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State of the Art on Durability Testing of Building Components and Materials

Larry W. Masters, Winthrop C. Wolfe, Walter J. Rossiter, Jr., James R. Shaver

Center for Building Technology
Institute for Applied Technology
National Bureau of Standards
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U. S. DEPARTMENT OF COMMERCE, Frederick B. Dent, Secretary

NATIONAL BUREAU OF STANDARDS, Richard W. Roberts, Director

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GLOSSARY

Aging (1) Change in physical or chemical properties with the passage of time. The effect of exposure to an environment for an interval of time on systems, components and materials.

(2) The process of exposing systems, components, and materials to an environment for an interval of time.

Weathering Changes occurring in systems, components, and materials due to actual exposure to climate and to other environmental factors.

Deterioration The loss of appearance and/or functional service with time; used interchangeably with aging.

Durability (1) Resistance to deterioration

(2) Service life or period during which a system, component or material remains above a minimum acceptable performance level.

Predictive testing Short-term testing of components or materials designed to predict the long-term performance (durability) of the components or materials.

Climate Mean physical state of the atmosphere and solar radiation in a given area over a period of time or total weather behavior in general.

Environment The sum of all weathering, stress and physical, chemical or mechanical incompatibility factors to which a housing system, component or material is exposed.

Weather The state of the atmosphere and solar radiation at a given time in a given area. The state of the atmosphere is defined by weather elements, the most important of which are clouds, precipitation, temperature, humidity, wind, pressure, and visibility.

Building Material The matter of which a building component is comprised such as brick, concrete, lumber, etc.

Building Component A part of a building formed by combining building materials such as a wall.

Building System A structure or building composed of various components and materials which have been combined in such a way as to provide a shelter for man or his property.

Sandwich construction A construction in which a core material is bonded on two sides by adhesion to facings (or skins) resulting in a composite structure which can be used as the walls, roof or floor in housing systems.

Structural component Component which is designed to carry a load or weight of the building or stresses to which the building is subjected in service, such as wind or snow loads.

Non-structural component Component which does not have a structural function or in which the primary function is decorative or protective rather than structural.

ABSTRACT

This report is a summary of the present knowledge pertaining to durability predictions for building components and materials which are subjected to the effects of outdoor exposure. The various chapters of the report include discussions of the nature of aging, the measurement of properties to predict durability, non-destructive evaluation techniques, outdoor exposure techniques, accelerated aging techniques, techniques for applying testing data to durability predictions and difficulties which arise in predicting durability. Conclusions and recommendations are also included.

An appendix, which summarizes ASTM Standards for durability testing of building components and materials, is included.

1.0 INTRODUCTION

The term "aging", when used in relation to materials, components and systems, refers to a change, with time, in some chemical or physical property which generally results in a decreased performance capability. Factors which affect the rate and extent of aging include climatic exposure, applied stresses (either sustained or cyclic), faulty construction or installation, inappropriate usage, and physical abuse.

The prediction of the rates and effects of aging is necessary in order to estimate maintenance costs and frequency of repair and replacement; in short, prediction is aimed at the proper types of usage of materials, components and systems in specific exposure environments.

Past research efforts have attempted to fulfill this need for predictive ability by developing laboratory based testing procedures. These attempts have either sought to provide quality control or to accelerate natural aging processes. The intent of the quality control type of procedure is to provide a means of comparing two or more similar materials by relating comparable changes in their properties resulting from short-term exposures. These procedures (or tests) do not in themselves produce estimates of long-term performance, but rather are used as the basis for estimating the performance of new or untried materials.

The goal of accelerated aging is to produce, in a much shorter time, the changes in a component or material that would occur in real time of extended duration. Thus, an acclerated aging procedure which fulfills its goal would permit short-term test results to be extrapolated to long-term performance.

Since existing testing and exposure procedures seldom yield results which can be correlated to long-term performance, durability predictions also include a judgmental factor which is based upon a knowledge of materials' behavior. This approach of predicting durability is inadequate, particularly so for new or innovative housing components and materials for which experience is not yet available.

Durability is usually defined at the building component or materials level because it is difficult, if not impossible, to either define or test for the durability of a building system. The durability of a total building system is difficult to define because each component or material comprising the system may have different durability requirements. For example, an exterior paint may be called durable if it performs five years whereas roofing shingles may be required to perform twenty years to be classified as durable. It is also difficult to determine the durability of a system by testing because each component and material comprising the system performs a specific function and must be evaluated in that particular performance function. For example, an exterior coating provides protection to the materials it covers and, at the same time, provides an esthetically pleasing appearance. Durability tests for this material must determine if the paint performs these function by testing for such properties as fading, chalking, embrittlement, etc. under environmental conditions to which it will be exposed. The function of a material such as a joint sealant is to seal the joints in buildings to prevent the penetration of exterior environmental factors to the interior of the system. To perform this function, the sealant must resist degradation by such climatological factors as solar radiation, moisture, and temperature changes and in addition, it must expand and contract with the movement of its adjoining materials. Tests for sealants must, therefore, reflect these performance requirements. Durability test procedures are, for this reason, designed for specific components or materials because it is not practical with present knowledge to either define or test for durability of total building systems.

1.1 Scope

This report is a review and summary of current technology and methodologies related to the predictive testing of building components and materials. A preliminary discussion of the nature of aging of building components and materials is followed by a review of methods used to measure changes in properties or deterioration. Methods for natural and accelerated aging are described and a discussion of how accelerated aging tests can be used to predict durability is presented. Research recommendations are also included. An appendix listing ASTM test methods for outdoor and accelerated aging is included.

The content of this report is limited to the consideration of the deterioration of exterior building components and materials; it is not addressed to the deterioration of other interior finishes or surfaces. Where possible, the report distinguishes between tests designed for structural and non-structural components and materials. Of the factors listed previously as affecting aging, this report will be concerned only with weathering and applied stresses.

1.2 Sources of Information

This report is based on a review of published literature in appropriate fields, ASTM Standards, and a survey of research laboratories that are active in durability testing. The authors contacted approximately 70 manufacturers of building components and materials by written correspondence and visited twenty-two of those contacted. The authors are in close contact with government laboratories knowledgeable in durability testing. In addition, liaison has been established with appropriate ASTM Committees, such as the Committee on Simulated Service and Performance Testing, Committee D-14 on Adhesives, E-6, on Performance of Building Constructions, and E-7 on Non-Destructive Testing.

2.0 NATURE OF AGING OR DETERIORATION

2.1 Rate of Aging

Durability testing consists of measuring the rate at which a critical property or characteristic of a material or component changes with time (ages) in an attempt to estimate when that property will fall below an acceptable performance level under either specific or general exposure conditions. The aging rate is determined by the nature of the material in question such as its strength, hardness, flexibility, etc., its compatibility with the adjoining materials, and by such factors as exposure, climate, use and maintenance.

The durability of a material may be hypothetically classified by one of four modes of performance over a specified period of time, as illustrated by Figure 1. In this figure, the y axis is a measured value of a property of a material which is essential to its performance, e.g. the shear strength of an adhesive, the transparency of a plastic glazing material, or the extensibility of a joint sealant. The x axis is divided into arbitrary units of time. In using this technique as a measure of durability, a predetermined level of performance for the particular property must be identified above which the material conforms to the criteria. This level is indicated as the "acceptable performance level."

Curve A in Figure 1 illustrates a material which is very stable with respect to the selected property, so that essentially no change occurs with time and the material is always above the acceptable performance level. Properties such as tensile and flexural strength of structural steel will not change appreciable with time, provided the steel is protected from corrosion or is not exposed outdoors.

Curve B illustrates a material which undergoes a rapid initial increase in the value of a desirable property. Then the material adjusts to its environment and the increase in value is gradual as the value approaches the acceptable performance level. Probably the best example of this is the curing of concrete, which reaches about 75 percent of its ultimate compressive strength in 7 to 28 days, depending on the type of portland cement used.

Curve C illustrates a material the performance properties of which degrade linearly with time. If the slope of the line is known, durability can be predicted. Gray and Cadoff [1][1/] found that a plot of color change versus outdoor exposure time in months was approximately linear for rigid polyvinyl chloride (PVC) polymers.

Curve D illustrates a common type of durability curve. After an initial decrease in property value, it tends to level off until some point in time where a sudden break occurs and the property drops below

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[1/] Figures in brackets refer to literature references at the end of this report.

the acceptable performance level. Obviously this represents a material the durability of which is extremely hard to predict accurately. This is particularly true of materials such as sealants and adhesives.

2.2 Environmental Factors Affecting Performance

The performance capabilities of a building component or material may be degraded by 1) chemical factors, 2) physical factors, and 3) microbiological attack.

Building materials such as adhesives, asphalt roofing and siding, coatings, plastics, sealants, etc., are composed of organic compounds. Organic compounds in general are susceptible to chemical reaction with such elements and compounds as oxygen and water, and these reactions can lead to aging. Physical factors may also lead to changes which result in aging, such as the warping in plastics brought about by mechanical stress. An example of the third possible mechanism for degradation, microbiological deterioration, is fungi, which can cause damage to building materials composed of organic compounds.

Accelerated aging tests are designed to yield results which can be extrapolated to some in-use time. These tests are normally designed to incorporate environmental (primarily climatic) factors that are considered to be important in the degradation process. Environmental factors which may, to varying degrees, be causes of degradation are moisture, temperature, ultraviolet radiation, oxygen, wind, sand, dust, ozone, pollutants, salt, acids, alkalies, mildew, rot organisms, bacteria, etc. The principal factors are probably moisture, temperature, and ultraviolet radiation, with the other factors having somewhat lesser effects. Individual factors may assume greater importance in specific climatic or geographical areas.

For example, salt spray is an important factor near an ocean as are wind and sand in desert areas and chemical pollutants in industrial areas.

2.2.1 Effect of Moisture

Moisture may lead to the degradation of building materials as a result of its role in reactions based upon hydrolysis. Organic polymers in building materials often contain hydrolyzable groups such as esters, amides, nitriles and acetals. However, in many instances, the physical nature of absorbed moisture is more important as a degradative influence. For example, moisture absorbed in a glass-fiber reinforced polyester (GRP) material may not be detrimental in chemical deterioration but when freezing and thawing occurs, the resultant expansion and contraction cycling may result in a mechanical separation of the GRP fibers. Surface-adhered moisture has been shown [2] to significantly reduce the ability of an adhesive joint to support a sustained load. Several of the laboratories visited during this study have indicated that moisture vapor has a greater deteriorating effect on adhesive joints than water soaking.

Vapor penetration in sandwich construction can cause delamination of the skin material by weakening the adhesive joint. Moisture may also result in chemical corrosion of the skin material or deterioration of the core material.

Since moisture is an important factor in aging, many test methods include exposure to moisture, as in humidity chambers and light and water exposure apparatus. These test methods will be discussed in Chapter 6.0, Accelerated Aging Methods.

2.2.2 Effect of Temperature

The temperature changes to which building components are subjected through normal seasonal changes result in substantial movements of these components. The expansion and contraction observed with temperature changes are, of course, material dependent. Restraint of component movement can result in increased stresses in a housing system. To illustrate this, consider a sandwich-type construction with a paper honeycomb core and steel skins. Differential expansion and contraction between the paper honeycomb and the skin can result in increased stresses on the adhesive bond. Movement of the materials in the sandwich panel also results in stresses upon the adhesive or sealant material used to join or seal individual panels.

Data published by the National Oceanic and Atmospheric Administration (NOAA) in Climatological Data - National Summary, show that normal daily temperature variations of 25-35°F are not uncommon in most parts of the United States. Also, recorded temperature extremes are often very large. For example, Havre, Montana, has experienced temperatures varying from a high of 111°F to a low of -57°F -- a difference of 168°F! The average temperature variation in Havre due to seasonal changes is 56°F from a high of 70°F to a low of 14°F.

Cullen[3] notes that a roof exposed to solar radiation absorbs heat, resulting in a surface temperature higher than that of the ambient air, and states that surface temperatures on outer housing components as high as 165°F are not unusual. Cullen also states that, by radiative cooling, the temperature of a roof surface at night can drop below the ambient air temperature.

The temperature changes observed in building components and materials may therefore be quite large on a daily basis and even more so on an annual basis.

2.2.3 Effect of Ultraviolet Radiation

Such materials as coatings and sealants, as well as those composed of plastics, are affected considerably by sunlight, which causes deterioration in appearance and very often in function. Exposure to ultraviolet radiation causes many coatings to fade, chalk, or crack. Such failures are not only unsightly but may result in loss of serviceability, since the function of non-structural components such as coatings is largely to protect other components. The protective function may be severely hindered by degradation.

The solar constant, which is approximately 1.92 cal/min cm^2, is the energy falling on one sq. cm. area at normal incidence, outside the earth's atmosphere, at the mean distance of the earth from the sun. Energy distribution is irregular in various parts of the spectrum, with 4% of the total energy falling in the ultraviolet (0.20 to 0.38 micrometers), 43% in the visible (0.38 to 0.75 micrometers), and 53% in the infrared (0.75 - 25 micrometers). The energy of the solar radiation decreases as the wavelength increases so that the ultraviolet range is the primary zone of photochemical action. In this range, radiation energy is sufficient to break the chemical bonds [4] in the polymers of plastics, paints and associated materials and is therefore considered to be the primary portion of the sun's energy spectrum which causes materials degradation.

2.3 Classification of Climates

Although there are many different generic types of climate in the United States, existing accelerated aging procedures have not been designed for the most part to account for climatic variations. To better understand the importance of specific climatic conditions on the deterioration of building materials, it is necessary to distinguish and identify types of climates. Trewartha [5] has developed a scheme in which six major divisions of climate are defined, varying from tropical and desert climates to polar climates; all divisions are found in the United States. A detailed discussion of Trewartha's classifications and the importance of climatological considerations in developing tests for durability will be presented in a report to be submitted as the second output of this study.

The value of any accelerated aging procedure depends on the correlation developed between the accelerated test results and natural aging in the specific environment of ultimate exposure. Obviously, the varying weathering factors which are important to the aging of building components and materials in specific climates must be defined, as new procedures for accelerated aging are developed, these factors must be incorporated. Studies are needed, therefore, to define these factors and to determine how they may be feasibly considered in accelerated aging techniques.

2.4 Mechanical or Stress Factors

Structural materials and components are subjected to various types of loads in-service, and the presence of these loads can be an important factor in their aging. In general, the structural component must support a given load due to the dead weight of the structure. The actual load will change from time to time as the live loads applied to the structure change, with large increases occurring when wind and snow loads are applied.

Most durability tests for structural materials do not require an applied load during the test, although quite often the change in the load-carrying capacity of the material is used as a measure of durability. For certain materials, such as adhesives, the effect of load is included in the durability test by requiring that a dead load be applied during the test. This, however, does not account for the fluctuating or cyclic nature of the load in the actual structure.

3.0 ESTIMATING THE DURABILITY OF BUILDING MATERIALS AND COMPONENTS BY MEASUREMENT OF PROPERTIES

A product being evaluated to predict its durability is first subjected to an exposure condition, whether outdoors or in the laboratory, and then is studied to determine what changes may have taken place as a result of that exposure. The quantification of those changes constitutes the basis for estimating the durability of building components and materials. The properties of the material or component which are studied must effectively indicate deterioration or aging and it is therefore important to distinguish between those properties relating to appearance and those intrinsic to the serviceability of the component. It is a prerequisite that the tests or evaluative techniques do, in fact, measure the extent of changes in the selected properties.

3.1 Properties Used to Determine Durability

The choice of the property or properties to be studied to determine durability depends largely on the component or material to be evaluated. Protection of structural components is the most important function of non-structural components. Second in importance is the control of the interior environment, and third is the appearance of the building.

A detailed discussion of properties used for predicting the durability of various components and materials is not included in this report because it would be too voluminous. The following discussion will briefly summarize the importance of changes detected by visual inspection and those detected by measurement of physical and chemical properties. Additional information on the measurement of properties may be obtained in review papers by Fenner[6] or Supnik [7] or in texts such as those by Greathouse and Wessel [5] or Brown [8].

3.1.1 Visual Inspection and Appearance Properties

Changes in appearance, which can be characterized by visual inspection, are usually not important to the durability of structural components unless such changes are indications of deterioration.

Climatic conditions initially affect the surface of materials exposed outdoors and therefore durability is often estimated by measuring only changes in surface appearance. Surface appearance changes include fading, discoloration, chalking, cracking, and dirt retention.

3.1.2 Other Physical Properties

Properties other than appearance which may be important parameters in evaluating the durability of non-structural components include hardness, softening point, gloss retention, permeability, and water solubility and others. For example, thermal coefficient of expansion is one of the most important properties of elastomeric sealants. Also of importance for sealants is adhesion to the building components on either side of the filled joints. Impact resistance is important for cladding and roofing.

Strength and stiffness are the primary concern in evaluating the durability of structural components. Strength properties relevant to durability are compressive, shear, and tensile strength. Stiffness may be characterized by flexure or racking tests.

3.1.3 Chemical Properties

In addition to measuring physical properties, it is also possible to measure chemical properties and attempt to relate them to durability. Aging is normally attributed, at least in some materials, to a chemical degradation mechanism, so that by measuring the rate of the degradation reaction one can attempt to extrapolate the results to predict long-term degradation.

The application of chemical techniques to measuring rate of degradation is illustrated by the references cited below. Gray and Wright [9] developed a colorimetric method for measuring polyester degradation due to accelerated and natural weathering. Wallder [10] described a method using multiple internal reflection spectroscopy in the infrared region to detect and measure the carbonyl molecules which are products of polyethylene oxidation. He found the aging period necessary to detect meaningful changes to be short -- on the order of 40 hours outdoor exposure. A method [11] was developed for detecting hydroperoxide groups, which served to indicate chemical degradation, during the early stages of polyethylene oxidation.

The chemical degradation approach has been useful in areas of product development and in the study of stability additives for building materials. Most building materials are composed of many different chemical compounds. The various chemical compositions of building materials, therefore, leads to many different types of degradation mechanisms. Thus the prediction of durability by chemical means would require many different chemical methods to adequately cover all types of materials. For this reason, measurement of chemical properties has not been given as much attention in solving durability evaluation problems as measurement of physical properties.

4.0 NON-DESTRUCTIVE EVALUATIVE TECHNIQUES FOR ESTIMATING DURABILITY

Most accelerated aging tests are destructive since the test specimen is degraded to the point of failure as part of the evaluative process. Destructive tests are disadvantageous in that only one test result per specimen is obtainable and the specimen is not usable after the test. Destructive tests present a particular liability in the testing of large scale components. For these reasons, testing laboratories are considering non-destructive test techniques in durability testing. Non-destructive testing techniques have also been used as a means of detecting incipient changes in building materials which indicate deterioration. If such changes could be detected and measured in the early stages of deterioration, it might not be necessary to accelerate the exposure with accompanying problems as discussed in this report.

Non-destructive techniques discussed in this chapter are pulsed acoustic energy testing, resonance testing, acoustic emission and scanning electron microscopy.

4.1 Pulsed Acoustic Energy Testing

The process of sending pulsed acoustic energy signals through a material to evaluate it non-destructively is commonly referred to by most authors as ultrasonic testing. The pulsed signal is monitored after transmission through the material or after reflection back to the origin of the signal. Instrumentation has been developed which utilizes either separate transmitter and receiver crystals or single crystal units which serve as both transmitter and receiver. The signal may be analyzed for velocity of travel through the material, by quantitative determination of the relative intensities of transmitted and received signals, or by both methods. Changes in velocity or intensity of the energy signals indicate changes in the material.

The transmission principle of pulsed non-destructive testing involves the use of separate transmitter and receiver crystals. In one form of this application the two crystals are aligned geometrically on opposite sides of the material so that the pulsed acoustic energy signal from the transmitter energizes the receiver. The quantitative difference between the transmitted and received signals or the velocity of the signal as the crystals are moved over the surface of the material may be used to evaluate the quality of the material. A tentative ASTM Method, C-597-68T [12] has been developed for determining the longitudinal pulse velocity through concrete.

Another technique frequently used in pulsed acoustic energy testing is the pulse-echo technique. This technique consists of transmitting pulsed energy signals through the material and utilizes the same transducer for transmitting and detecting the signal. The signal reflected back to the origin is measured in this technique. The primary advantage of the pulse-echo technique over the transmission technique is that there is no problem with geometrically aligning the transmitter and receiver crystals.

Dietz [13] has used the transmission technique to study glass-reinforced plastics and found the velocity of transmission of the ultrasonic pulses to be directly proportional to the ratio of glass to resin. Zurbrick [14,15] studied pulsed acoustic energy and γ-radiometric non-destructive tests in relation to glass fabric-reinforced laminates. In these studies, he illustrated the relation between elastic moduli and longitudinal wave velocity for various resin systems. Pulsed acoustic energy techniques have been applied to the evaluation of sandwich-type structures [16,17]. The pulsed tester, which measures the elastic modulus of the adherend, was used in these studies to detect voids in the adhesive or flaws in the adherends or core. Smith and Cagle [18] determined correlation between pulsed energy signal results and lap shear strength of bonds with aluminum substrates.

The primary use of pulsed acoustic energy tests thus far has been in quality control type tests, and the technique seems to work well in this application. Studies are being conducted to relate these test results to properties that would be useful in evaluating materials, such as strength. Certainly much work is needed in this area of non-destructive testing before it can be used for durability predictions.

4.2 Resonance Testing

The resonant frequency is a fundamental physical property of a specimen at which the specimen vibrates. It is dependent upon the mechanical properties, shape, and size of the specimen. The resonant frequency may be determined by exciting the specimen with manual energy such as that of a hammer blow, or electronically by the transmission of variable frequency energy. Methods determining the resonant frequency are often referred to as "sonic test methods." The determination of the resonant frequency provides a non-destructive means of determining the mechanical and elastic properties of many materials used in the construction field. Sufficient data can be generated with the measurement of the flexural, longitudinal, and shear resonant frequencies to determine Young's Modulus, shear modulus, and Poisson's Ratio.

The resonant frequency method has been used for studying the deterioration of concrete specimens subjected to repeated cycles of freezing and thawing. ASTM Standard Method C-666-71 [12] describes techniques for conducting these studies.

Dynamic mechanical testing using a torsion pendulum apparatus has been used to measure the shear modulus and the mechanical damping properties of boron fiber reinforced composites [19] and correlations have been obtained between the elastic shear modulus of the matrix materials and properties of the composite such as torsion shear modulus, ultimate flexural strength, and flexural modulus. Klapprott [20] obtained straight line inverse relationships between the elastic shear modulus and the tensile shear strength of adhesive joints.

These relationships may be very useful in determining strength properties of housing components non-destructively but much development work is needed in this area.

4.3 Acoustic Emission

Deformation of materials results in sound emissions of various intensity levels and attempts are being made to utilize these sound emissions to non-destructively detect flaws in materials and components. Acoustic emission is the term applied to the "low-level sounds" emitted by a material when it is deformed. Liptai and Harris [21] presented examples of sound emissions which are of such a "high level" that they are audible to the unaided ear. Such examples are the creaking of timber or the sounds produced by rocks when subjected to loads near failure.

Acoustic emission is an attempt to utilize sound emissions in predicting failure by detecting the low level emissions with sophisticated instrumentation. The detection systems normally use piezoelectric transducers to detect the emission and the signal is then amplified and processed by analysis circuitry. The analysis circuitry allows a quantitative display of the acoustic energy release. The total energy and the rate of release can be obtained concerning the integrity of the structure. A major advantage of the detection system is that the signals can be simultaneously analyzed by a digital computer so that the location of structural flaws can be determined.

The application of acoustic emission to the evaluation of structural integrity has been described by Hutton and Parry [22]. The authors described the use of the method to evaluate the structural integrity of fiberglas rocket chambers, metallic structures, welding processes, carbon steel pipe, laminated wood, ceramic materials, and underground structures. It would appear that such a non-destructive test offers promise for use in durability testing, because of its applicability to evaluating structural integrity. If the method is developed to the extent that the acoustic emissions can be quantified in a manner yielding durability predictions, it could be a major asset to durability testing of structural systems.

4.4 Scanning Electron Microscope Technique

Scanning electron microscopy (SEM) is a technique by which surfaces can be scanned, viewed, and photographed with a magnification factor up to several hundred thousand. Its application to weathering studies is based on the early visual detection of changes on the surface which are the result of degradation due to aging. Early detection of changes, indicative of degradation, would permit shorter exposure periods. Blaga [23] applied scanning electron microscopy to the detection of surface change of glass-fiber reinforced polyester sheets which were exposed at four outdoor weathering sites in Canada. He found the degradation on the side exposed to solar radiation to be much greater than that on the protected side and developed a chronological sequence for the degradation. Such studies possess the potential for supplying basic data as to the physical mechanism of degradation and may lead to techniques for reducing the aging breakdown. Their direct application to durability testing and prediction has not yet been accomplished. Much more work is needed in this area to determine the ultimate usefulness of the method in durability testing.

5.0 OUTDOOR EXPOSURE (NATURAL WEATHERING) TECHNIQUES

Outdoor weathering is used for durability testing because of the difficulty in simulating environmental conditions, particularly sunlight, in laboratory tests. The National Bureau of Standards maintains outdoor exposure sites at seven locations: Alaska, Washington, Nevada, New Jersey, Maryland (2), and Puerto Rico. Other laboratories have established their own outdoor weathering facilities as well, but there are also commercial exposure stations in southern Florida (subtropical environment) and in

New Mexico and Arizona (desert environment). Test areas in Florida and Arizona are most commonly used for outdoor weathering in the United States because of the availability of the maximum amount of solar radiation [24]. Commercial weathering stations in their periodic reports supply basic environmental data, such as rainfall, average relative humidity, and ultraviolet exposure. This type of data is not usually collected by laboratories maintaining their own weathering stations.

Most outdoor exposure tests in this country follow closely the recommendations of ASTM D 1435 [25] with regard to sample position, that is, maintaining the specimen at a 45° angle to the horizontal, facing south, and unrestrained. Also suggested in ASTM D 1435 is recording weather data such as average daily temperature, average daily relative humidity, daily rainfall, and total daily solar radiation in langleys (cal/cm^2) in the plane of the samples.

It is difficult to correlate outdoor weathering test results between various exposure sites because of the variation in climatic conditions and the lack of sufficient measurements of important environmental parameters.

The major problem with outdoor exposure methods is the time required to obtain test results. Several years of exposure are often required to achieve detectable changes in properties. It is not always practicable or economically feasible to wait for lengthy tests except for long range research purposes.

As new building technology is developed, it is necessary to evaluate their durability before they are used in construction in order to prevent possible costly or catastrophic failures. Manufacturers cannot afford to wait for several years of outdoor exposure tests before introducing new products to the building market.

A summary of outdoor aging methods in ASTM Standards appears in Table I of the Appendix. The tables in the Appendix which refer to outdoor weathering are as follows:

I. Outdoor Weathering Methods in ASTM Standards (1971)

III. Summary of Exposure Conditions and Procedures in ASTM Standards for Outdoor Weathering (1971)

V. Criteria for Outdoor and Accelerated Weathering Methods

6.0 ACCELERATED AGING TECHNIQUES USING LABORATORY EQUIPMENT

In order to overcome the problems of lengthy outdoor testing, methods have been developed to accelerate the aging process. This approach has raised a number of technical problems:

1) How can a laboratory method be devised to simulate outdoor weathering but accelerate its effect on building components?

2) What climatic factors cause the aging of building components, how can these factors be measured, and with what degree of accuracy?

3) What climatic factors can be accelerated and to what extent?

4) What is the chemical mechanism of aging and can this mechanism be easily accelerated?

5) By what criteria can the test results be evaluated?

6) Does the specimen size affect the test results?

7) Should systems, components, or materials be tested and how can we interrelate the results?

In devising a laboratory method to simulate, yet accelerate, the aging process, there is the question of the effect of acceleration on the mechanism of aging. If it is possible to accelerate the effects of aging caused by outdoor exposure, there are still the questions of whether the accelerated aging method can be related to outdoor exposure, whether the mechanism is the same, and whether there is the same relationship between time of exposure and change in whatever properties are measured. In both outdoor exposure and accelerated aging, criteria must be selected and these must be properties of the building components which are relevant to its service life or durability.

It is difficult at best to separate the individual effects of various environmental factors on the deterioration of building components. These factors are best considered in combination. Durability tests must be designed for the environment in which the product in question is to be used. However, there are a variety of environments in the United States, as previously discussed, and some thought has been given to the idea of developing durability tests to reflect the environments of various geographic areas of the country. In fact, ASTM Standard Specification for Brick, C 62-66 [26], has different requirements according to the geographic area. Such areas are indicated on a map of the United States and indicates where brick will be subjected to severe, moderate, or negligible weathering. Efforts are needed to apply classifications of this type to other building components and materials.

A summary of accelerated aging methods in ASTM Standards is presented in Table II of the Appendix. The tables in the Appendix which refer to accelerated aging are as follows:

II. Accelerated Aging and Weathering Methods in ASTM Standards (1971).

IV. Summary of Exposure Conditions and Procedures in ASTM Standards for Accelerated Weathering (1971).

V. Criteria for Outdoor and Accelerated Weathering Methods.

6.1 Accelerated Aging Procedures without Applied Stress

Most accelerated aging methods are used without the application of stress to the test specimen. While these methods are appropriate for non-structural building components, they are commonly used with structural components as well. They may involve continuous exposure to a given set of conditions, thermal cycling, humidity manipulation, water spray, etc. Tests are designed to determine the resistance of the material or component to such environmental conditions as temperature, moisture, oxidation, pollutants, solvents, acid, alkali, dust, sand, wind, salt, rot organisms, and bacteria.

6.1.1 Devices to Intensify Sunlight

One method for accelerating aging is outdoor exposure with a device to intensify the sunlight on the specimens, as EMMA [27] (Equatorial Mount with Mirrors for Acceleration). This type of device may be combined with water spray as in EMMAQUA [28]. EMMA is reported to accelerate outdoor aging by a factor of 6 to 10.

In one study [29] there was little correlation between data obtained from outdoor exposure of polypropylene and polyethylene using EMMA and data from accelerated aging tests with a light and water exposure apparatus.

Some commercial laboratories do not use EMMA or EMMAQUA on a routine basis because of the high cost, lack of reproducibility, and lack of correlation with outdoor exposure tests based on natural weathering, in which EMMA and EMMAQUA are not used. The authors know of one laboratory which uses EMMAQUA for screening materials for production control. Another commercial laboratory has found good correlation between EMMAQUA tests and natural weathering tests and reports that the accelerating factor of EMMAQUA is about 4.

6.1.2 Light Exposure Apparatus

Commercial light exposure apparatus is used to accelerate the effect of ultraviolet light under controlled conditions. Carbon arc lamps are commonly used but models with xenon arc lamps are available. Environmental conditions are usually continuous and are not cycled. Light exposure apparatus is not used as frequently as light and water exposure apparatus for testing building components and materials and is not considered as reliable for predicting durability. Building components and materials tested by both types of equipment include organic coatings, plastics, roofing, sealants, cladding, etc. Sample size is limited by the design of these devices to several inches in length and width.

6.1.3 Light and Water Exposure Apparatus

Devices to provide both light and water exposure combine ultraviolet radiation, water spray, and temperature, to simulate the effects obtained by continued outdoor exposure. Environmental factors may be cycled to simulate periods of sunlight, darkness, and rainfall. Types of apparatus differ mainly in the ultraviolet lamp used. Such lamps may be ultraviolet carbon arcs, sunshine carbon arcs, xenon, fluorescent lamps, or mercury arcs. The xenon arc spectrum is generally considered to most nearly simulate that of sunlight in the 300-720 mμ range. Carbon arcs exhibit spikes in the spectral curve in the range of 350-400 mμ, resulting in significantly more energy in that region than sunlight. Corex filters are used to reduce the spectral spikes in the sunshine carbon arc. Mercury arcs and daylight fluorescent tubes also exhibit spikes in the spectral curve and do not closely simulate sunlight.

The "dew cycle" [30] is frequently used in light and water exposure apparatus. This consists of irradiating the sample with unfiltered light from a carbon arc while spraying the backs of the specimens with cold water to induce the deposition of dew on the exposed face. Other cycles used include boiling water, immersion in vapor, and water soaking alternating with exposure in the light and water apparatus.

A fluorescent sunlamp-blacklamp [31] has been reported to yield accelerated aging results which correlate well with Florida and Arizona weathering of rigid polyvinyl chloride films [32]. The xenon arc light source has been used to accurately predict outdoor weathering of plastics [33]. However, the appropriate environmental factors for outdoor weathering must be measured. Another study [34] showed xenon arc weathering to compare favorably with outdoor weathering of plastics especially when the samples were sprayed periodically with water. Other studies with light and water exposure apparatus [29] have shown the accelerated test results to give a very conservative estimate of the outdoor durability of polyethylene. Studies to compare the light sources for artificial weathering have been reported [35,36].

Private discussions with other investigators indicate mixed feelings toward the usefulness of light and water exposure apparatus. With regard to studies using a twin carbon arc device, Jordan et al [37] state that the apparatus can be used effectively to screen the relative outdoor performance of certain copolymers, but that it should not be used by itself to predict absolute long-term outdoor performance. This same conclusion has been expressed by many investigators working in laboratories throughout the country. Most workers feel that it is a useful tool to screen materials and to compare the relative durability of similar materials.

One problem which adds to the confusion as to whether or not light and water exposure apparatus is useful is that very often accelerated aging reports do not specify the light source and other test conditions. It is important to specify these factors in discussions and publications.

6.1.4 Environmental Chambers

Environmental chambers used in accelerated weathering vary from small commercial humidity cabinets to large rooms accommodating a full-scale house. Such chambers are widely used in testing laboratories to simulate outdoor weathering or the influence of drastic environmental differences between the interior and exterior of buildings. The larger chambers or rooms can often be cycled through various environments to more closely simulate the actual effect of outdoor weathering, but such facilities are few in number. Some of the smaller testing facilities do have environmental rooms large enough to test a full-scale wall or ceiling system, however. The primary environmental factors controlled in these chambers are moisture and temperature.

Testing full-scale systems under controlled environments is considered to be the most meaningful test for some of the newer building components such as sandwich panels. One can test panels in such a way as to simulate interior-exterior environmental differences and evaluate these effects under a sustained load. But no direct correlation between these test results and in-service performance exists. Test results must be related to durability by the evaluator's judgment and intercomparison with other systems.

Full-scale testing raises the question of specimen size. Results of tests of large specimens do not usually correlate with small-specimen tests. It would be desirable to test new housing systems as an entire unit in order to predict their durability. However, this is not feasible from the standpoint of time and cost so the results of small-specimen tests must be heavily augmented with judgment.

Chambers for ASTM Standard Method C-481-62 (sandwich constructions) [38] have been built to accommodate 4 x 8 ft. panels, although most laboratories use specimens not more than 1 x 3 ft. in size. Very little correlation has been found between results of tests with large and small specimens but most laboratories feel that the larger the test specimen the more meaningful the results. Apparently, larger specimens exhibit more twisting and prompter indication of warping from thermal expansion differentials than do small specimens.

6.1.5 Continuous and Cyclic Testing

Exposure conditions may be held constant or cycled.

The use of various environmental conditions in a cyclic mode is basically sound, since the component is subjected to this type of environmental change in service. The problem is to accelerate the aging process by accentuating cyclic conditions. Experience of other laboratories indicates that increasing the severity of the conditions may not necessarily accelerate aging. Several testing laboratories have tried shortening the cycle time, thus increasing the frequency of cycling and this technique has had some success with specific sealant materials.

Cyclic tests are used to simulate alternating environmental exposures. ASTM Methods C-481-62 and D-1037-64 [38] are procedures for laboratory aging of sandwich constructions and wood-base fiber or particle panel materials, respectively. Both incorporate cycles of water soaking, steam or hot water spray, freezing, and oven drying.

An ASTM cyclic aging test for adhesives, D-1183-70 [38] provides different test cycles of temperature and moisture exposures for interior and exterior service. Cyclic aging of plastics is described by ASTM D-756-56 [25] and includes seven different procedures for various types of specimens. Each procedure in this test contains variations in the severity of temperature and moisture conditions.

Industrial laboratories often develop tests for their own materials, some of which involve cyclic exposure. Some of these cyclic tests are reported to yield reproducible results for specific materials applications. Exposure conditions used in cycles include outdoor exposure, light and water exposure apparatus, boiling water immersion, room temperature water immersion, dry heat, freezing, etc. In an unpublished procedure, a cycle of 4 hours water soaking and 20 hours exposure in a xenon arc light and water apparatus is used to evaluate coatings.

6.2 Accelerated Aging Tests with Applied Stress

The primary objective in developing weathering methods having an applied stress factor is to provide a means of evaluating structural components. Short-term test techniques provide a measure of the component strength under a limited set of conditions. The data are usually meaningless for engineering design purposes because the component strength decreases with aging. The parameter of true interest is the stress level the component will sustain for a predetermined time - the lifetime of the housing system.

Lewis [39] has proposed a model for the rheological response of a structural adhesive material to a static stress. This model is presented in Table 2. The model defines the types of damage at various levels of relative stress. The relative stress is the ratio of applied static stress to short-term bond strength. This type of model illustrates that the design strength must be much less than the strength obtained from short-term tests. For engineering purposes, the ultimate design strength based upon this model for adhesives should be less than 25 percent of the short-term strength. Although this model was developed for a specific material, the concept behind it (that the design strength must be less than the short-term test strength) applies to most structural components. Such models are useful in developing criteria and illustrating the distinction between short-term test results and strength retention with time.

The test methods to be described in this section are dead load (sustained load) testing, progressive load testing, crack propagation, and cyclic load (fatigue) testing. Sustained loading and progressive loading are more advanced in their application to durability testing than crack propagation and cyclic load testing. The scientific literature contains numerous articles describing the development of each of these methods and illustrating their applicability to durability testing. Some of these articles will be cited in the discussion of each of the methods.

6.2.1 Dead Load Testing

Dead load testing consists of applying a sustained load to a material and measuring either the time to failure or the change of a certain property with time. This approach has been used for years to simulate the effect of long-term loading. The material can be exposed to various environmental conditions while under the sustained stress in order to more closely simulate natural weathering conditions. The large environmental chambers mentioned earlier are very useful in this regard. For example, structural sandwich type panels can be built into a chamber and a sustained load placed on them to simulate the effect of various conditions on a wall construction. Structural beams of concrete are also frequently tested by sustained load tests.

More often, however, smaller specimens are evaluated by dead load testing. The smaller specimen approach is common for 1" x 6" dogbone samples of roofing or plastics and for evaluating adhesive bonded lap-joints. Various sustained loads may be applied to individual test specimens to obtain stress-rupture curves. Such a curve is a plot of one of the strength parameters versus time and is normally plotted on a semi-log or log-log scale. Studies such as those by Cass and Fenner [40, 41, 42] show a subsequent flattening of the curve so that for many materials the curve can be extrapolated to obtain long term predictions of performance from short-term data. The value obtained by extrapolation is called the endurance limit, which is defined as the stress level a material can withstand indefinitely. Practical limitations require that the endurance limit be determined for a finite time and this time has arbitrarily been taken in practice as 10,000 hours. A typical stress-rupture curve is shown in Figure 2. Acrylic and methacrylate based plastics have been evaluated by dead load testing using a cantilever flexure test [43] with outdoor exposure. Other publications describe studies of compressive, flexural, or tension loads on plastics under actual environmental conditions [44, 45, 46, 47]. Procedures developed under the auspices of ASTM provide methods for measuring the time-to-failure of plastics [25] and creep properties of adhesives [38].

The application of the dead load can be accomplished by using a testing machine, by hanging weights from the specimen or by the use of spring loaded devices such as that proposed by Sharpe [2]. Carter [48] has proposed an outdoor weathering rack in which lap-shear joints can be stressed up to 3000 psi. This device can accommodate up to 90 specimens 1" (2.5 cm) in width and 5 1/2" (14 cm) long. Wegman [49] has used both the Sharpe [2] jig with artificial environments and a stressed outdoor weathering frame in evaluating the durability of adhesive bonded joints, and both were found promising for durability testing. Other spring-loaded fixtures have been devised which permit periodic corrections for creep, thereby maintaining constant loads on the specimens. The use of suspended weights is also a popular method of applying a sustained load.

In the laboratories surveyed by the authors, several dead load fixtures based on suspended weights have been built. The current trend is to build the fixture so that test specimens can be enclosed in an environmental chamber. The dead load fixtures are designed so that test specimens are placed in series. One fixture when loaded might well accommodate several test specimens. This approach raises the question of stress distribution among the various specimens. For this reason, the single specimen fixtures may be more desirable than multi-specimen fixtures.

Sustained loading can be a very useful tool in evaluating materials durability. The basic principle behind dead load fixtures can be applied to many different building materials for which sustained stress might be a factor. The major drawback in most cases with the dead load approach is the relatively long time required to obtain meaningful curves which can be extrapolated to yield an endurance limit.

6.2.2 Progressive Load Testing

Progressive loading is a means by which one can determine the endurance limit of a stressed material in a much shorter time than that required by the stress-rupture curve, described above for dead load testing.

E. Marcel Prot [50] in 1948 proposed a method of accelerating the cyclic fatigue testing of materials. Prot showed mathematically that by progressively increasing the load on a specimen until failure occurs, one should be able to predict the stress level a specimen is capable of withstanding without rupture for an infinite time. This stress level should be nearly the same as the endurance limit as determined from the stress-rupture curve described by sustained loading. The Prot method consists of subjecting the specimen to progressively increasing loading rates to achieve failure. The failing loads are applied to mathematical equations so that one can obtain a graph which can be related to the endurance limit.

Boller [51] applied a modified Prot equation to the determination of the endurance limit of glass-reinforced plastic laminates. He concluded that the endurance limits from both the Prot and sustained load methods were in good agreement at 10,000 hours duration by the sustained load methods. Boller further stated, "The Prot method of test, which can be conducted on one material at one condition within 1 week, compared with 4 years by the Wohler (sustained load) method, is a substantial time saver and hence is a good, quick estimate of long-term strength characteristics."

Loveless, Deeley, and Swanson [50] developed a hyperbolic equation relating rupture stress and time to break, based on Prot's work. The equation developed was:

$$(S_R - E)\ t_B = k$$

Where S_R = stress at rupture

E = endurance limit

t_B = time to break

K = material constant

They found it more meaningful to relate the endurance limit to the slope of the curve because of the substantial extrapolation involved, whereas Boller had related the endurance limit to the intercept after extrapolation. They also found their equation to be useful in predicting reliable measures of long-term strength.

Lewis, Kinmonth, and Kreahling [53] found the Prot method, as modified by Loveless, Deeley, and Swanson, to give a reasonable estimate of the long-term endurance strength of an adhesive joint.

Several of the laboratories surveyed are working on the progressive loading method. All those contacted expressed optimism in developing the method to reliably predict endurance limits for building materials. It is felt, however, that much more work is needed in refining the method.

6.2.3 Crack Propagation

Fracture mechanics is a concept which makes it possible to measure quantitatively a material's resistance to fast crack extension in the presence of a flaw. Slow-moving cracks indicate high toughness while rapid extension of a crack is associated with low toughness.

Mostovoy and Ripling [54,55] have used the principles of fracture mechanics to evaluate the speed of crack propagation in epoxy bond systems. A contoured double cantilever beam adhesive specimen, a uniform double cantilever beam specimen, and a tensile specimen were used. The adherend, which is the material bonded by the adhesive, was aluminum.

In more recent work, Ripling, Mostovoy, and Corten [56] reviewed the basic concepts of fracture mechanics and emphasized those aspects that are applicable to the evaluation of structural adhesives. One major advantage of the method is that all adherend parameters are extraneous to the value of fracture toughness, which is measured because the test is designed so that no energy is lost to them during the course of crack extension. This permits comparison of a given adhesive with different adherends, which is impossible with tests such as peel and shear.

Gurney and Amling [57] presented a general theory of crack propagation and applied it to the normal separation of two bonded elastic strips. The work of tearing may be computed from a plot of load and deflection as the crack spreads if the adhered beams are sufficiently strong to resist bending.

Attempts are currently being made to utilize crack propagation in predicting adhesive durability. Thick adherends are used to prepare the contoured double cantilever beam specimen. The adherends on one end of the specimen are separated in a testing machine by the application of a certain load. The specimen is clamped in a manner to hold the stressed position and then placed in various environments. The crack which was initiated by the stress application grows and releases some portion of the applied load. A plot of crack length versus the number of days in the artificial environment is made and the curve eventually reaches some point in time at which the crack growth rate is constant. The constant growth rate at a particular stress can be used to determine the length of time necessary to rupture the bond.

This approach is new and results are, therefore, sparse. However, the results to date, reported by a laboratory surveyed by the authors, appear to be encouraging.

In its present state of the art the crack propagation method is being developed for adhesive bond evaluation; but if perfected, it may well be applicable to other load bearing housing materials.

6.2.4 Cyclic Load Testing

The sustained load that a loadbearing building material withstands is not in reality a constant load. Rather the load varies constantly with environmental changes. An example is a sandwich type construction with a paper honeycomb core and stressed steel facings. The steel facing exposed to sunlight may well reach surface temperatures of 160°F or higher which would result in expansion of the steel. Contraction of the steel would occur in cold weather. The differences in thermal expansion coefficients between the core and skin materials would result in differential movement between the two, thus producing a stress in the bond. This movement would place additional stresses on the composition of the sandwich panel. The effect cyclic loading has on materials is called fatigue. Test methods are currently under development and evaluation to simulate more closely this type of cyclic loading. Many of the laboratories surveyed definitely feel this is a feasible approach to take in developing durability tests for loadbearing components.

The technique would involve varying the load on the material around some predetermined load level. The predetermined load level and the amount of variation must be chosen experimentally - perhaps based upon the design load of the structure or the endurance limit from a stress-rupture type curve. One must also determine experimentally the rate of loading cycling. Various environmental factors such as temperature, moisture, ultraviolet irradiation, etc. could be included in the test method by developing a test apparatus so that the specimens could be enclosed in an environmental chamber. Test facilities to incorporate all these factors have been recently built in a few laboratories. Hearle [58] published a review of fatigue in fibers and plastics in which he described a fatigue test apparatus used in his studies. This apparatus was not adapted for environmental aging, however.

Fatigue testing of materials has been shown in a few of the laboratories surveyed to yield faster rupture than sustained loading at the same levels of applied stress.

Little [59] surveyed the three kinds of fatigue tests and included advantages and disadvantages for each. He based the discussion on the P-S-N surface model and described the three fundamental fatigue variables as:

S = fully reversed stress amplitude, or fully reversed strain amplitude
N = number of stress or strain cycles imposed
P = proportion failed prior to N stress or strain cycles.

Any two of these variables can be plotted against each other when the third is fixed. He defined the three basic fatigue tests as S-N (preliminary tests), P-N (life tests), and P-S (strength tests).

7.0 PREDICTING DURABILITY

The durability of housing materials is predicted largely on the basis of results of the testing and evaluative techniques described previously. The results of these accelerated aging tests or other short-term tests are compared with the results of similar materials which are known by experience to be sufficiently durable. The evaluator then applied a judgmental factor, based upon experience, to yield the durability prediction. The judgmental factor, then, is the key to durability predictions. The judgmental factor is a necessary part of durability prediction because short-term test procedure results do not yield quantitative durability measurements. There is a need, therefore, to develop better durability test procedures for all housing materials and components so that the need to reply on the judgmental factor can be minimized.

7.1 The Difficulties of Predicting Durability

7.1.1 Correlating Natural and Accelerated Aging

Many attempts have been made to establish valid performance tests for durability by correlating the results of accelerated aging procedures with data from outdoor exposure tests. Although some correlations have been established for specific materials, there is no general relationship between accelerated aging and outdoor exposure. The following are possible reasons for this lack of correlations:

(1) The conditions used in the accelerated aging procedure may not accurately simulate environmental conditions in service or conditions of the outdoor exposure.

(2) Conditions which cause deterioration in service or in outdoor exposure may not be known or if they are known they may not be accelerated or even present in the accelerated aging test.

(3) There may be a lack of knowledge or lack of adequate measurements of climatological and other environmental factors present in the outdoor exposure.

(4) There may be a lack of precision of control and measurement of conditions of accelerated aging test.

(5) There may be a lack of precision of measurement of the physical property change following the outdoor exposure or accelerated aging test.

7.1.2 Test Specimen Size

One of the major problems in durability testing is that of test specimen size. A consistent correlation between test results obtained with large and small specimens has not been established. The choice of specimen size is a particularly difficult problem in evaluating housing systems. For example, in sandwich type constructions, the stresses induced on the system by various environmental cycles may be considerably different in 4- by 8-ft. factory produced panels and 6- by 6-inch laboratory specimens. Obviously, it is much more desirable to test small specimens because of ease of handling and cost. Also, the lack of adequate test facilities in many laboratories prohibits testing a full 4- by 8-ft. panel, an entire wall or ceiling system, or an entire housing system.

Whenever possible, tests are based on the quantitative measurement of some property of the material or building component. Techniques of this type can yield results which can be plotted and extrapolated. However, extrapolations are subject to large errors, since the variance in data from physical property measurements is likely to be on the order of 10 to 20 percent.

The time, cost, and facilities required to test enough large specimens for statistical handling of data is extremely high but replication is necessary to obtain meaningful results because of the lack of precision of test methods. For a durability test to become widely accepted in the housing industry, it must be designed for specimens which are of a convenient size. However, the results from small test specimens are useful only if they can be related to the entire building system. It is therefore necessary to correlate results from large and small specimens in establishing a test method, using the minimum number of large specimens necessary to validate the method. If small specimens are used, the precision of data can be improved by increasing the number of replicates but this is impracticable with large specimens.

7.2 Rate Process Method for Predicting Durability

Predicting durability from accelerated aging tests involves extrapolation of data from short-term tests to long-term service life. One procedure which involves extrapolation of short-term data is called the rate process method which is based on the Arrhenius equation [60] normally expressed as:

$d \ln k = E/RT^2$, where

k = reaction rate constant

T = absolute temperature

E = activation energy

R = gas constant

The Arrhenius equation mathematically expresses that most chemical reactions proceed at a faster rate as the temperature is increased. When applied to durability testing, the rate of deterioration of the material (which is normally observed by a change in a physical property) is considered to be a rate of chemical decomposition. To apply the rate process method, the rates of deterioration are determined at exposure temperatures higher than those encountered in actual use. Assuming that the activation energy, E, is constant, a plot of rate versus inverse temperature produces a straight line and the line can be extrapolated to the lower temperature (in-use temperature). The rate of deterioration of the material at the lower temperature is thus determined. There are possible sources of error of which one should be aware when applying the rate process method. First, the activation energy may not be constant and this means a linear extrapolation will be erroneous. A larger source of error can arise from the fact that the chemical mechanism of the deterioration may involve more than one pathway. The relative rates of the different pathways may change considerably as the temperature is raised. Thus, the mode of deterioration at the higher temperature may not be the same as that at the lower temperature. That is, the normal path of in-service aging is not observed in the acceleration. In these two cases, the rate process method should not be used for predicting the service life of the material.

Although in durability testing one is normally concerned with changes in physical properties, Goldfein [61] states that if processes such as creep and rupture are defined as the separation and breaking apart of molecules, they may be treated as chemical reactions. This assumption, of course, makes it possible to apply the Arrhenius rate process to many types of tests which result in rupture of the material. Goldfein applied the rate process to stress-rupture, creep, chemical degradation, and thermal degradation. His derivations were similar to the empirically derived Larson-Miller [62] stress-time-temperature equation which was applied to stress-rupture and creep in glass-reinforced plastics. Raphael [63] found that by using an Arrhenius plot, an accelerated aging test could be based on temperature as the sole accelerating means for plastics.

Gillespie [64,65] has applied the rate process method to predicting durability of adhesive bonded wood joints. He postulated that moisture is the rate controlling influence in degradation of adhesive bonded joints and that temperature primarily accelerates the moisture attack. The procedure used involved exposing specimens to various environmental conditions for different intervals of time before measuring shear strength. By increasing the temperature and the concentration of other environmental factors, the rate at which a factor degrades a bond may be accelerated for laboratory evaluations. The data were plotted as the log of shear strength versus time for each temperature studied. The linear response was expressed mathematically by the Arrhenius rate equation in which the slope of the line is a constant, K, describing the rate of loss. The log of K was then plotted versus 1/T, where T was the absolute temperature. Gillespie found this plot to yield straight line responses which could be extrapolated to determine the bond strength half-life, the time required for the bond to lose one half its initial strength.

McAbee, et al [66] applied the rate equation of Coleman and Knox [67] to constant loading data to evaluate the feasibility of the rate process method for predicting adhesive bond durability. The data used in that work were obtained by sustained loading and measuring the time to failure using shear and tensile testing. They found the mathematical relations developed by them fit the data quite well.

The rate process method has been shown in the above reference to be applicable to durability predictions for plastics and adhesives joints. The method should also be applicable to other materials as well. The durability data obtained from the rate process method would seem to be reasonably reliable, even with the extensive extrapolation involved. Additional studies are needed with the rate process method to determine its applicability to other building materials and to fatigue type tests.

7.3 Mathematical Correlation Method

The mathematical correlation method, in which the rate of change of a material's property is expressed mathematically, represents another attempt to correlate accelerated aging test results with those of natural outdoor aging and service life. An empirical equation is used in attempting to predict the long-term behavior of the material after short-term aging. Thus, for a class of materials, the mathematical equations for indoor and outdoor exposures and the relationship between them are found. Then, for a new material of the same class its long term outdoor exposure lifetime is predicted based on its accelerated test data.

This approach uses statistical analysis of data to obtain the mathematical relationship. Before a statistical correlation can be obtained, a mathematical model must be chosen which corresponds to the actual physical mechanism by which the material deteriorates. For example, if the material ages linearly with time, one should not attempt to fit the data to an exponential model. Also the model equation must account for variations in aging due to climatic conditions. Thus, the model must contain terms which relate the exposure (aging) of the material to the exposure site (local climate). Such terms in the model equations have been named "exposure parameters" [68]. They are constants for a given exposure condition.

The mathematical approach to predicting the durability of plastics was first described by Kamal [68]. He artificially weathered three commercial plastics specimens under sixteen different exposure conditions. A xenon arc light source was used in all exposures. The variants in exposure conditions were temperature and water spray cycle. Kamal determined that for a given exposure, the change of a specimen property could be described by the equation:

$\mathrm{Ln}P = b_0 + b_1\,(t-250) + b_2\,(I-0.710)$ where

P = a property of the material

t = time of exposure in hours

I = intensity of light source in joules/hr/cm^2

b_0, b_1, b_2 = exposure parameters

0.710 = average relative intensity of the light during exposures

The exposure parameters b_0 and b_1, were related to the following three variables: 1) temperature, 2) the length of time of the wet portion of the cycle, and 3) the percent time that the specimen was wet during the cycle. The experiment was not designed to determine b_2.

With the assumption that average relative outdoor intensity varies little from 0.710, the above equation reduces to:

$$\mathrm{Ln}P = b_0 + b_1\,(t-250)$$

Kamal determined the primary environmental parameters at his outdoor exposure site and related this information to the mathematical equation developed by accelerated weathering. He then used the simplified equation to predict the length of time necessary for outdoor weathering to induce the same property changes for the same three commercial plastics.

Another example of the use of the mathematical approach is the work of Clark [69]. In that project, twenty plastics specimens were weathered outdoors at three different exposure sites. Clark determined that the change in ultimate elongation with time for fifteen of the twenty specimens could be described by the following equation:

$$Y = b_1 \exp \left[- \left(\frac{t + b_2}{b_3} \right)^{b_4} \right] + b_5 \text{ where}$$

Y = ultimate elongation

t = time

b_1, b_2, b_3, b_4, b_5 = exposure parameters.

Although there are numerous reports in the literature discussing the reliability of correlating indoor and outdoor exposures, there are too few reports describing the mathematical approach. There does not appear to be enough experimental evidence to judge the approach. The real value of this method would appear to be its ability to relate the model and the degradation of the material to the climatic conditions of the exposure site. In other words, by finding the model for deterioration and by knowing the primary weather parameters at the exposure site, a prediction of the durability of a material can be made. Of course, the reliability of such a prediction is only as good as the statistics involved in determining the model. However, even with good statistics, the approach still must be subjected to much more experimentation and possible refinement.

Studies have not been published to show the relationship between natural weathering and tests such as dead load, fatigue, crack propagation, rate process, and progressive load testing.

8.0 CONCLUSIONS

1. Of all the attributes required of building systems, components, and materials, durability is probably the most important and the most difficult to define and specify.
2. For the purpose of evaluation, durability must be specified at the component or materials level because each component or material may be required to have a different service life or life-cost.
3. At the present state of the art, it is virtually impossible to predict durability precisely with short-term testing.
4. Durability is predicted at present by a combination of testing, in-service performance, and scientific and engineering judgment and the current techniques of durability prediction are acceptable for some building components and materials, especially for those for which much experience has been obtained by in-service performance.
5. The current techniques of durability prediction are not acceptable for new or innovative components and materials that have not been used extensively in the past; hence, there is an immediate need for predictive techniques for these components and materials.
6. Criteria for judging the performance of building components and materials following durability tests are needed.
7. Evaluative techniques to provide durability data must be designed for specific building components and materials because
   (a) each component or material performs a different function and must be tested for that function.
   (b) each component or material is affected differently by the various environmental parameters.

8. Climatological and other environmental parameters and interactions affecting durability need to be better defined and understood as well as measured more meaningfully.
9. The phenomenon of aging is not well understood and studies are needed in this area
    (a) in devising techniques to accelerate aging mechanisms in such a way as to better quantify durability.
    (b) in devising and improving other predictive tests, such as non-destructive testing and detecting deterioration in its early stages.
    (c) in testing building components subjected to stresses in service.
10. Studies are needed to better correlate natural outdoor weathering or aging and accelerated aging.
11. Studies are needed to determine the relationship between the aging of small specimens and full-scale components.

9.0 SUMMARY OF RECOMMENDATIONS

The recommendations for research efforts to improve the state-of-the-art of durability testing of building components and materials are as follows for:

1. ENVIRONMENTAL FACTORS
    a. Define environmental factors (including weathering, stress and incompatibility) which are important in aging of building components and materials leading to a decreased performance capability.
    b. Classify climates in various geographic areas of the United States according to the deteriorating effect exhibited by the factors in those climates on building components and materials.
    c. Develop a scheme by which the environmental factors of importance for specific building components and materials may be incorporated into durability test procedures.
    d. Determine the best technique of accelerating the aging effect of specific environmental factors.
2. EVALUATIVE TECHNIQUES AND ACCELERATED AGING PROCEDURES
    a. Evaluate existing non-destructive evaluative techniques such as pulsed acoustic energy testing, resonance testing, acoustic emission and scanning electron microscopy to determine if these techniques can be applied to the durability testing of building components and materials.

b. Evaluate existing procedures of accelerated aging and develop new procedures as needed which:

    1) Incorporate environmental factors of importance and

    2) Yield meaningful results which can be related quantitatively to durability in the actual application of the building component or material.

c. Determine the feasibility and necessity of quantitatively measuring environmental factors which are used in the accelerated aging procedure.

d. Determine the physical and chemical properties most useful as indicators of deterioration for specific building components and materials.

3. OUTDOOR (NATURAL) AGING

a. Select test sites for outdoor exposure which are representative of the various climatological divisions defined previously.

b. Determine which environmental factors should be measured during the exposure and how such measured values can best be utilized in the durability testing of building components and materials.

4. CORRELATING ACCELERATED AND NATURAL AGING

a. Correlate on a quantitative basis the results of accelerated test procedures and the results of natural aging.

5. TEST SPECIMEN SIZE

a. Determine the relationship between

1) The results of accelerated aging tests of specific materials and the natural aging of the material in conjunction with other materials (a component).

2) The results of accelerated aging tests of small laboratory size components and the natural aging of full size components.

6. PERFORMANCE CRITERIA

a. Develop performance criteria by which the results of existing and newly developed durability test procedures can be evaluated.

7. GENERAL METHODOLOGY FOR DURABILITY TESTING

a. A research effort is needed to devise a methodology for predicting durability which will be of general application to building components and materials.

b. The research effort should reflect the content of recommendations 1 through 6 listed above and should utilize a specific housing component and/or group of materials to demonstrate the use of the general methodology.

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Table 1: Proposed Model for the Rheological Response of a Structural Adhesive Material to a Static Stress

Mechanism Designation	Relative (a) Stress Level	Mechanical Description (c)	Effect of Damage on Ultimate Short-Term Strength
0 - Hookean	< 0.1	Reversible elastic response of media; cracks distort but not permanently. No damage occurs.	None
I - Modulus Damage	> 0.1	Irreversible, isothermal, crack distortion; some crack opening may occur but crack length reaches a limit. Internal stress relaxation leading to a self-strengthening of the material occurs. Effective modulus of the stress-worked media is lowered.	None or Slight Increase
II - Strength Damage	0.25	Irreversible crack distortion and opening. Crack propagation continues and in time will eventually cause failure of the material. Proposed condition characterized by internal creep (local plastic straining) and stress relaxation. Reaction primarily isothermal, however, some local heating may occur especially in the range of higher stress levels. Effective modulus of the stress-worked media is lowered.	Lower Strength
III - Terminal Damage	0.9	Cracks propagate, grow and coalesce rapidly leading to catatrophic failure. This reaction most likely involves a combination of all described mechanisms, 0, I, and II.	Drastic Lowering (b)

(a) This ratio, $\frac{\text{Applied Static Stress}}{\text{Short-Term Strength}}$, is intended to illustrate the approximate stress levels at which each of these various damage mechanisms are operative. For example, the endurance limit can be defined as the threshold stress level relative to the onset of the strength damage reaction.

(b) Experimentally, the terminal damage regime may be difficult to observe since it requires the application of a static stress close to the ultimate strength; this failure reaction proceeds rapidly.

(c) The described mechanisms refer to occurrences within the strained volume elements in a functioning adhesive material. What mechanism predominates depends upon the stress concentration profile in the adhesive joint system.

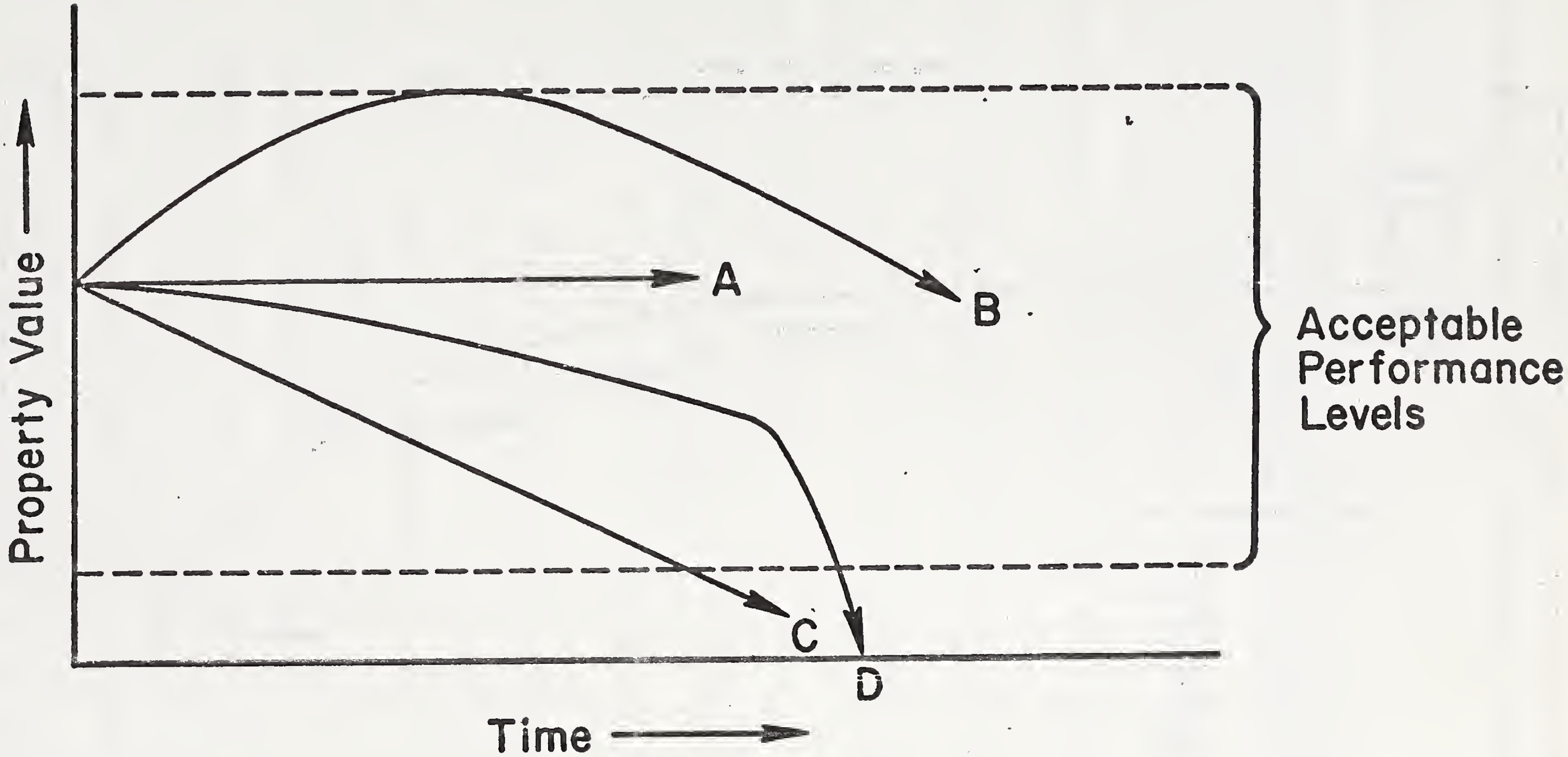

FIGURE 1 Hypothetical Performance Curves

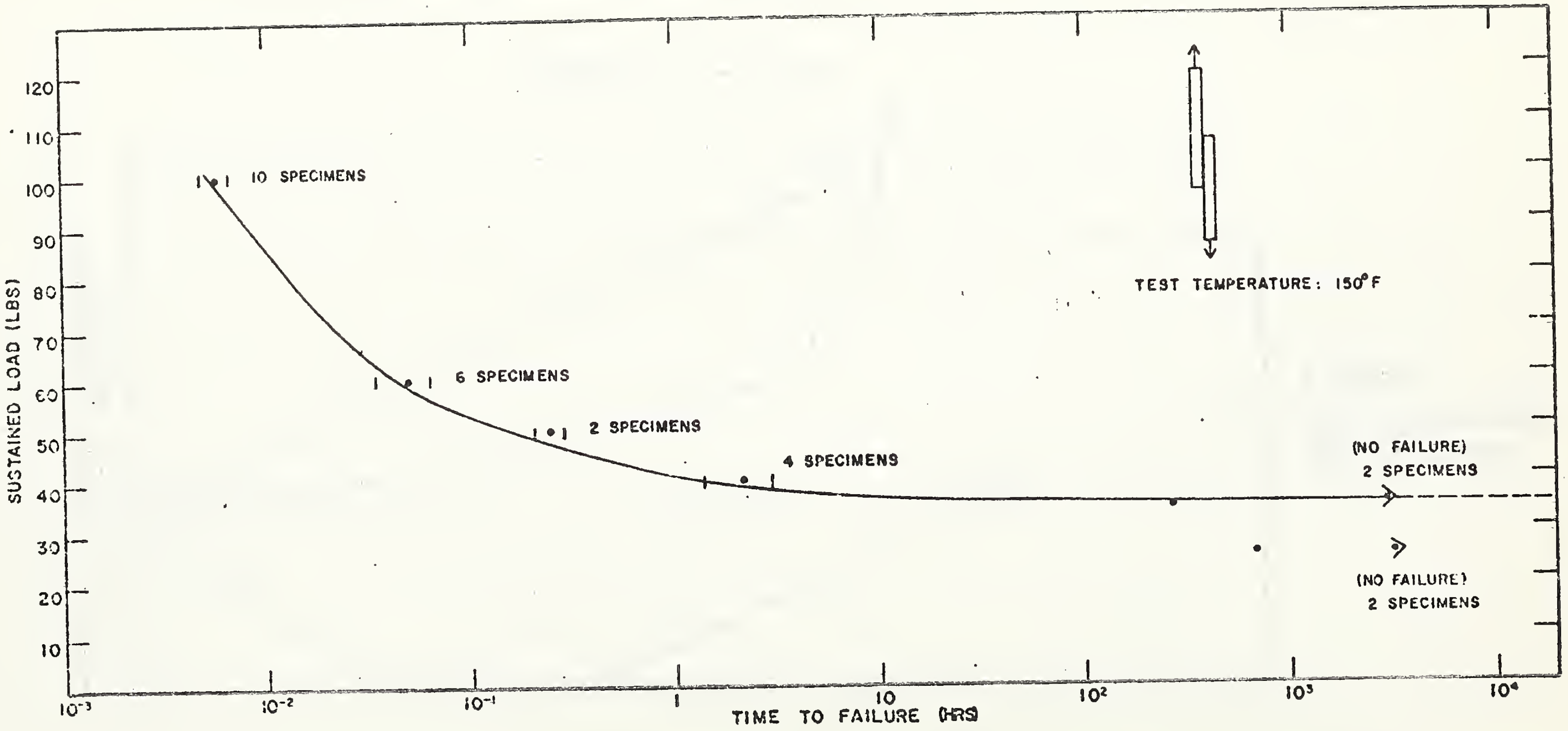

FIGURE 2 Typical Stress-Rupture Curve

APPENDIX

Accelerated aging and durability test procedures and evaluative techniques are included in the following:

(1) Published standards

  (a) Issued by standards-making organizations such as the American Society for Testing and Materials (ASTM), American National Standards Institute (ANSI), and the International Standards Organization (ISO).

  (b) United States Government standards, such as Federal and Military Specifications.

  (c) State standards, as those issued by the State University of New York.

  (d) Standards issued by foreign governments and other bodies outside the United States.

(2) Industrial practice, as discussed elsewhere in this report

(3) Research on test methods

  (a) Published proposed test methods

  (b) Published research on test methods or on the deterioration of materials and building components

  (d) Information on current research, as discussed elsewhere in this report.

The most comprehensive and best organized body of standard test methods is to be found in the Annual ASTM Standards and many other standards are based on these. Some of the ASTM Standards are test methods, some are procedures for exposure of specimens, and some are specifications for materials or components. The Standards are developed by technical committees from industry, government, universities, and consumer organizations. The set of Annual ASTM Standards is a very good summary of the state-of-the-art of test methods, covering durability, performance, and quality control. The 1971 Annual ASTM Standards consists of 33 parts, each a separate volume, of which Part 33 is the Index. The Index does not cover detail on durability tests such that the investigator can readily ascertain the state-of-the-art of durability testing. Therefore, we have prepared a set of five tables to complete our report on the state-of-the-art. The tables are as follows:

I Outdoor Weathering Methods in ASTM Standards (1971)

II Accelerated Aging and Weathering Methods in ASTM Standards (1971)

III Summary of Exposure Conditions and Procedures in ASTM Standards for Outdoor Weathering Methods (1971)

IV Summary of Exposure Conditions and Procedures in ASTM Standards for Accelerated Weathering Methods

V Criteria for Outdoor and Accelerated Weathering Methods and Evaluative Techniques in ASTM Standards (1971)

Methods listed are from the 1971 ASTM Standards. Where 1972 Standards were available, any necessary corrections were made from the later edition.

Table I, Outdoor Weathering Methods in ASTM Standards (1971), consists of three parts. Part A contains a listing of ASTM Standard Methods for outdoor weathering in numerical order, cites the part number of the ASTM Standard in which the method is found, and identifies the specific material covered by the method. Part B lists all outdoor weathering methods according to the type of material covered by the method. Following the number of the Standard Method, the ASTM part number is indicated in parentheses. Part C lists all outdoor weathering methods according to subject matter, classified as:

1) Atmospheres, Definitions

2) Climatological data, instrumentation

3) Exposure type

4) Positioning and Mounting of specimens

5) Rack, fence, exposure cabinet design

Table II, Accelerated Aging and Weathering Methods in ASTM Standards (1971), also contains three parts. Part A contains a numerical listing of ASTM Standard Methods for accelerated aging, cites the part number of the ASTM Standard in which the method is found, and identifies the specific materials covered by the method. Part B lists all accelerated aging methods according to the type of material covered by the method. Following the number of the Standard Method, the ASTM part number is indicated in parentheses. Part C lists all accelerated aging methods according to type of exposure.

Table III, Summary of Exposure Conditions and Procedures in ASTM Standards for Outdoor Weathering Methods (1971), contains the test method number, ASTM part number, test title, and a description of exposure details for ASTM test methods for outdoor weathering.

Table IV, Summary of Exposure Conditions and Procedures in ASTM Standards for Accelerated Weathering Methods, contains the test method number, ASTM part number, test title, and a description of exposure details for ASTM test methods for accelerated aging.

Table V is a list of criteria used in ASTM Standards to determine the effects of outdoor or accelerated weathering, methods used to measure these effects, and evaluative techniques used in ASTM Standards. The criteria are listed under ASTM Standards, arranged in order. Evaluative techniques include predictive tests not involving outdoor exposure or accelerated aging.

In using the tables, it should be borne in mind that ASTM Standards

(1) are mainly but not entirely for test methods. Some Standards cover specifications for materials and components.

(2) do not always cover complete test methods. Some Standards cover procedures for outdoor exposure or accelerated aging. Other Standards cover criteria and evaluative techniques for changes following exposure. These evaluative techniques may consist of visual or microscopic examination. Most techniques involve physical testing and some involve chemical tests.

It is also important to know that most test methods for durability consist of three steps:

(1) Exposure (outdoor or accelerated)

(2) Identify properties which indicate a change

(3) Tests to evaluate these properties

However, some tests predict durability by non-destructive methods for detecting or measuring flaws which might cause failure. Other tests predict durability after short periods of exposure by detecting or measuring incipient changes which precede failure.

The following information is available from the tables:

Outdoor exposure conditions and methods............. Table I

Detail on the same................................ Table III

Accelerated aging, exposure conditions and methods.. Table II

Detail on the same................................ Table IV

Criteria and evaluative techniques (tests) for
specimens after exposure (outdoor or accelerated)... Table V

Index of outdoor exposure methods.................. Table I

Index of accelerated aging methods.................. Table II

Building components and materials covered by
ASTM Standards

  for outdoor weathering......................... Table I

  for accelerated aging.......................... Talbe II

Table I OUTDOOR WEATHERING METHODS IN ASTM STANDARDS (1971)

PART A - Listing in Numerical Order

TEST NUMBER	(ASTM PART NUMBER)	(BUILDING MATERIAL)
B 537	(7)	(chromium plated steel and zinc die castings)
C 62	(12)	(brick)
C 216	(12)	(brick)
C 488	(14)	(finishes for thermal insulation)
D 518	(28)	(soft rubber)
D 904	(16)	(adhesives)
D 1006	(21)	(organic coatings on wood)
D 1014	(21)	(organic coatings on steel)
D 1435	(27)	(plastics)
D 1641	(21)	(varnishes)
D 1654	(21)	(organic coatings on steel)
D 1828	(16)	(adhesive bonded joints and structures)
D 2830	(20) (21)	(organic coatings on wood)
D 2918	(16)	(adhesive joints)
D 2919	(16)	(adhesive joints)
G 7	(30)	(nonmetallic materials)
G 11	(21) (30)	(pipeline coatings)
G 24	(24) (30)	(various materials)

Table I (continued)

PART B - Listed by Building Material

BUILDING MATERIAL: TEST NUMBER (ASTM PART NUMBER)

Adhesives: D 904 (16)

Adhesive bonded joints and structures: D 1828 (16), D 2918 (16), D 2919 (16)

Brick: C 62 (12), C 216 (12)

Chromium plated steel: B 537 (7)

Nonmetallic materials: G 7 (30)

Organic coatings: C 488 (14), D 1006 (21), D 1014 (21), D 1641 (21), D 1654 (21), D 2830 (20,21), G 11 (21,30)

on metal: D 1014 (21), D 1654 (21), G 11 (21,30)

on pipelines: G 11 (21, 30)

on thermal insulation: C 488 (14)

on wood: D 1006 (21), D 2830 (20, 21)

Varnishes: D 1654 (21)

Plastics: D 1435 (27)

Rubber: D 518 (28)

Various materials: G 24 (24,30)

Varnishes: See Organic coatings.

Zinc based die castings: B 537 (7)

Table I (continued)

PART C - Listed by Subject Matter

Atmospheres, Definitions

C 62	
C 216	Areas in the United States defined by Weathering Index (See Climatological data, instrumentation).
D 1435	As defined by National Oceanic and Atmospheric Administration (NOAA)
D 1828	Rural-pure (ASTM site: State College, Pennsylvania)
	Industrial-sulfurous gases present (Pittsburgh, Pennsylvania)
	Marine-seacoast where chlorides are deposited on specimens (Kure Beach, North Carolina)
	Tropical or southern Florida under conditions of heat and high humidity (Freeport, Texas)
G 7	Tropical or subtropical, inland
	Tropical or subtropical, salt atmosphere
	Temperature, inland
	Temperature, salt atmosphere
	Desert
	Arctic or subarctic
	Industrial, low pH
	Industrial, high pH
	Industrial, NO_2, SO_2, or O_3
	(Definitions of above are under study by ASTM Committee G-3).

Table I, Part C (continued)

Climatological data, instrumentation

C 62	
C 216	Areas in the United States defined and indicated in a map according to Weathering Index, which is, for any locality, the product of average annual number of freezing cycle days and average annual winter rainfall in inches. Areas in the map include those with: Severe index, over 500 Moderate index, 100 - 500 Negligible, less than 100
D 1435	Report shall include: Sunlight energy data if available, as integrated incident expressed in langleys (g-cal/cm^2) Description of climate and summary of data at site from NOAA Rainfall Percentage of possible sunshine Temperature average and extremes Humidity average and extremes
D 1828	Report shall include: Average monthly relative humidity Average monthly temperature Total monthly rainfall Average daily solar radiation, if available Total solar radiation on specimens, if available Air pollution data, if available References to instrumentation which meets NOAA requirements

Table I, Part C (continued)

G 7 Report shall include:

Daily maximum, minimum, mean temperatures

Daily maximum, minimum, mean percent relative humidities

Daily hours of rain and dew (wetness)

Daily total inches of rainfall

Daily irradiation: total langleys, spectral langleys (wavelength band specified), ultraviolet sun-hours (solar irradiation above an intensity of 0.823 cal/cm^2 min.)

1 langley = 1 g-cal/cm^2 = 11.62 W/m^2 = 41,840 J/m^2

G 24 Report shall include:

Date and location, including approximate latitude

Maximum, minimum, mean daily air temperatures and relative humidity. humidities

<u>Exposure type</u>

Direct (to all prevailing atmospheric conditions): B 537, C 488, D 518, D 1006, D 1014, D 1435, D 1641, D 1828, D 2830, G 11

Window (in cabinet under glass): G 24

Sunlight Exposure Method: Specimens exposed in glass-covered cabinet between 9:00 a.m. and 3:00 p.m. (standard time) on clear, sunny days. At all other times, specimens are removed from the cabinet and stored in a dark and dry storage area at normal room temperature.

Daylight Exposure Method: Same as for Sunlight Exposure Method except that the specimens are left in the exposure cabinet continuously 24 hrs. a day and are removed only for inspection.

Table I, Part C (continued)

Window (under glass, not in cabinet): D 904

Direct or Window: G 7

Positioning and mounting of specimens

C 488	45 degrees from horizontal, facing south
D 518	45 degrees facing south
D 904	45 degrees facing south
D 1006	Vertically facing both south and north on test fences. If dust collection and mildew resistance are not pertinent, north vertical exposure may be eliminated.
D 1014	45 degrees facing south 45 degrees facing north Vertical facing south Vertical facing north
D 1435	45 degrees facing equator 90 degrees facing equator Horizontal
D 1641	45 degrees facing south
D 1828	45 degrees facing south
D 2830	90 degrees on test fences as in D 1006
G 7	Most common: 45 degrees from horizontal facing equator Others: Vertical facing south and north Horizontal Angle from horizontal equal to latitude of location in degrees, facing equator Normal service position

Table I, Part C (continued)

Angle of 30 degrees from horizontal, facing equator

Angle of 5 degrees from horizontal, facing equator

G 11 Horizontal

G 24 Angle from horizontal equal to approximate latitude of location in degrees, facing equator.

Rack, fence, exposure cabinet design

Exposure cabinet: G 24

Racks: D 1435, D 1828, G 7, G 11

Test fences, racks: D 1006

Table II ACCELERATED AGING AND WEATHERING METHODS IN ASTM STANDARDS (1971)

PART A - Listed in Numerical Order

TEST (ASTM PART NUMBER) (BUILDING MATERIAL)

B 117 (7, 21, 31) (metals, coatings on metals)

B 287 (7, 21, 31) (metals, coatings on metals)

B 368 (7, 21) (chromium alloy plate on steel and zinc base die castings)

C 62 (12) (brick)

C 67 (12) (brick)

C 88 (10) (concrete aggregates)

C 216 (12) (brick)

C 217 (12) (natural slate)

C 481 (16) (sandwich constructions)

C 510 (14) (joint sealants)

C 666 (10) (concrete)

C 669 (14) (sealants used in back bedding and face glazing)

C 671 (10) (concrete)

C 682 (10) (concrete aggregates)

D 518 (28) (soft rubber)

D 529 (11) (bituminous materials)

D 545 (10, 11) (preformed expansion joint fillers for concrete)

D 750 (28) (vulcanized rubber)

D 756 (27) (plastics)

D 822 (21) (organic coatings)

D 904 (16) (adhesives)

D 1037 (16) (wood based hardboard, particleboard)

D 1101 (16) (adhesive joints in structural laminated wood)

Table II, Part A (continued)

D 1148 (28) (vulcanized rubber)

D 1149 (28) (vulcanized rubber)

D 1151 (16) (adhesive bonds)

D 1167 (11, 21) (asphalt emulsion coatings on built-up roofs)

D 1183 (16) (adhesives)

D 1499 (27) (plastics)

D 1501 (27) (plastics)

D 1565 (28) (vinyl foam)

D 1654 (21) (organic coatings on metal)

D 1735 (21) (organic coatings)

D 1754 (11) (asphalt)

D 1870 (27, 28) (polymers)

D 2126 (28) (rigid cellular plastics)

D 2246 (21) (coated metal)

D 2247 (21) (coated metal)

D 2248 (21) (organic coatings)

D 2249 (14, 21) (sealants used in glazing and bedding)

D 2366 (21) (exterior house paints on wood)

D 2445 (26) (propylene plastics)

D 2559 (16) (adhesives)

D 2565 (27) (plastics)

D 2803 (21) (organic coatings on metal)

D 2831 (20, 21) (latex paints on masonry and asbestos-cement shingles)

D 2898 (16) (fire-retardant treatment of wood)

D 2918 (16) (adhesive joints)

Table II, Part A (continued)

D 2919 (16) (adhesive joints)

G 23 (24, 27, 30) (nonmetallic materials)

G 25 (24, 30) (nonmetallic materials)

G 26 (30) (nonmetallic materials)

G 27 (30) (nonmetallic materials)

PART B - Listed by Building Material

BUILDING MATERIAL: TEST NUMBER (ASTM PART NUMBER)

Adhesives: D 904 (16), D 1183 (16), D 2559 (16)

Adhesive bonded joints and structures: D 1101 (16), D 1151 (16), D 2918 (16), D 2919 (16)

Asphalt: D 1754 (11)

Asphalt emulsion coatings on built-up roofs: D 1167 (11, 21)

Bituminous materials: D 529 (11)

Brick: C 62 (12), C 216 (12)

Chromium alloy plate on steel: B 368 (7, 21)

Concrete: C 666 (10), C 671 (10)

Concrete aggregates: C 88 (10), C 682 (10)

Concrete expansion joint fillers: See Preformed expansion joint fillers for concrete

Fire-retardant treatment of wood: D 2898 (16)

Hardboard: See Wood based hardboard and particle board

Joint sealants: C 510 (14)

Natural slate: C 217 (12)

Nonmetallic materials: G 23 (24, 27, 30), G 25 (24, 30), G 26 (30), G 27 (30)

Table II, Part B (continued)

- Organic coatings: B 117 (7, 21, 31), B 287 (7, 21, 32), D 822 (21), D 1654 (21), D 1735 (21), D 2246 (21), D 2247 (21), D 2248 (21), D 2366 (21), D 2803 (21), D 2831 (20,21)
  - on asbestos-cement shingles: D 2831 (20, 21)
  - on metal: B 117 (7, 21, 31), B 287 (7, 21, 31), D 1654 (21), D 2246 (21), D 2247 (21), D 2803 (21)
  - on wood: D 2366 (21)
- Particleboard: See Wood based hardboard and particleboard.
- Plastics: D 756 (27), D 1499 (27), D 1501 (27), D 2126 (26), D 2445 (26), D 2565 (27). See Polymers.
- Polymers: D 1870 (27, 28). See Plastics.
- Preformed expansion joint fillers for concrete: D 545 (10, 11)
- Rubber: D 518 (28), D 750 (28), D 1148 (28), D 1149 (28)
- Sandwich constructions: C 481 (16)
- Sealants: See Joint sealants.
- Sealants used in glazing and bedding: C 669 (14), D 2249 (14, 21)
- Slate, natural: See Natural slate.
- Vinyl foam: D 1565 (28)
- Wood: See Fire-retardant treatment of wood.
- Wood based hardboard and particleboard: D 1037 (16)
- Zinc based die castings: B 368 (7, 21)

Table II (cintinued

PART C - Listed by Type of Exposure

Light exposure apparatus

Carbon-arc type: G 25, D 904

Xenon-arc type: G 27

Light and water exposure apparatus

Carbon-arc type: C 510, C 669, D 529, D 750, D 822, D 1499, D 2249, G 23

Xenon-arc type: D 2565, G 26

Fog chamber: D 1735

Humidity chamber: D 2247

Humidity chamber and cold box - cycling: D 2246

Salt-spray cabinets: B 117, B 287, B 368, D 2803

Various exposure conditions: C 62, C 67, C 88, C 216, C 217, C 481, C 510, C 666, C 669, C 671, C 682, D 518, D 545, D 756, D 1037, D 1101, D 1148, D 1149, D 1151, D 1167, D 1183, D 1501, D 1565, D 1654, D 1754, D 1870, D 2126, D 2248, D 2366, D 2445, D 2559, D 2803, D 2831, D 2898, D 2918, D 2919

Table III SUMMARY OF EXPOSURE CONDITIONS AND PROCEDURES IN ASTM STANDARDS FOR OUTDOOR WEATHERING METHODS (1971)

The following ASTM Standards are included in this table: B 537, C 216, C 488, D 1006, D 1014, D 1435, D 1641, D 1828, D 2830, G 7, G 11, and G 24.

TEST NUMBER (ASTM PART NUMBER)	TEST TITLE AND EXPOSURE DETAILS
B 537 (7)	Standard Recommended Practice for Rating of Electroplated Panels Subjected to Atmospheric Exposure Direct exposure
C 216 (12)	Standard Specifications for Facing Brick (Solid Masonry Units Made from Clay or Shale)
C 488 (14)	Standard Method for Conducting Exterior Exposure Tests of Finishes for Thermal Insulation Direct exposure. Specimens mounted 45 degrees from horizontal, facing south.
D 518 (28)	Standard Method of Test for Surface Cracking Resistance of Stretched Rubber Compounds Direct exposure. Specimens mounted at 45 degrees facing south. For accelerated weathering method, see Table V.
D 904 (16)	Standard Recommended Practice for Determining the Effect of Artificial (Carbon-Arc Type) and Natural Light on the Permanence of Adhesives Window exposure not in cabinet. Specimens mounted at 45 degrees, facing south, protected with transparent shield which transmits solar radiation. For accelerated weathering method, see Table V.

Table III - continued

D 1006 (21)	Recommended Practice for Conducting Exterior Exposure Tests of Paints on Wood Direct exposure. Specimens mounted vertically facing both south and north on test fences. If dust collection and mildew resistance are not pertinent, north vertical exposure may be eliminated. Description of test fences and racks.
D 1014 (21)	Standard Method of Conducting Exterior Exposure Tests of Paints on Steel Direct exposure. Specimens may be mounted as follows: 45 degrees facing south 45 degrees facing north Vertical facing south Vertical facing north
D 1435 (27)	Standard Recommended Practice for Outdoor Weathering of Plastics Direct exposure. Specimens may be mounted as follows: 45 degrees facing equator 90 degrees facing equator Horizontal Description of racks.
D 1641 (21)	Standard Method of Test for Exterior Durability of Varnishes Direct exposure. Specimens mounted 45 degrees facing south.

D 1828 (16) Standard Recommended Practice for Atmospheric Exposure of Adhesive-Bonded Joints and Structures

Direct exposure. Specimens mounted 45 degrees facing south

Description of racks

D 2830 (20,21) Standard Method of Test for Durability and Compatibility of Factory-Primed Wood Products with Representative Finish Coats

Direct exposure.

90 degrees from horizontal on test fences as in D 1006

G 7 (30) Tentative Recommended Practice for Atmosphereic Environmental Exposure Testing of Nonmetallic Materials

Direct or window exposure.

Specimens usually mounted 45 degrees to horizontal facing equator. May also be mounted as follows:

- Vertical facing south and north
- Horizontal
- Angle from horizontal equal to latitude of location in degrees, facing equator
- Normal service position
- Angle of 30 degrees from horizontal, facing equator
- Angle of 5 degrees from horizontal, facing equator

Description of racks

Table III - continued

G 11 (21, 30)	Tentative Method of Test for Effects of Outdoor Weathering on Pipeline Coatings Direct Exposure. Specimens mounted horizontally Description of racks
G 24 (24, 30)	Standard Recommended Practice for Conducting Natural Light (Sunlight and Daylight) Exposures Under Glass Window exposure Angle from horizontal equal to approximate latitude of location in degrees, facing equator Description of exposure cabinet

Table IV SUMMARY OF EXPOSURE CONDITIONS AND PROCEDURES IN ASTM STANDARDS FOR ACCELERATED WEATHERING METHODS

The following ASTM Standards are included in this table: B 117, B 287, B 368, C 62, C 67, C 88, C 217, C 481, C 510, C 666, C 669, C 671, C 682, D 518, D 529, D 545, D 750, D 756, D 822, D 904, D 1037, D 1101, D 1148, D 1149, D 1151, D 1167, D 1183, D 1499, D 1501, D 1565, D 1654, D 1735, D 1754, D 1870, D 2126, D 2246, D 2247, D 2248, D 2249, D 2366, D 2445, D 2559, D 2565, D 2803, D 2831, D 2898, D 2918, D 2919, G 23, G 25, G 26, and G 27.

TEST NUMBER (ASTM PART NUMBER) TEST TITLE AND EXPOSURE DETAILS

B 117 (7, 21, 31) Standard Method of Salt Spray (Fog) Testing

(for organic coatings on metal)

(Specimens mounted between 15 and 30 degrees from vertical, such as to permit free settling of fog on surface; preferably parallel to horizontal flow of fog.

Salt solution: 5 ± 1 parts by weight NaCl in 95 parts distilled water; pH of salt solution shall be 6.5 to 7.2 when atomized at 35°C (95°F).

Exposure zone of salt chamber at 35° (+1.1 or -1.7)°C.

Period as agreed on. Recommended periods 16, 24, 48, 96, 200, 240, 500, or 720 hours.

B 287 (7, 21, 31) Standard Method of Acetic Acid - Salt Spray (Fog) testing

(for organic coatings on metal)

Specimens as in B 117

Salt solution: 5±1 parts by weight NaCl in 95 parts distilled water; pH of solution shall be adjusted with acetic acid to 3.1-3.3 as measured on a sample of the collected spray and measured at 25°C (77°F).

Temperature of exposure zone and periods of exposure as in B 117.

Table IV - continued

B 368 (7, 21) Standard Method of Test for Copper-Accelerated Acetic Acid - Salt Spray (Fog) Testing (CASS Test)

(for chromium alloy plate on steel and zinc base die castings)

Specimens 15 + 2 degrees from vertical, preferably parallel to horizontal flow of fog

Solution sprayed: 5 parts NaCl in 95 parts distilled water; 1 g $CuCl_2 \cdot 2H_2O$ per 3.8 liters salt solution; pH of the solution shall be adjusted with acetic acid to 3.1-3.3 as measured on a sample of the collected spray and measured at 25°C (77°F).

Exposure zone of CASS Test Chamber at 47±1°C.

Recommended exposure periods: 6, 16, 22, 48, 96, 192, 240, 504, or 720 hours.

Exposure zone of CASS Test Chamber at 49±1°C.

Recommended exposure periods: 6, 16, 22, 48, 96, 192, 240, 504, or 720 hours

C 62 (12) Standard Specifications for Building Brick (Solid Masonry Units Made from Clay or Shale)

See C 67

C 67 (12) Standard Methods of Sampling and Testing Brick

Exposure to Freezing and Thawing:

Specimens are half bricks with approximately plane and parallel ends. Specimens are dried, cooled, and weighed before and after exposure.

Table IV - continued

1. Submerge specimens in thawing tank in water at 75±10°F. (24±5.5°C) for 4 hours.
2. Stand specimens on edge in 1/2 inch of water in a pan and place pan in freezing chamber (temperature not over 16°F or -9°C) for 20 hours.
3. Remove from freezing chamber and immerse in thawing tank as in Step 1 for 4 hours.
4. Repeat Steps 2 and 3 in succession five times.
5. Store in drying room at 75±15°F (24±8°C) for 40 hours.
6. Repeat Step 1.
7. Repeat Step 4.

Continue exposure for 50 cycles or until specimen is broken or has lost more than 3 percent of its original weight.

C 217 (12) Standard Method of Test for Weather Resistance of Natural Slate Specimens soaked for 7 days in 1 percent solution of sulfuric acid, using fresh acid each day.

C 481 (16) Standard Method of Test for Laboratory Aging of Sandwich Constructions

Description of two aging cycles:

Cycle A:

1. Totally immerse specimen horizontally in water at 49±2°C (120±3°F) for 1 hour.
2. Spray with steam and water vapor at 93±3°C (200±5°F) for 3 hours.
3. Store at -12±3°C (10±5°F) for 20 hours.

Table IV - continued

4. Heat at 99±2°C (210±3°F) in dry air for 3 hours.
5. Repeat Step 2.
6. Heat in dry air at 99±2°C (210±30°F) for 18 hours.

Cycle B:

1. Totally immerse specimen horizontally in water at 49±3°C (120±5°F) for 1 hour.
2. Spray with hot water at 71±3°C (160±5°F) for 3 hours.
3. Store at -40±3°C (-40±5°F) for 20 hours.
4. Heat in dry air at 71±3°C (160±5°F) for 3 hours.
5. Repeat Step 2.
6. Heat in dry air at 71±3°C (160±5°F) for 18 hours.

C 510 (14) Standard Method of Test for Staining and Color Change of One- or Two-Part Joint Sealants

a) Expose for 100 hours in light and water exposure apparatus, Type A, conforming to ASTM G 23. Specimen temperature 140±5°F (60±3°C). Water temperature 75±4°F (24±2.4°C).

b) Expose other samples at 73.4±20°F (23±1.1°C) and 50±10 percent relative humidity for 14 days. Immerse in distilled water for 1 minute once a day (5 days per week).

C 666 (10) Standard Method of Test for Resistance of Concrete to Rapid Freezing and Thawing

Prepare concrete specimens as in C 192 and store in saturated lime water.

Table IV - continued

Subject specimens to freezing and thawing cycles. Alternately lower temperature from 40 to 0°F (4.4 to -17.8°C) in not less than 2 nor more than 4 hours. Continue for 300 cycles or until relative dynamic modulus of elasticity reaches 60 percent of the initial modulus, whichever occurs first, unless other limits are specified.

C 669 (14) Standard Specification for Glazing Compounds for Back Bedding and Face Glazing of Metal Sash

Specimens prepared and exposed as in D 2249.

D 518 (28) Standard Method of Test for Surface Cracking Resistance of Stretched Rubber Compounds

(for soft rubber)

Continuous exposure of rubber test specimens, held under stain, to weather and sunlight at 45 degrees facing south or to air-ozone mixtures as in D 1149.

D 529 (11) Recommended Practice for Accelerated Weathering Test of Bituminous Materials

(modification of G 23 with optional cold air exposure in Daily Cycle B)

Daily Cycle A:

1. Light only (140±5°F) (60±3°C) black panel temperature for	51 mins.
2. Light with spray (spray water 45±5°F or 7±3°C at nozzle) for	9 mins.
Total, 22 periods	60 mins.

Table IV - continued

Daily Cycle B:

1. Water spray only (70±5°F) (21±3°C) for	1 hour
2. Light exposure only (140±5°F) (60±3°C) for	1 1/2 hours
3. Water spray only (70±5°F) (21±3°C) for	2 hours
4. Light only (140±5°F) (60±3°C) for	16 1/2 hours
5. Cold (refrigerator) (0±10°F) (-18±6°C) for	1 3/4 hours
TOTAL	22 3/4 hours

D 545 (10, 11) Standard Methods of Testing Preformed Expansion Joint Fillers for Concrete (Nonextruding and Resilient Types)

Cycle in Section 7 (Accelerated Weathering Test):

1. Expose 7 days at 165°F (74°C).
2. Immerse in water at room temperature for 24 hours.
3. Place specimens on edge in pan; immerse in water to depth of 2 inches (50 mm) (1/2 height of specimens). Place in freezing chamber at +14 to -4°F (-10 to -20°C) until water is frozen to solid ice.
4. Partially immerse pan in water at 65-100°F (18-38°C) until ice has melted entirely.

Repeat cycle 10 times.

Remove from water and allow to stand in air at room temperature for 48 hours.

Table IV - continued

D 750 (28) Recommended Practice for Operating Light- and Water-Exposure Apparatus (Carbon-Arc Type) for Artificial Weathering Testing of Rubber Compounds.

(for vulcanized rubber) (modification of G 23)

Rubber specimens exposed either with or without elongation.

D 756 (27) Standard Methods of Test for Resistance of Plastics to Accelerated Service Conditions

Seven test procedures which prescribe conditions for different types of exposure: six cover exposure at graduated levels of temperature and extremes of humidity; the seventh covers alternate exposure to high and low temperatures.

Table IV - continued

Procedure	Cycle or Exposure
A	24 hrs. at 60°C (140°F), 88 percent relative humidity
	24 hrs. at 60°C (140°F) in oven
B	72 hrs. at 60°C (140°F) in oven
C	24 hrs. at 70°C (158°F), 70-75 percent relative humidity
	24 hrs. at 70°C (158°F) in oven
D	24 hrs. at 80°C (176°F) over water
	24 hrs. at 80°C (176°F) in oven
E	24 hrs. at 80°C (176°F), 70-75 percent relative humidity
	24 hrs. at -40°C (-40°F) or -57°C (-20.6°F) as specified
	24 hrs. at 80°C (176°F) in oven
	24 hrs. at -40°C (-40°F) or -57°C (-70.6°F) as specified
F	24 hrs. at 38°C (100.4°F), 100 percent relative humidity
	24 hrs. at 60°C (140°F) in oven
G	24 hrs. at 49°C (120.2°F), 100 percent relative humidity
	24 hrs. at 49°C (120.2°F) in oven

D 822 (21) Recommended Practice for Operating Light- and Water-Exposure Apparatus (Carbon-Arc Type) for Testing Paint, Varnish, Lacquer, and Related Products

(for organic coatings) (modification of G 23)

Exposure apparatus, as in G 23, specified in Table I for various panel sizes.

Duration of exposure may be mutually agreed on or may be the number of hours required to produce a mutually agreed on change in the test specimens or in a standard sample.

Table IV - continued

D 904 (16) Standard Recommended Practice for Determining the Effect of Artificial (Carbon-Arc Type) and Natural Light on the Permanence of Adhesives (See Table IV for outdoor exposure). Specimens exposed to carbon-arc, air temperature 35-50°C, for 10 hours or until significant change is observed. Specimens mounted vertically or at an angle not over 30 degrees such that the light from the arc has a normal incidence on the specimens.

D 1037 (16) Standard Methods of Evaluating the Properties of Wood-Based Fiber and Particle Panel Materials

(for wood-based hardboard, particleboard)

Accelerated aging cycle, Sections 118-123:

1.	Immerse in water at 120±3°F (49±2°C) for	1 hour
2.	Spray with steam and water vapor at 200±5°F (93±3°C) for	3 hours
3.	Store at 10±5°F (-12±3°C) for	20 hours
4.	Heat at 210±3°F (99±2°C) in dry air for	3 hours
5.	Repeat Step 2	3 hours
6.	Heat in dry air at 210±3°F (99±2°C) for	18 hours
	TOTAL	48 hours

Table IV - continued

D 1101 (16) Standard Method of Test for Integrity of Glue Joints in Structural Laminated Wood Products for Exterior Use

1. Impregnate specimens with water in an autoclave by means of two vacuum-pressure cycles (specimen immersed in water):

   1.1 Vacuum applied 20-25 in. (508-635 mm) Hg for 15 minutes

   1.2 Pressure applied 150±5 psi (1034±34 kN/m^2) for 2 hours

   Total time, 2 cycles, approximately ..... 4 1/2 hours

2. Dry in circulating air oven at 80-85°F (27-29°C), 25-30 percent relative humidity, circulation at a rate of 500±50 ft. (150±15 m)/min. .... 91 1/2 hours

   Repeat Steps 1 and 2 for total of.............. 8 days

D 1148 (28) Standard Method of Test for Discoloration of Vulcanized Rubber: Organic Finish Coated or Light Colored

Exposure to ultraviolet light source: calibrated sunlamp in test chamber.

D 1149 (28) Standard Method of Test for Accelerated Ozone Cracking of Vulcanized Rubber

Specimens under tensile strain exposed to various air-ozone mixtures in a chamber at various temperatures from ambient to 70°C (158°F)

D 1151 (16) Standard Method of Test for Effect of Moisture and Temperature on Adhesive Bonds

Test specimens preconditioned for 70 days at 50±2 percent relative humidity and 23±1°C (73.4±1.8°F), then subjected to designated exposure conditions as in Table 1 for prescribed time.

Table IV - continued

Table 1. Standard Test Exposures (D 1151)

Test Exposure Number	Temperature[a] deg. C.	deg. F.	Moisture Conditions
1	-57	-70	as conditioned
2	-34	-30	as conditioned
3	-34	-30	presoaked[b]
4	0	32	as conditioned
5	23	73.4	50 percent relative humidity
6	23	73.4	immersed in water
7	38	100	88 percent relative humidity
8	63	145	oven, uncontrolled humidity
9	63	145	over water[c]
10	63	145	immersed in water
11	70	158	oven, uncontrolled humidity
12	70	158	over water[c]
13	82	180	oven, uncontrolled humidity
14	82	180	over water[c]
15	100	212	oven, uncontrolled humidity
16	100	212	immersed in water
17	105	221	oven, uncontrolled humidity
18	149	300	oven, uncontrolled humidity
19	204	400	oven, uncontrolled humidity
20	260	500	oven, uncontrolled humidity
21	316	600	oven, uncontrolled humidity

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see footnotes, next page

Table IV - continued

a. The tolerance for test temperature shall be ±1°C or ±1.8°F up to 82°C or 180°F and ±1 percent for temperatures above 82°C or 180°F.

b. Presoaking shall consist of submerging specimens in water and applying vacuum at 50 cm (20 in) of mercury until weight equilibrium is reached.

c. The relative humidity will ordinarily be 95 to 100 percent.

Specimens are tested

(a) under conditions at which they are exposed;

(b) immediately after conditioning for 4 hrs. at 50±2 percent relative humidity and 23±1°C (73.4±1.8°F);

(c) immediately after conditioning for 7 days at 50±2 percent relative humidity and 23±1°C (73.4±1.8°F).

D 1167 (11, 21) Standard Methods of Testing Asphalt-Base Emulsions for Use as Protective Coatings for Built-Up Roofs

Heat Test, Section 12:

Dry asphalt coated steel panels in horizontal position for 48 hours at 70-80°F (21-27°C), 50 percent relative humidity. Heat in oven at 212±3°F (100±5°C) for 24 hours.

Water Resistance, Section 14:

Dry asphalt coated brass panels in forced draft air circulating oven for 24 hours at 140±5°F (60±30°C). Completely immerse panels in water in glass containers at 70-80°F (21-27°C) for 24 hours.

D 1183 Standard Methods of Test for Resistance of Adhesives to Cyclic Laboratory Aging Conditions.

Cyclic exposure to high and low temperatures, high and low relative humidities as defined in Table 1.

Cycles: Table 1. Test Procedures

Procedure	Name	Period hrs.	Temperature deg. C.	deg. F.	Relative Humidity percent
A	Interior	24	23±1.1	73.4±2	85 to 90
		24	48.5±3	120±5	less than 25
		72	23±1.1	73.4±2	85 to 90
		48	48.5±3	120±5	less than 25
B	Interior	48	60±3	140±5	less than 25
		48	38.5±2	100±3.5	85 to 90
		8	-18±2	0±3.5	about 100
		64	38.5±2	100±3.5	85 to 90
C	Exterior, land and air	48	71±3	160±5	less than 10
		48	23±1.1	73.4±2	immersed in water
		8	-57±3	-70±5	about 100
		64	38.5±2	100±3.5	about 100
D	Exterior, Marine	48	71±3	160±5	less than 10
		48	23±1.1	73.4±2	immersed in substitute ocean water
		8	-57±3	-70±5	about 100
		64	23±1.1	73.4±2	immersed in substitute ocean water

Table IV - continued

D 1499 (27) Standard Recommended Practice for Operating Light- and Water-Exposure Apparatus (Carbon-Arc Type) for Exposure of Plastics (modification of G 23)

Black panel temperature (spray off) 63±5°C (145±9°F) but lower temperature may be used if specimens are temperature sensitive.

If water spray is not required, proceed as in G 25.

D 1501 (27) Standard Recommended Practice for Exposure of Plastics to Fluorescent Sunlamp.

Definition of three exposure conditions for plastics:

Procedure A. Exposure to fluorescent sunlamp at ambient temperature

Procedure B. Exposure to fluorescent sunlamp in heated air at 50-60°C (131-140°F)

Procedure C. Exposure to fluorescent sunlamp at 55-60°C (131-140°F) with interruptions for exposure in fog chamber. Cycle as follows:

1.	Fog chamber........................	2 hours
2.	Heat and light as in Procedure B....	2 hours
3.	Fog chamber........................	2 hours
4.	Heat and light as in Procedure B....	18 hours
	Total..............................	24 hours

for total of 240 hours

Turntable and fog chamber recommended: Figures 3, 4, ASTM Recommended Practice D 795 (discontinued)

Table IV - continued

D 1565 (28) Standard Specification for Flexible Foams Made from Polymers or Copolymers of Vinyl Chloride

Air oven aging test, sections 22-27: Exposure of specimens in forced-ventilation oven for 22 hours at 100°C (212°F)

D 1654 (21) Standard Method of Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments

Scribe the specimen with a special tool vertically, near the center, penetrating the coating. For flat specimens, begin the scribe at approximately 1/2 inch from one edge and continue to 1/2 inch from the opposite edge.

Expose the specimen as in B 117, B 287, D 1014, or by any other method as mutually agreed.

Treat as in Method A or B:

Method A: Rinse with a gentle stream of water at 100±10°F (38±5°C) and clean with an air blast as prescribed.

Method B: Rinse with a gentle stream of water at 100±10°F (38±5°C) and scrape with a tool as prescribed.

D 1735 (21) Standard Method for Water Fog Testing of Organic Coatings

Specimens 15 degrees from vertical and parallel to horizontal flow of fog. Exposure zone of fog chamber 100±2°F unless otherwise specified. Recommended exposure periods intervals of 24 hours to the total of 96, 192, 504, or 1008 hours.

D 1754 (11) Standard Method of Test for Effect of Heat and Air on Asphaltic Materials (Thin-Film Oven Test)

Heating 1/8 inch film of asphlatic specimen in oven at 163°C (325°F) for 5 hours.

Table IV - continued

D 1870 (27, 28) Standard Method of Test for Elevated Temperature Aging Using a Tubular Oven

(for polymers)

Specimens heated at specified temperature in tubular oven and changes in physical properties measured.

D 2126 (26) Standard Method of Test for Resistance of Rigid Cellular Plastics to Simulated Service Conditions

Specimens conditioned and exposed to one of seven conditions of temperature and relative humidity:

Procedure	Temperature deg. C	Temperature deg. F	Relative Humidity percent
A	23±1	73.4±1.8	50±2
B	-29±3	-20.2±5.4	____
C	38±1	100.4±1.8	90 - 100
D	60±1	140±1.8	90 - 100
E	70±1	158±1.8	____
F	70±1	158±1.8	90 - 100
G	100±1	212±1.8	____

Table IV - continued

D 2246 (21) Standard Method for Testing Finishes on Primed Metallic Substrates for Resistance to Humidity - Thermal Cycle Cracking

Specimens in rack 0 to 30 degrees from vertical

Cycle as follows:

1. Humidity cabinet, 100°F (38°C), 100 percent relative humidity	24±1/2 hours
2. Cold box, -10±3°F (-23±2°C)	20±1/2 hours
3. Room temperature	4±1/2 hours
TOTAL	48 hours

Run for 15 cycles or as mutually agreed on.

D 2247 (21) Standard Method for Testing Coated Metal Specimens at 100 Percent Relative Humidity

Specimens placed in humidity chamber in such a way as to permit condensation on surfaces. Temperature of saturated air 38±1°C (100±2°F). Test may be used as a continuous humidity test or as part of a cycle.

D 2248 (21) Standard Method of Test for Detergent Resistance of Organic Finishes

(for organic coatings)

Test for resistance to detergent of organic coatings on metal panels by suspending the specimens vertically and immersing at least half of the surface area in a standardized detergent solution at 74±1°C (165±2°F), the solution being replaced every 168 hours. Period of test not prescribed.

Table IV - continued

D 2249 (14, 21) Standard Method of Predicting the Effect of Weathering on Face Glazing and Bedding Compounds on Metal Sash

(for sealants used in glazing and bedding) (modification of G 23)

Specimens knifed and pressed into a special aluminum and glass assembly to simulate face glazing and bedding.

One of the Units of Type D through G of G 23 used for exposure, with addition of 102-18 cycling cam and black panel thermometer accessories.

Specimens exposed vertically with surface of sealant facing light source, at black panel temperature of 60±3°C (140±5°F), with 102-18 cycling cam.

Specimens examined after each 100 hour exposure to a maximum of 300 hours.

D 2366 (21) Standard Method for Accelerated Testing of Moisture Blister Resistance of Exterior House Paints on Wood

Expose specimens in a blister box or cabinet containing water at a specified temperature; air temperature 100±2°F (38±1°C), 95-100 percent relative humidity. Exterior air temperature 77±2°F (25±1°C); relative humidity 50±5 percent.

D 2445 (26) Standard Method of Test for Thermal Oxidative Stability of Propylene Plastics

Exposure time determined for pellets of plastic to become embrittled in an oxygen atmosphere at 150°C (302°F)

Table IV - continued

D 2559 (16) Standard Specification for Adhesives for Structural Laminated Wood Products for Use Under Exterior (Wet Use) Exposure Conditions

Section 13:

Test for resistance to delamination during accelerated exposure:

1. Impregnate specimens with water in an autoclave by mean of two vacuum-pressure cycles (specimen immersed in water)
   1.1 Vacuum of at least 635 mm (25 in) Hg applied for 5 min.
   1.2 Pressure of 5.27±0.141 kg/cm^2 (75±2 psi) applied for 1 hour.

   Total time, 2 cycles, approximately ...... 2 1/6 hours
2. Dry in an oven at 65±2°C (150±3.6°F), relative humidity 15 percent or less, for...... 21-22 hours
3. Subject specimens to steam at 100°C (212°F) for 1 1/2 hours
4. Add water, apply a pressure of 5.27±0.141 kg/cm^2 (75±2 psi) for 40 mins.

   Repeat Steps 1 and 2; total test period........ 3 days

D 2565 (27) Standard Recommended Practice for Operating Xenon-Arc Type (Water-Cooled) Light and Water-Exposure Apparatus for Exposure of Plastics

(modification of G 26)

Water-cooled xenon-arc, Types A, AH, B, BH in G 26

Details on lamps, filters, operating procedures for equipment but otherwise not on exposure conditions.

D 2803 (21) Standard Method of Test for Filiform Corrosion Resistance of Organic Coatings on Metal

(Filiform corrosion is a special type which occurs under coatings on metal and is characterized by a thread-like structure and directional growth. This usually occurs between 21 and 35°C (70-95°F) and 60 to 95 percent relative humidity.)

Test procedure:

1. Scribe specimens as mutually agreed on. Recommended procedure: D 1654.
2. Expose specimens in a salt-spray cabinet as in B 117 for at least 4 hours but not more than 24 hours.
3. Remove specimens from the cabinet and rinse thoroughly with distilled or demineralized water.
4. Place the wet specimen in a humidity cabinet at 25±1.7°C (77±3°F) and 85±2 percent relative humidity unless otherwise specified.
5. Inspect the specimens at intervals of approximately 168 hours.

The normal test period is 6 weeks (1008 hours) but other periods may be used as mutually agreed.

D 2831 (20, 21) Standard Method of Test for Evaluating the Ability of a Latex Paint to Resist Efflorescence from the Substrate, Parts 20, 21.

Prepare test specimens from asbestos cement shingle blanks and latex paint as prescribed.

Table IV - continued

Test procedure:

1. Fill container with tap water so that the water level is 1 to 1 1/2 inch (2.5-3.5 cm) below the surface of the panels when in place.
2. Regulate temperature of water to 40±3°C (104±5°F).
3. Place panels on pan over the water, painted side down, and expose for 16-17 hours.
4. Turn panels over; dry 1-2 hours or more, flat, with painted side up.

D 2898 (16) Tentative Methods of Test for Durability of Fire-Retardant Treatment of Wood

Description of apparatus, test specimens, exposure cycles (Methods A and B)

Method A (cycle):

1. Water spray at 35-60°F (2-16°C).................. 96 hours
2. Drying in moving air stream at 135-140°F (57-60°C)............................. 72 hours

TOTAL 1 week

Method B (cycle): Ultraviolet light from sunlamps is evenly distributed over the specimen surface.

1. Water spray at not over 90°F (32°C)........... 4 hours
2. Drying at 150±5°F (63±3°C)..................... 4 hours
3. Repeat water spray as in Step 1................. 4 hours
4. Repeat drying as in Step 2...................... 4 hours
5. Rest... 8 hours

TOTAL 24 hours

Repeat for total of 1,000 hours

Table IV - continued

D 2918 (16) Standard Recommended Practice for Determining Durability of Adhesive Joints Stressed in Peel

Clamp upper end of test panel to frame and attach desired weight to lower end. Force on ahdesive should be a multiple of 450g (1.0 lb). Suggested stress 25, 50, 75 percent of normal peel strength as measured by D 1876.

Expose specimen to one of Standard Test Environments in Table 1.

Test at least 3 specimens under each set of conditions (test environment and stress)

Table 1. Standard Test Environments

Test Environment Number	Temperature[a]	Moisture Conditions[b]
1	23°C (73.4°F)	immersed in distilled or deionized water
2	23°C (73.4°F)	50 percent relative humidity
3	23°C (73.4°F)	15 percent relative humidity
4	35°C (75°F)	90 percent relative humidity
5	35°C (95°F)	100 percent relative humidity
6	50°C (122°F)	90 percent relative humidity
7	50°C (122°F)	100 percent relative humidity
8	35°C (95°F)	5 percent salt fog
9	Ambient (outdoors)	Ambient (outdoors)
10	Other (specify)	Other (including aqueous solutions or nonaqueous liquid (specify)

a. The tolerance for the test temperature shall be ±1°C or ±1.8°F for environments 1 to 8.

b. The moisture conditions may be provided by controlling the relative humidity of a box, room, or other chamber by any convenient means.

Table IV - continued

D 2919 (16) Standard Recommended Practice for Determining Durability of Adhesive Joints Stressed in Shear by Tension Loading.

Prepare lap-shear adhesive joints as in D 1002 except that the dimensions shall be as in Figure 2, D 2919.

Test six specimens to destruction as in D 1002 at 23.0±1°C (73.4±1.8°F) and 50±2 percent relative humidity.

Place at least six specimens in the fixture, Figure 1, D 2919, and apply the desired stress by means of the springs and grip bolts, not to exceed the initial failing stress.

Expose to one of the standard test environments as in Table 1 (same as Table 1, D 2918).

G 23 (24, 27, 30) Standard Recommended Practice for Operating Light- and Water-Exposure Apparatus (Carbon-Arc Type) for Exposure of Nonmetallic Materials (formerly E 42)

Description of apparatus and operating procedures for carbon-arc exposure apparatus without specifications for exposure conditions except as noted.

Specimens generally mounted vertically but may be mounted horizontally if vertical mount is impracticable.

Water strikes specimens as a fine spray, evenly distributed, at a temperature of 15±5°C (60±90°F); pH of water 6.0-8.0.

Types of light and water exposure apparatus described (12): A, AH, B, C, D, DH, E, EH, F, G, H, HH. Types AH, DH, EH, HH have automatic humidity control. Types A, AH, D, DH, E, EH, H, and HH have automatic temperature control.

Table IV - continued

G 25 (24, 30) Standard Recommended Practice for Operating Enclosed Carbon-Arc Type Apparatus for Light Exposure of Nonmetallic Materials

Description of apparatus and operating procedure for carbon-arc light exposure apparatus without specifications for exposure conditions except as noted.

Exposure intended to simulate G 24 Sunlight Exposure (Method A) or Daylight Exposure (Method B).

Specimens mounted vertically unless vertical mount is impracticable.

Temperature measurement and control based on black panel thermometer unit.

Two Types of exposure are described:

Method A. Continuous exposure to light and

Method B. Alternate exposure to light and darkness

In Method A, the relative humidity is adjusted to 30±5 percent at the exit of air from the chamber, unless otherwise specified. Black panel temperature is adjusted to 63±3°C (145±5°F). Controls are adjusted so that 20 hours continuous operation produces 18±2 standard fading hours as determined by color standards. In Method B, the relative humidity is adjusted to 35±5 percent during the light-on period and to 90±5 percent during the light-off period. Black panel temperature at equilibrium during the light-on period shall be 63±3°C (145±5°F).

Unless otherwise specified, controls shall be adjusted for a cycle of 1 hour darkness and 3 hours light.

Table IV - continued

Apparatus is calibrated in terms of standard fading hours by means of color standards.

G 26 (30) Standard Recommended Practice for Operating Light- and Water-Exposure Apparatus (Xenon-Arc Type) for exposure of Nonmetallic Materials

(formerly E 239)

Description of apparatus and operating procedures for xenon-arc light and water exposure apparatus without specifications for exposure conditions except as noted.

Specimens mounted vertically.

Temperature measurement and control based on black panel thermometer unit.

Water strikes specimens as a fine spray, evenly distributed, at a temperature of 60.8±9°F (16±5°C); pH of water 6.0-8.0

Types of light and water exposure apparatus described (6):

A, AH, B, BH, C, D

Types A, AH, B, BH are water-cooled.

Types C and D are air-cooled.

Types A, AH, C, D have automatic humidity control.

Types A, AH, B, BH, D have automatic temperature control.

All types have automatic cycle control.

G 27 (30) Standard Recommended Practice for Operating Xenon-Arc Type Apparatus for Light Exposure of Nonmetallic Materials

Description of apparatus and operating procedure for xenon-arc exposure apparatus without specification for exposure conditions except as noted.

Exposure intended to simulate G 24 Sunlight Exposure (Method A) or Daylight Exposure (Method B).

Specimens mounted vertically.

Temperature measurement and control based on black panel thermometer unit.

Apparatus may use water-cooled or air-cooled xenon-arc.

Type types of exposures (Methods A and B) are described as in G 25 with the same conditions. However, the apparatus is not calibrated in terms of standard fading hours but color standards are used as references with test specimens.

Table V - CRITERIA FOR OUTDOOR AND ACCELERATED WEATHERING METHODS AND EVALUATIVE TECHNIQUES IN ASTM STANDARDS (1971)

B 117 (7, 21, 31) (for organic coatings on metal)

  Extent of corrosion[a]

  Visual examination[b]

B 287 (7, 21, 31) (for organic coatings on metal)

  Extent of corrosion[a]

  Visual examination[b]

B 368 (7, 21) (for chromium alloy plate on steel and zinc base die castings)

  Extent of corrosion[a]

  Visual examination[b]

B 537 (7) (for chromium plated steel and zinc die castings)

  Extent of corrosion[a]

  Visual examination with numerical rating[b]:

    "Protection number": Ability of coating to protect the substrate from corrosion:

      $R = 3(2 - \log A)$, where

      R = rating

      A = percentage of total area covered by defects as determined by comparison with "dot charts"

      "Appearance number": Numerical rating based on degree to which surface coating defects affect appearance, as determined by comparison with reference photographs

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See footnotes next page

Table V - continued

a. Criterion

b. Evaluative technique or test

c. Predictive test not based on exposure. In most cases, criteria for durability are properties, changes in which are measured following outdoor exposure or accelerated aging. In some cases, however, predictive tests are applied to components or materials without exposure.

C 62 (12) (for brick) (See also C 67)

- Weathering Index and Map[a,b]
- Compressive strength[b]
- Dimensional tolerances[a]
- Visual examination[b]

C 67 (12) (for brick)

- Loss of weight as percentage of original weight[a]
- Number of cycles causing breakage[a]
- Modulus of rupture (Flexure Test)[c]
- Compressive strength[c]
- Absorption[c]
- Five-hour boiling test[c]
- Initial rate of absorption (Suction)[c]
- Efflorescence[c]

C 88[c] (10) Standard Method of Test for Soundness of Aggregate by Use of Sodium Sulfate or Magnesium Sulfate

(for concrete aggregates)

1. Immerse sieved specimens of aggregate (fine or coarse) in special solutions of sodium or magnesium sulfate for 16-18 hours, so that the solution covers the specimens to a depth of at least 1/2 inch, at 70±2°F (21±1°C)
2. Drain specimens for 15±5 minutes.
3. Dry in an oven at 230±9°F (110±5°C) to constant weight.

Repeat immersion and drying for required number of cycles.

Quantitative examination: Loss of aggregate by breaking into fine particles as determined by sieve test.

Qualitative examination: Number of particles coarser than 3/4 inch showing "distress", such as disintegration, splitting, crumbling, cracking, and flaking.

C 216 (12) See C 67

C 217 (12) (for natural slate)

Softening[a]

Depth of softening determined by Shear/Scratch Tester or by Hand Scraping Tool[b].

C 481 (16) (for sandwich constructions)

Measurement of properties before and after aging:

Shear test, C 273

Compressive strength, C 364

Delamination strength, C 363

Table V - continued

Tension test, C 297

Flatwise flexure test, C 393

Climbing Drum Peel Test, D 1781

C 488 (14) (for finishes for thermal insulation)

Blistering, chalking, crazing, cracking, discoloration, flaking, and shrinkage[a]

Visual observation[b]

C 510 (14) (for joint sealants)

Change in color of sealant as compared with control specimen[a,b]

C 666 (10) (for concrete)

Durability Factor[a], DF = PN/M, where

DF = durability factor of test specimen

P = relative dynamic modulus of elasticity at N cycles, percent

N = number of cycles at which P reaches the specified minimum value for discontinuing the test or the specified number of cycles at which the exposure is to be terminated, whichever is less

M = specified number of cycles at which the exposure is to be terminated

Relative dynamic modulus of elasticity, determined as in C 215[b]:

$P_c = (n_1^2/n^2) \times 100$, where

P_c = relative dynamic modulus of elasticity after c cycles of freezing and thawing, percent

n = fundamental transverse frequency at 0 cycles of freezing and thawing

n_1 = fundamental transverse frequency after c cycles of freezing and thawing

Table V - continued

C 669 (14) (for sealants used in back bedding and face glazing)

Changes not greater than illustrated by photographs in D 2249[a,b]:

Surface cracking and peeling, No. 5, Plate No. 1; Deep-bead cracking, No. 5, Plate No. 2; Loss of adhesion, Nos. 4,5, Plate No. 3; Wrinkling, Nos. 4,5, Plate No. 4; Oil exudation, No. 5, Plate No. 5.

C 671[c] (10) Tentative Method of Test for Critical Dilation of Concrete Specimens Subjected to Freezing

Prepare concrete specimens as in C 192, fitted with gage studs as in C 490, and position specimens in strain frame.

Test cycle: Cool specimens in water-saturated kerosene from 35 to 15°F (1.7 to -9.4°C) at the rate of 5±1°F (2.8±0.5°C), followed by immediate return of the specimens to the 35°F water bath, where they shall remain until the next cycle. One test cycle shall be carried out every 2 weeks. Test shall be continued until the critical dilation is exceeded.

C 682[c] (10) Tentative Recommended Practice for Evaluation of Frost Resistance of Coarse Aggregates in Air-Entrained Concrete by Critical Dilation Procedures

Coarse aggregates are sampled, graded, and conditioned, and used to prepare concrete specimens, fitted with gage studs as in C 671 and moded as in Method C of C 192. Tests are conducted as in Method C of C 671.

Mean value for test period of frost immunity or total test period for which critical diluation does not occur.

Critical dilation is that during the last test cycle before the dilation begins to increase sharply.

Table V - continued

Dilation is determined by measuring the vertical distance from a straight-line projection of the prefreezing length - time contraction curve (at constant cooling rate) and the maximum deviation of the strain trace from it. The curves are obtained from specimen length changes and cooling bath temperatures during the cooling cycle.

D 518 (28) (for soft rubber)

Appearance of first minute surface cracks[a] by visual observation, using 7X magnification[b]

Percent elongation of tapered specimens[a,b]

D 529 (11) (for bituminous materials)

Visual examination of the samples compared with unexposed samples[a,b], or

Failure Endpoint[a] as in D 1670: Number of cracks in film as determined by high-voltage spark and counting grid[b].

D 545 (10, 11) (for preformed expansion joint fillers for concrete)

Visual examination[b] for evidence of disintegration[a] (Section 7).

D 750 (28) (for vulcanized rubber)

Visual examination[b] for the degree and number of cracks[a] and for evidence of crazing[a]

Tensile strength and ultimate elongation, D 412[a,b]

(Specimen preparation for tests, D 15)

Table V - continued

D 756 (27) (for plastics)

Noticeable changes in surfaces, outline, general appearance including changes in color, surface irregularities, odor, splits, as in D 883[a,b]

Changes in weight and dimensions[a,b]

D 822 (21) (for organic coatings)

Visual examination[b] for:

Blistering, D 714[a]

Chalking, D 659[a]

Checking, D 660[a]

Cracking, D 661[a]

Erosion, D 662[a]

Flaking (Scaling), D 772[a]

Rusting, D 610[a]

Change in color, E 308, D 2244[ab]

Change in reflectance, E 97[a,b]

Change in specular gloss, D 523[a,b]

D 904 (16) (for adhesives)

Visual change in appearance[a,b]

Results of physical and chemical tests[a,b]

D 1006 (21) (for organic coatings on wood)

Recording on standard form as in D 1150[a,b]

D 1014 (21) (for organic coatings on steel)

Visual examination[b] for

Blistering, D 714[a]

Chalking, D 659[a]

Rusting, D 610[a]

D 1037 (16) (for wood-based hardboard, particleboard)

Visual inspection[b] for delamination or other disintegration[a]

Measurement of cupping and twisting[a,b]

Changes[a,b] in

Static bending

Lateral nail resistance

Nail withdrawal

Water absorption

Nail Head Pull-Through

D 1101 (16) (for adhesive joints in structural laminated wood)

$$\text{Percentage delamination}^{a,b} = \frac{\text{Length of open glue joint area on end-grain surface}}{\text{Total length of end-grain joints}} \times 100$$

D 1148 (28) (for vulcanized rubber)

Change in color or test specimen in relation to original sample[a] as expressed by numerical rating of degree of discoloration[b]

D 1149 (28) (for vulcanized rubber)

Cracking[a]

Time to first observed cracking, using 7X magnification, except for triangular specimens of Method D 1171, where the magnification shall be 2X[b]

D 1151 (16) (for adhesive bonds)

Various strength properties measured before and after exposure[a,b]

Performance A = (A/C) x 100[a]

Performance B = (B/C) x 100[a], where

A = average strength after exposure

B = average strength after exposure

C = original strength after conditioning

D 1167 (11, 21) (for asphalt emulsion coatings on built-up roofs)

<u>Heat Test</u>[b], Section 12:

Examine coating for sagging, slipping, blistering[a].

Record extent of sagging or slipping past reference line in decimals of inch, and the presence or absence of blisters.

<u>Water Resistance</u>[b], Section 14:

Examine for blistering and re-emulsification as evidenced by asphalt particles in the water[a].

D 1183 (16) (for adhesives)

Change in appearance[a,b]

Change in strength properties as[a,b]:

Cleavage strength of bond, D 1062

Impact strength of bond, D 950

Peel or stripping strength of bond, D 903

Flexural strength of assemblies, D 1184

Shear by tension loading, D 906, D 1002

Tensile properties of bond, D 897

Tensile properties of cross-lap specimens, D 1344

Table V - continued

D 1435 (27) (for plastics)

Appearance Properties

COLOR[a]

Color difference[b], D 1535, D 1729, D 2244, E 308

Yellowness[b], D 1925, E 313

GEOMETRIC DISTRIBUTION[a]

Gloss[b], D 523, D 2457

Haze[b], D 1003

Transparency[b], D 1746

Electrical Properties[a]

High-voltage, low-current arc resistance, D 495[b]

Dielectric breakdown, dielectric strength, D 149[b]

Mechanical Properties[a]

Dimensional change, D 1042, D 1204[b]

Impact, D 256[b]

Indentation hardness, D 785, D 2240[b]

Stiffness, D 747[b]

Tear resistance, D 1004, D 1938[b]

Tensile and elongation properties, D 638, D 882, D 1708, D 1923, D 2289[b].

D 1499 (27) (for plastics)

Evaluation covered in ASTM methods or specifications for specific materials.

Table V - continued

D 1501 (27) (for plastics)

Color change (none, slight, appreciable, extreme)[a,b]

Surface changes (as chalking[b], dulling) by visual observation[a]

Deep-seated changes (as checking, crazing, warping, discoloration)[a,b]

Physical and chemical tests to determine extent of degradation[a,b]

D 1565 (28) (for vinyl foam)

Percentage change in indentation-load deflection or compression-load deflection[a,b]

D 1641 (21) (for varnishes)

General appearance and visual observation[b] or checking[a], cracking[a], discoloration[a], dulling[a], recoatability[a]

D 1654 (21) (for organic coatings on metal)

Loss of adhesion[a], extent of blistering[a], corrosion[a], and rust[a] are evaluated by measuring the distance between the scribed mark and the edge of the unaffected area of the finish[b]. Numerical ratings are based on these measurements.

Rating Schedule No. 1: Report maximum and minimum creepage from the scribe and use numerical rating[b].

Rating Schedule No. 2: Rate by percentage failure as corrosion spots, blisters. Recommend use of counting grid. Photographic reference standards may be used as in D 610, D 714[b].

D 1735 (21) (for organic coatings)

Visual observation[a]

Blistering, D 714[b]

Rusting, D 610[b]

D 1754 (11) (for asphalt)

Reduction of penetration as in D 5[a,b]

Loss of weight[a,b]

D 1828 (16) (for adhesive bonded joints and structures)

General appearance dimensions (including warpage)[a,b]

Change in properties[a,b]

D 1870 (27, 28) (for polymers)

Change in physical properties in percent[a,b]

D 2126 (26) (for rigid cellular plastics)

Change in appearance[a,b]

Percentage change in weight, dimensions, and other properties[a,b]

D 2246 (21) (for coated metal)

Cracking[a] by visual observation[b], using a grid, and counting number of grid squares within which one or more cracks is visible.

D 2247 (21) (for coated metal)

Degradation of finish as observed visually[b]:

Blistering, D 714[a]

Corrosion, D 1654[a]

Rusting, D 610[a]

Loss of adhesion, D 2197[a,b]

Change in Indentation Hardness, D 1474[a,b]

Change in Specular Gloss, D 523[a,b]

D 2248 (21) Not prescribed but the usual coatings tests are applicable (D 523, D 610, D 714, D 1474, D 1654, D 2197, D 2248)

Table V - continued

D 2249 (14, 21) (for sealants used in glazing and bedding)

Visual estimation[a], using numerical scale[b], of loss of adhesion[a], surface cracking and peeling[a], deep bead cracking[a], wrinkling[a], and oil exudation[a].

D 2366 (21) (for exterior house paints on wood)

Evaluate degree of blistering and percentage of test area on which blisters occur after 1, 2, 4, 7, and 14 days[a] by D 714[b]. Percentage of panel area on which blisters have formed may be determined by means of a counting grid[b]:

$$\text{Area blistered, percent} = \frac{\text{Number of squares covering blisters}}{\text{Total number of squares over test area}} \times 100$$

D 2445 (26) (for propylene plastics)

Pellets tested for brittleness[a] by lightly applying a light compressive force manually and observing whether they crush easily to powder form[b]. The specimen has failed if at least 8 of the first 10 pellets tested are completely embrittled.

D 2559 (16) (for adhesives)

Section 13: Delamination on end-grain surfaces[a,b]:

$$\text{Percentage delamination} = \frac{\text{Length of open glue joint area}}{\text{Total length of bond line}} \times 100$$

D 2565 (27) (for plastics)

Appearance[a,b]

D 2803 (21) (for organic coatings on metal)

Note filiform corrosion as threads initiating at the scribe[a]. Description or photograph may be used for reporting[b].

D 2830 (20, 21) (for organic coatings on wood)

Visual examination[b] for appearance[a], mildew[a], and film failure[a]

Test for adhesion between the primer and top coat[a,b]:

Cut a small X to penetrate the substrate slightly.

Apply cellophane tape to cross the X; press; remove quickly.

D 2831 (20, 21) (for latex paints on asbestos cement shingles)

Visual observation[b] of efflorescence[a], rated as none, slight, moderate, or severe

D 2898 (16) (for fire-retardant treatment of wood)

Fire tests as in E 84, E 286, D 108[a,b]

D 2918 (16) (for adhesive joints)

Rate of peel of adhesive from joint[a,b]

Plot distance peeled versus time and divide the curve into six equal parts. If the peel rate varies less than a factor of 2 over all six parts of the curve, obtain the average peel rate (slope of the curve) for the specimen. To assess durability, compare peel rates under different levels of stress and environment and plot log peel versus stress.

D 2919 (16) (for adhesive joints)

Maximum, minimum, average length of time to failure of stressed specimens exposed to environment[a,b]

G 7 (30) (for nonmetallic materials)

One or more of the following may be pertinent:

Appearance, electrical and mechanical properties, D 1435[a,b]

Appearance, visual observation of checking, cracking, discoloration, dulling, and recoatability, D 1641[a,b]

Table V - continued

Visual observation[b] of

Blistering, D 714[a]

Chalking, D 659[a]

Checking, D 660[a]

Color Change, G 24[a]

Cracking, D 661[a]

Erosion, D 662[a]

Flaking (scaling), D 772[a]

Rusting, D 610[a]

Number of cracks in film as determined by high-voltage spark and counting grid, D 1670[b].

G 11 (21, 30) (for pipeline coatings)

Visual observation[b] of blistering[a], checking[a], cracking[a], corrosion[a], undercutting from intentional scribe[a,b].

G 23 (24, 27, 30)

Evaluation covered in ASTM methods or specifications for specific materials.

G 24 (24, 36)

Evaluation covered in ASTM methods or specifications for specific materials.

G 25 (24, 30) (for nonmetallic materials)

Evaluation covered in ASTM methods or specification for specific materials.

G 26 (30)

Evaluation covered in ASTM methods or specifications for specific materials.

G 27 (30)

Evaluation covered in ASTM methods or specifications for specific materials.

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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.)

This report is a summary of the present knowledge pertaining to durability predictions for building components and materials which are subjected to the effects of outdoor exposure. The various chapters of the report include discussions of the nature of aging, the measurement of properties to predict durability, non-destructive evaluation techniques, outdoor exposure techniques, accelerated aging techniques, techniques for applying testing data to durability predictions and difficulties which arise in predicting durability. Conclusions and recommendations are also included.

An appendix, which summarizes ASTM Standards for durability testing of building components and materials, is included.

17. KEY WORDS (Alphabetical order, separated by semicolons) Accelerated aging; aging of buildings; building components; climate; criteria; deterioration; durability; materials; mechanisms; non-destructive testing; testing.

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