Summary

The application of the term "engineering properties" to roofing systems is novel, and it was with reservation that the title of this symposium was selected. However, the authors of the papers have clarified the meaning of this title for us; each paper deals with stresses in roofs or with the sources of stress.

A shingle-type roof performs while the units of roofing remain in their intended locations. A membrane-type roof performs while its continuity is maintained and no holes develop. When we consider that a stress is essential to dislodge a shingle or to put a hole in a membrane, the significance of engineering properties is obvious. The roofing system is failing when it can no longer withstand the stresses resulting from its environment.

An important source of stress in roofing systems is the wind. Benjamin and Bono describe two laboratory test methods for evaluating wind resistance. The first of these methods employs a large fan which generates an air velocity of 100 mph and is used to test shingle-type systems. Comparisons are made between free-tab asphalt shingles, which lift at wind velocities of 25 to 35 mph, and self-sealing shingles, most of which withstood 100-mph wind after curing. Data on time-temperature conditions for the curing of self-sealing shingles are presented.

In the second test method, membrane-type roof systems are installed between pressure and vacuum chambers in which steady or pulsating pressures may be applied. This equipment has been used to test insulated metal roof deck systems, where best wind-uplift resistance was obtained by solid mopping with asphalt. Cold adhesive systems were also tested and found adequate. The design and installation of the clips for mechanically holding insulation to the deck may be critical. Roofing applied directly to a concrete deck gives the best wind resistance, while nailing to a wood deck was poorest. The authors recommend design wind velocities of at least 100 mph, with total uplift ratings from 30 psf minimum to as high as 90 psf.

Donegan and Butterfield explore the factors related to nail holding strength and wind uplift. Consideration of nail holding power, nail frequency, and resistance of base felt to tearing at the nail is required. A small-scale test procedure for the measurement of tear resistance at the nailhead is proposed, and results are correlated with tensile strength of the base felt and resistance of the built-up roof to blowoff. Available wind-uplift test methods at three testing agencies are described. Also noted was the lack of an adequate test method to evaluate resistance to peeling action, a common type of wind-stress failure which usually originates at the edges of roof areas.

An important source of stress in roofing systems is the building itself. From a structural engineer's point of view, Gumpertz discusses those features of a building which, principally by differential movement, may overstress roof membranes. Recommendations are made for the use of structural expansion joints to subdivide large areas and for control joints in roof membranes where concentrated deck movement may be expected. Also recommended are flashing designs in which base flashing and membrane are both supported by the same deck system.

A direct investigation of differential movement at a crack in a roof deck was the subject of Koike's presentation. This paper, incidentally, was the only one of this symposium dealing with nonbituminous roofing materials. The supported fluid-applied membranes which he tested were found not to be suitable where crack movement exceeds 0.5 mm. Such a number, of course, provides immediately useful information to the designing engineer or architect. Koike designed and used test equipment in which the crack opened and closed at a preselected distance and time interval, and operated in an environment from −45 to +100 C.

Martin used another approach to study the effects of movement at a crack in a roof deck. Employing the differential thermal-expansion coefficients of aluminum and wood, he set up test equipment in which bituminous built-up roof specimens were exposed outdoors, naturally occurring temperature variations producing the crack movement. He used as his criterion the time required for a membrane to rupture, and reported that the ability of a built-up roof to seal a moving joint without rupturing appears to improve with increased tensile strength of the raw fabric and a decrease in softening point of the asphalt binder.

The practical moving-joint methods of both Koike and Martin deserve the attention of investigators of roofing systems. However, more theoretical aspects of the problem have not been ignored in this symposium. Both the Cullen and Boone and the Jones papers take note of earlier work by Koike, in which the performance of a membrane over a moving joint was related to the tensile properties of the membrane and to the shear properties of the adhesive. Jones reported shear properties of mopping bitumens at low temperatures, and proposed that the mode of failure of an overstressed built-up membrane may be influenced by the thickness of the mopping layer. Tensile failures in the felts are to be expected above a critical thickness; shear failures in the bitumen occur at lesser thicknesses. As stated earlier, Martin also noted the significance of shear properties in his moving-joint test, and he presents data on shear properties of bitumens at moderate temperatures.

Majidzadeh and Herrin present data on tensile properties of asphalts, and how they vary with thickness and temperature. Three modes of failure in asphalt are discussed: ductile, brittle, and a combination of the two, tensile rupture or "cavitation." Two theories for predicting tensile failures are examined. Certainly, the information presented in this paper will ultimately prove valuable to investigators attempting to explain phenomenon observed in tests of roof systems.

Martin includes data on the tensile load-strain properties at 77 F for both raw and saturated felts, including the effects of cyclic load and of variations in strain rate. Jones, Cullen and Boone, and Richards all present tensile properties of bituminous built-up membranes over a range of temperatures. In addition, Richards gives load-strain data on composite constructions involving membranes and insulation, with and without insulation joint-taping materials. He found that the load-strain performance of these composites could be related to the characteristics of the components. Shear properties of the mopping asphalt were found to dominate the behavior of composites at −20 C.

In bituminous membranes, at least, significant stresses can originate within the membrane. Changes both in temperature and moisture content are known to cause stresses. Cullen and Boone present data on load elongation and combine this information with coefficients of thermal expansion published earlier to derive a thermal-shock factor. This factor, based on the well-known engineering principle of stress due to temperature change, will be a guide to evaluating relative resistances to thermal-shock conditions. Both the Cullen and Boone and the Jones papers conclude that on the basis of available information thermal shock alone will not rupture a bituminous membrane, but it must be considered when acting in combination with forces of other origin.

Shuman studied the combined effects of moisture and temperature changes in laboratory experiments. The compression and flexure forces resulting from the effects are recognized, and in some experiments ridging in the built-up roof was produced. The persistence of ridges is related to characteristic changes in length of the materials used, in which interstitial water prevents removal of significant amounts of intracellular water, as is essential for ridges to recede.

Hope for the eventual understanding of complex moisture-thermal action is held out for us by Tator and Alexander. Water-vapor transmission data on membranes and equilibrium-moisture content data on materials are presented, and it is proposed that moisture entry and absorption into membranes is predictable by Fick's law for water-vapor permeability. Using this predictability, a rational analysis of performance under service conditions has been proposed.

We do not claim that this symposium has produced large amounts of new or surprising knowledge, or breakthroughs in experimental technique. This symposium, however, has done something more fundamental.

It has given us a new viewpoint of roofing systems—an engineering viewpoint. In the past, research on roofing systems has depended heavily on chemical and rheological viewpoints. Important as this work has been, its significance has often been difficult if not impossible to communicate with designers and specifiers of roofing systems.

We may not care to admit it, but today's roofing systems are largely the products of intuition, trial and error. This symposium should be an important step in the development of roofing into a modern technology.

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