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A CRITICAL EXAMINATION

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General Characteristics

Urethane or polyurethane foam is the second most widely used rigid plastic in the construction industry. One of its unique properties -- its high strength to weight ratio -- makes it the strongest of all the common foam plastics. It comes in a variety of forms: rigid or flexible, low or high density, open or closed celled. It is normally used in a rigid closed celled form for building insulation. Both factory-made board stock and spray-on types are being used more extensively as insulations in building construction. Urethane foam is an effective material but there are limitations that must be understood if it is to perform effectively. This Note has been prepared in an attempt to aid that understanding.

Urethane is made from two components: a polyisocyanate and a polyhydroxyl. The components also contain catalysts, a surface-active agent, and a blowing agent, which is normally a fluorocarbon refrigerant. The refrigerant gases have large molecules that do not transfer heat readily and are easier to hold in the plastic material. Normally refrigerants R-11 and R-12 are used.

The reaction of the two components produces a large amount of heat which expands the gas, thus producing the cells. The catalyst controls the speed of reaction. The surface-active agent acts in controlling the cell structure and allows production of a foam with a fine cell structure, which is necessary for a good thermal insulation.

There are two basic types of isocyanates used in the production of commercial urethane insulation. These are termed TDI and MDI; chemical names and details can be found in any reference book on urethane. In addition, a wide variety of polyols are used. These are generally selected according to cost or the foam properties desired. In general, the more expensive the polyol used, the better the properties, although this can be influenced to some extent by the equipment used in mixing the components.

Mixing of the components is done either in spray nozzles or by a number of more or less secret processes. The mixing ratio of the two components must be maintained constant to within about 1 per cent to maintain a uniform product. The temperature of the components greatly affects the dispensing of the material. After mixing, the urethane expands 30 to 40 times in volume. This can be accomplished in one or two rises. When both R-11 and R-12 are used as the blowing agent in the foam, the material rises as the R-12 vaporizes and then rises a second time when the R-11 vaporizes. From 80 to 90 per cent of the cells are closed in a well-controlled, single-rise factory application. This means that the blowing agent does not escape immediately and the foam will maintain its high thermal resistance for a considerable time, that is, it will age slowly.

Normally the mixing is done in a factory under carefully controlled conditions but urethane can be sprayed on at sites using special equipment. There is little information on the closed cell content for spray-on urethane that has been applied under various field conditions. It could be expected to be lower on the average than for factory-made foam. In most factories an upper platen compresses the foam and prevents it from rising freely. This causes the cells to be ellipsoid in shape. As a result, the thermal resistance and vapour transfer resistance are increased and the material will age more slowly. Spray-on urethane has spherical cells or the cells are elongated in the direction of rise. This reduces the thermal resistance and vapour transfer resistance.

In both factory-made and spray-on urethane the open cells can form long chains in the direction of rise. Such a material has a "worm-eaten" appearance. These enlarged openings drastically reduce its effectiveness. It is more difficult to eliminate this type of cell structure in spray-on material than in factory-made material.

The density of urethanes can vary from 1.5 to 30 lb/ft^3 (24 - 480 kg/m^3). Most spray-on material is made in densities of 2 to 3 lb/ft^3 (32 - 48 kg/m^3). Lower density foam can be produced from improved formulations of polyurethane provided that well designed equipment is used; however, the condition of the surface and the environment become more critical. As material cost is directly proportional to density, low density materials are most often selected. The structural and thermal properties are generally more suitable for building purposes at densities between 2 and 4 pcf (32 - 64 kg/m^3).

Urethane foam has good chemical resistance, which helps in avoiding problems in selecting adhesives and coatings. It also increases its usefulness in industry where chemicals in liquid or vapour form are often present. Urethane is not resistant to all chemicals, however, so some caution is necessary. It is also not resistant to ultra-violet radiation.

The dimensional stability of urethane is affected by temperature and relative humidity. Although the material is more or less dimensionally "stable" (under 5 per cent change in each direction and under 15 per cent change by volume) up to 220°F (105°C) if dry and at a low relative humidity. At temperatures above about 120°F (49°C) and with relative humidity over 90 per cent, it becomes dimensionally unstable - changes of 5 to 20 per cent in each direction and 15 to 60 per cent by volume can occur. There is relatively little information on this important characteristic, making it difficult for designers to compensate for this shortcoming.

All urethanes have quite a high resistance to water vapour transfer. They must be covered, however, with coatings and vapour barriers to protect them because of problems with water absorption and dimensional instability. Although spray-on material has a skin which increases the resistance to water vapour transfer, the quality of the skin is not controllable. As well, the properties of the skin have not been established well enough to allow designers to make use of it in system design.

Urethanes can have a high flame-spread rating relative to other building materials. When burning they can give off large amounts of smoke and toxic fumes. The flame-spread rating can be reduced by adding phosphorous, chlorine, bromine or a combination of these to the basic components. In addition, the basic chemistry can be changed to produce an isocyanurate structure that is inherently more fire resistant. This increases the cost of the material and introduces undesirable characteristics such as friability and brittleness, and in certain cases reduced chemical resistance. Materials intermediate between urethanes and isocyanurates are being produced with a more acceptable mix of properties.

Other characteristics of urethane insulation

Polyurethane is one of the more expensive residential building insulations. On the basis of cents per unit resistance for a square foot area, the current cost of fully aged urethane runs from five to seven times that of glass fibre insulation and two to three times the cost of polystyrene insulation. Aluminum-foil covered material can be more cost competitive.

Spray-on urethane does have some advantages over other insulations. The cost of labour for applying the material is low, offsetting to some extent the high cost of the material. This is of particular advantage in structures that are difficult to insulate. There is little possibility for saving, however, in a standard frame house where the installation of glass fibre blankets or board-type insulation is relatively inexpensive.

Spray-on polyurethane can provide an excellent air barrier at the same time as it provides thermal insulation although its effectiveness as an air barrier has not been proven over long-term periods. Almost all cracks and openings can be sealed by the foam. In a frame house where relative movements between structural members are not large, the seal will probably remain intact for some time. Many older houses and some newer ones may, however, have movements so large that urethane will not maintain a seal. A lack of design data makes it difficult to judge when the seal will be maintained.

The ability of urethane foam to absorb acoustical energy is much lower than glass fibre insulation. The advantage provided by the air seal in reducing noise transmission is thus offset to some extent by this inability to absorb acoustical energy.

Polyurethane foam is basically a dimensionally unstable material. This is because the gas pressure in the cells increases to as much as 12 psi (83 kPa) above atmospheric pressure as air permeates into the cells. Thus there is a potential for a release of large forces when restrained or a large expansion if unrestrained.

As explained previously, at temperatures above 120°F (49°C) or at relative humidities approaching 90 or 95 per cent and temperatures above normal ambient, the material begins to "grow" if unrestrained. The cell walls stretch and the material expands.

High humidity has a detrimental effect on the material at high temperatures. Polyurethane is plasticized by the water vapour causing it to lose its strength and allowing the closed cells to return to a spherical form and then to expand. If expansion is restrained in one or two directions, larger expansions occur in the unrestrained directions. If it is completely confined, the material applies a force to the surrounding structure. This can be large enough to cause damage even to such strong structures as prefabricated concrete panels.

Polyurethane is best used in a cool, dry environment. A good design will ensure its protection from extremes in temperature and from becoming wet. It will also keep the foam dry by providing a vapour barrier that will keep excessive moisture from entering the material and condensing or freezing in the colder parts of the foam. Polyurethane does not have good freeze-thaw resistance. If the material is wet and is subjected to freeze-thaw cycles it may disintegrate after only a few dozen cycles.

Air penetration and refrigerant gas loss lead to a reduction in the thermal resistance of the foam, termed "ageing." Only metal skins have proved effective in preventing this ageing. The rate of ageing for non-metal clad foams depends on the formulation and structure of the foam. The effect of ageing is to reduce the time-averaged thermal resistance of the foam. Manufacturers provide little information on the ageing of their materials. The energy standard for France specifies a time-averaged value of thermal resistivity of 5 (Btu/hr/ft^2/°F-in.) (35 m·°C/W). This value is applicable for thicknesses of 2 or 3 inches (50-75 mm). A resistivity between 5 and 6 is probably more pertinent for thicknesses over 3 inches (75 mm). Isocyanurates may "age" more rapidly than urethane due to the brittleness of the cells and less closed cell content.

At temperatures below +50°F (10°C) the refrigerant gas in the cells, normally R-11, will condense causing some small shrinkage of the material and reducing its resistance to heat flow. This becomes progressively worse as the temperature is reduced to -50°F (-45°C), where the gas is almost all condensed. The effect of this decrease in thermal resistance is to reduce the economic attractiveness of urethane as an insulation for cold storage buildings. The exact extent of the effect on aged urethane foam is unclear. Air-filled foam plastics can be much more economical for these applications and can take little or no extra space.

Special Problems With Spray-On Polyurethane

As spray-on urethane is a material that is manufactured on site, the applicator must take the responsibility for the very important job of quality control. This usually involves inspection by a trained individual who understands the process thoroughly and can adjust it to maintain a good quality product.

The quality of spray-on urethane depends on many factors including: the ratio of the two components used, the temperature of the components in the tank, the temperature and relative humidity of the surrounding air, the type of equipment used, the operator's skill, contaminants and dust on the surface to which the material is applied (substrate), and even thermal conductivity of the surface material and temperature on the other side of the substrate.

The quality of the bond between the foam and the substrate depends on many of these factors as well. If the first layer does not rise properly it will probably not adhere very well. This layer can also rob some of the constituents from the next layer of foam leaving it weak and friable. A failure in adhesion may occur at this next layer rather than right at the surface.

Polyurethane foam can also be sprayed on surfaces in the form of a froth, which is partially expanded foam. A froth is normally produced by using both R-12 and R-11 refrigerant in the material. R-12 boils at a lower temperature, partially expanding the liquid. This is then sprayed against the surface, where the heat of reaction of the two components heats the froth causing the R-11 to boil and finish the foaming. It is claimed that the surface and atmospheric conditions have less effect on urethane applied in this way. The type of equipment necessary to produce a froth is not yet commonly available nor is much known about the problems of this kind of operation.

New spray equipment will probably reduce the difficulty in producing good quality spray-on urethane in future. For example, in the past, many machines had adjustments to control the mixing ratio and the machines tended to go out of adjustment. The newer machines, however, are set to a fixed ratio which suits the components selected; they cannot be adjusted nor go out of adjustment. This had reduced the amount of on-site supervision necessary to assure a good quality foam. Other factors may still cause the mixing ratio to vary.

There are a large number of manufacturers producing one or both of the components used in making urethane foam. The quality of these components is continually being improved. In addition, special formulations are being developed to allow spraying under less favourable conditions. In particular, cold weather formulations are being developed.

Wind is a problem when spraying on the outside of a structure. Overspray can cause a mess, which may result in expensive clean-up charges and a health hazard; it also greatly reduces or eliminates the profit of the applicator. Also, the overspray and fumes are dangerous to the operators and persons in the immediate area during spraying operations. It is recommended that the operators use fresh-air masks. Surrounding areas should be well ventilated and cleared of all personnel. Nearby furniture and finished surfaces may require protection.

A number of large companies use spray-on urethane to insulate their structures and equipment. Some of these control the quality of the product they receive by constant inspection, sampling, and testing. If the material is substandard it must be removed and replaced. This is not feasible for an individual or small contractor. The reputation of the applicator must, therefore, be relied upon. It is not easy to determine this reputation without an extensive investigation. The individual or small contractor is therefore gambling when he uses a spray-on urethane. A long-term guarantee from the applicator would not help as the cost to replace spray-on urethane, once it is built into a structure, is so great that it may not be practical.

Applicators' associations are now being formed which encourage proper training, proper supervision and a certain amount of financial bonding. This may alleviate the risk.

Although this Note has pointed out the negative aspects of polyurethane insulation, the material has many positive features that have not been emphasized here. The material itself is quite acceptable for use in buildings as long as it is used for the correct application and applied properly. An understanding of the negative aspects is essential in defining the correct application.