EVALUATING THERMAL STABILITY OF NONWOVEN POLYESTER

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Nonwoven polyester reinforcement fabrics were subjected to different temperature controlled tests to observe their thermal stability. The nonwoven fabrics considered in this study were spunbond, utilizing either a mechanical (needlepunched) process or non-mechanical means, to maintain nonwoven fabric integrity. Static heat distortion behavior was studied on both needlepunched and non-needlepunched fabrics. The non-needlepunched fabrics were either thermally bonded or used a combination of thermal and chemical means to establish the textile structure of the fabric. Results from the static heat distortion test show that needlepunched polyester fabrics suffer noticeably less distortion when subjected to constant heat. The internal bond strength can be significantly weakened on non-needlepunched fabrics by dynamic temperature cycling. This paper suggests that these two tests should be used as additional tools for evaluating the performance characteristics of nonwoven polyester fabrics for use in roof assemblies.

INTRODUCTION

The use of nonwonven polyester reinforcement fabrics in roofing products has continued to grow. Nonwoven polyester is primarily used in prefabricated modified bitumen sheets; it is also used in hot applied and cold process built-up roofing.

The majority of polyester fabrics in use are spunbond, utilizing a continuous filament process which produces a flexible, nonwoven reinforcement fabric. Typically, the polyester fabrics range from 170 to 250 grams/square meter in weight. Lighter weight fabrics are available and in use. The fabrics provide good tensile, elongation and tear strength to a roof membrane, whether factory or field (BUR) applied. The combined properties of tensile, elongation and tear strength yield a parameter called toughness, making the polyester fabric an ideal reinforcement for incorporation into modified bitumen roll roofing and built-up systems.

One parameter of concern, however, is the thermal stability of the polyester fabric, since polyester is a thermoplastic material. Two temperature related effects are of concern: dimensional stability and temperature durability. Dimensional stability is a critical concern in that the nonwoven polyester fabric must withstand thermal and mechanical stresses during assembly into roll roofing. Temperature durability is normally defined to be the maximum working temperature the nonwoven polyester fabric may tolerate before disintegrating. Of these two parameters, dimensional stability is of most concern since the fabric will be subjected to hot asphalt during impregnation (factory or field) followed by temperature cycling of the roof environment. Additionally, manufactured roll roofing will be subjected to heat due to installation, either by torch welding or hot asphalt.

Two types of tests are used in this paper to evaluate dimensional stability. Their results suggest the incorporation of these test methods in evaluating nonwoven polyester fabrics for use in roof membranes.

- Static Heat Test
- Dynamic Temperature Cycling

These tests allow for the observation of thermal distortion tendency of the fabric on a comparative basis and quantification of cohesive (peel) strength within the nonwoven assembly itself.

BACKGROUND

Since most nonwoven polyester fabrics are made of continuous thermoplastic filaments, the mat may be held together by thermal bonding, resin binders and/or needlepunching. Historically, the roofing industry has used needlepunched fabrics; resin binders were also present. This process yielded a fabric which had excellent dimensional stability under thermal stress.

The advent of copolymers and different binder products has allowed nonwoven mats to be introduced which are not needlepunched. Thus, a measure of concern is proper evaluation of a nonwoven polyester fabric which does not rely on mechanical fixation (needle-punching) to provide dimensional stability and fabric integrity.

THEORETICAL—DYNAMIC TEMPERATURE CYCLING

Pronounced thermal stresses can be generated because of different thermal expansion coefficients of the various materials within a roof membrane. This stress, known as thermoplastic stress, has been shown to be important in other areas, such as advanced structural composites.[1] The motivation of this work is to quantify the importance of thermoplastic stress in roofing materials under service conditions. Peel testing was performed on nonwoven polyester fabrics, both before and after thermal aging and cycling, to determine the effect of thermoplastic stress on roofing materials.

To understand the mechanism of thermoplastic stress, it is important to understand how different thermal expansion can lead to large stresses. While installed to the roof of a building, asphalt saturated and coated roofing membranes are subjected to transient temperature gradients. The bottom surface of the membrane remains at a relatively constant temperature due to the thermal inertia of the structure, while the surface faces the direct weathering elements and temperature cycling. Polymeric materials, such as polyester and asphalt, have very different coefficients of thermal expansion. Because of this, large distortions in dimensions are induced with relatively small changes in temperature. This difference in size between materials linked with a common interface, is a source of thermoplastic stress. In addition, the modulus of a polymer is greatly influenced by temperature. At low temperatures (below the glass transition temperature) polymers become glassy and possess a modulus in the range of 10^8 to 10^9 Newtons/m^2, while at higher temperatures (above the glass transition temperature) they are rubbery and have a modulus in the range of 10^5 to 10^6 Newtons/m^2. At even higher temperatures, polymers melt and have fluid-like properties. It is the combined effects of differing thermal expansion and temperature dependent modulus that leads to the mechanism of the thermoplastic stress.

Based on the previous discussion, the bending beam analysis by Timoshenko[2] can be used to understand the phenomenon of fatigue and delamination of roofing materials. Timoshenko developed an expression, Equation 1, to relate the stress of a linearly elastic bimaterial strip with its radius of curvature. Roofing materials can be modelled as a bimaterial strip. A schematic is shown in Figure 1 which shows the sample both without a temperature gradient and with a temperature gradient.

$$_1 = 1/R\, E_2t_2/6(1 + m)m\, [(1 + 6y/t_1)n\, m^3 + 6y/t_1\, n\, m^2 + 1\}(1)$$

$_1$ = stress in layer 1
y = distance from the center of the layer
t_1 = thickness of layer 1
t_2 = thickness of layer 2
R = radius of curvature
n = ratio of the moduli (E_1/E_2)
m = ratio of the thicknesses(t_1/t_2)

Using the Timoshenko equation, an order of magnitude estimate of the stress present in the polyester sheet can be calculated using values typical for polymers. Calculations of the stress using $t_2 = 0.003$ m, $t_1 = 0.001$ m, $E_2 = 10^9$ N/m^2, $E_1 = 10^6$ N/m^2 and $R = 100$m^3, leads to a value of 10 lbs/in. As will be shown, this value of stress is of the right order of magnitude to cause failure in certain nonwoven membrane materials.

EXPERIMENTAL

Static Heat Test

Samples of various weights of nonwoven polyester mat were subjected to a constant heat while fixed in a steel frame. The individual samples were 12″ X 12″ (304.8mm X 304.8mm); the frame was held 0.5″ (12.7mm) above a large hot plate. The reaction to the heat source was immediate (less than 20 seconds). The results are shown in Figure 2 along with the various mat weights. It is interesting to note that only Sample D is a needlepunched mat. All others either depend on thermal bonding and/or resin binders to hold the mat together.

The results of the test show that needle-punching imparts an internal mechanical bond to the mat which controls heat distortion (Sample D). Samples A and B are similar in weight, but have different bonding mechanisms within the mat; they do behave comparatively well, but distort more than Sample D. Sample C was found to have a machine direction effect built into it. Several samples of each were run (machine and cross machine); only Sample C showed a longitudinal stress built in.

Dynamic Temperature Cycling

Samples of spunbonded nonwoven polyester fabrics which were not needlepunced were adhered with hot (steep) asphalt on three different surfaces; aluminum, plywood and an insulating material. In addition to the mounted pieces, samples were left free standing as controls. All of the samples were first subjected to the following thermal history; 300 cycles of surface temperature change between 80°F (26.7°C) and 180°F (82.2°C). The temperature of the attached (bottom) surfaces were maintained at 70°F (21.1°C) by a heat exchanger. After completion of this temperature cycling, representive samples were removed from each surface for peel testing. Then the remaining samples were additionally subjected to 20 cycles of surface temperature change between 140°F (60°C) and 35°F (1.7°C). These samples were then removed from their mounting and prepared for peel testing. The first temperature cycle is referred to as heat cycled, while the additional cycling tests were referred to as cold cycled.

Peel testing was performed on an MTS materials testing machine to determine if the thermal history had an effect on the initial bond strength of the polyester reinforcement. To examine these effects, it was first necessary to remove the asphalt from the polyester membranes. This was accomplished by placing the samples in a mechanically agitated bath of toluene for several hours at room temperature. The asphalt saturated toluene was removed and replaced with fresh toluene as needed. After sitting overnight, the samples were removed and toluene was poured over them to remove any residual asphalt. The desaturated polyester sheets were then left in a fume hood to dry.

180° Peel Tests

Samples of the desaturated polyester were prepared for peel testing; three strip samples, 1 in. X 5 in. (25.4mm X 127mm), were made from each specimen.

The MTS Systems materials testing machine was used to conduct the peel test. It is equipped with a 1,000 lb. (453.6 kg) load cell. To obtain the highest sensitivity, the load range was set to 10 percent or 100 lbs. (45.4 kg) (full output of -10 V to ^{3}10 V). Data was taken using an IBM PC with a Metrabyte DAS-16 A/D conversion and control board. The board was configured to give a full voltage reading at 5 volts, thus allowing the system to accurately measure forces as low as 0.5 lbs. (0.2 kg). The MTS was set in stroke control to pull the sample at a constant rate of one inch (25.4mm) per 100 seconds (0.6 inches per minute). One inch (25.4mm) jaws were used to grip the sample being tested. Three replicates of each sample were tested to maximize reproducibility. Data was taken at a rate of 10 points per second for 300 seconds in each run.

The results of the experiments are shown in Table 1; all peel tests were run at room temperature. As can be easily seen, subjecting the sample to repeated cycling at high temperatures had little or no effect on the average peel strength of the polyester sheet. Cycling to low temperatures, however, had a profound effect on the strength of the material, even after only 20 cycles. Based on the different results for the different mounting materials, it is clear that transient temperature gradients within the sample during thermal aging are the major cause of failure due to thermoplastic stress. The free standing sample had little or no reduction in peel strength since the temperature rises and falls symmetrically across the thickness direction of the sample during cycling. The other samples had a significant loss in peel strength (approximately 50 percent), in order of how quickly the temperature would become uniform across the sample. The aluminum mounted sample, which would be the first to equilibrate, had the smallest loss in strength. The wood mounted sample, which had a lower equilibration time, decreased in strength by 50 percent. Note that the reason only cold cycling promotes delaminations is the greatly enhanced modulus of asphalt at low temperatures. This is further evidence of the potency of thermoplastic stress in causing delamination.

Based on the bimaterial strip model, using the Timoshenko equation, it was estimated that approximately 10 lbs/in of stress would be present in the polyester mat. Comparison of these values with the peel test results shown in Table 1 (of the force necessary to delaminate a virgin sample) illustrate thermoelastic stress is indeed a source of failure in some polyester mats.

CONCLUSIONS

Nonwoven polyester mats used for roofing reinforced do need a thermally stable internal bonding mechanism. Needle-punching accomplishes this mechanically. The static heat test has shown that manufacturing effects may be found and comparative thermal distortion behavior observed.

Thermoelastic stress has been shown to be an important factor in failure of roofing materials subjected to low temperature gradients. Using the Timoshenko equation, the stresses induced in the aging was calculated to be of the same order of magnitude as that necessary to peel apart certain nonwoven substrate materials. Hence, this problem deserves industry awareness and further research.

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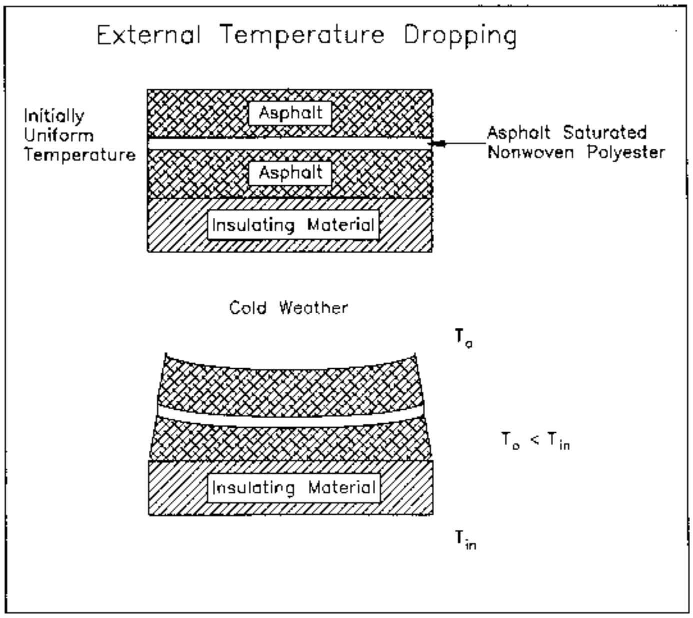

Figure 1 *Schematic illustrating one cycle of the repeated flexing experienced by a roofing sheet due to dynamic temperature cycling. The membrane is adhered to an insulating underlayer with the external temperature dropping (T_O). The top-most layer shrinks against the polyester, inducing a complex stress field with the net effect of promoting cohesive delamination of the polyester mat. When the external temperature increases, the reverse dimensional distortion occurs.*

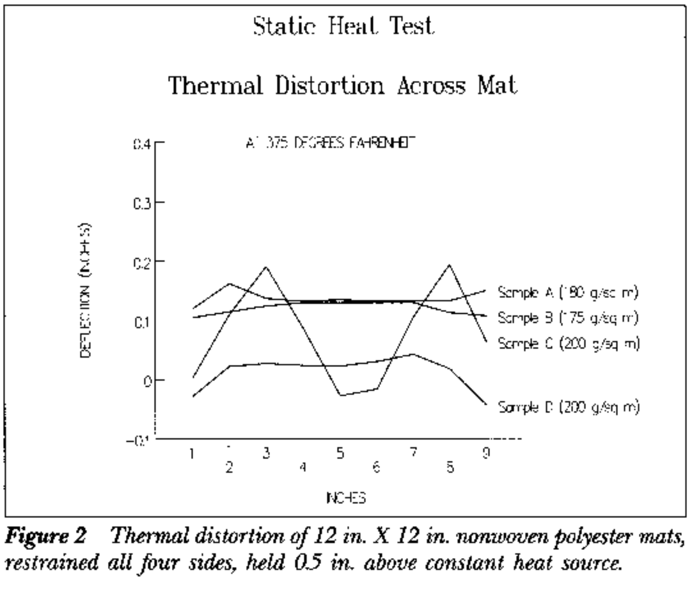

Figure 2 *Thermal distortion of 12 in. X 12 in. nonwoven polyester mats, restrained all four sides, held 0.5 in. above constant heat source.*

Sample	Average Peel Strength (Lbs/In)
Control Sample	6·7
Heat Cycled (Aluminum Mounted)	7.0
Heat Cycled (Free Standing)	5.7
Cold Cycled (Free Standing)	7.3
Cold Cycled (Aluminum Mounted)	5.2
Cold Cycled (Insulator Mounted)	3.6
Cold Cycled (Wood Mounted)	3.0

Table 1