TEMPERATURE-DEPENDENT WATER VAPOR DIFFUSION THROUGH SHAPE-MEMORY POLYMER LAMINATES: PERFORMANCE COMPARISON WITH OTHER WATERPROOF-BREATHABLE LAMINATES

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ABSTRACT

Shape Memory Polymers, which are presently under evaluation for military protective clothing applications, are claimed to show temperature-dependent permeability. Comparison testing with a wide variety of commercially available water-vapor-permeable laminates show that these claims are false.

INTRODUCTION

The U.S. Army evaluates waterproof-breathable membrane laminates for various environmental protection applications. The standard rainwear material used by the military consists of a three-layer Gore-Tex membrane laminate. The U.S. Army has recently been evaluating the performance of a class of materials known as “Shape Memory Polymers” (SMP). SMPs are polyurethane films that have a glass transition temperature (T_g) tailored to be in a specific range of environmental and body temperatures. The resulting laminated fabric is waterproof, windproof, and allows the passage of water vapor. It is claimed that SMPs undergo a transition near the T_g, which results in an increase in water vapor permeability of the polyurethane membrane due to enhanced micro-Brownian motion (Hayashi et al., 1993; Jeong et al., 2000). SMP materials evaluated in this study include Diaplex polyurethane membranes from Mitsubishi Heavy Industries, and Dermizax polyurethanes from Toray Industries. Dermizax also comprises the membrane incorporated into the commercial laminate trade-named “Membrain” from Marmot Mountain, Inc.

RESULTS

Figure 1 shows the baseline water vapor diffusion resistance for a variety of commercial breathable shell fabrics and laminates. Materials that have lower resistance are more “breathable.” The particular test method used allows one to separate concentration-dependent permeability from temperature-dependent permeability (Gibson, 2000).

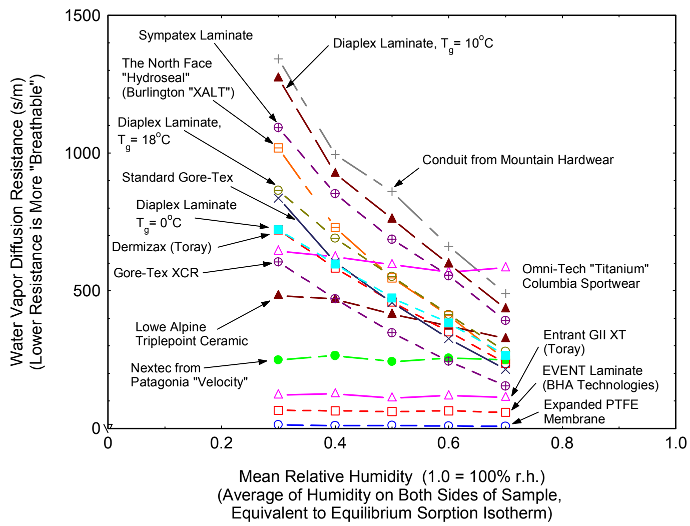

Fig 1. Water vapor diffusion resistance of SMP membrane laminates and comparable materials at 30°C.

Figure 2 shows water vapor flux as a function of temperature for a subset of the materials shown in Figure 1. Over the temperature range of 5°C to 40°C, the expanded polytetrafluoroethylene membrane (ePTFE) is the most breathable, followed by the EVENT laminate (an ePTFE laminate), and then Gore-Tex XCR. Many of the materials are fairly equivalent -- this includes Standard Gore-Tex, the Diaplex laminates, Dermizax, etc. The materials which were less breathable were the Sympatex laminate, and the SMP Diaplex laminate with a T_g of 10 °C. The results are plotted on a log plot to help show the transitions in permeability that are claimed to occur with SMP membrane laminates. If there were a transition in water vapor permeability at some temperature, it would show up best in a plot such as Figure 2. None of the materials tested showed any indication of being more or less permeable at various temperatures. The water vapor flux simply increases proportionally to the vapor pressure of water as the temperature goes up. The slope shown for all the materials is only due to the variation of water vapor pressure with temperature, and not to any special variation in the permeability of the membranes or laminates.

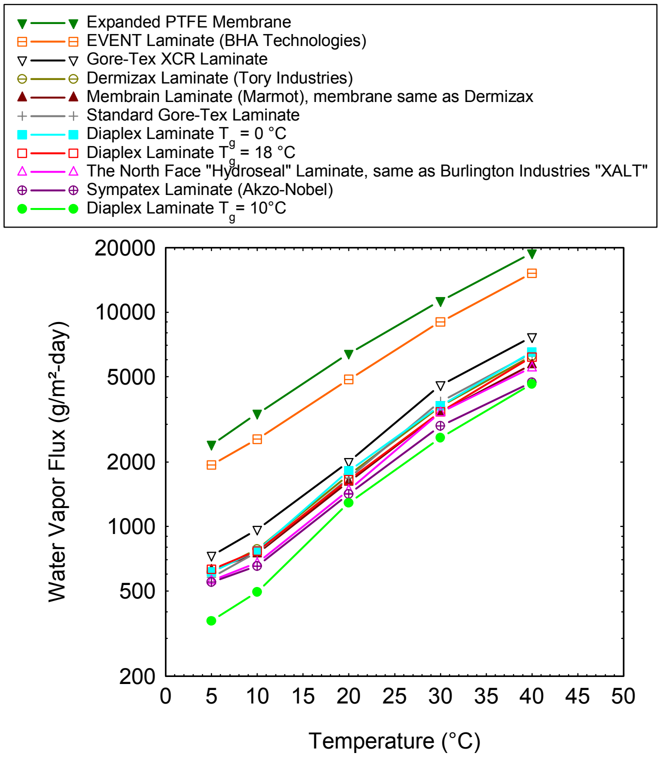

Fig. 2. Water vapor flux as a function of temperature for Shape Memory Polymer laminates as compared to various commercial waterproof breathable membranes and laminates.

A possible explanation for misinterpretation of temperature-dependent permeability for SMP laminates is evident in the experimental procedures cited in claims of temperature-dependent permeability (Hayashi et al., 1993; Jeong et al., 2000). Flaws in test methodology, combined with a failure to test standard or control materials alongside the SMPs have apparently resulted in mistaking the vapor-pressure temperature curve present in the experimental results for actual changes in polymer permeability at different temperatures. An example of the type of plot which is often mistaken for temperature-dependent permeability is shown in Figure 3, which is simply a few of the materials shown in Figure 2 replotted without the log scale on the y-axis. The shape of these curves follows exactly the saturated vapor pressure - temperature relation for water.

CONCLUSIONS

Temperature effects are much less important than concentration-dependent effects in the hydrophilic polymer membrane laminates, most of which are based on water vapor permeable polyurethanes. Observed changes in water vapor flux at different temperatures are primarily due to the relationship between temperature and the saturation vapor pressure of water, and not to intrinsic changes in polymer permeability. Shape Memory Polymer films show no special increase in permeability as compared to other waterproof breathable materials. The SMP laminates are comparable to standard Gore-Tex, so they are fairly functional in terms of being "breathable", but they don't have any unique behavior with regard to permeability at different temperatures.

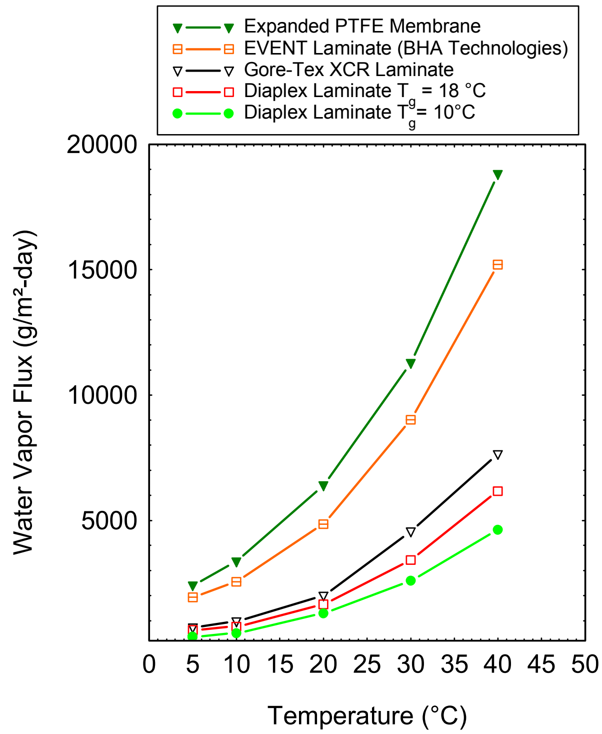

Fig. 3. Possible explanation for misinterpretation of experimental temperature-dependent water vapor permeability common in the literature.

REFERENCES

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