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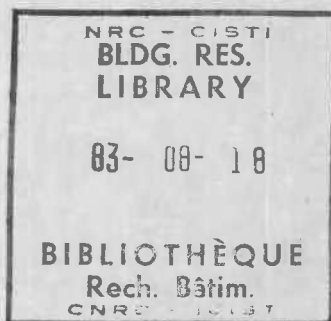
EVALUATING THE PERFORMANCE OF ORGANIC COATINGS AND BUILDING MATERIALS

by H.E. Ashton

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RÉSUMÉ

Dans cette étude, on relève certaines erreurs des méthodes globales d'évaluation de la durabilité des matériaux, notamment à cause des différences entre les matériaux organiques et inorganiques. Les méthodes utilisées dans les laboratoires pour lesquels travaille l'auteur y sont présentées avec des exemples dans les domaines des plastiques, des revêtements organiques et des produits d'étanchéité. L'étude énonce les principes qui découlent des travaux sur les matériaux de construction organiques et inorganiques et qui sont nécessaires pour prévoir leur durabilité.

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H. E. Ashton¹

Evaluating the Performance of Organic Coatings and Building Materials

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ABSTRACT: Some faults in the overall approach currently used in evaluating the durability of materials, particularly in relation to the differences between organic and inorganic materials, are discussed. The strategies used in laboratories with which the author is associated are outlined, and examples from the fields of plastics, organic coatings, and sealants are reviewed. Principles arising from work on inorganic as well as organic building materials, and required for regimens for predicting permanence, are stated.

KEY WORDS: evaluation, performance, durability, accelerated testing, organic coatings, organic building materials

Permanence, which along with its prediction was the topic of the ASTM symposium on Permanence of Organic Coatings, is defined as the property of being permanent, that is, lasting or meant to last indefinitely without change. In Webster's dictionary, permanence is said to mean durability, which is believed by some to be an inherent property of a material. As pointed out in a paper [1]² at the RILEM/ASTM/CIB 1977 symposium on Performance of Building Surfaces [sponsored by the International Union of Testing and Research Laboratories for Materials and Structures (RILEM), the American Society for Testing and Materials (ASTM), and the International Council for Building Research, Studies, and Documentation (CIB)], this belief that durability is a property is not true because durability varies with the material used, the conditions of its use, and even the attitude of the

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²The italic numbers in brackets refer to the list of references appended to this paper.

user. Because it is not a single property, the method used to evaluate durability, or permanence, must be reasonably related to the service environment. Consequently, in selecting, or in some cases developing, evaluation methods, the Materials Section of the Division of Building Research, National Research Council of Canada (DBR/NRC), has emphasized this point rather than the rapidity of testing. The overriding philosophical principle is that meaningful results should not be sacrificed in the interest of speed, as there is little benefit in getting quick but misleading results.

Another common practice that has caused innumerable problems in evaluating materials is the general application of an accelerated test developed to evaluate a specific type of material. This misapplication, usually after little or no validation testing, occurs because the principles behind the procedure and their relation to the properties of the material for which the test was developed have been ignored. For example, most organic materials are subjected to accelerated weathering tests in which one of the chief degradative factors is radiation, which frequently contains a fairly high proportion of near ultraviolet (UV) radiation. This is a reasonable approach because the carbon-carbon bonds in organic materials can be broken by solar radiation received at the earth's surface. Inorganic compounds are not affected by this radiation, but there are still occasional requests to evaluate this kind of building material in the Weather-Ometer. Conversely, most inorganic nonmetallic building materials, because of the manner of their formation, are usually porous so they readily absorb and desorb water, with resulting significant dimensional changes [2]. If frozen when water saturated, many of these materials are damaged or destroyed. As a result, exposure to freeze-thaw cycles while wet is commonly used to test this type of material. Because many organic materials are not porous and absorb relatively little water, this test is not appropriate for them. Owing to their composition and inherent porosity, inorganic materials are also prone to attack by some chemicals that have little effect on organic materials. Hence, tests used to determine the chemical resistance of inorganics are not likely to be applicable to organics, and vice versa.

An example of the potential adoption of a technique valid for one situation but not necessarily for another appeared in a recent paper [3] in which one of the drawbacks in using the salt spray test for evaluating anticorrosion coatings was said to be the lack of UV radiation. Radiation is unrelated to corrosion of metals, however, and on coated structures there can be considerable corrosion in locations where there is no direct, and often little indirect, irradiation. On a series of coated test panels exposed at an angle of 45 deg from horizontal facing south at several sites, the corrosion was frequently more severe on the underside, indicating that the occurrence of surface wetting and drying is a more important factor than UV. It is, in the author's judgement [4] and that of others [5,6], the lack of intermittent wetting and drying, owing to the test being run at a continually high temperature and relative humidity, that is the main reason for the lack of correlation between

the results of salt spray tests and actual exposures of organic coatings, except perhaps in locations where a significant amount of salt is present in the environment.

The salt spray test is the preeminent example of misapplication of a test. ASTM Salt Spray Testing [B 117-73 (1979)]—as indicated by the title of the paper that introduced the method, “Test for Metallic Protective Coatings” [7], and the name of the committee responsible, ASTM Committee G-1 on Corrosion of Metals—was developed to evaluate the performance of metallic coatings on metal, especially chrome-plated steel. Evidently it did a reasonable job in that field so its use was extended to organic coatings without considering that fact that most anticorrosion primers protect steel by a different mechanism (passivation) than zinc (sacrificial) and other metallic coatings (barrier) do. Since then, use of the test has become so widespread that coatings for concrete and masonry are now being reported as resisting the salt spray test for thousands of hours. It would be surprising if they didn’t because the substrate does not rust and sodium chloride is most detrimental to concrete at freezing temperatures, not at the 35°C (95°F) of the test.

However, besides listing some of the faults in the general approaches to predicting performance, this paper presents some examples of what one hopes is a more logical procedure. The author’s intent is to show that the evaluation tests used by the DBR/NRC are based on two strategies. The more fundamental one is to obtain through research an understanding of the mechanisms involved in the degradation processes. The other is to measure the actual conditions to which organic building materials are exposed in practice and then, if possible, not exceed the maxima of these conditions in the corresponding accelerated tests.

Plastics

The first technique is illustrated by the case of two poly(vinyl chloride) (PVC) sheet materials, the color of which, regardless of hue, appeared to fade badly after a few years exposure in Ottawa, Canada. The author’s first impression was that the pigments used were not light-fast, but it would be unlikely that all the pigments selected by both manufacturers of the material would fade. Dr. A. Blaga, of the DBR/NRC, showed [8] that an epoxidized soybean oil plasticizer was hydrolyzed in the sheet under hot humid conditions in the presence of traces of hydrogen chloride arising from the vinyl resin. As the result of alternate swelling and shrinking caused by changes in temperature and relative humidity, the hydrolyzed plasticizer, which was no longer compatible with the resin, migrated to the surface, where it was deposited as a white layer that increased in thickness with time. Tests on the mechanical properties of the PVC sheet revealed a moderate decrease in tensile strength and a marked decrease in elongation at break, confirming the loss in effectiveness of the plasticizer.

Elucidation of the reasons for the failure provided the basis for an exposure test that would produce the whitening in the laboratory in a few months. The degradation mechanism postulated that cyclic variation in temperature and relative humidity caused the migration of the plasticizer to the surface. An accelerated test in which such changes are the dominant factor was selected as most likely to produce the same effect, so the cycle used in the Aminco Climate Lab to test anticorrosion primers [4] was modified. As shown in Fig. 1, the apparatus operated for 7 h at 56°C (135°F) and 100 percent relative humidity followed by 5 h in which the temperature went from 56 to 10°C (135 to 50°F) and back to 56°C (135°F) while the relative humidity varied from 100 to 25 percent and back to 100 percent, with the humidity changes preceding those of temperature by 1 to 2 h. After 1 month of exposure a thin layer appeared on the surface, and after 6 months the deposit was thick enough to make the various colors look white (Fig. 2). Heating the vinyl sheet for 3 months in an oven maintained at 56°C (135°F) and about 10 percent relative humidity did not produce any trace of exudate. Similarly, 6 months' exposure in a conventional twin carbon arc weathering machine using the ASTM cycle of 51 min of light without water and 9 min of light with water spray had no effect, in spite of the presence of near UV radiation which might be expected to degrade PVC. It was concluded that the short spray period operating concurrently with the light did not allow sufficient time for water to diffuse in to cause hydrolysis and migration of the plasticizer.

Another example from the plastics field also demonstrates the importance of cyclic changes in temperature and humidity in the weathering process. Glass-reinforced polyester (GRP) fails by two mechanisms. The first is the process whereby glass fibers near the surface become free from the resin matrix—starting with ridging above the fibers, rupture of the resin along the ridges, and, finally, release of the fibers for much of their length (sometimes called fiber “pop-out”). The other process is the development of isolated microcracks in the resin matrix, leading to a network of microcracks. Both types of failure are shown in Fig. 3.

Work in the DBR laboratories [9] has shown that the latter process takes place only in the presence of radiation but that the former can be produced by changes in temperature and humidity alone. As with the vinyl, exposure to a constant temperature of 56°C (135°F), but in this case at nearly 100 percent relative humidity, did not produce so much as fiber ridging. Similarly, cycling the temperature from 10 to 56°C (50 to 135°F) without moisture present had no effect. However, cycling the temperature at constant high humidity and cycling the humidity at constant high temperature did cause fiber ridging and resin rupture after a few days, but no fiber release occurred within a year. This result showed that, to cause accelerated failure in the laboratory of the type known to occur in natural weathering, both factors need to be cycled.

In this study, fiber release occurred most quickly in a weathering machine

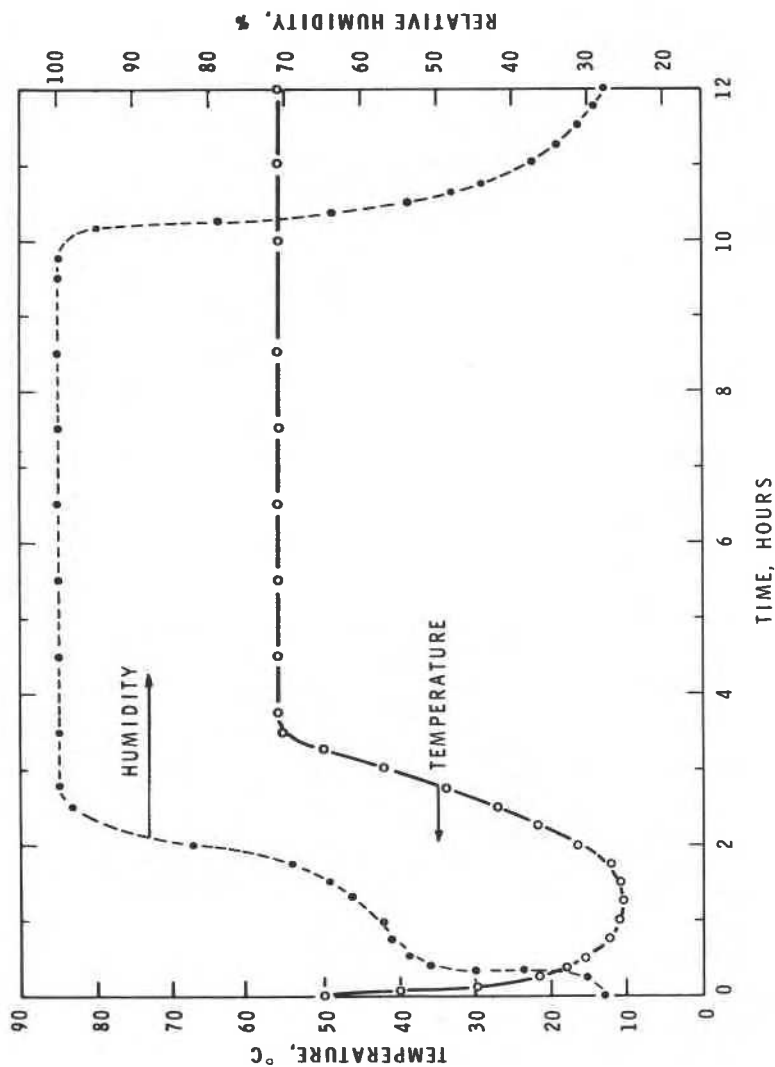


FIG. 1—Humidity-temperature cycle (12 h) in the Aminco Climate Lab.

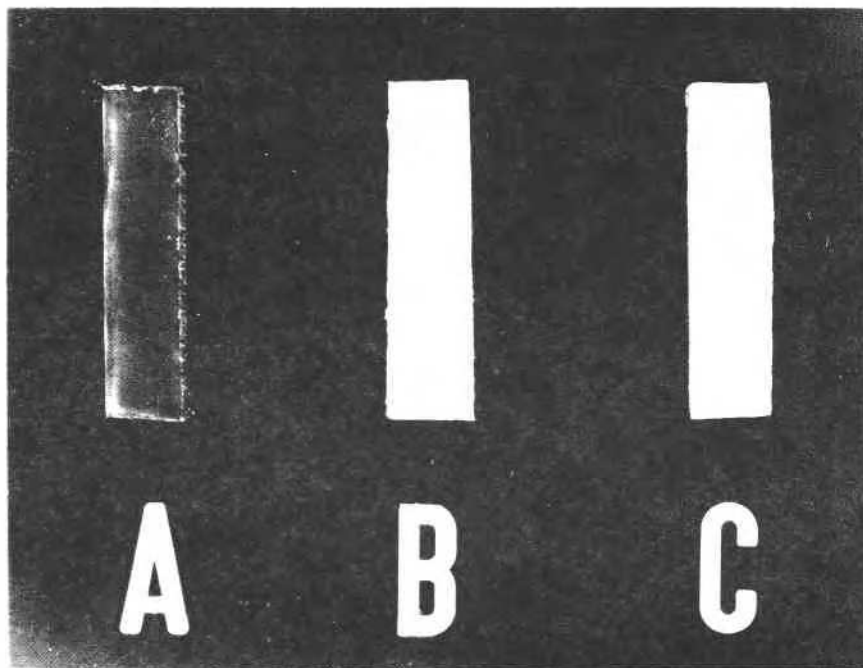


FIG. 2—Green PVC sheetings: (A) control, (B) weathered outdoors for 5 years, (C) aged in the Aminco Climate Lab for 175 days (350 cycles).

equipped with a 6000-W borosilicate-filtered xenon arc. The Weather-Ometer was *not* operated on the ASTM 51/9-min or 102/18-min cycles because previous work [4,8] had shown that when both light and water are in action at the same time, their degradative effects are reduced. Instead, a cycle of 4 h of light without water and 4 h of water spray without light was used to produce a temperature range similar to that in the Aminco Climate Lab and relative humidities of 100 percent during the spray period and 50 percent when the light was on (Fig. 4). It should be noted that this is not the "dew" cycle because the specimens are sprayed on their test faces (spraying the back of plastic or wood panels does not produce condensation). The more rapid degradation of GRP in this exposure is due in part to the great thermal shock caused by the cold water striking the hot surface when the spray first starts, with a smaller shock when the light comes on, and in part to radiation causing cross-linking in, and deterioration of, the resin, making it more susceptible to rupture.

The latest stage in developing an accelerated test for GRP was reported at the first international conference on Durability of Building Materials and Components [10]. By doubling the intensity of the UV radiation at 340 nm, but still using borosilicate filters and not exceeding observed natural inten-

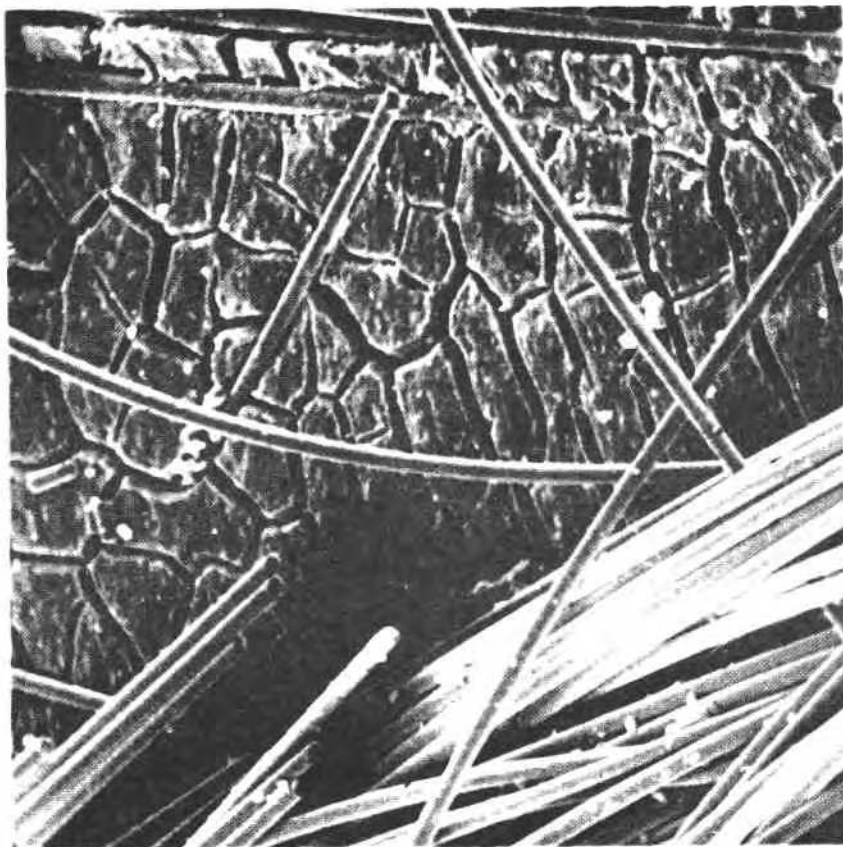


FIG. 3—Surface of a GFRP sheet (top side) weathered outdoors for 12 years.

sities, the length of the light period could be cut to two h to maintain the same total UV irradiance per cycle. Also, the number of thermal shocks per cycle was kept the same by reducing the spray time to 40 min so that the total cycle period was shortened from 8 to $2\frac{2}{3}$ h. Consequently, the various stages of degradation should occur three times faster. In tests with three different GRPs, fiber release took place from 2.3 to 2.5 times faster, while the microcrack network formed 3.5, 2.3, and 2 times faster with a fire retardant, a non-gel-coated, and a conventional GRP, respectively. The nature of the failures was similar to those occurring in the 4/4-h cycle and in natural weathering, including the eventual formation of surface microcracking on conventional material in natural weathering.

Although this cycle accelerated the fiber release of GRPs by factors of 5 to 13 over natural weathering at Ottawa, another test revealed a feature that has been found to be quite common in our fairly extensive studies on artifi-

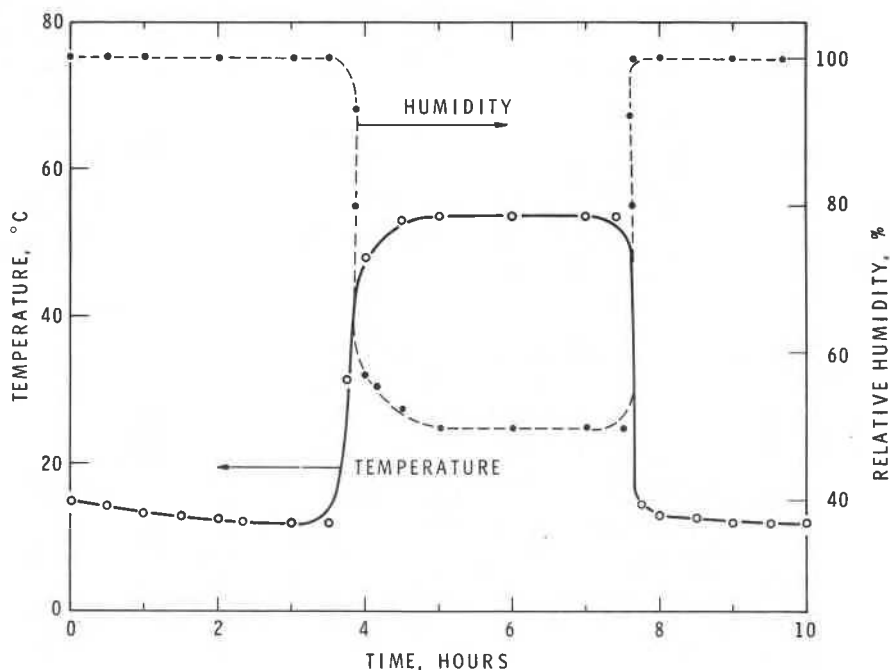


FIG. 4—Humidity-temperature cycle (8 h) in the Atlas xenon arc Weather-Ometer. The temperature was measured on a colorless GRP panel (exposed side).

cial weathering. That is, a cycle developed for one material is not necessarily applicable to others, even ones that may be considered fairly comparable in composition.

Coatings

The cycle just described was compared with two others in a study to determine which came closest to producing the effects of 1 year's exposure to natural weathering in Halifax, Nova Scotia, on eight alkyd enamels. Exposure to the other cycles took place in two machines equipped with enclosed carbon arcs—one with twin arcs and operating on the Canadian General Standards Board cycle of 8 h of light only, 10 h of light and water spray, and 5½ h of water only, the other utilizing a single arc and the DBR cycle of 12 h of light without water and 12 h of water spray without light. The color and gloss were measured after the 1-year natural exposure and at intervals of artificial weathering up to a total of 30 days. The changes in gloss and color at the ends of the periods of natural and accelerated weathering are given in Table 1.

TABLE 1—Color and gloss changes after weathering for eight alkyd enamels.^a

Exposure No.	Natural Weathering, 1 year	Artificial Weathering, 30 days ^b		
		XE	BR	CG
60-deg Gloss Loss, gloss units				
1104	5	30	28.95	20
944	11	30.1	34.95	15.8
1115	21	27.2	22.85	13.7 ^c
1073	41	28.1	27.8	17.0
840	42	39.9	41.25	30.3
1003	49	35.65	34.4	34.05
1116	68	49.3	43.85	39.65
1117	69	41.1	40.1	29.85
Change in ΔE , Adams Color Space, Scale A ₂ , color difference units ^d				
1116	1.23	0.67	0.38	0.92
1115	1.5	0.45	2.46	3.35
1117	1.75	0.78	1.05	0.92
944	2.2	0.69	0.74	0.45
1073	2.5	0.93	1.01	0.67
1104	4.0	2.4	1.29	0.94
1003	4.3	0.99	0.70	0.97
840	4.4	0.88	0.77	0.8

^aValues are the mean of two panels except where noted.^bKey to abbreviations:

XE = xenon arc on 2/0.67-h cycle.

BR = single carbon arc on 12/12-h cycle.

CG = twin carbon arcs on 8/10/5¹/₂-h cycle.^cThis value is for a single panel.^dASTM Instrumental Evaluation of Color Differences of Opaque Materials (D 2244-79).

Examination of the table reveals that there are many anomalies in the results, but conclusions can be reached. One of the most important is that the coatings with the best gloss retention do not necessarily have the greatest resistance to color change (for example, No. 1104) or vice versa (No. 1116). Hence, studies that use gloss retention as the sole criterion for evaluating durability can be misleading. This is, unfortunately, a common practice because of the ease of measuring gloss and the difficulty of quantifying evaluation of general performance.

It is also apparent that the artificial weather exposures caused greater losses in gloss than natural weathering for those enamels that had the best gloss retention on natural exposure. However, artificial weathering did not decrease the gloss as much for enamels that suffered the largest drop in gloss when exposed naturally. In other words, all three accelerated weathering cycles were less discriminating than natural weathering.

Regardless of these findings, the point being emphasized here is that after 30 days' exposure the 2/0.67 xenon arc cycle, which markedly accelerated the degradation of GRP specimens, did not consistently cause the greatest

color change or loss in gloss. With six of the eight alkyd enamels, the 12/12-h cycle utilizing a single enclosed carbon arc produced gloss decreases that were surprisingly similar to those brought about by the high-intensity, 6500-W xenon cycle. This trend is also evident with color change, but not to the same extent, owing to the greater variability in those results. Consequently, it should not be assumed that the cycle that causes the fastest change with one material will be the most rapid with another.

The fact that different materials react dissimilarly to accelerated weathering is also illustrated in the DBR study on the retention of mechanical properties by clear phenolics and alkyds subjected to weathering [11]. In this investigation the films were weathered on tin foil as specified in the ASTM Test for Elongation and Tensile Strength of Free Films of Paint, Varnish, Lacquer, and Related Products with a Tensile Testing Apparatus [D2370-68(1973)]. The natural weathering took place at an angle of 45 deg from horizontal facing south at Ottawa, while the artificial weathering was done in a twin carbon arc machine operating on the cycle of 12 h of light without water and 12 h of high humidity without light. In this experiment the water spray was not used, to avoid damaging the free films. Analysis of the results revealed that 30 days' exposure to accelerated weathering was not long enough to increase the tensile strength of the medium and long oil alkyds to the same levels as occurred after 10 to 14 months of natural weathering. Also, the elongation results after 30 days were equivalent to only 9 months of actual exposure. Conversely, 12 days of artificial weathering produced greater changes in the tensile strength of phenolics than occurred in 1 year of natural weathering. This is probably due to the absorption by phenolics of the peaks that occur near 350 nm in enclosed carbon arc radiation. Whatever the reason, the results show that an exposure cycle applicable to one type of finish is not necessarily appropriate for another, at least as far as free films of clear finishes and enclosed arcs are concerned.

With regard to evaluating corrosion resistance, reference has already been made to our disenchantment with the salt spray cabinet and its replacement with a machine in which temperature and humidity are cycled. The cycle used with coatings consists of 2 h of cooling at 4.5°C (40°F), raising the temperature to $32 \pm 3^\circ\text{C}$ ($90 \pm 5^\circ\text{F}$) in warm, moist air, maintaining the high temperature and humidity for 5 h, and then gradually lowering the temperature to 23°C (73°F) and then the relative humidity to 35 percent in 4 h, thus drying off the panels. The test was developed on the basis of observations that water blisters seldom occur in atmospheric weathering because wetting is intermittent [12]. When 88 organic coatings were exposed to this cycle, the type of failure was much more representative of natural exposure than that obtained in the salt spray test. The more realistic failures occur because cycling prevents the cumulative absorption of water that takes place in tests run at constant high temperature and humidity, leading to blistering

artifacts. There is renewed interest in demonstrating, on a wider basis, the advantages of this type of test over the salt spray test.

Sealants

When work in this field first started at DBR, little information was available on the movements to which sealants are subjected in practice. This meant that the tests called up in specifications for evaluating the ability of sealants to withstand joint movements were essentially arbitrary. To overcome this situation, one of the first investigations was to determine the extent and rate of joint movements on real buildings. Because, as with all visco-elastic materials, sealants can accommodate slow dimensional changes more readily than rapid ones, establishing the rate of movement was as important as determining the distance moved. This study revealed that the tensile testing rates commonly used for sealants were about ten thousand times faster than the maximum rate measured in the building joints [13]. Based on this finding, in subsequent tensile tests to establish the effect of movement rate on mechanical properties of sealants, the range covered was from the previously used high speeds of up to 125 mm/min (5 in./min) down to approximately the maximum found in practice.

This work confirmed the hypothesis that as the strain rate decreases more relaxation can occur [14]. It was also shown that although the failure envelope [15] can be determined by plotting log strain against log stress, the plot of log strain versus log time is more relevant for evaluating the performance of sealants. By use of the latter, the extensibility of a sealant after 6 months can be established (Fig. 5). This is important because in that period sealants reach their most extended state in the yearly cycle. The degree of extensibility and whether it is affected by temperature vary with the type of sealant.

The effect of daily cycling on the extended sealant could also be determined as it had been found that the daily movement was about ± 4 percent of the joint width for a joint that moves ± 25 percent of its width in a year. Because this type of evaluation involves intensive use of a tensile machine capable of cycling, a rack was developed to subject sealants to cyclical movements caused by the weather (Fig. 6). The amount of extension to which the sealants are exposed varies automatically with the temperature, through use of the difference in the coefficients of thermal expansion of white painted steel and black painted aluminum [16]. With this arrangement, the movement above which a sealant starts to fail can be determined by observing specimens placed at positions of different movement. The rack, however, is large and relatively expensive, so a device was developed to subject specimens to intermittent movements while exposed to natural or test conditions [17]. The apparatus operates similarly to a vise (Fig. 7) and, at intervals, can be

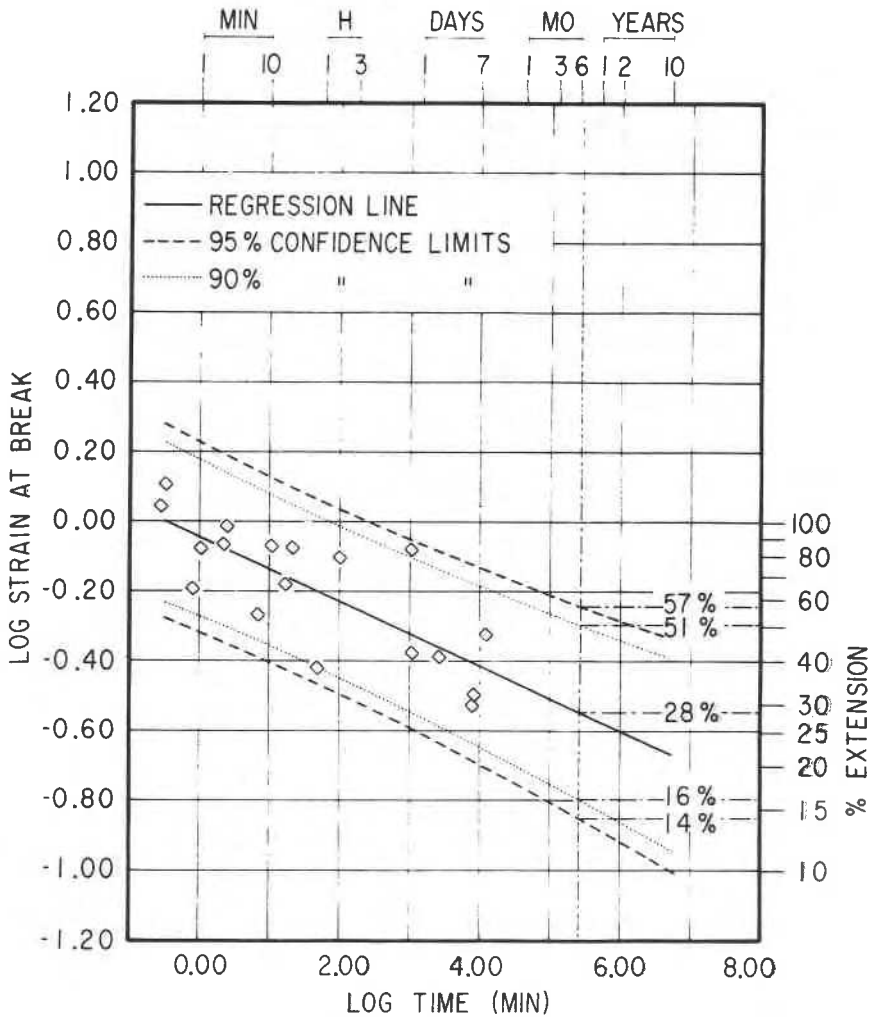


FIG. 5—Time dependence of strain at break for sealants, at 22.2°C (72°F).

adjusted to impose on the sealant the extension or compression that would be present at that time of year if the sealant were in a building joint or exposed on the large differential rack. The effect of cyclical movement can be accelerated by increasing the amplitude and frequency of adjustments. The difference between the stressed and unstressed states on the weathering behavior of a sealant can also be determined by exposing the same material both on vise holders and on holders that are deliberately prevented from moving so that the only factor is weathering. This type of vise can also be used with

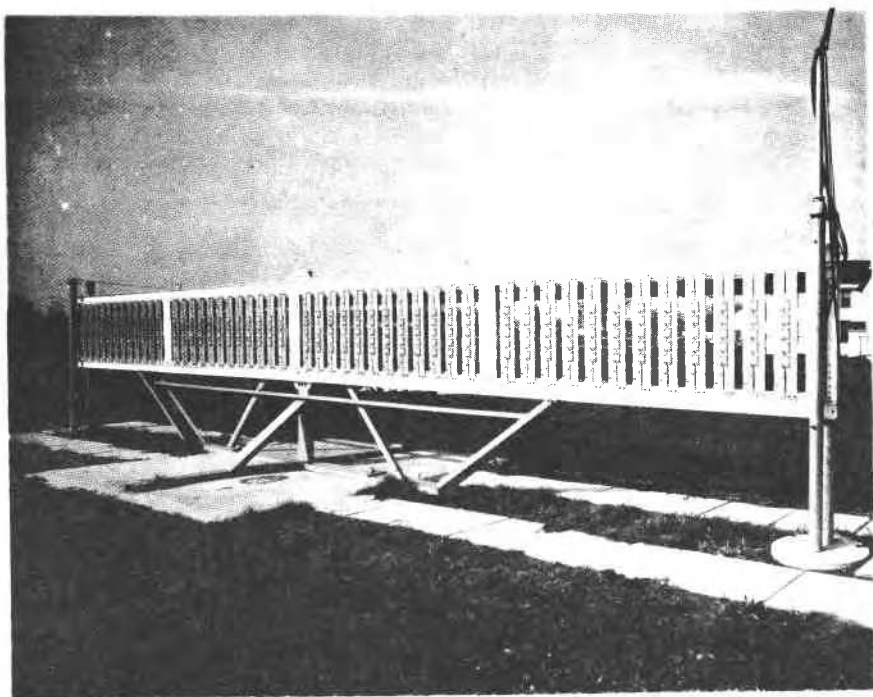


FIG. 6—Sealant weathering rack.

other materials, such as roofing membranes and rubbers, that are intended to resist relatively large dimensional movements in service.

Another finding of interest in a publication on predicting performance, and one that is contrary to usual assumptions, is that Florida is not the place to evaluate sealants rapidly. Light and moisture have relatively little effect on sealants because the degradation they cause is mostly on the surface. On the other hand, cycles of dimensional movement when the sealants are most extended are highly detrimental because failure can occur at the interface or cohesively. Since extension is caused by low temperature contracting the building elements, a cold climate is more severe on sealants than a warm one and causes more rapid failure.

Roofing Materials

Up to the 1970s, roof coverings were generally bituminous based. Because of numerous failures with this type of roofing, however, many new synthetic materials have been introduced during the past decade, especially for flat roofs. As these materials had no history of performance in service, owing to

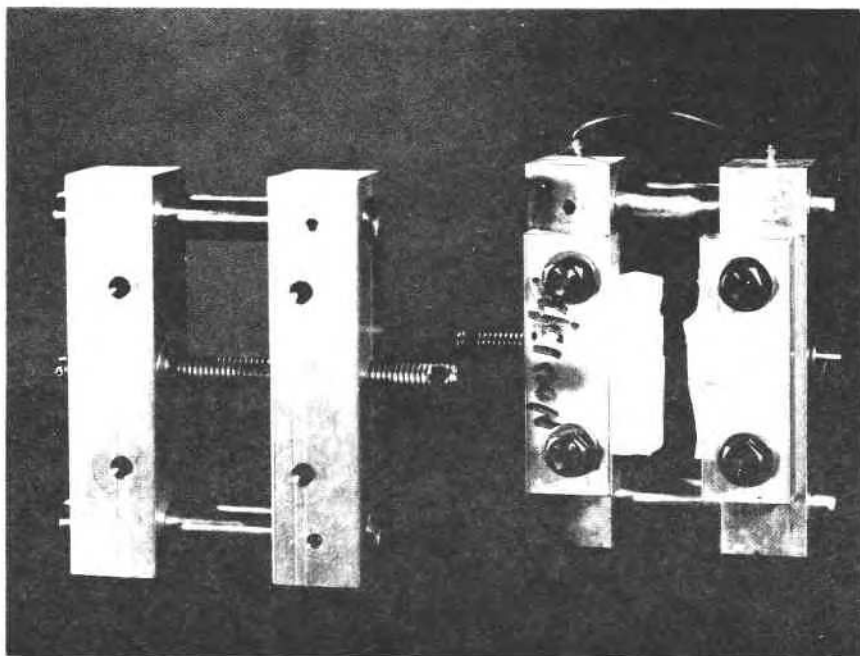


FIG. 7—Cyclic movement device for testing sealants.

their recent rapid introduction, it was necessary to try to assess their adequacy by laboratory tests.

One method already discussed was exposure to cycling temperature and humidity with qualitative assessment of the results. This exposure turned out to be a rapid screening test as several materials, supposedly intended for use under extremely moist conditions, swelled markedly and could easily be rejected for this service (Fig. 8). Radiation was not included because in many cases the roofing membrane is not exposed, being either covered with gravel or used in the inverted roofing system.

Because of the need for a quick evaluation of these new materials, it has been impossible to follow the more fundamental approach, mentioned at the beginning of this paper, of first establishing the degradation process involved. Rather, it has been necessary to provide as much information as quickly as possible to agencies responsible for accepting the use of these materials on buildings and to standards writing organizations in Canada and the United States. Owing to the great variety of the materials it has not yet been possible to establish quantitative criteria that apply to all. Instead, the policy adopted was to arrange them into groups of similar composition and then determine the effects of different service conditions on their physical properties. A material that is markedly changed in one or more properties is

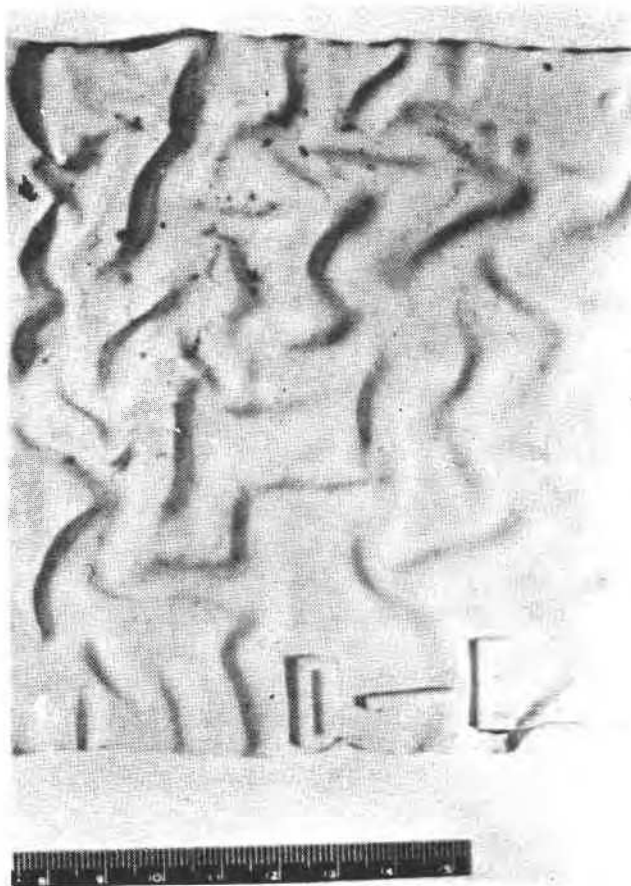


FIG. 8—Liquid-applied modified polyurethane membrane after 110 days' exposure in the Amino Climate Lab. Note the swelling and deformation.

considered less likely to perform satisfactorily than one that is little affected. However, the responsibility for accepting or rejecting a material or for setting limits in a specification is not that of DBR but of the agency for which the work is done or the standards group that issues the specification.

In selecting the range of conditions to which specimens should be exposed to determine the effects on their properties, it is important that the actual service conditions be taken into consideration. The weather factor of greatest importance to roofing in most localities is water, followed closely, at least in Canada, by great temperature changes. Consequently, the resistance to water at normal and elevated temperatures, as measured by changes in weight, dimension, and mechanical properties, has received the greatest attention. It was found that at 50°C some cold-applied bituminous-modified urethane

roof coatings absorbed water up to 27 percent by weight and changed in length by 8.4 percent, while hot-applied rubberized asphalts absorbed practically no water [18]. The former are likely to buckle or delaminate in service except in dry climates.

The effects of low and high temperatures on tensile strength and elongation at break have also been used in the evaluation, the former because retention of flexibility at low temperatures is essential and the latter as a means of accelerating natural aging. Three other tests involving mechanical properties—the ASTM Test for Ductility of Bituminous Materials (D 113-79) and tests for flexibility and crack bridging—have been used mainly to characterize rubberized asphalts at low temperatures. Some results on the effect of heat on the mechanical properties of PVC membranes (Table 2) indicate the problems that can arise in using temperatures much higher than in the normal environment to produce accelerated degradation. Since Specimen A decreased in elongation by 25 percent after heating for 5 h at 163°C (325°F) while a specimen supplied by the manufacturer showed no change after 8 years' natural exposure, the decrease is more likely to be due to decomposition of the vinyl resin, known to occur at 150°C (300°F), than to loss of plasticizer. The elongation of the glass-reinforced PVC (Specimen B) decreased by about 43 percent for the heated specimen, while the manufacturer's naturally aged material was unaffected after 5 years but decreased in elongation markedly after 10 to 11 years of weathering. The initial low tensile strength of Specimen B was not affected by heating but increased considerably with time. Because the accelerated aging procedure did not reproduce the naturally caused changes in the tensile strength of Specimen B or the elongation of Specimen A, the differences in the elongation results for Specimen B may be caused by the use of different specimens. The uncertainties about results such as these show that despite the pressure for immediate answers, it may be more beneficial in the long term to establish the causes for degradation of the materials in service and then try to develop accelerated tests based on the same mechanisms.

Summary

The results of 30 years' work on building materials at the Division of Building Research, National Research Council of Canada, show that regimens for predicting permanence must be based on four principles.

The first is that it is preferable to investigate only a few basic properties at a time instead of several, especially when interlaboratory testing may ultimately result [4]. A similar conclusion on test factors was stated by F. L. LaQue, a former president of ASTM, at another symposium on testing and service performance [19]. After discussing the inadequacies of the salt spray test, he stated, "It is doubtful that any test that is called upon to integrate many factors into a single test will be able to measure anything but large differences at any level of quality."

TABLE 2—*Effect of heat on the mechanical properties of poly(vinyl chloride) roofing.*

Specimen and Type	Test Direction ^a	Original Material		Heated at 163°C (325°F)				Natural Aging		
				75 min		300 min				
		TS ^b	Elongation ^c	TS	Elongation	TS	Elongation	Years	TS	Elongation
Specimen A (unreinforced)	MD	214	321	211	260	229	240	8	218	345
								5	138	282
Specimen B (glass fiber reinforced)	MD	117	289	112	242	125	166	10	155	215
								11	230	19
								5	148	308
								10	115	138
								11	214	50
	CMD	115	294	119	266	128	160			

^aMD = machine direction; CMD = cross-machine direction.

^bTS = tensile strength, in kg/cm².

^cElongation = elongation at break, in percent.

The second premise is that acceleration of degradative factors must be reasonably related to service conditions to obtain meaningful results. Reliable acceleration is thus obtained by continuity of exposure to maximum levels of the appropriate factors rather than by overacceleration through the use of excessive levels. This means that the conditions to which a material is exposed in practice should be measured to provide a valid basis for the test. The more the test conditions depart from natural levels, the more restricted the applicability of the test will be, as noted by Stieg in his discussion of the origins of the dew cycle [20].

Related to this last observation is the conclusion that tests developed for one material should not be applied to another without first establishing that the properties of the second are related to the basis of the test. The logical outcome of this is that there is no universal test, or even a universal cycle for accelerated weathering machines.

Finally and of the greatest importance, an understanding of the fundamental processes involved in the degradation of a material is essential for the development of a reliable accelerated test. Certainly, the most progress has been made with both organic and inorganic materials when this approach has been adopted, not only for evaluating but also for improving materials. The author most heartily concurs with a conclusion from a similar symposium sponsored by ASTM Committee D-1 on Paint and Related Coatings and Materials over 40 years ago which stated, "We need to make a much more careful study of the 'deteriorating' factors that promote changes in protective coatings under different service conditions. More of such fundamental knowledge is an obvious necessity for any progress in accelerated laboratory testing" [21]. It is regrettable that many investigators, the author included, did not heed this advice earlier, and one hopes that those who consult the studies in this volume will be more responsive and responsible.

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