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DESIGN AND SERVICE LIFE

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In nature there are many mechanisms that act to break down or decompose materials. They are essential to life on earth, but they must be prevented from acting on the materials of buildings or their action must at least be retarded if buildings are to perform satisfactorily for a reasonable period of time. The basic function of buildings, that of enclosing space whose environment is different in some way from the natural environment, also requires that nature's forces be controlled. In both cases, command of nature must be gained, but this can only be accomplished by compliance with nature's laws. Designers, therefore, must have a knowledge and understanding of these laws if they wish to realize truly successful buildings. Thus, it may be necessary to reconsider some basic concepts and gain new ways of thinking about the design of buildings and the use of materials.

It is necessary to recognize that no material is, of itself, durable or non-durable. Interaction of elements of environment with the material determines its durability. For a material to deteriorate there must be one or more elements of environment acting upon it; but in any specific case deterioration can be prevented if any one of the essential factors can be eliminated.

Sulphate attack on normal portland cement concrete occurs when a solution of sulphate salt in water contacts and reacts with two components of the cement matrix. It can be prevented if a water seal on the wall surface can be achieved. It may be more positive, however, to prevent the sulphate solution from contacting the concrete wall by incorporating a drained network of voids. The most common method of controlling sulphate attack on concrete is to use a cement that has a very low tri-calcium aluminate content. It is important to recognize that in this case durability can be gained by either of two means: use of a slightly different material; or design of the assembly so as to change the environment at the concrete surface.

Decay of organic matter only occurs when there is a spore, organic matter for it to feed on, oxygen, and suitable temperature and moisture conditions (CBD 111). Control of any one of these factors will prevent decay. It is common practice to treat organic materials with a fungicide, but total penetration is not always possible, and untreated parts are left open to attack. A design that provides the material with a dry environment is generally the best means of controlling decay.

Designing a building must involve more than matching material properties to the functions to be performed. Economic considerations of long service life dictate that materials must suit their service environment or that the environment must be altered to suit the material (since durability is determined by the interaction of environment with the material). Thus the three factors of function, material, and environment must all be manipulated in order to gain the optimum solution to any design problem. It must be borne in mind that a decision or change involving one factor will influence the other two and that all three must be considered collectively. The fact that the ice of an igloo is durable as long as it is frozen should serve to emphasize the importance of the interaction of environment and material.

Design and the Functions of Materials

It is the function of a wall or roof to maintain separation of two dissimilar environments (CBD's 48, 67). There are many components of environment, however, and this general function is actually made up of a multitude of sub-functions. Their number and nature are dependent upon the differences between the two environments and the degree of separation required. An interior partition must be a physical barrier providing privacy, sound separation, and some degree of security, and meet certain aesthetic requirements. An exterior wall must, in addition, prevent rain and air leakage, control vapour migration, control heat and radiant energy transfer, and resist physical loads.

Where several materials are to be used to perform a complex over-all function, it should be recognized that each material, by virtue of its particular properties, will cause the environment on one side to be different from that on the other. Its location in an assembly is an important factor in determining its environment and function as well as that of all other materials in the system. This understanding can be used to advantage in both minimizing the critical nature of the function imposed on each material and in improving the environment in which most of the materials must perform.

The functions of a precast concrete wall panel, where insulation and plaster are applied to its inside face (Figure 1(a)), include provision of the aesthetic appearance, radiation interceptor, rain penetration control, air barrier and structure. The insulation provides resistance to heat transfer; the plaster provides a serviceable interior surface, and paint the aesthetic finish and water vapour impermeance, unless an additional vapour barrier has been incorporated. In fulfilling its multitude of functions, the concrete panel is subjected to movements and stresses resulting from variations of temperature and moisture content. A perfect seal against air and rain leakage is almost impossible to achieve or maintain under such conditions. Rather non-critical functions are imposed on the plaster, but it has the best environment in which to perform. Unless the plaster is installed in such a manner that it also acts as an air barrier, however, convection of air past it and through the inevitable spaces in the insulation layer will result in condensation on the concrete.

When the wall assembly is reversed (Figure 1(b)), the concrete panel must provide a structural air barrier, vapour flow resistance, and interior surface. With the insulation on the outside, the concrete panel is provided a relatively constant thermal environment and movements or stresses that might cause cracks are at a minimum. Stucco performs the aesthetic, solar, and rain shielding functions, but is itself subjected to movement. These are of little concern, however, for the stucco has no structural function and can be free to move as it must. Changing the position of the materials in this example makes it possible for the wall to fulfil its total function in such a way that only the least critical sub-functions are imposed on each material.

A sealant located at the exterior of a joint must provide a seal against the passage of both air and water and this necessitates perfection. When a sealant is located toward the interior of the joint, an air space in the joint, pressure equalized and drained to the outside, can control the main forces causing rain penetration (CBD's 40, 96). Because water will not reach the air seal and some air leakage can normally be tolerated, the function of the sealant is far less critical.

The two examples show clearly that the function of a material can differ greatly with location in an assembly. This approach can be applied to almost all parts of a building and must become a basic concept for design if long service life at the lowest total cost is to be assured.

Design and Materials

Material properties can seldom be changed at the whim of a designer and an all-perfect material may never be realized. In the practical world of building problems must be solved "now," and only known materials can be used. Selection of materials must be based on the designer's knowledge of their physical properties, the function he plans to impose upon them, and the nature of the environment in which he is going to place them. The more knowledge the designer has of the nature and availability of materials, the broader will be his range of choice. His ability to impose the least critical functions on each material and to locate it where mechanisms that could cause its deterioration are least active will enhance his range of acceptable materials.

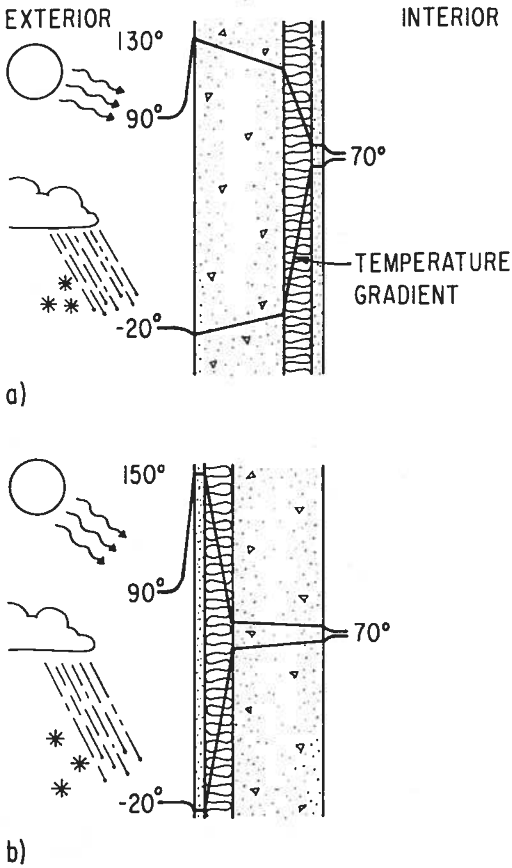

Figure 1. Wall Section.

In choosing a material to fulfil a function, the designer must be aware that it will possess properties other than those required. Frequently, these will have greater influence on its durability in service than the properties that dictated its choice. Consequently, all properties of all materials must be considered in the light of both function and the effects of the environment.

A common example of failure to consider all properties of a material is the use of mineral wool on the inside of exterior walls for sound absorption. In this application a vapour barrier cannot be used on the room side of the mineral wool, and its thermal insulating property causes the material outward of it to be cold in winter so that condensation results. This excess of water could, in turn, permit several mechanisms of deterioration to operate.

Design and the Environment at the Material

Environment may be defined as surrounding conditions. In dealing with durability of materials, therefore, one must consider three scales of environment: that surrounding the total assembly, the general environment; that surrounding the piece of material, the macro-environment; and that surrounding a microscopic part of the material, the micro-environment. It should be emphasized that deterioration of materials commences at the micro-environment.

Weather as the main general environment is normally defined as the state of the atmosphere with respect to temperature, humidity, precipitation, wind and radiation at a specific time and place. This could be changed to read the state of the mass and energy at a specific time and place. In considering environment, it too could have this definition except that people, animals, insects, bacterial and biological factors, contaminants and loads should be added to climatic factors despite the fact that they are also combinations of mass and energy.

In performing its function of separating two dissimilar environments, a wall must prevent, limit, or allow the flow of mass and energy through it. As a result, concentrations of mass and energy vary from one side to the other and the two general environments establish the general gradients through the wall. All materials differ one from another in their resistance to these flows, however, and the gradients are not uniform through the assembly. Materials also have thickness; because resistance varies with thickness, the micro-environment at one point in a material will be slightly different from that at another point in the path of flow.

A post in an open field is surrounded by the general weather environment, but simply because of its orientation and inherent resistance to the flows of mass and energy the precise local environment varies all the way round its surface and throughout its interior. This is characterized by moss growing on the cool, damp-north side.

Similarly, a large stone on the ground will experience a temperature gradient from the centre to the exposed surfaces during the onset of winter owing to its heat storage capacity. The stresses resulting from such a temperature differential may cause some materials to break. On the micro-scale there is unidirectional freezing, and in a wet stone this will develop far higher forces with a correspondingly higher probability of fracture.

Environmental differences are intentionally imposed across walls, windows and roofs by mechanically altering the balance of heat, air and moisture inside the space. With these building elements a great deal can be accomplished by varying the position of the various materials of which they are composed. As mentioned in an earlier example, changing the position of the insulation in a wall can completely change the thermal and hygrometric aspects of the environment in which other materials of the wall as well as the insulation itself will have to serve.

In a roof assembly where a bituminous membrane is placed over insulation on top of the roof deck severe deterioration from many mechanisms can occur because of the environment at the membrane. One mechanism, that of photo-oxidative degradation of the bitumen, has long been recognized and the environment at the bitumen surface is modified by the use of gravel to provide shading from ultraviolet radiation (CBD 65). Even more could be accomplished if the bituminous membrane were covered with insulation for it would then be in an environment free from extremes of temperature, radiation and physical abuse (CBD's 75, 99). The insulation, however, may need to have special properties or have its service environment modified.

A coat of paint, despite the fact that it is exceptionally thin, causes the environment on one side of it to be different from that on the other. A paint with low permeance to both water and air can eliminate or reduce the concentration of these elements of environment at its interface with steel, providing an environment in which corrosion cannot occur. A transparent coating such as varnish also produces differences, but it permits the passage of some radiant energy that can attack the lignin of a wood substrate. With the resulting deterioration of the wood surface, the varnish itself may not deteriorate but merely peel off. Again, these common examples show that each property of a material must be considered in design.

Walls below grade are also separators of dissimilar environments. In this situation the environment in the soil must be understood, and it should be recognized that the environments can again be modified. Temperature variations at the exterior of the wall can be reduced by placing insulation on its outside surface or perpendicular to it just below the surface of the ground. Water, as an element of the general environment underground, need not be part of the environment at the wall surface if it is prevented from contacting it. This is easily accomplished by having a network of interconnected voids at the wall surface that are adequately drained at its base. The common approach to preventing the wetting of below-grade walls is by the application of an impermeable coating. This could be successful if an acceptable material, which would be durable in the below-grade environment and could be applied to be complete and perfect, were available. These conditions, however, are rarely met.

A sealant located at the exterior of a joint not only has critical functions to perform but is also exposed to environmental factors that cause and accelerate its deterioration. Ultraviolet radiation, extremes of temperature, wetting, extreme movement at low temperatures, and inquisitive fingers all have adverse effects on the material. If concealed toward the inside of the joint, as suggested earlier to reduce the critical nature of the imposed function, the sealant can be protected from most of the factors that could cause or accelerate its deterioration. In this position and because of the non-critical nature of its function, especially if it is inward of the thermal insulation, loss of some properties common to most sealants could be tolerated.

Conclusion

The basic rules for long service life of materials are (a) to design so as to impose the least critical function upon a material, (b) to select a material that can perform the function and be durable in its service environment, or (c) to alter the environment to suit the properties of the material that must be used.

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