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Improved Stored Thermal Energy Burn Prediction for Enhanced Turnout Composites Incorporating Highly Breathable Moisture Barriers

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What Are Stored Energy Burns?

Firefighters can incur burns when exposed to thermal energy under a wide range of fireground conditions. Some of these burns occur during sub-flashover conditions without significant visual degradation to the turnout composite.

In sub-flashover fireground environments, thermal energy transferred to the firefighter will cause the skin temperature to increase, and if the combination of skin temperature and exposure time is sufficient, a thermal burn will result. Wet turnout gear from moisture sources, such as nozzle spray and/or sweat, can further increase the risk of sustaining a thermal injury. Compression of the turnout composite can contribute to a rapid discharge of the stored thermal energy, thus rapidly increasing skin temperature and shortening the time to thermal burn.

Firefighters have called these burns stored energy burns, compression burns, and scald burns . As well, experience and historical information suggests that these burns are often associated with non-porous materials attached to the outer shell, such as reinforcements and reflective trim.

Addressing the Issue

For years, firefighters and the NFPA 1971 Committee expressed concerns regarding sub-flashover burns. W. L. Gore & Associates, Inc. decided to investigate ways of improving stored thermal energy (STE) test performance, and to contribute to the NFPA 1971 Technical Committee proposal for a new STE test performance criterion.

A challenging observation was reported from an earlier investigation:

- The Fire Protection Research Foundation[1] (FPRF) issued a report in late 2008 that identified key factors associated with stored energy burns. The report's key finding stated that, under moist conditions: "in systems incorporating vapor permeable moisture barriers, the presence of non-porous reflective trim or non-porous reinforcing generally degrades STE performance." The report also stated: "in areas with these non-porous attachments, increased moisture barrier vapor transmission rate (MVTR) decreased STE performance." Notably, however, in areas without non-porous attachments, increased MVTR did not degrade STE performance. The FPRF also found that thermal liner weight or thickness and the outer shell color or construction had a much lesser effect. Additionally, porous materials, such as leather knee reinforcements or an additional outer shell layer, such as a pocket, did not degrade STE performance. Interestingly, under non-porous trim, non-compliant, non-breathable neoprene moisture barriers produced favorable STE results.

Additionally:

- NIOSH / NPPTL funded North Carolina State University (NCSU) to develop new instrumentation and test procedures that simulated the conditions and observations seen in stored energy burns.

  The new STE instrumentation exposes a turnout composite specimen to sub-flashover radiant heat followed by compression. These test conditions produce extended, relatively low, and variable thermal flux through the test specimen. Thus, the STE apparatus incorporates an enhanced sensor, capable of measuring low, variable flux, while a complex mathematical model continuously calculates predicted skin temperatures and time to thermal burn.

- In early 2010, ASTM issued a new stored energy test method — ASTM F2731. The method establishes consistent practices between labs and allows interested parties to further investigate and address STE issues.

[1] "Thermal Capacity of Fire Fighter Protective Clothing," The Fire Protection Research Foundation, Quincy, MA, 2008.

The ASTM F2731 method sets the radiant heat exposure at 0.2 cal/cm² sec. which is within the "ordinary" range of firefighter hazards as defined by Utech[2]. Test specimens are exposed for a user-specified time, followed by compression. A preconditioning step is available to add a reproducible amount of moisture to the specimen. The method establishes parameters for the mathematical model and if certain burn criteria are met, reports times to 2nd and 3rd degree burn.

NFPA 1971 Stored Energy Proposal for Turnouts

In June 2010, the NFPA 1971 Technical Committee proposed a new stored energy performance criterion for turnouts. The Committee's proposal - based on the collaboration of the test laboratories participating in the investigations, including Gore - stated that all turnout composites with any attachment to the outer layer must meet a minimum time of 130 seconds to 2nd degree burn. The performance criterion is limited to the turnout ensemble sleeve where the committee believes the majority of the stored energy burn issues reside.

Gore's Investigations

Gore purchased the first commercially produced STE apparatus capable of performing the ASTM F2731 test, and in late 2009, initiated a series of STE investigations. Gore's goal was to determine if any practical turnout enhancements existed that would improve STE results for composites with dense, non-porous outer shell attachments (i.e., trim) that also contained high MVTR (i.e. highly breathable) moisture barriers. For purposes of improved heat stress reduction, the fire service industry had transitioned over the past decade to mostly high THL composites, or composites with high MVTR moisture barriers. Since moist turnout composites with trim were identified as the major condition leading to degraded STE performance, the success of Gore's study depended on the ability to obtain equivalent or better STE results for enhanced composites with a high MVTR moisture barrier and trim, when compared to the base composite without trim.

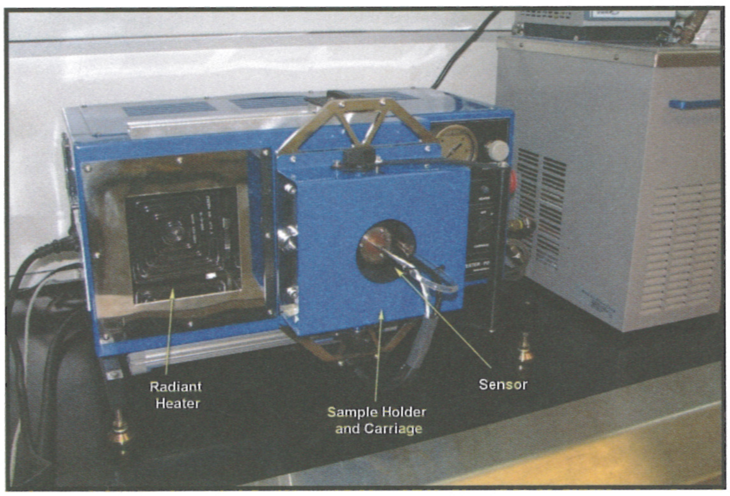

Figure 1. Gore's STE apparatus showing machine components.

Gore investigated multiple commercially available base composites with and without trim, as well as a series of enhancements to the composites with trim. Thoroughness dictated choosing composites that represented a broad range of material components commonly used in current firefighter turnouts. Garment manufacturers present at the NFPA committee meetings contributed to identifying the composites that would be most useful to examine in this study. All test composites in the study were third party certified to the performance criteria of NFPA 1971, 2007 edition. Recognizing that both Thermal Protective Performance (TPP) and Total Heat Loss (THL) are significant factors when choosing turnout ensembles, the test composites were selected to represent a wide range of these values. Thus, it was possible to capture and report significant trends across a wide material spectrum.

The investigation incorporated:

- 7 base composites, that:
  - had a TPP range of 36-51
  - had a THL range of 224-315
  - included either CROSSTECH® moisture barrier, CROSSTECH® 3-layer moisture barrier, or GORE® RT7100 moisture barrier
  - used single and/or multiple layer thermal liners, needle punch or E-89
  - had 7.5 oz/yd² outer shells composed of 100% meta-aramid, para-aramid, basofil, PBI, and PBO or blends thereof
  - had reflective trim attached

[2] H. P. Utech, "High Temperatures vs. Fire Equipment," International Fire Chief, Vol. 39, 1973, pp. 26-27.

- 5 "Enhanced" versions of each base composite with trim, which encompassed three "enhancement" types.
- Tests were performed per ASTM F2731, with 120 second exposure and 60 second compression. All specimens were "wet" preconditioned.

Enhancements:

The "enhancements" were composed of three types as described below (also see Figure 2):

Type 1. <u>An additional insulation layer, the width of, and aligned under the trim.</u> The study examined three insulation layer locations within the composite: Under trim, under outer shell and under moisture barrier.

Note: The FPRF report stated that thicker thermal liners, although a lesser contributor, did improve STE results. Therefore, a thicker, overall insulation component would be expected to further improve the test results.

Type 2. <u>A non-porous, impermeable layer, under the moisture barrier, the width of, and aligned under the trim.</u>

Note: The FPRF report stated that trim-attached composites with non-breathable moisture barriers (i.e. neoprene) performed well in stored energy testing. The non-porous layer attempts to simulate this type of composite, under trim only.

Type 3. <u>Porous reflective trim.</u>

Note: The FPRF report indicated that porous attachments did not degrade STE results. Thus, STE results were predicted to increase with the use of porous trim.

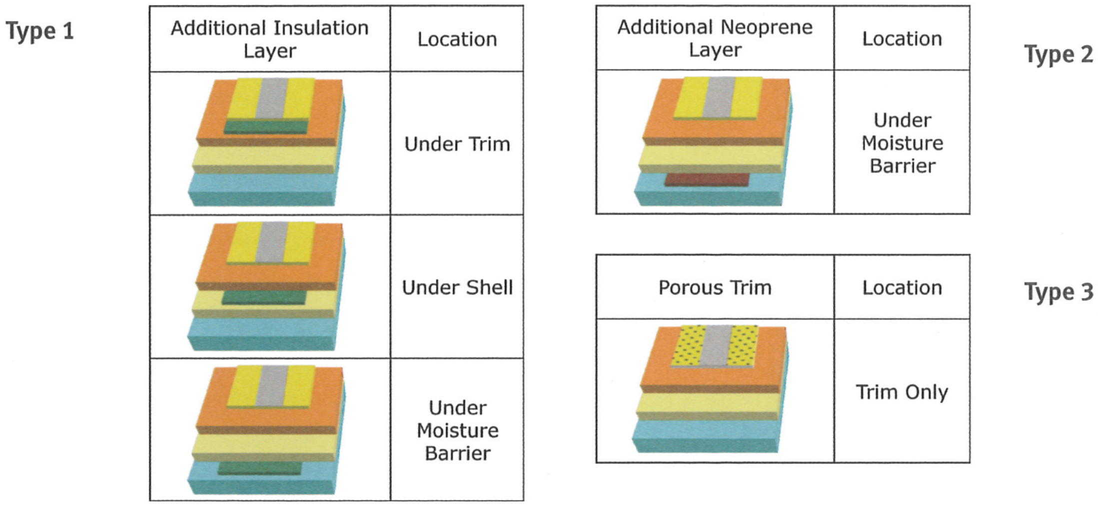

Figure 2. Illustration of the five "enhanced" composite configurations.

Results

The data, shown in Figure 3, show the overall range of results for each configuration across all seven composites. It should be noted that 180 seconds represents the end of the test. If no burn was reported in the test, then a value of 180 seconds was assigned to the test result.

As predicted by the FPRF report, the non-porous trim configuration had significantly poorer results compared to the no-trim base composite configuration.

The results also indicate that each "enhanced" configuration improved the wet STE results of composites with trim to various degrees.

Results for the Type 1 enhancement (additional insulation layer) "under trim" or "under moisture barrier" configuration indicate that these enhancements would meet the NPFA proposed criterion. However, for the "under moisture barrier" configuration, the lower end of the range is below 130 seconds, suggesting that not all composites using this enhancement configuration would meet the NFPA proposed criterion.

Both Type 2 and Type 3 enhancements (non-porous layer under the moisture barrier, or, the use of porous trim) gave the overall best results. The average values, as well as the lower end of the range, were significantly above that of the base composite and easily met the proposed NFPA criterion. This much-improved performance suggests a higher probability that other composites outside this study would also meet the NFPA criterion.

Porous trim attached to the outer shell may be the best overall option for moist composites. It enables good STE performance with composites that have high MVTR moisture barriers. It also involves minimal additional material or manufacturing effort to align and secure additional layers under the outer shell attachments.

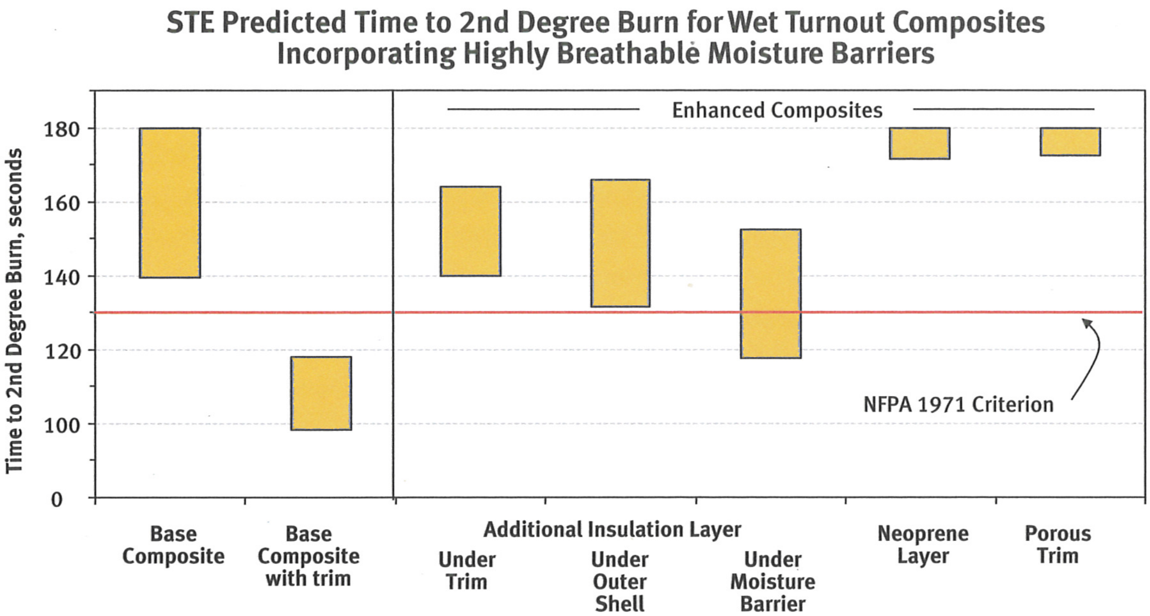

Figure 3. ASTM F2731 test results for the turnout composite configurations. Each block represents the result range for each configuration. A method of obtaining equivalent or better STE test performance between the base composite and composites with outer shell attachments (such as trim) was critical to meeting the proposed NPFA stored energy criterion.

Conclusion

The Gore study demonstrated that there are practical enhancements that could be made to standard turnout composites that have trim and high breathability moisture barriers, such that they would meet the proposed NFPA 1971 stored energy criterion for turn-out composites. The testing indicated that the burn prediction results for some of the composite enhancements employed in the study are on par with, or better than, the burn prediction results for the base composite by itself.

The proposed stored energy criterion is part of a long investigative process aimed at improving firefighter PPE. Thermal exposure and burn injuries represent a constant risk to firefighters. While a single test does not represent all fireground conditions, these results indicate that there are multiple options available to manufactures that can improve the stored energy test results of composites with highly breathable moisture barriers and outer shell attachments.

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