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Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/40000882
Canadian Building Digest, 1969-09

Canadian Building Digest

Division of Building Research, National Research Council Canada

CBD 117

Weathering of Organic Building Materials

Originally published September 1969

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Please note

The durability of materials used in building and subsequently exposed to weather is of great interest to the architect, the builder and the ultimate user. This digest will consider the effects of weather on building materials classed as "organic."

Composition of Organic Materials

Although there are 92 natural chemical elements, relatively few are plentiful enough to be widely used. Metals such as iron, aluminum, zinc and copper can be utilized in the elemental form but most are so reactive that they normally exist as combinations with one or two other elements in small, simple molecules. Sodium chloride (common salt) and calcium hydroxide (slaked lime) are examples of these compounds.

One element, carbon, can form compounds with itself and other elements that can contain from two to hundreds of thousands of atoms in the molecule. In addition, the general arrangement of carbon atoms - in rings or in chains - and the order of assembly of different groups in the molecule give rise to different compounds. Consequently, there is an almost limitless number of compounds of carbon, and it is these that are categorized as organic. As with most classifications, there is an intermediate area where compounds can be considered either organic or inorganic, but in general the distinction is clear.

Organic compounds differ from most inorganic compounds by having relatively low melting and boiling points. Many of the simple ones are liquids or gases, indicating that the attractive forces between the small molecules are weak. As discussed in **CBD 76**, organic molecules must be large to possess the properties needed for use in a building material. Even most of the large molecules, polymers, will melt or decompose at temperatures of 300 to 400°C. Because carbon can be oxidized to carbon dioxide and the hydrogen usually present to water, organic compounds are not often stable at elevated temperatures in the presence of air, as are inorganic materials. Although they may be simple molecularly, the latter generally have strong attractive forces that result in high melting points and structural strength. On the other hand, organic polymers, because of their low melting points, can readily be formed into desired shapes and usually are less brittle.

Types of Organic Building Materials

Organic materials used on or in buildings can be classified according to their use. They include liquid coatings (paints), plastics, sealants, and roofing materials. Wood, although often placed in a separate category, is really an organic building material. Organic materials frequently contain inorganic compounds such as pigments, but the basic properties of the mixture derive from the organic matrix in which the particles are dispersed. The differences between the kinds or organic materials are principally due to the type and molecular weight of the resin or binder used.

Because coatings are applied as liquids that must turn into solids, the original molecular size is small to intermediate and never becomes extremely large, even when the film is completely cured. With lower molecular weight materials the final polymer is formed predominantly after application, as described in **CBD 76**. If the resin is already in its polymeric form before application, the coating is called a lacquer if dissolved in a solvent or a latex paint if dispersed in water. Because of their molecular size, coatings do not have great structural strength and are, therefore, applied to substrates.

If molecular size is increased to provide more resistant coatings, the viscosity of dissolved resins increases so much that the amount of solvent necessary for application results in impractically thin films. Similarly, dispersed resins become too hard to flow into a continuous film after application. It is necessary, therefore, to find other methods of application, and one is to melt the resin by applying heat either to the resin or a solution of it. In the latter case, application of the material is by hot spray, while solid resin is melted after it has been applied in the form of a dispersion or dry powder.

Increasing molecular weight also leads to increasing structural strength because of greater molecular attraction and entanglement of long chains. When the material becomes strong enough to support itself at the temperature of use, a substrate is no longer required and the material is called a plastic. Strictly speaking, any material that exhibits plastic flow at normal temperatures is a plastic, but the term has come to apply chiefly to those organic materials that at a suitable stage in manufacture can be moulded or cast through the use of heat, pressure, or both, into the desired shape. Plastics can vary from hard and brittle (unplasticized polyvinyl chloride) to soft and flexible (urethane foam and synthetic rubber). Again, there is no distinct line between plastics and coatings. In some cases, one resin can be melt-applied, when it is called a plastic, or applied from solution, when it is called a coating.

Sealants contain resins that are intermediate in molecular size to those used in coatings before application and plastics because they must have certain unique properties in order to perform their function. They must have sufficient flow to be applied, but not so much as to run out of the joints and are, therefore, more viscous than liquid coatings. Sealants, however, must retain their extensibility and should not solidify like coatings. Thus less cross-linking occurs in the curing of sealants, which are most closely related to rubbers.

Until recently, organic roof membranes have been based almost exclusively on asphalt or coal tar pitch reduced to application viscosity by solvents (cold-applied or "cut-back") or heat. Two or three plies of reinforcement are generally used to give structural strength, and the bituminous or tar base provides the waterproofing. Because they are black and absorb most of the incident radiation, these materials are degraded by sunlight and thin films rapidly check (crack in a pattern of small squares). On roofs, therefore, they are applied in relatively thick films and light coloured or white gravel is embedded in the surface to protect them from light and to reduce surface temperature by reflection. In the past several years roofing based on liquid- or film-applied synthetic resins has been introduced. These materials can be supplied in white or light colours, but to date most have exhibited undesirable dirt collection or chalking.

Wood is an organic material that has extremely high molecular weight molecules. In addition to the normally strong forces between large molecules, the chemical groups on cellulose exert extra attraction and link together in bundles. The chemical groups are attractive to water as well, and this accounts for the ready swelling of wood by water; but the bundles are also cemented together with a more water resistant material called lignin. Because of this structure there is no solvent for cellulose unless it is first modified chemically. As wood is produced by a living organism, which must resist certain forces during its life, it has a strongly oriented structure. This orientation causes the large differences in strength and dimensional changes described in **CBD 86**.

Weathering

The process of weathering is defined as the action of atmospheric elements in altering the colour, texture, composition or form of exposed objects, ultimately leading to disintegration or failure to perform a function. The well-known elements of weather are radiation, moisture, thermal conditions and gases.

Radiation from the sun at the earth's surface is composed of near ultraviolet, visible and near infrared portions of the spectrum. Moisture results from rain (or snow), water vapour (humidity), and condensed water vapour (dew or frost). Thermal aspects of the weather relate to the presence or absence of heat (high or low temperatures) and the rapidity of change from one condition to the other (thermal shock). Gases that can enter into the weathering process directly are the normally present oxygen and carbon dioxide, plus pollutants such as ozone, sulphur dioxide and oxides of nitrogen.

Radiation

As described under composition, organic building materials are chiefly composed of long-chained molecules with carbon-to-carbon backbones. These are attracted to each other by secondary forces, although if the material is "cross-linked" there are also chemical bonds between the long chains. The amount of energy required to break these primary bonds and thus disrupt the individual molecules can be calculated. As the wavelength of radiation decreases, its energy increases and reaches the breaking energy of the carbon bonds at a wavelength of 350 nm. This is well within the range of solar radiation received at sea level. Fortunately, the proportion of shorter wavelength radiation is small at the earth's surface so that the intensity of the most destructive wavelengths is very much reduced. Ultraviolet makes up about 10 per cent of the sun's radiant energy, but at the earth's surface at noon it provides 5 to 7 per cent of the energy; biologically active UV is about one per cent of the total energy. These proportions decrease markedly before and after noon because of atmospheric scattering at lower angles. If this were not the case, no organic material would have any exterior durability.

The degradation of organic building materials attributable to UV can take two paths. With some, the energy starts a process the reverse of the polymerization reaction that produced the large molecules. This is the so-called "unzipping" of the polymer that leads to catastrophic failure. As it is a chain reaction, the aim of materials chemists is to prevent it from starting, a task much easier to state than to accomplish. The inclusion of pigments that reflect the UV or absorb it preferentially to the polymer is the most common remedy; e.g., carbon black in polyethylene. In the other degradation mechanism, the smaller molecules produced by chain scission frequently react across the chains. This results in more cross-linking than was originally present so that the material becomes harder and more brittle. If some flexibility is required for the material to perform its function, the induced brittleness causes cracking. Most organic building materials fail in this manner. On a gross scale, it is called cracking; on a reduced scale, with a rectangular pattern, it is called checking. On plastics, on a small scale, the result is referred to as crazing, while with coatings microscopic cracking leads to chalking as the top layer erodes away.

Even though the organic material itself may be resistant, it is possible for UV light to cause undesirable changes if the material is coloured and the colorant, many of which are organic, is not resistant. Fading, which is usually not acceptable, will occur. UV can also cause yellowing. It may alter a resin's chemical structure so that it absorbs blue visible light and appears to be yellow. Fortunately in many cases visible light has the effect of bleaching these induced colours.

As only short wavelength radiation possesses sufficient energy to break the primary bonds, it follows that longer wavelengths can only directly affect the secondary forces. Visible and infrared radiation lead chiefly to increased temperature and thus to softening in materials that do not contain much cross-linking. The indirect effect is to increase the rate of chemical reactions that may be occurring from other causes. This increase in temperature due to solar radiation can be substantial (**CBD 47**, **CBD 70**).

Moisture

Water is one of the most prevalent elements of weather. Because most organic building materials are hydrophobic and not porous, they are not so readily damaged by the freezing action of water as are many inorganic materials. Wood, being composed of a hydrophilic polymer in cellular form is readily swollen by water. The polymer however, does not dissolve in or react with water, so that wood does not disintegrate when swollen, even if later frozen. Water is necessary for the degradation of wood by micro-organisms, even though one type is called "dry" rot (**CBD 111**).

Some organic coatings intended for use on wood, particularly oil paints pigmented with zinc and titanium oxides, swell markedly when immersed in water. When water (from either the exterior or the interior of a building) collects at the back of such a paint film, it expands in area more than the corresponding substrate and is forced off the surface, with resultant blisters. Water can also cause blistering of coatings that swell only slightly if more moisture collects at the interface than can be transmitted through the film. When the hydrostatic pressure exceeds the adhesive strength of the film, blistering occurs. Swelling properties, permeability and adhesion to moist surfaces have, therefore, been considered important parameters in the assessment of exterior coatings for wood. Moisture can cause degradation of coatings on metal if it can permeate the film and initiate corrosion, the products of which can disrupt the coating.

Roofing materials, which are used for their waterproofing ability, and plastics are generally little affected by water. Glass-reinforced plastics can be damaged if the fibres are too close to the surface or the resin weathers away, allowing water to wick along the fibres and reduce the reinforcing action. Frozen water in the form of hail can damage brittle plastics by impact. Sealants in the bulk are unaffected by water, but their adhesion can be destroyed if water attains access to the interface. Such failures occur most often on porous substrates that can absorb water.

Temperature

Temperature can have both a physical and a chemical effect. Physically, a change in temperature alters such attributes as hardness and strength, which are related to the tensile properties of the material. A temperature increase softens materials that do not contain much cross-linking between the molecules, i.e., the thermoplastics. Those that are highly cross-linked usually decompose before much softening occurs; these are the thermoset materials.

Decrease in temperature increases the hardness or modulus of organic building materials and if they become too hard they may not perform their function properly. In addition, a sudden change in temperature in either direction can cause internal stresses in thick sections owing to the low rate of heat transmission of most organic materials. With such a change, the outer surface responds quickly to the new conditions while the inner portion is still at the original temperature. Thermal shock can thus lead to surface cracking if the exterior contracts rapidly while the interior is expanded, or to interior cracking under the reverse conditions.

Chemically, temperature changes the rate of reactions. Oxidation, which is a slow reaction at room temperature with most materials, takes place much more quickly at elevated temperatures.

After coatings have been cured, low temperatures do not affect them particularly unless they are subjected to impact. Neither do higher temperatures experienced in weathering have any direct effect. Because coatings are applied in thin films, thermal shock is not generally important.

Sealants that have been properly formulated resist the forces exerted by high temperatures (softening of the material and thermal expansion of the jointed units), which tend to make them flow. Low temperatures, such as those experienced in many parts of Canada, place extreme demands upon sealants because they must elongate most when they are least able, owing to hardening or stiffening. Rate of temperature change is also important because organic materials, in general, can accommodate slow rates of strain much more readily than fast rates of strain.

Plastics designed for use in buildings are not softened in hot weather, although the ability of thermoplastics to support a load may be reduced owing to creep. Low temperatures make them stiffer but most do not become brittle. Rigid (unplasticized) polyvinyl chloride, which is only used where extreme chemical resistance is required, and polymethyl methacrylate, which has good clarity, already have little impact resistance because they are in the glassy state at normal temperatures. Thermal shock, especially when cyclical, can cause cracking or exudation of plasticizer from plastics.

Temperature extremes also place demands upon asphaltic and tar roofing materials. If a hard material is used so that it will not flow in the summer sun, it may become brittle and crack badly at low temperatures, and vice versa. Thus the selection of the proper grade requires considerable care (**CBD 95**). Because of the need to resist flow at high temperatures, the material can only withstand low temperature shrinkage that is uniformly distributed, emphasizing the importance of design. Moderate flow at high roof temperatures is designed to overcome small cracks caused by low temperatures.

Gases The atmospheric gas most damaging to organic materials because of its high concentration and reactivity is oxygen. Chemical linkages that are not completely "saturated" or satisfied (chemically called double bonds) are particularly susceptible to oxidation. Indeed, this is the basis of the drying mechanism of oil paints and other coatings that cure through oxidative polymerization. Because it is impossible to have a binder that contains the exact number of double bonds to cause solidification but no more, the reaction continues past the optimum stage and becomes part of the degradation process. Hence, oil paints, which depend solely upon this drying process, are more susceptible to continued oxidation than coatings, which include other methods of polymerization, e.g., alkyds.

Natural and many synthetic rubbers contain unsaturation and consequently oxidize, leading to discoloration, hardening, crazing and finally cracking. Unsaturation, however, is not essential for oxidation; polymers that contain reactive hydrogen atoms are also attacked: polystyrene and polyethylene, for example. Because oxygen must diffuse into the material to continue the reaction, oxidation often occurs only at the surface unless the material is in a thin film.

The other major gases, carbon dioxide and nitrogen, do not react with organic building materials and are frequently used in chemical synthesis as inert atmospheres. Rapid movement of the normal atmosphere, wind, can cause weathering by impinging rain, sand or dust upon exposed surfaces. Degradation of coatings is usually more severe on the sides of buildings that bear the brunt of storms.

Ozone is normally present only in the upper atmosphere and can be considered a pollutant at ground level. Being an unstable modification of oxygen, containing three instead of the normal two atoms, it is extremely reactive. Materials that oxidize will therefore react with ozone. An illustration of this is ozone-cracking of rubbers. Sulphur dioxide, present in industrial atmospheres from the burning of sulphur-containing fuels, is the other common pollutant. Its action is to form sulphuric acid, which may diffuse through organic coatings and attack the underlying metal.

Combinations

Two elements of weather, acting together, almost invariably produce greater deterioration than either one alone. There are many examples of this synergistic action. When UV breaks a polymer chain, water can remove low molecular weight materials that could act as plasticizers, thus adding to the brittleness caused by cross-linking. Leaching by water of irradiated lignin is responsible for the greying of exposed wood. Materials that have been irradiated, oxidize much faster than those that have not, and photo-oxidation is one of the chief reactions in degradation. Most polymers are much more stable to heat in the absence of oxygen than they are in its presence; and more stable to oxygen in the absence of heat. For example, toughened polystyrene can be heated at 260°C for 20 hours without change, but in air either heat or UV cause yellowing and embrittlement at lower temperatures. Plastics softened by heat are more readily eroded by wind-driven sand. Both oxygen and water are involved in the rusting of iron, which disrupts organic coatings. Ozone cracking occurs sooner when the material is under mechanical stress. If three elements act together, the result is even more complicated.

Summary

The actual weathering process can be extremely complex, involving a number of weathering factors acting together and resulting in other process interactions within or on the material. This Digest has attempted to characterize various organic building materials and to deal with their reaction to weather factors individually as a simplification of the total process. An appreciation of these individual factors and processes is necessary for an understanding of material behaviour and as a rational basis for prediction of performance.