrane is applied. Bonded sheet systems are generally designed to provide reinforcing of the membrane at cracks and joints or allowed to float free at these locations. Loose laid sheet systems do not require reinforcing at joints and cracks in the concrete.

Lightweight insulating concrete fills are not recommended as substrates for bonded membranes because of the high dimensional instability and moisture content of these fills. They may be suitable substrates for loose laid sheet systems although evidence of the performance of this application was not found.

Plywood decks should be constructed of smooth-surfaced, exterior grade panels. All edges of the plywood should be supported so as to prevent differential deflection between adjacent panels. When applying a liquid membrane to plywood, the joints should be prepared before application. Joint preparation has been accomplished by taping or by applying a narrow strip of elastomeric sheet material. Another method consists of covering the joint with a liquid membrane material, adding a reinforcing fabric to the liquid and coating the top of the fabric with a second application of the membrane material. A fourth method which has been suggested consists of applying a high performance sealant into tapered joints in the plywood and covering with the liquid membrane. With bonded sheet systems, it is common to cover the joints in the plywood decks with a bond breaker such as masking tape or a strip of elastomeric sheet material before applying the sheet membrane. When preparing cracks and joints in either concrete or plywood, the preparation should be carried out the same day as the membrane is applied to prevent moisture from being entrapped between the materials used to prepare the joint and the membrane.

Rigid insulation boards have also been used as substrates for both liquid and sheet applied elastomeric roofing. However, experience has shown that liquid applied membranes over rigid insulation boards have not in general performed satisfactorily, therefore this application is not recommended. As is the case for applying bonded sheet membranes over concrete and plywood decks, joints between the insulation boards should be prepared by taping or applying an elastomeric sheet material before application of the membrane. Semi-rigid insulation boards, which may excessively deflect or deform under foot traffic, are not suitable substrates.

A common application of elastomeric membrances is the protection of spray-in-place polyurethane foam insulation from the effects of weathering. It is interesting to note that one elastomeric material, silicone, is recommended for application only on spray-in-place polyurethane foam and not any other substrates since its performance on other substrates was not satisfactory. To obtain satisfactory membrane performance from spray-in-place polyurethane roofing, the foam should have a relatively smooth surface, possess adequate mechanical properties and be dimensionally stable. Some manufacturers and applicators recommend using foams having densities within the range of 2-1/2 to 3 lb/ft^3 (40 to 48 kg/m^3) to obtain these properties. It is also recommended by some manufacturers that the elastomeric membrane be applied the same day as the polyurethane foam is applied to assure adequate adhesion and prevent moisture entrapment in the foam.

Experience has shown that some liquid membranes over spray-in-place polyurethane foam are susceptible to hail damage and their resistance to hail may decrease with aging [10, 13]. Some manufacturers have recommended a 50 percent increase in the thickness of the liquid membrane in geographic areas subject to relatively high incidence of hailstorms.

Elastomeric membranes have also been used for reroofing or remedial roofing of bituminous built-up membranes. Some systems are marketed primarily for remedial roofing applications. Weathered bituminous built-up membranes are suitable in many cases as substrates for elastomeric sheet membranes providing that the surfaces of the bituminous membranes are properly prepared and other application guidelines as discussed in Section 5 are followed. As stated in Section 5, asphalt and coal tar pitch may be harmful to some elastomeric materials. Compatibility of materials and adequate protection techniques should be determined prior to application.

3.5 Attachment of the Membrane to the Substrate

As discussed previously, there are three methods for attaching elastomeric membranes to substrates: totally bonded, partially bonded and loose laid (non-bonded). The attachment of the membrane to the substrate or its ability to remain in place throughout its service life is critical to the performance of the roofing system.

Liquid applied and some sheet systems are intended to be totally bonded to the substrate. For the liquid systems, adhesion is achieved during application and curing of the liquid coating; while for the sheet systems, total bonding is normally achieved through the application of an adhesive. It is worth repeating that the substrate for adhesive bonded systems must be smooth, clean, dry, and and free from dust, dirt, grease, oil, wax and loose particles. It is recommended for many bonded systems that the substrate be primed before application of an adhesive to achieve greater bond with the membrane than with an unprimed substrate. The primer should be compatible with the membrane and the substrate.

Contact adhesives are generally used to bond sheet membranes to the substrate. They are important elements in elastomeric roofing systems and their properties and performance should not be neglected. The contact adhesives are applied to both the top surface of the substrate and the bottom surface of the elastomeric sheet. The adhesive solvent must be allowed to evaporate completely before the two surfaces are brought into contact. The adhesive is generally ready for bonding 15 to 30 minutes after application when it no longer feels tacky upon touching. Since these adhesives form a bond directly upon contact, in fabrication of the membrane care must be exercised to align the individual sheets properly. Attempts to lift a misaligned sheet and re-apply it to the substrate may result in damage to the sheet or poor adhesion at the membrane seams and between the substrate and the membrane.

At least one sheet membrane system is available which is self-adhering, i.e., the bottom surface of the sheet adheres to the substrate without an adhesive. The bottom surface is protected with a layer of release paper to prevent bonding during transportation and handling. The release paper is removed immediately before application of the sheet to the substrate. Adequate bond requires application of pressure to the membrane in addition to proper preparation of the substrate.

Partial bonding is another method of attaching a sheet membrane to the substrate and may be accomplished by the use of adhesives, mechanical fasteners or a combination of both. The primary function of partial bonding is to allow the membrane to float free over a crack or joint in the substrate and thus distribute stress in the membrane between bonded areas. Partial bonding should not be intended to serve as or replace an expansion joint. Partial bonding when using adhesives is achieved by placing a bond breaker between the substrate and membrane at cracks and joints to eliminate concentrated stress in the membrane at these locations. This method of attachment has been observed to perform satisfactorily in situations where total bonding might have failed. An example is the previously mentioned roof system of the Terminal Building at Dulles International Airport.

In a partially bonded adhesive system, there are voids between the membrane and the substrate. If moisture enters those voids and moisture vapor pressure builds up and cannot be released, blistering of the membrane or delamination from the substrate may occur.

Mechanical fastening (nailing) of elastomeric membranes has also been used for attaching the membrane to the substrate. Mechanical fastening allows the membrane to float free between fasteners which in general allows greater movement between the membrane and substrate than for partially bonded adhesive systems. Mechanical fastening may allow sheet membranes to be installed over some substrates such as gypsum or lightweight concrete fills which could not accept adhesive bonded elastomeric membranes. When using mechanical fastening, precautions should be taken to assure that the membrane is not stressed at the point of attachment or damaged by misapplication of fasteners. Mechanical fasteners with large heads (disks) should be used and after installation they should be covered with pieces or patches of the membrane material or the membrane itself.

During the course of this survey, the installation of a mechanically fastened sheet membrane was observed during a remedial roofing application. The membrane was installed directly over the existing roof system which consisted of a cable suspended steel panel deck, rigid insulation and an elastomeric membrane. After unrolling the sheet, metal battens were placed along one longitudinal edge and nails were driven through the battens, new elastomeric sheet and existing roof system. After placing masking tape (bond breaker) on top of the metal battens, a second elastomeric sheet was unrolled so that it overlapped the nailed battens and about 2 inches of the first sheet. At the overlap, the sheets were bonded together with a contact cement. The edge of the second sheet opposite the overlap was nailed to the deck as just described. This process was repeated throughout the application of the membrane.

The third method of securing the membrane to the substrate is by loose-laying whereby the sheet membrane is placed upon the substrate without bonding and held in place by ballast. Attachment to the roof is only at the perimeter and at penetrations. Since the membrane is independent of the substrate, stresses in the substrate are not normally transferred to the membrane. Flashings at the perimeter and at penetrations should be carefully designed and constructed since these areas may be subjected to high stresses.

Gravel is commonly used as a ballast on loose-laid membranes and is installed at a minimum recommended weight of 10 lb/ft^2 (49 kg/m^2) of roof area. The gravel should be of sufficient size, smooth surfaced and free of sharp, rough edges so that it will not puncture the membrane. Riverbottom gravel is recommended. Care must be used when loading and spreading the gravel on the membrane to prevent punctures. Wheel barrows or buggies loaded with gravel should not be transported across a previously graveled section of the roof. Smooth surfaced concrete pavers may also be used as ballast.

3.6 Seams in the Membrane

Liquid applied membranes are seamless, whereas sheet applied membranes contain seams wherever sheets are bonded together. Seams in sheet membranes have been a source of roof leaks resulting from their improper fabrication or premature bond failure. Seams can be fabricated on the roof or in a manufacturing facility; in either case, proper fabrication of seams is a critical factor in the performance of the membrane. Because of environmental conditions and available facilities, seams can in general be better controlled in the manufacturing facility than on the roof. The number of seams that may be fabricated in a manufacturing facility is limited because of the difficulty in handling large membranes and applying them around roof penetrations. As a consequence, some seams must be fabricated on the roof.

Two procedures are normally used to join sheets together: lap seams whereby one sheet is overlapped on the other, and less commonly butt seams whereby the two sheets are butted together and covered with a strip of sheet material on top of the seam. Quality workmanship is necessary in the fabrication of either type. After the membrane is installed, all seams should be carefully observed to assure that they are properly bonded.

Joining of elastomeric sheets to form a membrane generally requires the use of an adhesive. Careful consideration should be given to the selection of the appropriate adhesive to provide adequate bond between sheets at the seams.

Seams in thermosetting membranes, such as neoprene or EPDM, are commonly fabricated using a contact adhesive. The surfaces to be bonded must be clean and dry, and dirt, if present, should be removed by wiping with an applicable solvent. Sheets should be unrolled and aligned before application of the contact adhesive. Adequate pressure must be applied to the seams after joining the sheets to achieve expected bond strength. A problem which may occur with the use of contact adhesives is the formation of fishmouths in the seams, whereby the two sheets are not in complete contact with each other. Fishmouths can be readily repaired by cutting the raised portion of the sheet enabling cut sections to adhere smoothly to the membrane. A patch should be added to the repaired area. Unrepaired fishmouths, even if not leaking, may retain water which may eventually penetrate the seam.

Seams in thermoplastic sheet membranes, such as PVC, are commonly fabricated using a solvent-cement or by heat welding. Seams formed with solvent-cements are fused together because the thermoplastic resin sheet is somewhat soluble in the solvent cement. Surfaces to be bonded by this technique may be immediately joined together after application of the solvent-cement to each surface. The solvent-cement should not be allowed to dry on the surfaces before bonding the sheets together. A seam formed with a solvent-cement does not achieve full bond strength until after all the solvent evaporates. This may require a period of days depending on atmospheric conditions which affect the rate of evaporation of the solvent. However, the initial bond between sheets is strong enough to allow construction of the membrane and provide adequate bond between sheets strong enough to allow normal construction of the membrane and provide adequate water tightness. Adequate pressure must be applied to the seams after joining the sheets to achieve expected bond strength.

The alignment of adjoining sheets is not as critical with solvent-cement as with contact adhesives since some initial movement between sheets can occur without affecting the bond. If it is necessary to realign the sheets or improve bond at some locations, additional solvent-cement may be added. If fishmouths occur, they should be repaired as previously described by cutting, adhering and patching.

In fabricating seams in thermoplastic membranes by heat welding, heat is applied to the overlapping sheets to fuse them together. This process generally requires specially designed equipment. The heat applied should be carefully controlled so that the sheets are fused together but not melted because of excessive heat. The amount of heat applied depends on the thickness of the sheet and the type of material.

For some sheet systems manufacturers recommend that a bead of sealant be placed at all seam edges, as added insurance that the seam is watertight. The bead of sealant is intended to prevent water from entering the seam at the edge of the overlap. Water retained at the edge of the overlap may eventually cause failure of the seam.

3.7. Workmanship During Application

Proper workmanship during application of an elastomeric membrane may be the most important factor affecting the performance of the membrane. Care must be taken in the application of the membrane to prepare the substrate properly and to apply the materials strickly according to the designer's and manufacturer's specifications and instructions. It has been suggested that elastomeric roofing did not achieve the success forecast for it in the early 1960's because of unacceptable performance resulting from poor workmanship. The industry is currently aware of the importance of proper workmanship and most manufacturers require that their material be applied by approved applicators. This requirement is intended to reduce the possibility of improper application, particularly for new or non-conventional materials with which roofing mechanics may not be familiar.

Because elastomeric roofing membranes normally consist of one ply, workmanship has more significance for these systems than for those containing multi-plies. In cases where elastomeric roof systems are custom-designed by manufacturers to enable proper use and application of their materials, workmanship should be consistent with the manufacturers' designs.

4. DISCUSSION AND COMMENTS

Elastomeric roofing has in many cases performed satisfactorily as an alternative to conventional bituminous built-up roofing, and has succeeded where bituminous roofing has not been practicable. On the other hand, there have been cases where systems have not exhibited satisfactory performance. In the survey, an attempt was made to identify the requirements of elastomeric systems necessary for proper performance. It was found that performance criteria for quantitatively evaluating or predicting the performance of elastomeric roofing were not available. Methods for evaluating and predicting the performance of elastomeric roofing systems are qualitative, and the decision whether or not to use an elastomeric roofing system is in general based on judgment. The selection of a roofing system should be made after examining all the factors involved in its performance. These factors include advantages, disadvantages, limitations and past in-service performance of the systems under consideration along with design requirements of the roof.

To assist those considering the selection of elastomeric roofing systems, the following discussion points out the advantages, disadvantages and limitations of these systems. In compiling the advantages, disadvantages and limitations, information was obtained from the literature [2-13] and from discussions with manufacturers, contractors, consultants and researchers. It is noted that an advantage in one system may be a disadvantage in another because of the variety and diversity of elastomeric roofing materials and systems. For example, an adhered sheet membrane may be lightweight, but if the same sheet is loose-laid and covered with ballast, the system is no longer lightweight.

4.1 Advantages of Elastomeric Roofing

There are many advantages associated with elastomeric roofing regarding performance and cost benefits, conservation and substitution of materials and adaptability to roofs having a wide range of configurations. The advantages of elastomeric roofing identified in this survey include:

- Extensibility
  The ability of the membrane to elongate and accommodate movement in the substrate. The extensibility or elongation at room temperature of certain systems may be as high as 700 to 800%. Elastomeric membranes may bridge "non-working" joints and cracks in the substrate without cracking and splitting provided they are not bonded or are reinforced at these locations.
- Cold temperature resistance
  The ability of the membrane to remain flexible at low temperatures. Some elastomeric membranes will remain flexible at temperatures as low as -50 °F (-46 °C), as compared to conventional bituminous membranes which become brittle within a range of about 0 to 45 °F (-18 to 7 °C). Also, some elastomeric membranes retain their ability to elongate at low temperatures although the elongation is reduced from that at room temperature, about 68 °F (20 °C).
- Lightness in weight
  Elastomeric roofing systems are available which may weigh less than 10 pounds per 100 square feet (<0.5 kg/m^2) of roof area in comparison to smooth surfaced bituminous systems which may weigh about 150 pounds per 100 square feet (7.3 kg/m^2) of roof area.
- Architectural attractiveness
  Many modern buildings have roofs designed to be architecturally attractive as well as functional. These roofs are available in a variety of configurations, such as domes, barrels, and hyperbolic paraboloids which are not normally suitable to be roofed with conventional materials. Elastomeric membranes have the ability to conform to a variety of shapes and

contours. This makes them suitable for roofing these modern architectural designs. In addition, some elastomeric roof membranes are available in a variety of colors which may enhance the attractiveness of the roof. Colors can be selected to be reflective, thus reducing the absorption of solar radiation resulting in lower roof temperatures.

- Ease of application

  Elastomeric membranes may be easily applied by a variety of techniques such as brush, roller, squeegee, and spraying for the liquid systems and by unrolling and securing (through adhesives or ballast) for sheet systems. These materials are in general easier to transport, handle and apply than bituminous membrane roofing materials. Most elastomeric materials do not have to be heated during application.

- Application under adverse environmental conditions

  Some systems may reportedly be applied at subfreezing temperatures. As an example, it has been recently reported that two roofs were covered with a loose-laid sheet system in Alaska during January and February when the temperature was approximately 0 °F (-18 °C) [23]. This extends the available months during which a building may be roofed or reduces costly construction delays due to adverse temperature conditions. In the application of some loose-laid sheet systems moisture may not be a critical factor and may be tolerated to a certain extent. For example, some sheets with relatively high water vapor permeability may be applied over decks on which moisture is present in the form of condensation or dew.

- Reduced labor costs

  Since elastomeric membranes are normally one ply, the amount of labor necessary in their construction is normally low compared to that required to fabricate multi-ply membranes. Reduced labor costs result from the application of only one ply and less material to handle and transport. Some liquid applied systems offer self-flashing characteristics that greatly simplify application at terminations and penetrations.

- Ease of repair

  Membrane damage such as puncture, split or tear may be easily repaired for both sheet and liquid applied systems. For the sheet systems a patch of the membrane material can be adhered over the damaged area. Repairs to the liquid applied systems are normally made by using the same type of liquid material from which the membrane was fabricated, although patches of an applicable sheet material or application of an applicable sealant have been used. It is important to note that proper bond to resist peeling and wind uplift is dependent on proper selection of repair materials and adequate preparation of the membrane surface.

- Ease of finding leaks

  Leaks are generally easier to locate in smooth surfaced roofs than in those covered with gravel or slag surfacing. In cases of membranes totally bonded to substrates which prevent water from being transported laterally within the roofing system, water most likely penetrates the roof in the immediate area of the leak. However, leaks may be difficult to find in roofs covered with loose-laid systems.

- Ease of removal

  A loose-laid elastomeric roof system may be removed by taking off the ballast, cutting the membrane wherever necessary and removing the sections of sheets and in some cases the insulation. This application may have utility in temporary roofing and in circumstances where plans are made to raise the height of the building at some time after its construction. If the removed membrane is in good condition it may be possible to apply it to another roof.

- Seamless membranes

  Liquid applied membranes are seamless, thereby eliminating the possibility of leaks through faulty joining of sheet materials. For some liquid applied systems, the membrane and base flashing at roof penetrations and edges are constructed as a continuous, seamless waterproofing layer.

- Availability of materials

  In cases of shortages of conventional roofing materials, elastomeric roofing provides an alternative system. Bituminous roofing accounts for approximately 85 percent of industrial roofing in the United States. Shortages of bituminous roofing materials could result in costly delays in building construction if suitable replacements are not available. National concerns regarding materials conservation and shortages encourage substitution of more readily available or less costly materials.

- Advanced technology

  Elastomeric roofing is an outgrowth of the chemical and rubber industries. These industries have produced materials and products which have made significant inroads in the building industry and through research are attempting to develop other materials and products with improved performance for building applications.

4.2 Disadvantages of Elastomeric Roofing

In selecting a roofing system, the disadvantages of elastomeric roofing should be considered along with its advantages. Disadvantages that were identified in this survey are listed as follows:

- Lack of long-term exposure

  Although some of the elastomeric systems have been in use for many years, many materials and systems are relatively new and have not had long-term exposure as roofing membranes. Evaluative techniques based on short-term tests or exposure are not available to predict the long-term performance or durability of new membranes. With proper maintenance roofing systems should perform satisfactorily over a period of about 15 to 20 years. Past experience has shown that some elastomeric systems have performed satisfactorily for over 20 years, while others have failed prematurely and were removed from the market. New materials and systems should be thoroughly evaluated and should be introduced and used with caution.

- Lack of performance and design criteria

  As previously mentioned, performance criteria for evaluating or predicting the performance of elastomeric roofing are not available. Criteria will enable the quantitative evaluation of new materials and serve as guidelines for their development. There are many manufacturers of elastomeric roofing materials and each manufacturer produces specific systems which in general differ from those produced by other manufacturers. Thus, a wide variety of elastomeric roofing systems is available. Each manufacturer has his own guide specifications for designing and applying his systems. General guidelines and design criteria to assist the designer in the selection and use of elastomeric roofing are not available and are needed within the industry. Initial steps in the preparation of guidelines for the use of elastomeric roofing are presented in Section 5.

- Dependency on workmanship

  Workmanship is important in all roofing applications, however, it is considered critical in elastomeric roofing. Experienced or trained roofing mechanics are required to install the complex one ply membrane systems. Application of these systems necessitates an awareness of many factors such as closely following instructions to assure proper chemical reactions during curing processes, adequate amounts of liquids and adhesives for membranes and seams, proper alignment and tolerances in sheet systems, care in handling materials to prevent damage, proper preparation of substrates, and cleanness of substrates and membrane surfaces, especially at seams.

- Small safety factor of membrane integrity

  Most elastomeric roof membranes consist of thin, single ply coatings or sheet coverings. In sheet systems seams are critical since they have been a greater source of roof leaks than the sheet material itself. A failure in a single ply membrane, including seams, will most likely result in a roof leak, whereas the watertight integrity of a multi-ply system will be maintained if one ply fails.

- Possible high cost

  Although labor costs are comparatively low for elastomeric roofing, relatively high materials costs may make the total cost of the system more than that for conventional bituminous membrane roofing. Higher costs may be justified to achieve better performance or aesthetic requirements. In some instances elastomeric systems, particularly liquid applied, have been lower in cost than some bituminous membranes.

4.3 Limitations of Elastomeric Roofing

There are specific roofing applications for which elastomeric membranes are generally not recommended. This limits the use of these systems or requires certain provisions in their design and application. The limitations associated with the use of elastomeric roofing noted in this survey are as follows:

- Substrate

  Liquid applied and bonded sheet membranes are normally installed over structural concrete or plywood substrates. They are also applied over precast concrete decks. Spray-in-place polyurethane foam is also a common substrate for liquid applied systems. Loose-laid sheet membranes have been applied over many different types of substrates. Elastomeric membranes should be compatible with the substrate and particular consideration should be given to compatibility requirements for reroofing applications. Some elastomeric membranes, both modified with bitumen and non-modified, are not compatible with bituminous substrates. If the membrane and substrate are not compatible these components should be kept separated by using an appropriate barrier between them. The major factors with regard to the substrate which limit the selection of elastomeric roofing are dimensional stability, moisture content, joints and cracks and compatibility. Excessive movement of joints or cracks in substrates may cause rupture of bonded membranes above these locations. For example, a crack of 1/32 in (0.8 mm) widening to 1/8 in (3.2 mm) would require a bonded membrane to elongate 300 percent, which may exceed the ultimate elongation of some membranes.

- Foamed plastic insulation

  Solvents in some liquid applied materials and those used in some adhesives for sheet materials may dissolve or damage foamed plastic insulations, particularly polystyrene. This applies to systems where insulation is used either below or above the membrane.

- Protection of membrane

  Some elastomeric membranes are not resistant to ultraviolet (UV) radiation and should be protected. Protection has been accomplished by several means such as application of a second elastomeric or reflective coating, covering with an applicable foamed plastic insulation and ballast, surfacing with mineral aggregate embedded in a cold-applied asphalt coating, and covering with concrete pavers. When a second coating is used as a weathering surface, it may have to be reapplied after a few years. The protection for non-weathering membranes should be applied to all exposed areas including flashings. It is necessary to use coatings for protecting flashings when non-weathering membranes are protected with materials which are not suitable for flashings, such as gravel or concrete pavers. Protective coatings, particularly those containing solvents used during their application, must be compatible with the membranes.

- Ballasting loose-laid membranes

  Loose-laid membranes are normally ballasted with a minimum weight of 1000 pounds per 100 square feet of roof area (49 kg/m^2) to keep the membrane in place and prevent blow offs due to wind uplift. The technique of loose-laying membranes is limited to roofs designed to support the weight of the ballast. For remedial roofing applications the load capacity of the roof should be known.

- Flammability

  Elastomeric roofing membranes are organic materials and will burn and support combustion. Most local code jurisdictions require a fire rating for roofing which also applies to elastomeric systems.

  Many liquid applied materials and adhesives containing solvents are very flammable during their application and prior to evaporation of the solvent. On open roofs the fire potential may be less than in enclosed spaces with poor ventilation. No open flames, sparks or smoking should be allowed in areas where materials containing flammable solvents are being applied.

- Toxicity

  Some materials and solvents used in the construction of elastomeric membranes may be toxic. During the survey, no reports were found that indicated toxicity posed a problem to workers, provided that proper care and precautions are taken. In particular, when spray applying a liquid membrane caution should be used to avoid inhaling the spray. Care should also be taken to keep toxic materials from the skin by wearing gloves, and long-sleeved shirts and long pants. Proper labeling and safety instructions should be provided by the manufacturer.

Solvent toxicity, as in the case of solvent flammability, may pose a minimum of risk to the worker on an open roof. However, in enclosed spaces with poor ventilation, solvent toxicity may be a problem. Forced-air ventilation through the use of fans may be necessary to keep the solvent concentration in the air at an acceptable level. If fans are used to reduce the concentration of solvents which are flammable, the fans should not produce sparks or otherwise increase the risk of fire.

5. GENERAL GUIDELINES FOR THE USE OF ELASTOMERIC ROOFING

This section presents general guidelines to assist the user in the selection and application of elastomeric roofing systems for both new and remedial roofing. These guidelines are intended to be used in conjunction with manufacturers' guide specifications. It is not possible to offer a specific set of guidelines because of the variety of elastomeric roofing systems which are available. The guidelines are based in part on information which is presented in other sections of the report.

5.1 New Roofing Applications

Guidelines for the use of elastomeric membranes in new roofing applications include:

1. The design of the elastomeric system must be thoroughly examined, taking into account the materials properties, advantages, disadvantages, limitations, and the past performance of the systems under consideration. Strict attention should be paid to the design of construction details such as flashings and expansion joints. Other requirements of the roof such as fire and wind resistance should also be considered during design.
2. The substrate for an elastomeric membrane should be stable and contain as few joints as possible. Acceptable substrates for elastomeric sheet membranes include structural concrete, precast concrete, plywood, rigid insulation board and spray-in-place polyurethane foam. Liquid applied membranes can be used on all these substrates except rigid insulation board. The compatibility between insulation, particularly polystyrene, and elastomeric materials should be determined before application. Some concrete curing agents may be incompatible with some elastomeric membranes and cause premature deterioration of the membrane. Some concrete curing agents may cause poor adhesion between the substrate and bonded membrane systems. Elastomeric membranes should not be applied to concretes covered with curing agents unless it has been established that these materials are compatible and that the curing agent will not adversely affect the performance of the membrane. For plywood substrates only smooth surfaced, exterior grade plywood should be used. The panels must be adequately supported on the edges to prevent differential deflection of adjacent panels and spacings at panel edges and ends should be 1/8 and 1/16 in (3 and 2 mm), respectively [24]. For spray-in-place polyurethane foam substrates the elastomeric membrane should be applied the same day as the polyurethane foam.

3. Semi-rigid insulation boards, lightweight insulating concrete fills and gypsum decks are not acceptable substrates for totally bonded elastomeric membranes. Consideration may be given to their use as substrates for mechanically fastened or loose-laid sheet membranes.
4. The substrate should be properly prepared to receive the elastomeric membrane, i.e., it should be clean, dry, smooth and free of dust, dirt, grease, oil, wax and loose particles. Priming is often recommended to increase adhesion between the substrate and the bonded membrane and the primer should be compatible with the membrane. Joints and cracks in the substrate should be taped or filled prior to applying bonded sheet or liquid applied membranes. Taping or filling of joints and cracks and application of membranes should be accomplished the same day.
5. If movement is anticipated at joints, preference should be given to sheet membranes over liquid applied systems. Bond breakers should be provided between the substrate and sheets at joints to allow bonded membranes to float free and distribute stress over a larger area at these locations. Loose-laid sheet systems may also be used over substrates where significant movement is expected at joints and cracks.
6. The minimum recommended slope for elastomeric roofing is 1/4 inch per foot (20 mm/m), 2 percent. Roofs which pond water are not acceptable. (This statement applies equally well to bituminous membrane roofing.)
7. Quality workmanship is mandatory throughout the application. It is essential that the applicator be familiar with the system and application equipment either through previous experience, training or assistance provided by a manufacturer's representative during application. Quality workmanship requires proper preparation of the substrate, use of appropriate and clean equipment, skillful application of the system as recommended by the manufacturer and paying strict attention to details including the following:

   - liquid systems should be applied uniformly at recommended thicknesses. For spray applied systems care should be taken to prevent overspray during application.
   - two applications of liquid systems are recommended by some manufacturers to assure adequate coverage. The second application in these cases should be applied 90 degrees to the first application. It would be helpful if the second application was a different color to ascertain complete coverage. The second application should be applied to a moisture free surface.
   - weather conditions during installation should be favorable. For most systems, liquid applied in particular, the chance of rain occurring during application should be slight. Proper application of most systems requires that they be kept dry during all phases of their construction.
   - installation should be performed between temperature limits of both the air and substrate as recommended by the manufacturer. Many manufacturers recommend that their materials not be applied below 40 °F (4 °C); however, there are some systems available which may be applied below 40 °F (4 °C).
   - some materials have shelf lives and should not be applied if the shelf lives are exceeded. Liquid applied materials should be stored at temperatures recommended by manufacturers. Aqueous emulsions should not be allowed to freeze.

- a two component liquid system, upon mixing, should be applied within the specified pot life of the mixture.
- moisture curing materials should not be applied if the relative humidity is below the level recommended by the manufacturer.
- a liquid system should not be solvent thinned or heated in order to lower its viscosity for ease of application unless specific instructions are provided by the manufacturer.
- when using contact adhesives the solvent should completely evaporate before bonding is performed.
- when using solvent-cements bonding should be completed without allowing the solvent to evaporate and the solvent-cement to dry.
- sheet membranes should not be stressed or stretched during application. If a sheet cannot easily conform to the contour of the substrate without stressing, it should be cut and seamed. Cant strips should be provided at the intersections of vertical and horizontal surfaces when applying bonded sheet systems.
- semi-cured sheet materials for some systems may be applied to contours where the sheets have to be somewhat stretched or curved to form a membrane. These materials adapt to the configuration of the contour and cure completely after they are installed.
- if fishmouths occur at the seams of sheet membranes, they should be repaired by cutting, adhering and patching.
- seams in sheet membranes which may retain water along the edge should be caulked to prevent water from penetrating the edge of the lap.
- seams in sheet membranes should be thoroughly inspected after completion of the membrane to assure water tightness.
- when ballasting a loose-laid membrane, care should be exercised to prevent puncturing, tearing or ripping of the membrane. Loaded wheelbarrows or buggies should not be moved across gravel surfaced membranes.
- flashings should be constructed in strict accordance with design details and specifications.
- non-weathering membranes should be completely covered to protect them from deterioration due to ultraviolet radiation. If gravel surfacing is used to cover the membrane, vertical membrane surfaces or flashings should be protected by coating.
- liquid materials or coatings purposely formulated for applications to vertical surfaces and flashings should be applied at these locations. Liquid applied systems are available from some manufacturers in two grades for either horizontal or vertical application. The two grades differ mainly in their viscosity.
- equipment should be properly maintained during application of the membrane system.

5.2 Remedial Roofing Applications

Remedial roofing is the application of new membranes over old roofing systems. Elastomeric membranes have been used for remedial roofing of bituminous built-up membranes. Considerable cost savings may be gained by reroofing a failing, deteriorated bituminous built-up membrane without removing it. Some elastomeric roofing systems are being offered primarily for remedial roofing.

It is emphasized that the condition of the substrate is critical in order to achieve acceptable performance of elastomeric roofing systems. The condition of the built-up membrane depends upon factors such as moisture, blistering and surface smoothness and cleanness. When properly prepared, weathered bituminous membranes which are in good condition are acceptable substrates for some sheet elastomeric membranes. General guidelines for using elastomeric membranes in remedial roofing applications include:

1. If there is evidence that the bituminous membrane will not be an acceptable substrate, it should be removed. Excessively wet insulations below deteriorated built-up membranes constitute unacceptable substrates. In cases where small amounts of moisture are present in the insulation, consideration may be given to installing vents during remedial roofing. The effectiveness of vents has not been determined from technical studies.
2. Gravel or slag, if present on the surface of the bituminous membrane, should be removed if an elastomeric membrane is to be applied directly to the bituminous membrane. If an insulation or protection board is used between the old and new membranes, only the loose gravel or slag need to be removed.
3. Defects, such as blisters or splits, should be repaired. For the application of bonded elastomeric sheet membranes, all components of the bituminous system should be properly adhered to each other and to the deck. If adhesion at any interface in the system is poor, bonded elastomeric membranes should not be applied.
4. The bituminous membrane should be clean, dry, smooth and free of loose particles. As part of the preparation of the bituminous membrane, consideration should be given to the application of a primer, the addition of a single-ply base sheet, mopped or nailed in place, or the addition of an insulation or protection board. For the application of bonded elastomeric sheet membranes, the protection board, if used, should be adhered or attached to the bituminous membrane and the joints taped.
5. Loose-laid elastomeric membranes may be applied over bituminous roofing systems including those having poor adhesion between components. The substrate for the loose-laid membrane should be smooth and firm to prevent puncturing the membrane by the ballast which may be subjected to foot traffic or other concentrated forces. If a layer of insulation or protection board is used between the bituminous and loose-laid membranes, these boards need not be adhered nor the joints taped. The roof should be capable of supporting the ballast required for loose-laid systems without excessive deflection.
6. Direct contact between asphalt and coal tar pitch or materials containing these bitumens should normally be avoided. For remedial roofing applications these bitumens may be compatible if the bituminous membrane has experienced considerable weathering and lost most of its volatiles and oils. Certain non-bituminous, elastomeric membranes may be incompatible with and adversely affected by roofing bitumens, in particular coal tar pitch. The compatibility between bituminous substrates and elastomeric membranes should be determined prior to the selection of a remedial roofing system.
7. Guidelines for applying elastomeric membranes in new roofing applications, as discussed in Section 5.1, should be followed for remedial roofing wherever they are applicable.

6. SUMMARY

This report has presented the findings of a review of the state-of-the-art of elastomeric roofing in the United States. The information contained herein was gathered from an extensive search of the literature complemented by discussions held with persons knowledgeable in the field including users, contractors and manufacturers. The generic materials most commonly used to fabricate elastomeric membranes in the United States were listed along with test methods for measuring membrane properties. Factors affecting the performance of elastomeric roofing, as well as its advantages, disadvantages and limitations were discussed. Finally, based on the information gathered in the survey, general guidelines were presented to assist consumers and applicators in the selection and use of elastomeric roofing materials.

It was mentioned more than once within this report that criteria are not presently available for evaluating or predicting the performance of elastomeric roofing. Consequently, it is not possible to make a quantitative judgment when selecting an elastomeric roofing system. This fact is disconcerting, especially when the increased use of these systems and the number of new systems entering the market are considered. Material properties of the many membranes available cover a wide range of values. No technical basis has been established for choosing one value instead of another as the minimum value required for acceptable performance. For example, the tensile strengths and ultimate elongations of current membranes range approximately from 50 to 4000 lbf/in^2 (0.3 to 28 MPa) and from 100 to 800 percent, respectively. The minimum value of either property necessary for satisfactory performance of the membrane in the system employed (e.g., loose-laid or bonded) has not been specified. Performance criteria are needed and should be developed to assure satisfactory performance of elastomeric roofing.

6.1 Suggested Performance Characteristics

As a first step in the development of performance criteria for elastomeric roofing membranes, preliminary performance characteristics are suggested in this report. Table 3 shows these suggested performance characteristics along with suggested preliminary levels of performance and test methods for determining the performance levels.

Research is needed to develop performance levels for elastomeric roofing from the suggestions given in table 3. An examination of table 3 shows that for most of the performance characteristics, preliminary levels of performance can not be established at this time. Of the remaining performance characteristics for which preliminary performance levels are suggested, it is felt that preliminary levels of performance for fire resistance and wind resistance can be definitely established at this time. These levels of performance have in general gained acceptance for all roofing systems within the industry.

Two other preliminary levels of performance, chemical and fungus resistance, can be specified but it is not necessary that these performance levels be quantitative. These performance characteristics are considered to be important in applications where the membrane may be exposed to chemical or fungus attack during service. In these cases, the chemical or fungus resistance of the membrane should be determined before application according to the applicable test procedure.

The suggested preliminary performance levels for hail and punching shear resistance given in table 3 have been selected from criteria proposed for bituminous built-up roofing membranes [25] on the basis that elastomeric roofing should perform as well as bituminous built-up roofing. Research is needed to establish data on which the recommended level of performance for hail and punching shear resistance may be based. The recommended level of performance for these performance characteristics depends on the substrate.

The suggested level of performance for the strength of seams in sheet membranes has been taken from Martin's recommendation that seams with T-peel strengths less than 6 lbf/in (1 kN/m) should be considered suspect for use in exposed applications [8]. The relationship between the T-peel strength and the in-service performance of seams has not been fully established [8].

Finally, the suggested preliminary level of performance that the membrane be weather-resistant for a minimum period of 15 years seems well-founded since some elastomeric membranes have performed satisfactorily for 15 years or even longer. Moreover, it is usually anticipated that conventional bituminous built-up membranes will be weather-resistant for 15 to 20 years or longer. Elastomeric membranes should perform as well as conventional membranes. For either type of membrane, bituminous or elastomeric, routine maintenance is expected and necessary during the service-life.

It is of course difficult to predict the weather resistance of a new material whose service life is expected to be 15 years or longer. The ultimate test of weather resistance is in-service performance, but this is not practical in the cases of new materials. Thus, laboratory tests are used in attempts to predict performance. The relationships between laboratory tests and weather resistance are difficult if not impossible to establish. Table 3 lists some laboratory test methods which may be used in efforts to predict the weather resistance of elastomeric membranes. Criteria are not presently available to enable the prediction of weather resistance from these test methods and need to be established.

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Table 3. Suggested Performance Characteristics for Elastomeric Membranes

Performance Characteristic	Suggested Preliminary Level of Performance	Method of Test	Comment
Adhesion between layers	Not established	Not established	Multi-layered membranes should resist delamination, blistering or peeling between layers.
Chemical resistance	Should be resistant	ASTM D 543	Elastomeric membranes should be resistant to solvents and chemicals to which they may be exposed during both application and service life.
Color stability and reflectivity	Percent allowable change not established	Not established	Color stability is to be considered an essential performance characteristic when the color of the membrane is chosen to reflect solar radiation. In these cases, the reflectivity of the membrane should not be altered by color change or dirt retention.
Creep resistance	Not established	Not established	This level of performance may depend upon the design of the roofing system.
Fire resistance	Class A, B or C	UL 790 [26]	UL 790 has been accepted by the roofing industry as a test procedure for indicating the fire resistance of roofing membranes.
Fungus resistance	Should be resistant	ASTM G 21	--
Impact resistance	Resistant to a 1-1/2 in (38 mm) hailstone falling at 112 ft/s (34 m/s)	Hail Test [27]	This level of performance has been recommended for bituminous roofing membranes [25] and may be applied to elastomeric membranes. Lower limits may be established for areas which are not subjected to severe hailstorms. Resistance depends on the substrate.
Resistance to foot traffic, wind blown particles and similar forces.			
o abrasion	Not established	Not established	--
o hardness	Not established	ASTM D 2240	--
o punching shear	Not less than 250 lbf/in^2 (1.7 MPa)	NBS Test Method	The test described in Building Science Series 55 [25], is conducted at 73 °F (23 °C) using a 3/4 in (19mm) diameter probe. This level of performance has been recommended for bituminous membranes and may be provisionally applied to elastomeric membranes. Resistance depends on the substrate.
Strength of seams (sheet systems)	Not less than 6 lbf/in (1kN/m)	ASTM D 1876	This level of performance is selected from Martin [8] who suggested that seams in sheet membranes should be considered suspect for use in exposed applications, if the strengths of the seams are less than 6 lbf/in (1kN/m) as measured by the T-peel test.
Stress resistance			The level of performance for stress resistance may depend upon design of the roof system. It may be necessary to establish levels of performance for stress resistance which are a function of both tensile strength and extensibility.
o tensile strength	Not established	ASTM D 412	
o ultimate elongation	Not established	ASTM D 412	
o tensile fatigue	Not established	Not established	
Tear resistance	Not established	Not established	ASTM methods of test D 624, D 751, D 1004 and D 1922 have been listed as means for measuring the tear resistance of elastomeric membranes [22].

Table 3. Suggested Performance Characteristics for Elastomeric Membranes (continued)

Performance Characteristic	Suggested Preliminary Level of Performance	Method of Test	Comment
Thermal expansion	Not established	ASTM D 696	This level of performance may depend upon the design of the roofing system.
Water resistance			
o absorption	Not established	ASTM D 570	--
o vapor transmission	Not established	ASTM E 96	This level of performance will depend upon the design of the roofing system which may require either a non-permeable or permeable membrane.
Wind resistance	Class (30), (60) or (90)	UL Test Procedure [28]	This level of performance is believed adequate for most areas in the United States. Other tests such as those recommended by Factory Mutual may be suitable [29,30].
Weather resistance	Should be resistant for a minimum of 15 years	Experience and laboratory tests in conjunction with engineering judgment.	It is not unreasonable to expect a minimum service life of 15 years since some elastomeric membranes have performed satisfactorily for longer periods. Maintenance will be necessary during the service life. The ultimate test of weather resistance is in-service performance; laboratory tests may be conducted to predict weather resistance but the relationships between the laboratory tests and weathering are difficult if not impossible to establish. The decrease in performance characteristics after weathering should be limited.
o Accelerated aging	Not established	ASTM D 2565	These tests may provide an indication of the weather resistance of elastomeric membranes. Relationships between test results and performance need to be determined. The level of performance for brittleness may depend on expected winter temperatures.
o brittleness	Not established	ASTM D 2137	
o dimensional stability	Not established	ASTM D 1204	
o heat aging	Not established	ASTM D 573 or D 865	
o ozone resistance	Not established	ASTM D 1149	
o pollutants	Not established	Not established	
o volatile loss	1% maximum	ASTM D 1203	Loss of plasticizer may lead to embrittlement.

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APPENDIX

SUMMARY OF SELECTED REFERENCES

A major source of information in this survey on elastomeric roofing was the literature. However, in spite of more than 20 years of use in the United States, few articles have been published on this subject. The majority of articles uncovered in the literature survey were qualitative, describing reasons for using elastomeric roofing and advantages over conventional roofing systems. Few articles were found which were quantitative. In general, as stated in the text, information was not available to assess, evaluate or predict the performance and service-life of elastomeric roofing systems. This appendix presents a summary of selected references, both qualitative and quantitative, from the literature survey.

A.1 Qualitative References

Many authors have listed advantages associated with using elastomeric roofing [2-4]. Gumpertz discussed both the advantages and disadvantages of these roofing materials in a 1977 article in which he listed some liquid applied products available in the United States [3]. Baker stated that the advantages included lightness of weight, high elasticity, high reflectivity, resistance to foot traffic, and ease of roofing unusual contours such as curved shells, domes, hyperbolic paraboloids and folded plates [4].

In a 1971 publication, Disney outlined the advantages of both liquid applied and sheet applied membranes [5]. For liquid applied systems he listed the advantages as:

- o relative ease of application,
- o ability to conform to shape and form of substrate or irregular design without waste of material,
- o continuous waterproofing free of joints and seams,
- o high degree of adhesion to conventional substrates, and
- o ease of handling and transporting materials since they are packaged in conventional pails.

For sheet applied systems, the advantages according to Disney were:

- o the thickness of the membrane is determined prior to application,
- o the material is generally precured so that the physical properties are readily determined before application and there is no need to rely on atmospheric curing after application, and
- o more deficiencies in the deck can be tolerated. Proper installation will provide greater tolerance for more severe movement, and expansion and contraction of the roof deck. In addition the sheet can be allowed to "float free" and remain unbonded over concentrated areas of movement.

Cleary discussed elastomeric roofing stating that these materials offer improved physical and chemical properties, such as greater flexibility at lower temperatures and resistance to solvents, corrosive chemicals and fire [6]. He also stated that elastomeric roofing is subject to some of the shortcomings of bituminous roofing, such as certain design limitations and a need for quality workmanship during application.

One of the more detailed articles on elastomeric roofing was written in 1969 by Gumpertz [7]. He described the various systems available at the time. In addition he discussed performance properties, design limitations, and problems involving the deck, the materials and application. Gumpertz suggested that the use of elastomeric roofing was acceptable if the following precautions were observed:

- o the material and its manufacturer were known,
- o the pecularities of the elastomeric system were matched to the roofing requirements,
- o the previous performance of the system was checked,
- o a suitable substrate for proper application was provided,
- o proper joint and flashing details were developed, and
- o skilled application was insured as specified.

A.2 Quantitative References

One of the earlier articles describing research on elastomeric roofing systems was published by Cleary [6]. He reported some preliminary data from a laboratory and field program which compared some materials properties and field performance of some elastomeric membranes [6]. In the laboratory phase, he measured the values of low temperature flexibility, water vapor permeability, tensile strength, elongation, seam strength (for sheet systems) and resistance to accelerated weathering for neoprene-chlorosulphonated polyethylene, silicone, butyl, polyvinyl fluoride composite, neoprene and ethylene propylene diene terpolymer membranes. The results of Cleary's measurements are presented in table 4. It is difficult to correlate these material property values with those from other sources since Cleary did not describe the test methods by which the values were measured. In his paper, he stated that the results of accelerated weathering indicated that the materials in the test program were generally resistant to weathering, although he admitted that it is difficult to relate accelerated weathering to in-service performance.

In the field study, Cleary exposed 8 x 8 ft (2 x 2 m) test roofing specimens consisting of a cement-asbestos board deck, glass-fiber or wood-fiber board insulation with taped joints and an elastomeric membrane [6]. Each test specimen had one-third of the deck area sloped at 30 degrees, a 6 in (150 mm) cant around the flat section, a 4 in (100 mm) drain and a 4 in (100 mm) stack vent installed through the flat portion of the deck. The outdoor performance of the test specimens was reported after 6 months exposure which is considered too short a time period for evaluation; nevertheless, some differences in the performance of the systems were observed. The ethylene propylene diene terpolymer lifted from the insulation at the intersection of the cant and sloped roof section, became slightly chalky and changed color in the flashing. The butyl sheet membrane delaminated

Table 4. Laboratory Data for Some Elastomeric Roofing Materials, According to Cleary [6].

Material	Thickness mils (mm)	Flexibility -67 °F (-55 °C)	Permeability perms (kg/Pa·s·m^2)	Tensile Strength lbf/in^2 (MPa)	Elongation %	Seam Strength lbf/in^2 (kPa)	Accelerated Weathering 1000 hours
Liquid-Applied							
Neoprene-CSP[1]	18-20 (0.46-0.51)	fail	0.007 ($4x10^{-13}$)	1495 (10.3)	653	na[2]	considerable chalking
Neoprene-CSP	18-20 (0.46-0.51)	fail	0.008 ($5x10^{-13}$)	1120 (7.7)	495	na	severe chalking; moderate yellowing
Silicone	22 (0.56)	pass	0.234 ($1.34x10^{-11}$)	203 (1.1)	24	na	slight chalking
Sheet-Applied							
Butyl (black)	30-45 (0.76-1.1)	pass	0.001 ($6x10^{-14}$)	742 (5.1)	535	21.3 (147)	no change
Butyl (white)	30-45 (0.76-1.1)	pass	0.001 ($6x10^{-14}$)	609 (4.2)	479	23.0 (159)	severe chalking; surface tacky when wet with water
Butyl sheet II (black)	30-45 (0.76-1.1)	pass	0.001 ($6x10^{-14}$)	942 (6.5)	674	11.6 (80)	same as unweathered sheet
Polyvinyl fluoride composite	25 (0.64)	pass	0.0387 ($2.22x10^{-12}$)	1068 (7.4)	105	na	same as unweathered sheet
Neoprene	65 (1.6)	fail	0.009 ($5x10^{-13}$)	2557 (17.6)	301	75.1 (518)	slight chalking
Ethylene propylene diene terpolymer (EPDM)	50 (1.3)	pass	0.001 ($5x10^{-14}$)	493 (3.4)	493	10.3 (71.0)	same as unweathered; some failure of adhesive.

(1) CSP indicates chlorosulphonated polyethylene
(2) na indicates not applicable

from the insulation at the intersection of the cant and the sloped roof area, and underwent splitting at the extremities of the vent flashing and at 90 degree bends, where the membrane was stretched during installation. Some joints of the polyvinyl fluoride composite membrane failed. The neoprene-chlorosulphonated polyethylene membrane system and the silicone membrane system showed no changes with the exception that the tapes over the joints of insulation boards buckled.

Martin conducted an experimental program in Australia whereby he measured the tensile strengths and ultimate elongations of sheet membranes, both unexposed and exposed to outdoor and accelerated aging, evaluated the capability of the membranes to bridge moving joints, and measured the peel strengths of lap seams in sheet membranes [8]. Sheet membrane materials evaluated by Martin included asbestos-backed chlorosulphonated polyethylene, polyisobutylene, butyl, ethylene propylene diene terpolymer, polyurethane, polyethylene, polyvinylchloride and polyvinyl fluoride. Martin concluded from the program that a number of plastic sheet materials offered promise of improved roofing performance in comparison to conventional materials used in fabricating membranes.

The results of Martin's tensile evaluation of these sheet materials are given in tables 5, 6 and 7. Martin evaluated the capability of the sheet materials to bridge moving joints by affixing them to a moving joint tester which was exposed outdoors. The joint width changed dimension as the temperature varied. At 77 °F (25 °C), the joint of the tester was set at a width of 100 mils (2.5 mm); it would close to 20 mils (0.5 mm) at 176 °F (80 °C) and open to 140 mils (3.5 mm) at 32 °F (0 °C). The performances of some elastomeric membranes on the moving joint tester are summerized in table 8.

The third phase of Martin's program evaluating the performances of elastomeric sheet membranes consisted of determining the bond strengths of lap seams for the sheets included in the other phases of his study. Bond strengths were determined by the T-peel test described in ASTM test method D 1876-72. Based on the results of his testing, Martin concluded that values of T-peel strengths less than 6 lbf/in (1 kN/m) indicated that the system should be considered suspect for use in applications where the lap seam is exposed, although there was little information available to relate T-peel test results to in-service performance. Using this criterion he considered that the potential applications of butyl rubber and polyisobutylene as roofing membranes were limited because he found that it was difficult to obtain high bond strengths with these materials.

Stafford reported the results of a field program conducted in Ottawa, Canada in which 10 roofing system specimens were exposed for 2 years [9]. He evaluated the performance of these systems by periodic visual inspections. The systems, some of which were experimental and some of which are not commercially available today, are presented in table 9. The roofing systems 1 through 11 were attached to plywood panel decks and mounted on racks 6 ft (2 m) off the ground so that air freely circulated around the specimens. System 12 was fabricated on an insulated wood deck on top of a small building whose interior temperature was maintained constant during the winter. All specimens were sloped to insure adequate drainage.

Table 5. Tensile Assessment of Chlorosulphonated Polyethylene Sheets, According to Martin [8].

Specimen(1)	Exposure	Breaking Load(2)			Elongation at Rupture(2)
		lbf/in	kg/mm(3)	kN/m	%
English white	unexposed	25	0.45	4.5	570
	outdoors 18 months	31	0.55	5.5	390
	outdoors 36 months	35	0.62	6.2	400
	xenon-arc 2000h	28	0.50	5.0	440
	xenon-arc 6500h	36	0.65	6.5	370
English black	unexposed	28	0.50	5.0	400
	outdoors 18 months	34	0.60	6.0	290
	outdoors 36 months	44	0.78	7.8	280
	xenon-arc 2000h	34	0.60	6.0	350
	xenon-arc 6500h	39	0.70	7.0	290
English green	unexposed	25	0.45	4.5	660
	outdoors 18 months	28	0.50	5.0	390
	outdoors 36 months	45	0.81	8.1	360
	xenon-arc 2000h	31	0.55	5.5	430
	xenon-arc 6500h	36	0.65	6.5	370
American white	unexposed	28	0.50	5.0	460
	outdoors 12 months	28	0.50	5.0	390
	outdoors 30 months	29	0.52	5.2	400
	xenon-arc 2000h	31	0.55	5.5	430
	xenon-arc 6500h	25	0.45	4.5	370
American black	unexposed	39	0.70	7.0	250
	outdoors 12 months	50	0.90	9.0	180
	outdoors 30 months	64	1.15	11.5	170
	xenon-arc 2000h	50	0.90	9.0	170
	xenon-arc 6500h	59	1.05	10.5	150
Australian white	unexposed	25	0.45	4.5	580
	outdoors 12 months	28	0.50	5.0	420
	outdoors 30 months	30	0.53	5.3	430
	xenon-arc 2000h	25	0.45	4.5	460
	xenon-arc 6500h	34	0.60	6.0	360

(1) Specimen was designated by Martin according to country or origin and color. Thicknesses were not reported.

(2) Determined according to ASTM D 412-68, using die C, test temperature was not reported.

(3) The units, kg/mm, are used by the author in the quoted reference [8].

Table 6. Tensile Assessment of Various Elastomeric Sheets, According to Martin [8].

Specimen(1)	Exposure	Breaking Load(2) lbf/in	Breaking Load(2) kg/mm(3)	Breaking Load(2) kN/m	Elongation at Rupture(2) %
Polyisobutylene A	unexposed	29	0.52	5.2	575
60 mils (1.5 mm)	outdoors 30 months	28	0.50	5.0	565
	xenon-arc 5000h	29	0.51	5.1	540
Polyisobutylene B	unexposed	14	0.25	2.5	315
20 mils (0.5 mm)	outdoors 12 months	13	0.23	2.3	270
	xenon-arc 5000h	11	0.20	2.0	170
Butyl rubber A	unexposed	49	0.88	8.8	475
40 mils (1.0 mm)	outdoors 30 months	52	0.93	9.3	490
	xenon-arc 5000h	57	1.01	10.1	390
Butyl rubber B	unexposed	29	0.52	5.2	580
20 mils (0.5 mm)	outdoors 12 months	30	0.53	5.3	550
	xenon-arc 5000h	34	0.60	6.0	420
Soft ethylene	unexposed	5	0.09	0.9	110
propylene	outdoors 36 months	9	0.16	1.6	70
100 mils (2.5)	xenon-arc 5000h	16	0.28	2.8	75
Soft butyl tape	unexposed	1	0.02	0.2	600
80 mils (2.0 mm)	outdoors 12 months	3	0.05	0.5	300
	xenon-arc 5000h	3	0.05	0.5	150
Polyurethane	unexposed	22	0.39	3.9	66
100 mils (2.5 mm)	outdoors 36 months	25	0.45	4.5	45
	xenon-arc 5000h	34	0.61	6.1	42

(1) Designation includes the thickness of the specimen.

(2) Determine according to ASTM D 412-68, using die C, test temperature was not reported.

(3) The units, kg/mm, are used by the author in the quoted reference [8].

Table 7. Tensile Assessment of Various Thermoplastic Sheets, According to Martin [8].

Specimen (1)	Exposure	Breaking Load (2) lbf/in	Breaking Load (2) kg/mm (3)	Breaking Load (2) kN/m	Elongation at Rupture (2) %
Black polyethylene 4 mils (0.1 mm)	unexposed	7	0.12	1.2	260
	outdoors 30 months	7	0.12	1.2	145
	xenon-arc 5000h	6	0.10	1.0	85
Black polyvinyl chloride 6 mils (0.15 mm)	unexposed	12	0.22	2.2	280
	outdoors 30 months	20	0.36	3.6	15
	xenon-arc 5000h	17	0.30	3.0	10
Gray polyvinyl chloride, asbestos-backed 20 mils (0.5 mm)	unexposed	45	0.84	8.4	60
	outdoors 36 months	54	0.96	9.6	18
	xenon-arc 5000h	67	1.20	12.0	15
White polyvinyl chloride nylon-reinforced 12 mils (0.3 mm)	unexposed	336	6.00	60.0	200
	outdoors 36 months	347	6.20	62.0	60
	xenon-arc 5000h	352	6.30	63.0	56
Green polyvinyl fluoride 20 mils (0.5 mils)	unexposed	8	0.14	1.4	98
	outdoors 36 months	8	0.15	1.5	70
	xenon-arc 5000h	8	0.15	1.5	70

(1) Designation includes the thickness of the specimen.
(2) Determined according to ASTM D 412-68, using die C, test temperature not recorded.
(3) The units, kg/mm, are used by the author in the quoted reference [8].

Table 8. Synopsis of Martin's Results Assessing the Capability of Elastomeric Sheet Membranes to Accommodate Joint Movement in the Substrate [8].

Material	Results(1)
Chlorosulphonated polyethylene asbestos-backed, white Australian	no rupture of the membrane over 36 months exposure; the asbestos backing ruptured; considerable loss of bond between asbestos backing and the membrane wrinkled over joint.
Soft butyl tape	failed after 3 months exposure; retained bond to substrate.
Soft ethylene propylene	no rupture over 15 months; no loss of bond to substrate.
Butyl rubber	no failure over 36 months exposure; loss of adhesion to the substrate in the vicinity of the moving joint.
Polyisobutylene	no failure over 36 months exposure; loss of adhesion to the substrate in the vicinity of the moving joint.
Polyurethane	no failure over 36 months exposure; loss of adhesion to the substrate in the vicinity of the moving joint.

(1) Test was conducted according to the test method described by Martin [8].

Table 9. Roofing Systems Included in Stafford's Outdoor Exposure Program [9].

Specimen No.	Exposure Years	Specimen Description
1	5	A polyisobutylene sheet bonded to a supporting reinforcement made of elastomer impregnated asbestos felt and coated with a white acrylic latex.
2	5	An asphalt membrane, reinforced with glass fabric and surfaced with aluminum-metal foil, bonded to a base sheet of glass or asbestos and saturated with asphalt.
3	5	A black butyl sheet membrane composed of a copolymer of isobutylene and isopren, applied to the substrate with a contact type adhesive.
4	5	A butyl sheet like No. 3 but white in color.
5	5	A thin film roofing, produced by the application of several liquid neoprene coats, and coated with successive layers of chlorosulphonated polyethylene.
6	5	(a) a two component liquid-applied white rubber, used in conjunction with a silicone primer (b) a glass-fabric reinforced silicone sheet, applied with a contact adhesive.
7	5	A cold process roofing system, employing roofing felts, cold applied sclvent adhesive and a cold applied emulsified asphalt.
8	5	A single-ply roofing system, consisting of a white polyvinyl fluoride film, factory laminated to an asbestos felt which is impregnated with a neoprene latex.
9	5	A white liquid-applied butyl latex system in which is embedded a lightweight glass fiber mat, topcoated with chlorosulphonated polyethylene.
10	5	A conventional built-up membrane consisting plies of type 15 saturated felt bonded together with hot asphalt and surfaced with gravel.
11	2	A single-ply white roofing sheet, made of ethylene propylene terpolymer, and applied with a contact adhesive.
12	2	A single-ply sheet, comprised of white chlorosulphonated polyethylene coated over a thin polyurethane foam bonded to the substrate with an adhesive.

Stafford reported that the principal failings of the non-conventional roofing systems included in the field program were the adhesives used at the overlaps and flashings, and the thin liquid-applied top-coatings which underwent relatively rapid failure. While pointing out the failings of these systems, he suggested that they still might be employed because of their distinct advantages, such as ease of maintenance and inspection due to lack of gravel, ease of application, reflectivity and lightness in weight.

In concluding his report, Stafford stated that of the ten systems exposed for 5 years listed in table 9, four of them were performing in a superior manner [9]. These were the foil-surfaced bitumen sheet, the cold-process asphalt roofing, the polyvinyl fluoride-asbestos sheet and the hot asphalt built-up membrane. He also stated that the two systems exposed for 2 years were performing well and showed no evidence of premature failure.

Keeton, Alumbaugh and Humm have recently published the results of a detailed study which evaluated the in-service performance of experimental polyurethane foam roofing systems [10]. In this study, the roof of a metal building located in Clifton, New Jersey, was insulated with spray-in-place polyurethane foam which was protected with five elastomeric coatings applied to different sections of the roof. The performance of the entire roofing system including the elastomeric coatings was evaluated by periodic visual inspections over 22 months. Temperatures were monitored at various locations including at the base of the foam, on top of the foam, in the attics of the buildings and outside the buildings. Heating fuel consumption for 2 years before and for 2 years after application of the foam roofing system were compared to determine the reduction in fuel usage attributed to insulating the roofs.

The five elastomeric coatings studied by Keeton, Alumbaugh and Humm are presented in table 10 along with the tensile strengths, elongations, the authors' performance ratings over 22 months of exposure, and descriptions of the conditions of the coatings after 22 months. Table 10 shows that the performance of the silicone coatings were reported to be superior to that of the other coatings.

In their report, Keeton, Alumbaugh and Humm described the effect of a hail storm which occurred just prior to the 22 month visual inspection on the performance of the experimental roof. Hail damage was sustained on coatings 3, 4, and 5, although the damage to coating 5 was less than that to coatings 3 and 4. No evidence of hail damage occurred on either of the silicone coatings 1 and 2. From this observation, the authors suggested that an elastomeric coating for use on spray-in-place polyurethane foam roofing should have a minimum tensile strength of 300 lbf/in^2 (2.1 MPa) to exhibit resistance to hail [10].

Koike and Tanaka have tested nine elastomeric sheet materials commercially available in Japan to determine their resistance to ozone [11] and to weathering [12]. The materials studied in this program included four different sheets composed of butyl/EPDM blends, three different butyl sheets, one neoprene sheet and one polyisobutylene sheet. The materials were tested as dumbbell shaped specimens elongated to 20, 40, 60, 80 or 100 percent between gage marks and tested bonded to cement-asbestos boards containing a joint whose width could be varied. Both types of specimens were also tested under dynamic loading to assess the ozone resistance of the sheet materials.

Table 10. Elastomeric Coatings for Spray-In-Place Polyurethane Foam Roofing, Evaluated by Keeton Alumbaugh and Humm [10].

System Number and Material	Tensile Strength lbf/in^2	Tensile Strength MPa	Elongation %	Performance Rating	Condition of the Coating After 22 Months Exposure
1. Catalyzed Silicone with granules without granules	311	2.14	97	 Excellent Very Good	Coating with granules in slightly better condition; no hail damage observed on either section of this system
2. Moisture-curing Silicone	389	2.68	204	Very Good	Very comparable in performance to system 1 without granules; deterioration limited to a few very small scattered areas where coating was removed and foam had degraded.
3. Catalyzed Butyl-Chlorosulphonated Polyethylene	117	0.81	308	Poor	Coating has deteriorated to the point of near failure in many areas due to severe checking, cracking, erosion and hail damage.
4. Chlorosulphonated Polyethylene Mastic	227	1.56	489	Poor to Fair	Most severe deterioration was due to hail damage; also had severe erosion of coating exposing foam on the south side of the roof.
5. Catalyzed Butyl-Chlorosulphonated Polyethylene	142	0.98	79	Fair to Good	Coating exhibited only very light, scattered deterioration until hail damage occurred.

Resistance to ozone was evaluated by placing the test specimens in a chamber containing an ozone concentration of 50 parts per hundred million (pphm) by volume in air, and by visually determining the degree of cracking occurring in the specimens as a function of time [11]. Regarding ozone resistance, Koike and Tanaka reported the following results:

- the sheets composed of butyl/EPDM blends were superior to the butyl sheets.
- the butyl and neoprene sheet were inferior to the other sheets.
- the polyisobutylene sheet did not crack when exposed to ozone under static loading, but easily ruptured when exposed dynamically, indicating that this material had poor resistance to fatigue.
- for any specimen loaded statically, the greater the elongation, the sooner cracking occurred in the sheet.
- for specimens bonded to cement asbestos boards, materials adhered with flexible adhesives performed better than those adhered with rigid adhesives.

Koike and Tanaka evaluated the resistance of the sheets to weathering by exposing the test specimens outdoors at Kokyo and Sapporo for 4 years and by periodically inspecting them for cracking [12]. The results of the outdoor exposure indicate that:

- the materials performed better in Sapporo than in Tokyo. (Sapporo reportedly has a cleaner environment.)
- the sheets composed of butyl/EPDM blends were more resistant to weathering than the neoprene sheet which was more resistant than the butyl sheets.
- for any specimen loaded statically, the greater the elongation, the sooner cracking occurred in the sheet.
- for bonded specimens, materials adhered with flexible adhesives performed better than those adhered with rigid adhesives. Some of the bonded sheets showed no cracking during outdoor exposure although they cracked when exposed alone as dumbbell specimens.

In comparing the results of the ozone and weathering tests, Koike and Tanaka reported that in general sheets which showed cracking early in the ozone test also cracked early during outdoor exposure. They also reported that although the butyl/EPDM blends were relatively resistant to ozone, they cracked comparatively early during outdoor exposure.

In a comprehensive report, Jones has recently described the U.S. Bureau of Reclamations's laboratory and field program to investigate new roofing materials used over substrates such as concrete, wood and insulation boards [13]. One phase of the investigations evaluated the performance of exposed elastomeric roofing membrane systems. In this phase tests were conducted to determine the peel strengths, resistances to uplift forces and resistances to indentation of sheet membrane materials such as butyl, EPDM and neoprene bonded to various insulation boards. Other tests were conducted to evaluate the performance of chlorosulphonated polyethylene reflective coatings used to reduce the surface temperatures of black elastomeric sheetings. In addition, a review of the in-service performances of more than 60 elastomeric roofing systems was described. These systems included liquid applied neoprene/chlorosulphonated polyethylene membranes over vegetable fiberboard insulation or concrete, sheet neoprene/ chlorosulphonated polyethylene membranes over vegetable fiberboard insulation, and butyl or EPDM membranes over vegetable fiberboard or extruded polystyrene insulations.

The performances of these systems as described by Jones [13] were as follows: the only two liquid applied neoprene/chlorosulphonated polyethylene membranes applied over insulation boards failed, reportedly because of embrittlement and too thin an application due to absorption of the liquid material into the insulation boards during fabrication. Comparable membranes performed satisfactorily over concrete with the exception of some blistering problems.

Four of the 20 sheet neoprene/chlorosulphonated polyethylene membranes over fiberboard insulation experienced failures attributed to ozone cracking or embrittlement. Of the 40 membranes fabricated from butyl or EPDM sheets, two membranes failed because of improper sealing in locations where two seams overlapped at right angles. Another membrane failed because mechanical fasteners, attaching the insulation to the deck, loosened and punctured the membrane from below. It is noted that Jones did not report any failures within these 60 systems which were attributed to inadequte bonding of lap seams in sheet membrance. In summarizing his findings concerning the in-service performance of exposed elastomeric membranes, Jones stated that butyl and butyl/EPDM blends have performed the most satisfactorily to date. However, he believed that the relatively short exposure of these roofs precluded a final assessment of performance at this time.

Another phase of the Bureau of Reclammation's program to evaluate new materials for roof construction involved the performance of spray-in-place polyurethane foam roofing and protective elastomeric coatings for these systems [13]. Tests conducted on the coatings were primarily limited to determining resistance to impact, accelerated aging upon exposure to a xenon-arc, and outdoor exposure at Denver, Colorado. The elastomeric coatings were generally classified as acrylic, butyl, chlorosulphonated polyethylene, polyester, silicone, urethane and vinyl. An aluminum-pigmented asphaltic coating was also included in the study.

Concerning the performance of the coatings evaluated, Jones reported the following observations [13]. The silicone coatings indicated excellent resistance to ultraviolet radiation, resistance to flow during application and satisfactory resistance to light foot traffic and hail storms. The one acrylic coating in the study showed good resistance to impact and promising resistance to weathering, but the data were considered insufficient to allow a long term evaluation. Some urethane coatings showed high resistance to hail damage, but poor resistance to ultraviolet radiation and to flow during application. The chlorosulphonated polyethylene coatings performed well but rapidly lost flexibility at low temperatures and were susceptible to hail damage after 2 to 4 years. The butyl coatings indicated possibilities for long term service but Jones noted that they should be applied at thicknesses greater than recommended to compensate for chalking and to prevent cracking. The vinyl, polyester and asphalt-based coatings showed embrittlement and failed after relatively short periods of exposure.

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15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

In recent years the use of elastomeric roofing systems in the United States has been increasing. A survey was conducted to ascertain the current state-of-the-art of these roofing systems. The information obtained in the survey was gathered from a literature search complemented by the opinions of people knowledgeable in the field including researchers, contractors, manufacturers and users. A listing of the current elastomeric roofing materials was compiled, along with test methods for determining the properties of membranes fabricated with these materials. The principal materials, available in either liquid or sheet applied systems, included acrylic, butyl, chlorosulphonated polyethylene, EPDM (ethylene propylene diene terpolymer), neoprene, polyvinyl chloride (PVC) and vinyl, silicone and urethane. In addition to these materials some composite membranes were also available.

Factors affecting the performance of the membranes were identified including durability, design of the roofing system, substrate condition at the time of application attachment of the membrane to the substrate and workmanship during application. The performance of elastomeric roofing was discussed based on its advantages, disadvantages and limitations. Guidelines to assist the user in the selection and use of elastomeric roofing were prepared for both new and remedial roofing applications.

Criteria were not available to evaluate or predict the performance of elastomeric roofing. As a first step in the development of criteria, preliminary performance characteristics were suggested.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

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