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Properties of Bituminous Membranes

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An important function of a building enclosure is the prevention of water leakage. To fulfil this requirement at locations such as roofs and foundations waterproof membranes are frequently used. Bituminous waterproof membranes are the most common, and are made by combining asphalt or coal tar pitch with felts, mats or fabrics of organic or inorganic fibres. Their popularity is mainly attributable to the waterproof and adhesive characteristics of the bitumen, the availability of the materials, their low cost, and ease of installation.

The waterproofing properties of a bituminous membrane depend upon the existence of continuous films of bitumen. To prevent rupture or flow of the bitumen a sheet material (felt) is normally incorporated. Felts add strength and spanning ability to the membrane but may, in turn, be responsible for membrane failures. A bituminous membrane acts as a single composite structure, but its behaviour is influenced by the properties of the materials from which it is made, the surface to which it adheres, and the environment in which it must serve.

Properties of Bitumen

Bitumen, a material that behaves as a viscous fluid at some temperatures and as an elastic solid at lower ones, has been employed for centuries in construction because of its waterproofing and adhesive properties. Through long experience many of its limitations have been recognized, but improved understanding of the factors affecting its performance has been gained through scientific research. Bituminous materials have been discussed in **CBD 38** and only properties related to membranes will be considered in this Digest.

The waterproofing capability of bitumen is partly due to the non-wetting nature of its surface, but it is primarily a result of its nonporous characteristic. Although absorption of water by bitumens does occur, it is generally very limited and of little significance. For bitumen to perform as a water barrier there must be a continuous film free of any voids, pin holes or cracks. Provided this continuity is achieved the film can be as little as 0.005 inch thick, but deterioration of bitumen and other practical considerations usually dictate the use of a much thicker film.

Adhesion of bitumen to a surface depends upon both the nature of the surface and the state of the bitumen. Because it must make intimate contact with a solid surface, its viscosity must be lowered by heating or dissolving in an acceptable solvent (cut back). In this fluid state good adhesion to most surfaces can be obtained, provided the surface is clean and dry, but surfaces such as metal and concrete require priming with a cut back. Even after bitumen has been successfully applied, the bond can be decreased or destroyed by the migration of water to the interface between bitumen and solid.

The cohesion, or internal strength, and the flow properties of bitumens vary considerably with temperature and stress conditions. Bitumen behaves in a viscoelastic manner, and under the influence of an applied strain its deformation will depend upon the rate of strain and the temperature at which it occurs. At a warm temperature bitumen behaves as a liquid; at lower temperatures it behaves as an elastic solid. As the behaviour of both solid and liquid materials is involved, any mechanical properties such as load-strain must be related to the rate of deformation and temperature. Its thermal expansion also varies with temperature, being greatest when cold.

Deterioration, or loss of the desirable properties of bitumen, normally takes the form of hardening. The net result is a decrease in adhesive and flow properties and an increase in the softening point temperature and coefficient of thermal expansion. Hardening of a bitumen results in a reduction in its ability to accommodate deformations without splitting. The actual mechanisms of deterioration are not fully understood, but it is known that photo-oxidation is a major factor and that it is most active at high temperatures under solar radiation. Water, dissolved compounds from atmospheric pollution, attack by microbiological organisms, and changes in its internal structure are other factors contributing to hardening of bitumens.

Many of the undesirable characteristics of bitumens can be modified by the addition of specially formulated compounds. There are a number of additives that improve adhesion properties, making it possible for bitumens to adhere to a wet surface and even retain their bond when later wetting of the bitumen-solid interface occurs. Anti-oxidants retard the rate of hardening from chemical and internal structure changes resulting from oxidation. Certain polymers added to bitumens act to resist softening and flow at high temperatures, while maintaining plasticity at low temperatures. Modification by these means, although adding to the material cost, can have definite economic as well as technical advantages, especially when a bituminous membrane is to be buried under expensive terrace surfacing materials or concealed below grade.

Properties of Membrane Reinforcement

Reinforcement is employed in a bituminous membrane to stabilize the bitumen film, to provide the strength required to span irregularities in its supporting surface, and to distribute local strains over a greater dimension. Several layers of reinforcement are normally used to give greater strength and provide several layers of bitumen in the hope that minor failures in one film will not cause immediate total failure. Although one continuous film of bitumen can be waterproof, the safety factor gained by using several layers or plies, as in built-up roofing (**CBD 24**), appears to be economically sound because of the low cost of the materials. One sound layer, however, can be very much better than several poor layers.

Organic felts made from wood fibres and a small amount of waste rag are the most common reinforcing materials. Asbestos felts, glass fibre mats, and glass, cotton and jute fabrics are also frequently employed. Both organic and asbestos felts are made by a paper manufacturing process, which produces a general fibre orientation in the long dimension of the sheet and results in a directional variation in their properties. Fabrics, however, do not normally exhibit this characteristic to the same extent. Adhesion between the bitumen films and reinforcement is essential, and it is normal to factory prime these materials by saturating them with hot bitumen. Bitumen saturation also minimizes the water absorption of felts, but since saturation is not complete they do absorb moisture and are not vapour impermeable. Bitumen coating of saturated felts further reduces the vapour permeance and increases the resistance to moisture penetration.

Even when saturated, felts can absorb and hold water - up to 80 per cent of their weight. On absorption of water they expand up to 0.2 per cent parallel and 1.5 per cent perpendicular to the fibre direction. The amount of water absorbed and the resulting expansion varies from one material to another and according to the degree of saturation. It must also be recognized that as felts dry there is an accompanying shrinkage, which in some cases can be greater than the original expansion. When exposed to water and air, organic fibres are open to rot, attack by fungi, and roots of vegetation may grow into them.

The mechanical properties of bitumen-saturated felts are those of a non-isotropic material with a viscoelastic character. They have a higher tensile strength and lower breaking strain parallel to the fibres of machine direction when compared to the cross-machine direction, but the values vary with temperature and rate of strain.

Performance of a Built-up Bituminous Membrane

A bituminous membrane is employed to prevent the passage of water and water vapour but is itself adversely affected by water. Reduction of bond between the bitumen and felts as well as between the membrane and its substrate can occur because of moisture accumulation. Moisture changes in the felts will cause swelling and shrinkage, not only in the total membrane but also in localized areas. When the bottom felt of a membrane is not bitumen-coated, as frequently occurs over insulation joints, the localized dimensional changes due to moisture absorption will result in ridging of the membrane. Following ridging, the bitumen will flow off the steeply sloped sides of the ridge on the outside so that eventual failure of the membrane results. Blistering of a membrane can also occur as a result of the increase in vapour pressure caused by a rise in the temperature of moisture trapped between it and the substrate or between plies, especially since the moisture present also reduces the adhesion of the bitumen.

To prevent moisture problems in a membrane it is necessary to provide a continuous film of bitumen on both of its surfaces. Because of the difficulty in achieving this between the membrane and the surface to which it is applied a bitumen-coated base felt should be employed. Of equal importance, however, is the manner in which the materials are combined and installed to produce the membrane. Great care must be taken to provide complete films of bitumen, to gain good adhesion of felts with no gaps or wrinkles, and to prevent the inclusion of moisture between plies.

Temperature variations also affect the performance of bituminous membranes. High temperatures accelerate the deterioration of bitumens and are, of course, accompanied by expansion and softening of materials (**CBD 70**). At low temperatures the coefficient of expansion is quite large and the membrane is brittle and not capable of withstanding large strains. The thermal expansion of bituminous membranes is of particular interest because it varies with temperature, the materials used, and the direction of fibre orientation. This variation is illustrated by the values in Table I.

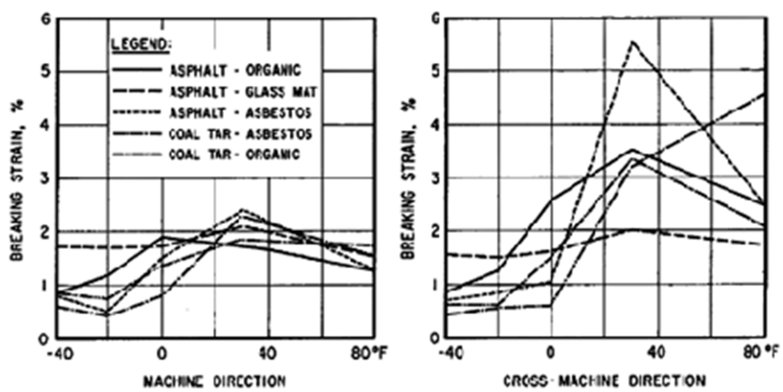
Table I. Thermal Expansion Coefficients for Bituminous Membranes for Temperature Range From -30°F to +30°F

Type of Membrane	Machine Direction	Cross-Machine Direction
Asphalt-organic	11×10^{-6}	21×10^{-6}
Asphalt-asbestos	8×10^{-6}	20×10^{-6}
Asphalt-glass mat	18×10^{-6}	26×10^{-6}

Coal-tar-organic	19×10^{-6}	29×10^{-6}

Splitting occurs in a bituminous membrane when its ability to accommodate strain is exceeded. The stress producing strain may be caused by temperature variations, shrinkage due to aging, moisture changes, and the behaviour of the structure to which it adheres. Adhesion to a rigid substrate can cause the strain to take place uniformly over the membrane, but any differential movement in the substrate at joints or cracks causes great risk of high local strains and splitting.

The ability of a membrane to endure strain without failure varies with the type of materials used and the temperature and rate at which the strain takes place. The graphs of Figure 1, determined at a rate of strain of 1.1 per cent per minute, show breaking strains both parallel and perpendicular to the fibre direction for several membrane systems at different temperatures.



Conclusion

To achieve successful and durable bituminous waterproof membranes the designer must consider the properties and behaviour of both bitumen and reinforcement, the nature and behaviour of the surface to which it is applied, and the conditions of exposure or properties of the environment in which it must serve. The composite membrane has certain desirable properties, but is subject to several mechanisms of deterioration that can be allowed for or guarded against by design. The protection or shading of a membrane from solar radiation (**CBD 65**) has great value in extending its life, as does provision for drainage and the avoidance of trapped moisture. In some cases the occurrence of membrane failure can be prevented by a planned program of periodic maintenance. The manner of installation and quality of workmanship, however, are of fundamental importance to the performance of bituminous membranes.