NATIONAL BUREAU OF STANDARDS REPORT

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IDENTIFICATION AND PREDICTION OF AGING PROPERTIES OF BUILDING MATERIALS

NBS

U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

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The National Bureau of Standards[1] was established by an act of Congress March 3, 1901. Today, in addition to serving as the Nation's central measurement laboratory, the Bureau is a principal focal point in the Federal Government for assuring maximum application of the physical and engineering sciences to the advancement of technology in industry and commerce. To this end the Bureau conducts research and provides central national services in four broad program areas. These are: (1) basic measurements and standards, (2) materials measurements and standards, (3) technological measurements and standards, and (4) transfer of technology.

The Bureau comprises the Institute for Basic Standards, the Institute for Materials Research, the Institute for Applied Technology, the Center for Radiation Research, the Center for Computer Sciences and Technology, and the Office for Information Programs.

THE INSTITUTE FOR BASIC STANDARDS provides the central basis within the United States of a complete and consistent system of physical measurement; coordinates that system with measurement systems of other nations; and furnishes essential services leading to accurate and uniform physical measurements throughout the Nation's scientific community, industry, and commerce. The Institute consists of an Office of Measurement Services and the following technical divisions:

> Applied Mathematics—Electricity—Metrology—Mechanics—Heat—Atomic and Molecular Physics—Radio Physics[2]—Radio Engineering[2]—Time and Frequency[2]—Astrophysics[2]—Cryogenics.[2]

THE INSTITUTE FOR MATERIALS RESEARCH conducts materials research leading to improved methods of measurement standards, and data on the properties of well-characterized materials needed by industry, commerce, educational institutions, and Government; develops, produces, and distributes standard reference materials; relates the physical and chemical properties of materials to their behavior and their interaction with their environments; and provides advisory and research services to other Government agencies. The Institute consists of an Office of Standard Reference Materials and the following divisions:

> Analytical Chemistry—Polymers—Metallurgy—Inorganic Materials—Physical Chemistry.

THE INSTITUTE FOR APPLIED TECHNOLOGY provides technical services to promote the use of available technology and to facilitate technological innovation in industry and Government; cooperates with public and private organizations in the development of technological standards, and test methodologies; and provides advisory and research services for Federal, state, and local government agencies. The Institute consists of the following technical divisions and offices:

> Engineering Standards—Weights and Measures — Invention and Innovation — Vehicle Systems Research—Product Evaluation—Building Research—Instrument Shops—Measurement Engineering—Electronic Technology—Technical Analysis.

THE CENTER FOR RADIATION RESEARCH engages in research, measurement, and application of radiation to the solution of Bureau mission problems and the problems of other agencies and institutions. The Center consists of the following divisions:

> Reactor Radiation—Linac Radiation—Nuclear Radiation—Applied Radiation.

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> Information Processing Standards—Computer Information — Computer Services — Systems Development—Information Processing Technology.

THE OFFICE FOR INFORMATION PROGRAMS promotes optimum dissemination and accessibility of scientific information generated within NBS and other agencies of the Federal government; promotes the development of the National Standard Reference Data System and a system of information analysis centers dealing with the broader aspects of the National Measurement System, and provides appropriate services to ensure that the NBS staff has optimum accessibility to the scientific information of the world. The Office consists of the following organizational units:

> Office of Standard Reference Data—Clearinghouse for Federal Scientific and Technical Information[3]—Office of Technical Information and Publications—Library—Office of Public Information—Office of International Relations.

[1] Headquarters and Laboratories at Gaithersburg, Maryland, unless otherwise noted; mailing address Washington, D.C. 20234.
[2] Located at Boulder, Colorado 80302.
[3] Located at 5285 Port Royal Road, Springfield, Virginia 22151.

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IDENTIFICATION AND PREDICTION OF AGING PROPERTIES OF BUILDING MATERIALS

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ABSTRACT

Aging denotes the process of unwanted change which occur in a building material during service. The philosophy of accelerated aging testing of materials and the relation of test results to in-use performance is discussed. The durability of materials program area of the National Bureau of Standards is described giving examples of test methods developed and techniques employed to measure aging properties of materials. Two approaches useful in predicting performance of materials in service as part of a building system on the basis of laboratory testing are presented. The part that quantitative aging criteria has to play in the development of realistic performance standards is also considered.

IDENTIFICATION AND PREDICTION OF AGING PROPERTIES
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1. DURABILITY - THE TIME DIMENSION OF PERFORMANCE

For the purpose of this paper, aging denotes the process of change which occurs in a material during normal usage in a building system for a normal period of time. The rate of aging is determined by the nature of the material as well as by a number of other factors which include among others, exposure, use and maintenance. The nature, intensity and frequency of the aging forces acting alone or in concert with others, often synergistically produce unwanted changes which alter the performance characteristics of the building material or composite. The ability of the material to resist or adjust to these forces which produce unwanted changes, for a normal period of time with normal usage is identified as durability, the time-dimension of performance. Therefore, durability, per se, becomes a very desirabile performance characteristic for materials used in each building component or system from the basic structural system to the decorative covering on the kitchen wall. It is recognized that the durability of most building products can be increased at the trade off of an increased cost Therefore, longevity of the specific material becomes an important factor in the economics involved in the manufacture, selection and application of materials from the respective viewpoints of the producer, applier and consumer. In other words, the benefit-cost relation between longevity and economics should be a prime consideration in placing durability in perspective.

So far we have attempted to establish that aging is an important performance characteristic of building materials and systems. Now, the question arises as to how can we identify and predict the aging characteristics of the multifarious materials used in building construction and how can these performance characteristics be related to performance standards?

2. PURPOSE OF THE REPORT

The purpose of this report is to present examples of test methods and techniques which are employed by the Building Research Division of the National Bureau of Standards to measure and predict in-service durability of materials and their composites used in building construction. A further purpose is to discuss the philosophy of accelerated aging tests and the interpretation of results of such short term tests in terms of actual in-service use. The relation of aging properties to the development of realistic performance standards is also considered.

3. PROGRAM ON DURABILITY AND DETERIORATION OF BUILDING MATERIALS AT NBS

The materials durability program in Building Research Division is predominately concerned with the identification of the aging process and the determination of aging rates of building materials used in foundation, flooring, exterior and interior cladding and roofing applications. The materials include paints, bitumens, plastics, sealants, elastomers, stones, metals and ceramics. Analytical methods are developed and improved to quantitatively measure the chemical and physical properties of materials, initially and after exposure to natural and simulated environments. The data obtained in these tests are useful in predicting the long-term aging properties in use based on the results of short-duration accelerated tests. The knowledge of change rates in chemical and physical properties are used in conjunction with known parameters of the intended exposure environment to predict aging. Relevant chemical properties include, among others, composition, molecular structure and thermodynamics, while load, strain, density, viscosity and elasticity are among the physical properties which are considered important in the aging process.

A three-prong approach is used to study the aging process of building materials intended for outdoor exposure.

a) Accelerated testing using such devices as xenon, carbon arc, high pressure mercury arc, fluorescent black lamp-sunlamp radiant energy sources in weathering machines. A comment about relevancy of accelerated testing appears worthwhile here. The critical question asked by prospective users of accelerated weathering tests is: For a new material where I have only accelerated test data, what level of confidence can I have that these data will come within + or -x% of the long term outdoor test results? To be responsive to user needs the test results must provide a clear answer to this question even if we must make some assumptions about projecting the value of x. The point is made that engineering judgment plays an important role in answering the question posed.

b) Outdoor exposure testing at one or more locations comprising a network of eight NBS exposure sites representing climates experienced in North America. The locations are in Alaska; Puerto Rico; Nevada; Takoma, Washington; Baltimore, Maryland; Cape May, New Jersey; and Gaithersburg, Maryland.

c) Data are gathered from on-site investigations of the performance of materials in actual use and are related to the results in accelerated and outdoor exposure testing.

The facilities for conducting the program on materials research include a modern analytical laboratory equipped with infrared, ultraviolet and atomic absorption spectrometers, gas chromatographs, differential thermal analysis equipment, a thermal mechanical analyzer, universal testing machines, and many others. Facilities and equipment are available for simulation and acceleration for both the natural and man generated aging processes in the form of accelerated weathering machines, salt spray and other environmental chambers, abrasion devices, wear machines, impact apparatus including a hail gun and such other devices as necessary to simulate in-service performance.

4. RESEARCH ON THE AGING OF BUILDING MATERIALS AND COMPOSITES:

Several classes of materials used in building construction are investigated in Building Research Division, including, bitumens, plastics, paints and coatings, sealants and caulks, metals and building stone. Since these materials, alone or as composites, are used in assemblies, often in contact with other assemblies, to make up a building system, the predicting of aging characteristics become important considerations to the performance of the total structure. The performance characteristics are influenced by many and frequently complex variables. As far as aging is concerned, the inherent properties of specific materials are sometimes completely overshadowed by other factors, including compatibility with other materials, susceptibility to environmental changes, manufacturing techniques and construction practices. Therefore, it is our strong opinion that the three prong approach to measure and predict aging by accelerated weathering, controlled outdoor exposure testing and in-service performance appears to offer the better solution to understanding the aging process.

4.1 Plastics

In the past decade plastics have attained an increasingly important role in building construction. In addition to the many uses of plastics in the interior of a structure in flooring, wall coverings, counter tops, fixtures and the like, their use is increasing in outdoor applications such as roofing, paints and coatings, exterior siding and waterproofing. Here, of course, weather resistance becomes the dominant factor in the aging process.

A major program is currently underway in the Building Research Division to develop rapid methods to accurately predict the weatherability of plastics.

The method is based on statisical characterization of outdoor deterioration as an aging process. The procedure consists of:

a) Measuring significant properties of plastics exposed outdoors and in accelerated-testing devices,

b) Fitting the exposure data with a mathematical model,

c) For a given class of plastics, relating the accelerated and outdoor exposure results,

d) Calculating outdoor life for a new plastic of the same class from accelerated-testing data.

The use of mathematical models lies in their ability to confidently predict the future outdoor performance on the basis of behavior measured to the present. As with all prediction procedures, the longer-range the prediction the less certain it is.

Outdoor performance in different climates can be compared by fitting the model to exposure data from different sites and relating the parameters of the model to weather variables characteristic of the site.

The applicability and statisical reliability and failure analysis techniques to weatherability is illustrated by fitting a mathematical model (Weibull-type) to physical deterioration data for diverse types of plastics in 3 climates. Criteria for selecting this type of model were: a) exponentially decreasing function, b) asymptotically approaching the time axis, c) describes increasing failure rate with time, d) flexibility, and e) successful application to fatigue problems. In addition, one of its parameters can be associated with "characteristic life" of a material.

In the more applied areas, roofing systems which employ plastics as a major component are under study. The systems include polyurethane foams, fluid-appied elastomeric coatings, and sheet-applied elastomeric and plastomeric materials. Initially, these materials are considerably more expensive than the bituminous roofing materials which they are intended to replace. Hence a knowledge of their aging properties when used as part of the total system must be gained in order to make sound economic judgments in the selection of a plastic roofing system. The approach which is used to study the aging properties is to identify chemical structure, measure physical properties, then put the material through a series of rigorous simulated service tests and periodically to measure changes which occur in the materials under study during the aging process. Observations of the performance of these materials in actual service are made periodically in order to relate the results of simulated service tests to actual performance. The ultimate objective of the program is the development of information and criteria which can be incorporated into realistic performance specifications.

4.2 Paints and Coatings

The major effort in the paints and coatings area is directed toward the development of test methods to determine the properties of these materials as they relate to their performance while they are protecting other building systems from the aging process. Analytical techniques are developed to separate and identify the various constituents of coatings as well as their inherent performance characteristics. Once the chemical structure and physical properties are known, it becomes a relatively simple task for those expert in coatings technology to predict aging properties provided, of course, that this knowledge is used in combination with sound scientific judgment.

Under this program materials of known composition are selected and applied to various substrates in film form as intended for actual use. The specimens are exposed outdoors at one or more sites where the various exposure parameters are known, either by data supplied by the U. S. Weather Bureau or by direct measurements made by NBS scientists of such factors as ultraviolet radiation and air contaminants such as ozone and the oxides of sulfur and nitrogen which are common to some urban environments. Concurrently, replicate specimens are exposed to accelerated aging tests under laboratory conditions. The accelerated weather apparatus is operated under accurately controlled conditions of temperature, relative humidity, dew cycling, ultraviolet radiation and air contaminants in concentrations varying from 0.5 to 2.0 ppm. The test specimens are examined periodically for evidence of chemical and physical changes by modern analytical techniques including infrared or atomic absorption spectroscopy, gas chromatography, thermal mechanical analyses, color and load-strain properties. The changes which occur in the measured properties in the accelerated aging tests are related to changes which occur in the outdoor exposure tests. The data are fitted to mathematical models which assist in the predicting of aging properties in actual service over extended periods of exposure.

4.3 Sealant and Caulking Materials

Curtin walls have become a predominant part of many high rise structures. For example, the ratio of glass to total surface area has shown a marked increase in modern structures. This type of construction increases the need for efficient and durable sealing methods at the junction of both similar and dissimilar materials as glass to glass, glass to stone, metal to stone, wood to metal and the like. The materials and techniques for making permanent weatherproof seals is an important consideration in the design and construction of most high rise as well as residential structures. The application cost is frequently many times the materials cost. Therefore, the durability of sealants and caulks is of primary concern to the architect when he considers long term performance.

The sealant research program in the Building Research Division has for its primary objective the development of performance requirements, performance criteria and test methods to predict performance, including durability in service. Durability or aging properties is recognized as the prime factor in the requirements of the specifications which are the end product of the research. In the sealant research program modern analytical methods, which are used to measure changes in accelerated durability tests, are developed in the laboratory. The resulting criteria are incorporated into the specifications to insure satisfactory performance in service. The test include adhesive and cohesive property measurements of sealants when they are used in contact with various materials as glass, stone, metal, wood, and the like. Further, the composite specimens are exposed to movements simulating in rate and magnitude to those which are experienced under service conditions. Flow, peel, staining and viscosity tests are also used to identify acceptable performance levels for sealants and caulking materials. Once these properties are determined and limits are established, the designer is free to select the sealant most economically suited to perform the functions he desires.

4.4 Bituminous Materials

Approximately 85% of the alomost 70 billion square feet of roofing applied annually in the United States consists in one form or another of asphalt or coal tar pitch. The predominate factor in the durability of roofing is its resistance to weather since roofings, per se, are always exposed to the outdoor elements of the particular area in which the roof is exposed. Moisture, temperature, radiant energy and time are the four basic parameters which determine the useful life of a roof.

A number of studies are underway at the National Bureau of Standards to shed light not only on the fundamental deterioration process which occurs in the bitumen itself during weathering but also on the performance on the total composite which makes up the roofing system in place. The research includes studies of the oxidation rates of the bitumens when exposed to ultraviolet radiation sources. Infrared spectroscopy and gas chromatographic techniques are employed to detect changes directly and indirectly in chemical structure of bitumens during aging. Other methods are used to detect physical changes that occur which often have a profound effect on the in service performance. These include thermal mechanical analysis, load strain testing as well as viscosity measurements using the sliding plate and parallel plate viscosimeters. The resulting measurements assist in the identification of unwanted effects of processing methods and application techniques of the bitumens which affect aging properties. A case in point is the prevention of slippage failures which are plaguing the built-up roofing industry to the amount of millions of dollars annually by predicting the performance on the roof by a rather simple laboratory test. The early detection by this method of undesirable properties causing slippage before the roof is applied results in large economic savings.

The severe and rapid temperature changes bituminous built up are subjected to in certain climates experienced in the United States have caused costly failures in built-up roofs. The research in Building Research Division has produced a rapid method for predicting the susceptibility of a given roof in a specific climate to this type of failure. The technique consists of measuring the load-strain properties of a small specimen of the composite membrane at a low tempeature, generally about 0°F. The coefficient of linear expansion is also determined over a relatively low temperature range, i.e. from 30°F to -30°F. From these data a thermal shock resistance factor can be calculated. The value of this factor together with a knowledge of the anticipated temperature in the climate where the roof is intended for exposure appears to be a valid measure for the predicting of the roof life in that area as it relates to thermal properties.

4.5 Miscellaneous Materials

Research programs are underway to determine aging properties of other materials used in building construction such as building metals, use alone or with protective coatings, building stone and other inorganic materials such as concrete and gypsum. These programs are continuing at a relatively low level in the Building Research Division at this stage due to either the limited importance of these materials in building construction use or lack of facilities and funding and the shortage of expert research personnel to conduct the programs. Every effort is being extended to increase the research activity in these areas to complement the major effort of the whole Building Research Division which is currently under expansion.

4.6 Materials Aging in the Building System

The discussion of research programs in the materials area of the Building Research Division has thus far been limited to the aging process of the basic materials used in construction as plastics, paints, sealants, metals and bitumens. We recognize that the more important information is concerned with the performance of the building system which incorporates the materials therein. Active research programs are being conducted in the areas of roofing, flooring, waterproofing exterior cladding and foundation systems. The information developed in the materials research are translated into performance of the total system. In addition supplementary tests are developed and utilized on large scale composites to predict aging of the total system. These include among others, simulated and actual service tests to determine effects of environment, both natural or man generated. The data which are generated in each series of tests are reduced and then used in combination with expert scientific and experienced judgment, to predict durability as well as other performance characteristics of both existing and innovative materials and systems.

5. PATHS TO STANDARDS DEVELOPMENT

The primary function of a building system is to act in concert with other systems to provide protection of the contents and comfort to the occupants from certain elements of the environment for some period of time. If this rather elementary statement is extended and translated in terms of the performance concept, we have, for all intent and purposes stated the performance requirement for any building system be it the foundation, floor, siding or roof. The remaining elements in the performance hierarchy are the identification of performance criteria, development of test methods to give quantitative values for performance which in turn leads us to the ultimate goal of providing specifications, standards and codes as the case may be. Two paths which lead to these goals are worthy of exploration. Certainly there are others. The selection of any particular path depends on many factors. One path may be identified as the "performance path" while another path, may be referred to as the "logic path".

5.1 Performance Path

The first step in the performance path is to determine the functional requirements which are desired or expected of the building system under study.

The second step along the performance path is the development of testing procedures and resulting criteria which will be required to evaluate the system against the performance requirement. Ideally the performance criteria should be expressed in quantitative terms. However, as we have learned from experience, this is not an easy task. The final step is the validation of the results of the accelerated simulated service tests by field tests, preferably using complete real size structures in real time.

This path leading to the development of performance standards looks very enticing, but so does die Lorelei. This approach requires further investigation. What are the aging requirements of a given building system? One requirement might be that it remains serviceable for ten, twenty or fifty years. The question arises as how to perform the accelerated aging test on materials used in the complete building system? One approach is to put up a building incorporating the desired materials and observe the results for the required period of time. Another method is to design simulated service tests to be performed in the laboratory on large-scale models, cycling the environment through heat, cold, sunshine, rain or snow to speed up the deterioration process. Each of these approaches is cumbersome, slow and expensive. Although this path will give high values for confidence, the benefit-cost ratio of employing this path must be considered.

5.2 LOGIC PATH

A second path, the logic path, leading to the development of performance standards is related to arithmetic. We learned at an early age that it is unrealistic and unnecessary to memorize products of all combination of numbers to be multiplied. If the products of the numbers 0 to 9 are known it is easy to determine the results by multiplying any combination of these numbers. When funds and time required for full scale testing are limited, the logic approach appears to offer the better and faster solution.

If three parameters are known about various materials used in a building system, their behavior can be predicted with some degree of accuracy in any combination of use. This approach results in a tremendous simplification in the development of performance standards. We, in the materials area of building research, concentrate on a comparitively few basic materials instead of dealing with the multifarious materials which can be utilized for one end use. The three parameters which should be determined are (1) the chemical and physical properties, (2) the changes which occur in these properties when exposed to the intended environment and (3) the compatibility of materials with other materials which make up the building system in question. There are a number of steps along this path which are not necessarily consecutive nor have to be determined in any particular order.

One step is the determination of the pertinent properties of the material. This step presents no difficult problems since much of the information is available in the open or industrial literature. Lacking this source, the properties can be measured rather easily in the laboratory. Another step is to determine the interaction between or among materials used in the building system. This type of information is determined by a basic knowledge of chemistry and physics, or is available from the open or industrial literature or from experience with building materials in actual use. This step does not appear to propose any serious barriers.

A more difficult step to traverse is the determination of the effects of time and exposure on the pertinent properties related to the aging process. This information is not always readily available and often requires great ingenuity on the part of the scientific and engineering personnel to acquire from laboratory and field testing.

The final step is to calculate from the data which are obtained in the other steps the behavior of the material under study as it relates to the total building system. Ideally, the calculated behavior must then be verified by known in-service performance. Once this information is known the development of durability criteria and the prediction of service life is a relatively easy task.

6. SUMMARY AND COMMENT ON AGING AND STANDARDS

I have attempted to give a general view of our philosophy and approach to the measurement of aging process in materials as they relate to the performance of a building system. I have described in general terms, with examples of typical materials research areas, the materials program in Building Research Division as it relates to the universal problem of measuring and predicting the aging of building materials. I have also presented two elementary approaches which can be used either alone or, more often in combination with other approaches to seek solutions to the materials aging problems. However, I do not wish to imply that we have reached the ultimate in accelerated aging testing. We have only scratched the surface. Much more research is required by many disciplines in order to predict with increased accuracy the long term performance of building materials and systems based on data from short term testing. The performance concept appears to offer a workable solution.

I would feel remiss if I did not comment on the archaic nature of many of the specifications and standards which are in use by the building industry. I believe the traditional evolutionary approach of the building community to standards development is largely responsible for this undesirable situation. To combat the age old problem, I contend that a revolutionary approach to standards development must be adopted to produce meaningful performance standards. The question arises, is such an approach feasible in this day and age? The answer can be both "yes" and "no". No, if the current laissez faire trend in the development of material standards in the whole building industry continues. Yes, if a concerted effort is made on the part of all factions of the construction industry to discourage the promulgation and use of archaic standards with the leadership coming from the Standards generating groups. I propose a method to accomplish this end. Each and every specification and standard, be it for a material, system, should contain a "self destruct" clause as part of the document which would automatically eliminate the standard after some predetermined period of time. This method will force the building industry to keep standards current with the state-of-the-art as it advances with increasing activity and interest in building technology.

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