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Accelerated Durability Tests for Organic Building Materials

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Please note

Field performance is the ultimate test of suitability. Only when an old material is to be used under new circumstances or a new material is to be introduced does need arise for an accelerated durability test. The problem is accentuated for new materials because commercial use is inhibited until there is a history of practical performance. Accelerated tests are frequently called upon to provide the basis for selection. They should, however, be used with the realization that durability is not a unique property unrelated to the conditions of use. For an accelerated test to have validity there must be a reasonable relation between it and the service environment.

Natural Weathering Tests

Except under extremely severe exposure conditions natural weathering is too slow to help in the selection of suitable materials by the ultimate user or his agent. The long delay also restricts its use in the development of highly durable materials. Natural weather is quite variable in most localities, so that isolated tests may not present a true picture of a material's weatherability. Highly replicated or statistically well designed tests are required to average out or eliminate the variability encountered with natural weathering; repeated exposure of control samples can markedly reduce the effect of different exposure periods on test results. In spite of these limitations of time and variability, natural weathering results should be obtained wherever possible to serve as a yardstick of suitability for accelerated tests.

As discussed in **CBD 117**, natural weathering is a complex process involving a number of individual elements and their combinations. Because chemical reactions are not understood many accelerated durability tests designed to predict what will happen in service have mainly involved the effects of environment on physical properties. For simplicity, the first approach is usually to determine the effect on one property of the material of one component of the use environment.

Single Property Tests

Coatings, the oldest of the organic building materials, have long had their physical properties described by apparently simple attributes such as flexibility, hardness, and resistance to impact, scratching and abrasion. It was natural, therefore, to try to predict durability by following changes in these properties. Many of the tests, however, are qualitative and not readily evaluated numerically. Hence, many attempts were made to convert them to instrument versions so that readings of some kind could be obtained. Unfortunately, in many cases the measurement obtained is related not to a single basic property but to a combination of several properties and this complexity leads to difficulties if accurate numerical assignment is attempted. When an instrument is precise enough to differentiate between materials that are similar in character but different in levels of performance, the results from various laboratories frequently disagree. Such tests may be useful in a single laboratory, but for general use, especially where results are to be compared, they can cause considerable confusion.

Because of these difficulties, many workers prefer to concentrate on tests that determine one of the more basic properties of a material. The chief difficulty is that instruments are usually so expensive as to be beyond the reach of smaller companies, which of necessity continue to use the older, less precise methods. This naturally impedes standardization.

Mechanical properties such as tensile strength at break, elongation at break, work to break (toughness), yield strength, flexural strength, creep, stress relaxation, elastic modulus, and relaxation modulus govern how a material will respond to physical forces such as impact or abrasion. They are, to some degree, interrelated. The rapidity and extent of changes in them, following exposure, indicate how the material reacts to its environment.

Because tensile properties of organic materials are dependent upon the rate as well as the temperature at which a test is conducted, test conditions must be described before the values listed for an organic material can be meaningful. When conditions are identical for a series of tests and bear some relation to the service environment, information on the durability of materials can be obtained by following changes in tensile or compression properties. In this way changes in creep, breaking strength or elastic modulus have been used to predict the suitability of plastics for a given use. It is evident that a material that retains an original moderate level of a desired property will last longer in service than one that has a very high level which is soon lost. One cannot, however, use a creep test as an indication of how a plastic will react to very rapid loading, or the converse.

Tensile tests are probably most useful with plastics, sealants and roofing membranes, which are used in relatively thick cross-sections. With thin coating films, small edge imperfections cause drastic decreases in both strength and elongation at break. Many samples therefore have to be prepared when the effect of weathering on coatings is to be studied. Special procedures are required for testing sealants because they are too soft to be gripped in the jaws of most instruments. Difficulties may be encountered in ensuring that air bubbles are not incorporated in the sample and in differentiating between the effects of adhesion and cohesion. If a sealant fails first by loss of adhesion, an adequate measure of tensile properties cannot be obtained.

The adhesion of sealants and coatings, which must stick to a substrate to function properly, has been studied as a means of predicting satisfactory service. The question arises, however, as to whether adhesion is a single basic property. It may well be a combination of different forces. This might account for the difficulties experienced in trying to measure it or to relate it to another single property such as surface tension. Most of the devised tests incorporate pulling or cutting the material from the substrate, so that mechanical properties are mixed into the measurement. To date there is no adequate adhesion test.

Single Element Tests

In contrast with mechanizing and instrumenting some physical aspect of the service life of a material, it is possible to isolate an element of the weather that can be measured or kept constant and to determine the quantity or time required to cause an undesirable effect on a material or see whether it is unaffected after a given time. The element is one of the four components of natural weather - temperature, radiation, moisture and gases. The effect may be detected by visual observation of the onset of a change, e.g., first cracking or rusting, or by instrument readings of appearance factors or physical properties. The latter should be one of the basic properties. Appearance, while often important, may not always be the prime consideration: gloss measurements do not necessarily relate to the corrosion resistance of a coating for metal. It is essential to choose a measurement that is directly involved in the degradation process to be studied.

Temperature

Tests to determine the effect of relatively high temperatures on organic building materials are performed for two reasons: to predict the suitability of materials that will be exposed to heat in service; to accelerate aging. The stability of plastics that are heat moulded is evaluated to show that they will not be degraded during production. Plastics with chemical plasticizers incorporated in them are subjected to heat to accelerate loss of more volatile plasticizers and thus the tendency to embrittlement. Coatings designed to be heat resistant are heated continuously until discoloration occurs.

The use of high temperature as an accelerated durability test is valid where temperature is the only effective element in the use environment and the conditions of the test correspond as closely as possible to those of service. It is then possible to extrapolate results obtained at several elevated temperatures, and to estimate the time required at operating temperature for the same change to take place. If, however, another effect becomes predominant at lower temperatures, the extrapolation will not be valid.

Radiation

Because radiation from the sun is a major factor in weathering, many accelerated durability tests have been based on exposing a material to a source of radiation. With natural sunlight, problems of time and variability are introduced. Artificial light sources are used, therefore, and the acceleration of weathering can result from one or both of two effects. (1) If a source that consistently emits natural light is run continuously, variability is eliminated and the time factor is reduced because of the continuous and concentrated exposure. Unfortunately, most sources change with use and are deficient in one part of the spectrum and too strong in another. (2) A further acceleration of the effect of radiation occurs if the source is too strong in the ultraviolet, either from emission peaks in the near UV or from radiation of shorter wavelength than that present naturally. Although the time factor may be reduced, the results may be misleading. If a material absorbs strongly where the emission peaks occur, it will degrade much faster than if it absorbed at a different wavelength. Two sources commonly used, carbon arcs and mercury lamps, do have peaks in the UV. Uncharacteristic degradation may occur because the shorter the wavelength the greater the number of chemical bonds it can break. Thus, materials that may be resistant to natural radiation will appear to have poor durability if they contain linkages destroyed by the shorter UV. The xenon source, which has become popular in recent years, duplicates natural UV closely when properly filtered. If quartz filters are used to speed up failures, UV considerably shorter than natural is transmitted so that the results are less reliable. Also, without proper filters, the xenon light's large emission peak in the near infra-red is transmitted, and this might cause erroneous results with materials that absorb in this region.

Owing to the difficulties of obtaining an artificial source that duplicates natural sunlight exactly, exposures are frequently carried out in areas such as Florida and Arizona where the duration and intensity of sunlight are greater than those in more northerly regions. In some cases mirrors or racks that follow the sun are used to concentrate its effect, but natural variability is re-introduced.

Moisture

Because water in its various forms is an active element in weathering and because it is readily available in the laboratory, diverse tests involving water have been developed. Coatings are usually applied to tinplate or steel panels or to glass test tubes and immersed in a beaker of water to give a qualitative assessment of water resistance. If free films of coatings are used, quantitative measurements on the amount of water absorbed and the degree of swelling of the film can be made. Plastics are also immersed in water and weight gain noted. To simulate rain, water sprays are sometimes used in place of immersion in qualitative tests. Blistering of coatings on wood is related to the migration of water through the substrate-coating system. Accordingly, tests that maintain conditions of high humidity at the back of the wood and low humidity on the coating side to cause water transmission are used to estimate blister resistance, test cabinets being referred to as blister boxes. Again, more quantitative results are obtained by measuring the water vapour permeability of coating films. Permeability measurements are also made on plastic films, which are used as vapour barriers.

Exposure to constant high humidity is sometimes used as a test of the corrosion resistance of coated metals. Because metallic corrosion is an electro-chemical process, the effect of water immersion on the electrical resistance or conductance of primers applied to metals is frequently determined. As organic building materials are not usually porous, the soak and freeze tests applied to inorganic materials are not commonly used.

The suitability of these water tests for predicting durability varies somewhat, probably with the degree to which they are consistent with service conditions. It has been the experience at DBR/NRC that the results of immersion tests on coated metals relate closely to exposures only where there is actual immersion. Swelling tests on coatings for wood correlate well with practice because films that absorb water markedly often have poor blister resistance. Some workers have claimed that blister boxes are too severe and that test houses give a better indication of the performance of coatings on wooden homes.

Permeability results have not always differentiated between coatings, suggesting that more than one process is involved in this type of failure. Constant high humidity tests do not correlate with actual exposures (except perhaps in the tropics) because, in atmospheric weathering, wetting is intermittent and insufficient water to produce blisters is absorbed; the elevated temperature used in the test to increase absolute humidity causes excessive and abnormal blistering. Cyclic condensation tests in which the temperature is raised and lowered predict corrosion resistance more reliably. Electrical tests are also reported to correlate well with performance.

Gases

As oxygen is an important factor in many degradation processes, its individual action on organic materials other than coatings has been examined extensively. Most tests involve exposing the material to an atmosphere of oxygen and following any change in the material or any decrease in oxygen pressure, either of which indicates that oxygen is being absorbed. Elastomers and plastics that are prone to oxidize have been studied both to elucidate the basic chemical reactions and to find stabilizers that will inhibit the process. Although useful in improving the oxidation resistance of the basic polymer, the tests are reported to be not selective enough when all the specimens are stabilized. In spite of the importance of oxidation in the curing of coatings, the effect of oxygen on them has only occasionally been tested. For corrosion resistant coatings, oxygen permeability may be at least as important a property as water permeability, but because of more difficult techniques it is not usually determined.

Atmospheres containing ozone have also been used in basic and empirical tests on polymers. Because ozone is normally present in the parts per billion range, low concentrations (0.01 per cent) in oxygen are used in accelerated tests. Owing to its reactivity, high concentrations might lead to completely erroneous results. Sulphur dioxide, which is usually present in corrosive atmospheres, and oxides of nitrogen are pollutants that are also tested at low concentrations, but there has been little fundamental work on their effects on organic building materials.

Combined Element Tests

Weathering is the result of the separate or combined actions of several elements, the effects of which are not usually additive; i.e., a combination produces a greater effect than the sum of the individual effects. Because of this synergism, attempts were soon made to develop accelerated tests that included two, three or all of the weather factors. Although this complicated the study of basic reactions it was hoped that the over-all results would be more indicative of what occurred naturally.

The problem in developing such a test has been to select the proportions of weather elements, and much experimental juggling has been, and still is, being carried out with the idea of obtaining a combination that accurately predicts weatherability. There is also the question of the degree to which factors should be concentrated and the ease of concentration. Light can readily be concentrated by placing samples close to a source, but in most artificial weathering tests oxygen is not concentrated because it is simpler to use air. In general, the greater the concentration, the more rapid is the acceleration but the less reliable are the results.

Accelerated Weathering

Durability is often taken to mean weatherability, and artificial weathering has been one of the most common accelerated tests. It has also been said to give rise to the greatest discussion and least agreement among users. The two main elements operating in the test are radiation and water, with thermal shock a factor in some cycles. Although oxygen is not concentrated, some light sources produce ozone as a by-product.

The possible combinations of light and water are almost endless, but fortunately only a few have come into common use. In Canada they are: a cycle of 102 minutes radiation alone and 18 minutes simultaneous radiation and water spray in each 2-hour period, American Society for Testing and Materials (ASTM); cycle of 8 hours light only, 10 hours light and water and 5½ hours water only per day, Canadian Government Specifications Board (CGSB); and the "dew" cycle of 1 hour light only, followed by 1 hour of high humidity without light. There are indications that in cycles where both elements operate at the same time, they tend to counteract each other, thus reducing acceleration.

The different sources discussed under *Radiation* can be used in the combined tests, but the same comments apply. The xenon arc, the open carbon arc ("sunshine" arc) and the enclosed carbon arc are all in common use. With the latter, either one or two arcs may be operated. Water sprayed on the specimens has caused problems. Owing to the high evaporation rate in the ASTM cycle and the large volumes used in the CGSB cycle, small amounts of impurities in the water result in deposits on the samples. If the deposit is heavy, it may protect the test surface from radiation, while thin deposits interfere with assessment of results. The spray water must be filtered and deionized to reduce this effect.

As might be expected with such a combination of factors and properties, the reproducibility of accelerated weathering tests, especially for subjective ratings, has not been good. Nevertheless, the tests do have their uses. Provided that the test conditions are related to the properties of interest, that too many factors are not introduced, and that the active elements are not disproportionately accelerated, the results are quite useful in development work. For acceptance of materials, tests should include controls known to have both good and poor durability in the accelerated test and under natural conditions. With these controls, accelerated weathering provides a good indication of the durability that can be expected of a material.

In discussing accelerated weathering results, it is essential to describe test conditions completely. The number, type and filtering of the light source and the cycle used must be detailed so that an intelligent assessment of the significance of the results can be made.

Summary

Accelerated durability tests include those that study a single property, those that incorporate a single environmental factor, and those that include several factors and one or more properties. Reliability of prediction and reproducibility of results are closely related to the fundamental nature of the property measured and to the degree of acceleration. Some workers maintain that accelerated tests are of little use; others place great faith in them. As usual, the truth is somewhere between and proximity to either extreme varies with the individual test.