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Canadian Building Digest

Division of Building Research, National Research Council Canada

CBD 122

Radiation and Other Weather Factors

Originally published February 1970

H.E. Ashton

Please note

This publication is a part of a discontinued series and is archived here as an historical reference. Readers should consult design and regulatory experts for guidance on the applicability of the information to current construction practice.

The nature of solar radiation and the changes it alone brings about in organic building materials were discussed in **CBD 121**. The process of weathering, however, encompasses the action of elements in addition to radiation; and the combination of factors produces an effect greater than the sum of the individual effects. Degradation due to radiation is accelerated when the other elements operate at the same time. This synergism, or reinforcing action, has been demonstrated many times in studies on durability. Hence, the combined actions as well as the individual processes must be appreciated, the latter being a necessary first step before the former can even be attempted. Only in this way can an adequate understanding of the weathering process be achieved.

Radiation and Water

Fortunately, two elements of weather, radiation and water, tend to operate at different times. Materials can be irradiated, however, after having been wet by rain or when they have a high moisture content from overnight high humidity. Time of wetness, therefore, is an important parameter in relating climatic conditions to exterior degradation. The action of the combined elements can follow several paths, with radiation accelerating the effect of water or the converse.

Most organic building materials are resistant to attack by water at normal temperatures. It is possible, however, for radiation to raise the temperature to the point where solution or hydrolysis can occur. Thus, plasticizers for vinyl coatings and plastics may be removed if they are appreciably soluble in water at elevated temperatures. Strength of polyester laminates can also be reduced through attack by water either on the resin itself or on the bond between the resin and the glass fibre. These actions are not so marked as in actual immersion in hot water, but they can contribute to the degradation process.

When coatings containing drying oils are irradiated by ultraviolet light, both cross-linking and scission of the oil chains occur. The low-molecular fragments from scission could act as plasticizers, but they are removed by water, adding to the brittleness caused by cross-linking. Loss in flexibility then leads to cracking, which allows water to reach the substrate and results in loss of adhesion. This is why cracking and peeling generally occur together in coating failure. Radiation can cause cross-linking of sealants, and the resultant loss of extensibility may lead to cracks between the building component and the sealant. Water can thus gain access to the

interface, producing a further reduction in adhesion. Leaching by water of irradiated lignin is responsible for the greying of exposed wood.

Radiation and Oxygen

A natural weathering combination that has probably even greater effect is oxygen and radiation, referred to technically as photo-oxidation. Materials subjected to oxygen are degraded much faster in the presence of radiation than in its absence and vice versa. For example, discoloration of polystyrene occurs more rapidly when irradiation takes place in air or oxygen, as shown in Table I. Also, the oxygen content of the product is about ten times greater when both elements operate together. It has been demonstrated that rubber can absorb 5 per cent oxygen in the dark without major changes, but when rubber containing only 2 per cent oxygen was irradiated the elongation at break decreased from 1100 to 10 per cent. In a third case, the light from a 150-watt bulb accelerated the absorption of oxygen by natural rubber. With saturated polymers there is little damage from oxygen at room temperature if UV is absent.

Table I. Photo-Oxidation of Polystyrene

Oxygen Pressure, mm	UV Radiation Time, hr	Oxygen in Product, %	Colour
0	0	0.11	Nearly colourless
0	250	0.13	Light yellow
20	0	0.10	Nearly colourless
20	250	0.14	Yellow-orange

Total exposure time 250 hours at 115-120°C in all cases.

National Bureau of Standards, "Polymer Degradation Mechanisms," NBS Circular 525, 1953, p. 206-214.

Because of the synergistic action of radiation and oxygen, anti-oxidants as well as UV absorbers are generally added to plastics designed for exterior use. Such a combination of additives has proved to be more effective than UV absorbers alone in preventing yellowing of polystyrene by radiation, provided the antioxidant does not absorb UV. If it does absorb radiation, photochemical degradation is accelerated, emphasizing the care needed in selecting additives.

Irradiation in space might be expected to cause greater damage to organic materials owing to the presence of shorter wavelength UV, but with some polymers the effects are actually less deleterious because of the absence of oxygen. In a vacuum they cross-link rather than depolymerize, so that while the material may become brittle it does not evaporate. With such resins it has been possible to produce coatings that maintain the temperature of satellites within design limits.

Radiation and Heat

The radiation referred to in this combination is again ultraviolet; infrared radiation is converted to heat. Degradation reactions that proceed only at temperatures higher than those reached on natural exposure may occur at much lower temperatures under the influence of UV. Thus, polystyrene heated in a vacuum remains colourless as it depolymerizes at 320°C. Pre-irradiated polystyrene rapidly turns yellow, then brown, and finally black at considerably lower temperature. Polyvinyl chloride also is degraded faster thermally after or during irradiation. Plastics that have been held at high temperatures too long during molding are more susceptible to UV degradation upon exposure.

Finally, there is the combination of the three elements: heat, radiation and oxygen. As expected, together they are more damaging than any combination of only two of the factors. This is illustrated in Table II.

Table II. Degradation* of Polyvinyl Chloride

Condition	Atmosphere		
	Heat	Nitrogen	Oxygen
1 hr, 150°C		0.0035	0.0043
1 hr, 150°C		0.009	0.021

and by amount of HC1 produced.
 Bureau of Standards, "Polymer Degradation Mechanisms," NBS Circular 525, 1953, p. 91.

Reducing the Effect of Radiation

Because the effects of the combined elements are so severe, damage to organic building materials might be mitigated if one of the factors could be eliminated or even minimized. The examples given in Table 1 & Table 2 show that radiation tends to be the most important of the three factors of heat, oxygen and radiation. Although heat can be controlled, one cannot normally remove oxygen from the environment. Consequently, many attempts have been made to diminish radiation, there being three basic approaches that can be taken to achieve this objective.

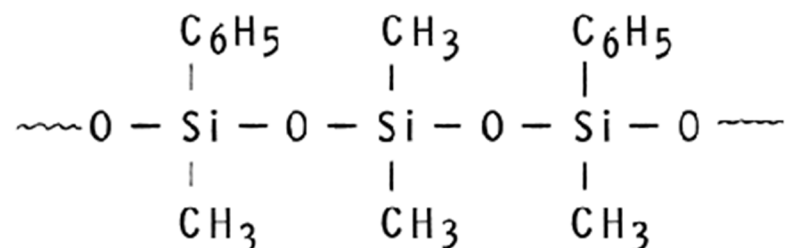


Figure 1. Silicone polymer structure.

The first method of minimizing the effect of radiation is to use polymers that do not absorb it. As discussed in **CBD 121**, it is difficult to achieve complete transparency except on the laboratory scale. Thus, polyethylene, which should be transparent to UV, readily degrades on exterior exposure. The second method would be to make polymers from combinations of elements whose bond strengths exceed the energy available in solar radiation. Unfortunately, most such combinations form simple compounds instead of polymerizing. Of the few polymers that can be made, many are readily decomposed by the other factors, water or oxygen. Hence, the possibilities of success with this approach are limited. The best known polymers of this type are probably the silicones in which there is a silicon-oxygen backbone with organic side-groups, as shown in Figure 1. The silicon-oxygen bond is only broken by radiation of wavelengths below 270 nm, and this is not received at the earth's surface. The organic groups are necessary for the material to have the properties required of a polymer; without them the material is quartz or silica - SiO₂. Fluorocarbon polymers are another example. Although fluorine is not part of the molecular backbone (Figure 2), the high strength of the fluorine-carbon bonds in the side groups contributes markedly to their excellent exterior durability.

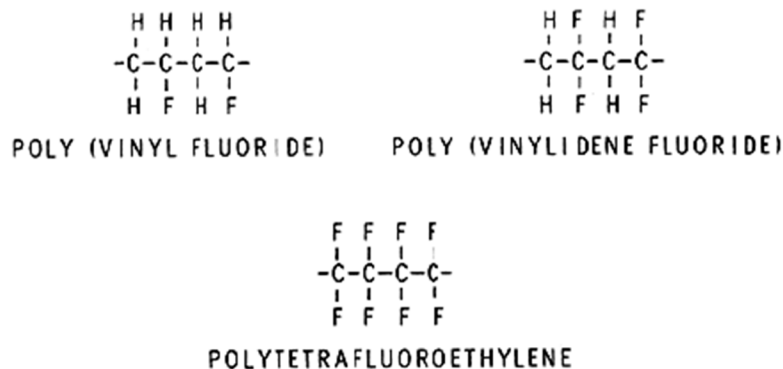


Figure 2. Fluorocarbon structures.

The final and most common procedure in minimizing the effect of radiation is to prevent the polymer from absorbing it. If the material does not have to be transparent this can readily be accomplished through the incorporation of pigments that reflect radiation or absorb it preferentially. Reflection usually occurs at the pigment surfaces within the resin so that the radiation has to pass through the top layers twice. Some degradation can, therefore, occur at the surface, and this is why materials frequently lose gloss on exposure. For complete absorption to take place the pigment must be black. Incorporation of black pigment is very effective, as shown by the increase in durability of polyethylene from one year to 20 years with the addition of 1 per cent carbon black. The colour, however, is not always acceptable. For other colours titanium, zinc or iron oxides can be used, but higher concentrations are required.

If the polymer must be clear, it is much more difficult to prevent it from absorbing radiation. It is necessary to use compounds that are, in effect, dyes that absorb UV but not visible light. In order to continue providing protection, however, the compound itself cannot be destroyed but must dissipate the energy harmlessly as heat. As it is already a problem to obtain dyes that are stable to visible light, it is much more difficult to find some that are resistant to the higher energy UV radiation.

The few compounds that do perform satisfactorily are referred to as UV absorbers or stabilizers. These materials are most efficient when used in materials that have a thick cross-section because the amount required is a function of concentration and thickness. Thus, a plastic 20 mils thick might be stabilized with 0.5 per cent absorber but require 1 per cent at 10 mils and 2 per cent at 5 mils. This relation is not strictly linear; effectiveness is reduced at higher concentrations so that more is required than calculated from the formula. Clear coatings, which are applied at 1 mil per coat, require an absolute minimum of 5 per cent to be effective on exterior wood in two or three coats. Unfortunately this quantity almost doubles the cost of the raw materials, and it becomes economically prohibitive. In addition at high concentrations, compatibility of the UV absorber and the polymer being protected may become a problem.

Another complication is that compounds are rather specific in their action - even absorbers that are closely related chemically may show large differences in effectiveness with different resins. As a result, comprehensive tests are needed to determine the type and amount of absorber to be used with any given polymer. It must also be appreciated that absorbers do not last indefinitely, but are slowly degraded, and that the absorption they are intended to prevent will ultimately occur.

Summary

This Digest has discussed how radiation affects organic building materials when its action is associated with the action of other elements of weather. Because the severity of damage is increased with the combined attack, preventive action must be taken to reduce degradation to an acceptable level. This includes production of polymers unaffected by UV or incorporation of compounds that reflect or absorb UV. Although these steps are normally in the hands of the material producer, building designers should be aware of their Importance and of the limitations they may place on performance.

