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Putting PPE Solutions to the Test— Onsite Pour Testing for PPE Evaluation

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Introduction

Personnel working in mills, foundries, chemical processing plants and a wide variety of industrial settings are routinely exposed to splash hazards as they handle molten metals, petrochemicals and other hot or flammable liquids. Such personnel are generally required to wear outer garments that are manufactured using thermal textile solutions to guard against these frequently occurring hazards. Thermal textile solutions are usually layered combinations of fabrics with varying properties, and the complete outer garment or thermal protective system falls into the broader category of personal protective equipment (PPE).

Design of effective PPE requires careful consideration and balance of many factors. Economic considerations of cost and durability are important in all industries. Technical considerations of the ability of a fabric to resist flames, to block heat transfer, and to shed a specific hazard vary from one facility to another. In addition, the level of comfort provided by a PPE solution must be carefully evaluated.

A review of incident reports [1, 2] indicates that injuries were avoided or minimized when individuals wore prescribed PPE. However, reports of incidents in which serious injuries and fatalities occurred frequently mention that the prescribed PPE was not worn or not properly worn. A newspaper article [3] described an accident at a steel mill that resulted in a fatality. This report claimed that the fatality could have been avoided had appropriate PPE been used and gave the following quote from an experienced workplace safety consultant:

> "[B]ecause it's hot and because it's cumbersome to wear that clothing around molten metal, people have resisted it. They don't want to wear it."

The article explained that instead of an appropriate "silver suit," the victim wore flame-resistant cotton clothing, commonly referred to as "greens," at the time of the accident. In all likelihood, the victim probably felt that wearing the more comfortable greens provided adequate protection. However, the reality is that greens provide minimal protection against the hazards faced in this particular facility. In the words of the safety consultant, greens "burn like paper" when they come into contact with molten metals.

Clearly, corporate executives and union representatives are charged with a daunting task when they are asked to select appropriate PPE to safeguard against the specific hazards workers encounter in their facilities. The simplest, low-cost approach to selecting PPE is to choose products designed to protect against generic threats. In general, PPE designed to protect against a generic hazard is over-designed, and over-designed PPE is less flexible and less comfortable to wear. When issued PPE that is uncomfortable and restricts movement, personnel frequently fail to comply with regulations regarding the use of the PPE, and failure to use or improper use of PPE is frequently cited as a cause of injury in incident reports. Therefore, providing decision-makers with the information and tools needed to verify the ability of PPE to guard against the specific hazards routinely encountered in their facilities will lead to more informed choices of PPE that will receive higher levels of compliant use, which will lead to improved workplace safety.

To address these concerns, Chapman Innovations, the company that manufactures the CarbonX® brand of flame-resistant fabrics and apparel, has produced a testing platform that allows for mobile pour testing and onsite evaluation of existing and potential PPE solutions. Onsite evaluation of PPE options allows safety managers and line workers to participate in and observe testing and provides real-time test data relevant to the actual hazards faced by personnel at the facility. Onsite testing and evaluation instills confidence in all stakeholders regarding the effectiveness of PPE.

Evaluation of PPE for Splash Hazards–Pour Testing and the Stoll Curve Comparison Test

As a globally recognized leader in the development and promulgation of voluntary consensus standards, ASTM International has established two relevant procedures for assessing the ability of PPE to protect against splash hazards. ASTM F955–07 [4] is used to assess a fabric's ability to protect against molten metal splashes, and ASTM F2701–08 [5] is used to assess a fabric's ability to protect against hot liquid splashes. The methodology for both of these standards centers on pour testing and the Stoll curve comparison test. An outline of the general procedure for a pour test and the Stoll curve comparison test is:

1. A fabric swatch is spread over a low thermal conductivity board. The board is equipped with slug calorimeters. A slug calorimeter is simply a copper disk with a thermocouple welded to its center point.
2. A splash hazard is simulated by pouring a hot liquid or molten metal onto the fabric swatch, and time-dependent temperature profiles of the slug calorimeters are recorded using a data collection system.
3. A thermodynamic model based on the known dimensions and thermophysical properties of the slug calorimeters is used to calculate the amount of thermal energy that flows through the fabric into the calorimeters as a function of time.
4. The amount of thermal energy transferred to the slug calorimeter per unit across a sectional area of the calorimeter is then plotted as a function of time and compared with the Stoll curve.

The Stoll curve [6] is an empirical model that is widely used to determine whether an individual will incur a second-degree skin burn. A fabric is given a pass/fail rating based on whether the amount of thermal energy per unit area (J/cm^2) exceeds the Stoll curve at any point in time. Example results obtained in a pour test and the subsequent Stoll curve comparison test are presented in Figure 1.

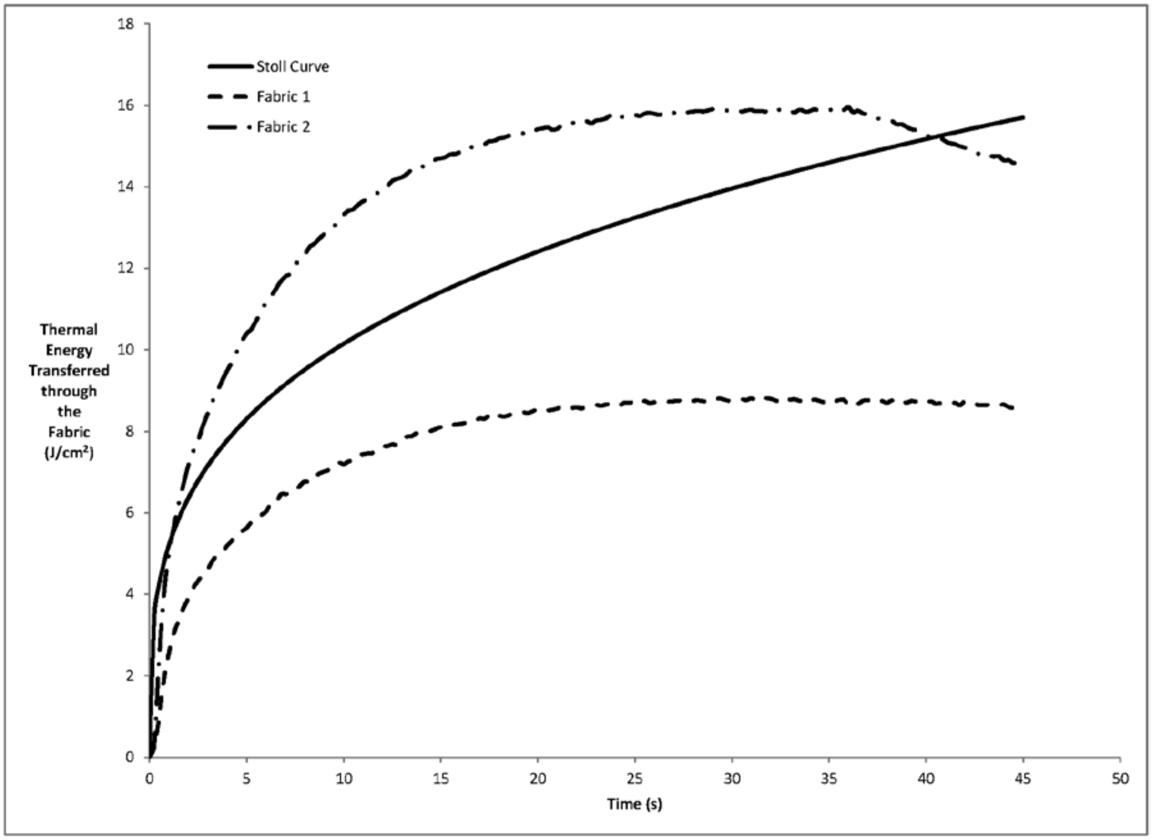

Figure 1. This figure shows examples of data obtained during pour testing and used to conduct a Stoll curve comparison test.

The data presented in Figure 1 indicates that personnel wearing PPE constructed using Fabric 1 would avoid receiving a second-degree skin burn when exposed to this particular splash hazard, while personnel wearing PPE constructed using Fabric 2 would incur a second-degree burn if exposed to this particular splash hazard. Therefore, Fabric 2 would fail the Stoll curve comparison test, and Fabric 1 would pass the Stoll curve comparison test.

Mobile Platform for Onsite Testing of PPE Designed for Splash Hazards

Chapman Innovations' mobile testing platform has been designed to provide decision-makers with the information and tools needed to verify the ability of PPE to guard against the specific splash hazards routinely encountered in their facilities. This first-of-its-kind testing platform was developed in collaboration with the Department of Mechanical Engineering at Brigham Young University.

Although not intended to replace standardized laboratory testing and certification processes, the mobile testing platform has all the capabilities needed to conduct pour tests as specified in ASTM F955–07 [4] and ASTM F2701–08 [5]. The slug calorimeters embedded in the ceramic plate are constructed according to the specifications of these standards. Any fabric combination may be placed on the ceramic plate. As required by the ASTM standards, the slope of the testing platform's ceramic plate can be adjusted in order to evaluate how effectively the fabric sheds the particular molten metal or hot liquid. As may be seen from examination of the Stoll curve, the more quickly a fabric sheds a splash hazard, the less likely it is that a serious burn will occur.

The time-dependent temperature profiles of the slug calorimeters are recorded using a specially designed data acquisition system. The data acquisition system transmits the data to a laptop computer, where standard spreadsheet software or data analysis software is used to rapidly conduct Stoll curve comparison tests. The system may operate using batteries in situations where electrical power is not easily accessed. Also, in particularly hazardous locations, the data acquisition system has the capability of transmitting the data wirelessly, so personnel may view and evaluate the data at any safe distance from the mobile testing platform.

Chapman Innovations' mobile testing platform for onsite evaluation of PPE based on pour testing and the Stoll curve comparison test is shown schematically in Figure 2, and several photographs of the testing platform are presented in Figure 3.

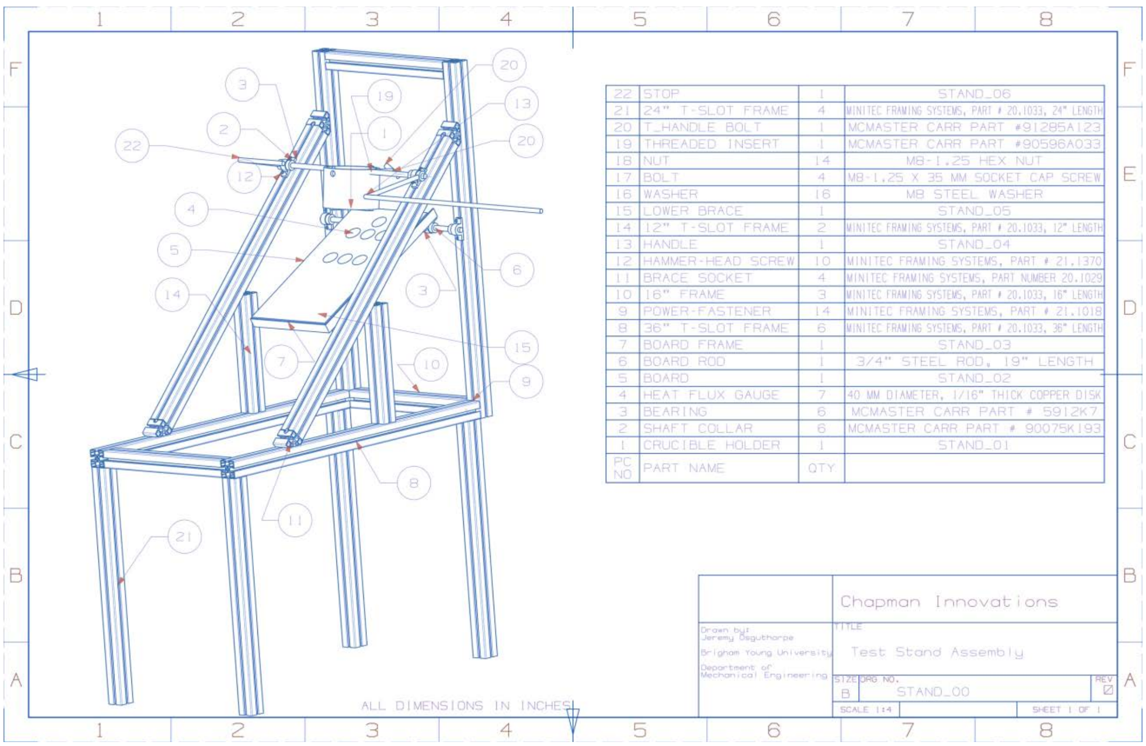

Figure 2. This figure is a detailed schematic of Chapman Innovations' testing platform.

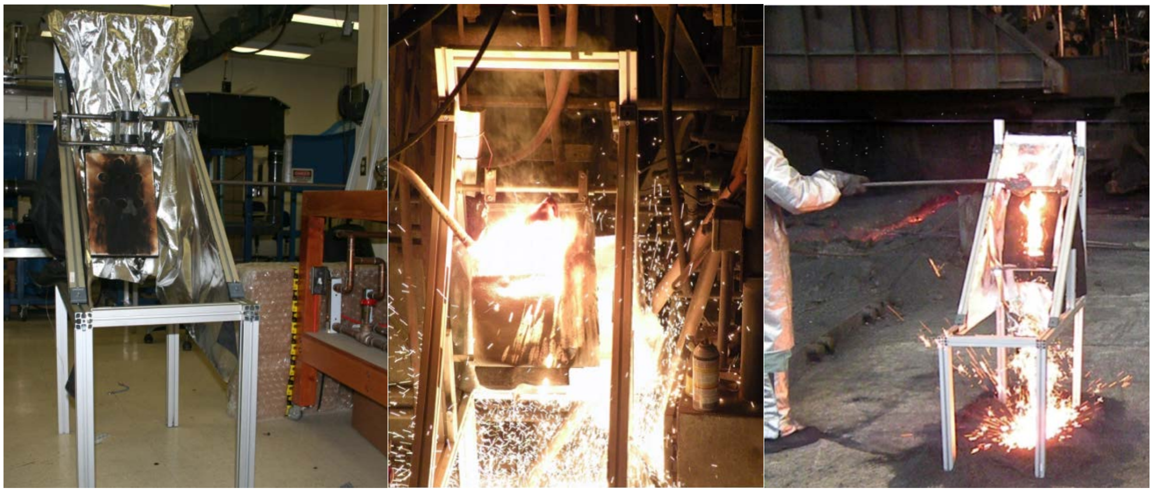

Figure 3. These photographs illustrate the use of Chapman Innovations' mobile pour testing platform.

Chapman Innovations' mobile pour testing platform provides decision-makers the opportunity to evaluate PPE onsite, and the advantages of onsite evaluation of PPE are significant. Decision-makers must carefully weigh several factors, including a product's ability to shed splash hazards, its flame and extreme heat resistance, and the level of comfort it provides, in addition to economic considerations like cost and durability.

The decision to purchase a particular PPE product is frequently based on limited and sometimes peripheral information. Information is frequently limited because product specifications provided by the fabric and/or apparel manufacturer is couched in self-serving sales pitches, and the costs (both in time and in money) associated with sending fabric or apparel samples to certified laboratories to confirm a manufacturer's claims is generally prohibitive. Even if samples can be sent out for independent testing, the information is sometimes peripheral due to the fact that it is very unlikely that the certified laboratory will be able to perform tests under scenarios that accurately reflect the hazards to which workers are routinely exposed.

The testing platform's flexibility and portability allow for testing of any molten substance or hot liquid in any amount in as realistic an environment as possible. Onsite evaluation of PPE allows decision-makers to extract the specific hot liquid—molten metal, petrochemical, etc.—from the process that generates the splash hazard and to conduct pour tests and Stoll curve comparison tests under environs that represent the actual conditions encountered in the facility where the PPE will be used.

In its first few months of service, the testing platform has been used to provide real-time test data against a variety of hazards, including phosphorous, steel, iron, zinc, aluminum and grease. One company used the testing platform to evaluate how well its PPE solutions protected against contact with phosphorous, a highly flammable chemical that self-ignites upon contact with air. The testing platform and conditions were specially arranged to test various products' resistance to this volatile element. In another demonstration, a company used the testing platform in its evaluation of molten iron. The safety director was able to then use the pour test results and in-person demonstration to convince line employees as well as senior management to update the company's PPE solution.

Future Development of PPE Designed to Protect Against Specific Splash Hazards

Extensive analytical modeling and experimental work has been done in predicting the ability of PPE to safeguard against large-scale, uniform exposures in which the PPE is exposed to a spatially uniform hazard [7, 8, 9]. An example of this type of hazard is the intense radiative heat flux faced by fire fighters or by operators working near a blast furnace. Protecting against this type of hazard requires that the thermal protective solution be designed to minimize the heat transferred through the PPE. When subjected to a spatially distributed, relatively uniform heat flux, the cross-plane heat transfer is reduced by simply minimizing the material's cross-plane thermal conductivity, and consideration of the in-plane thermal conductivity is irrelevant. Simple, isotropic fabrics that have the same thermal conductivity in all directions are usually the least expensive and simplest way to protect against exposures to these hazards.

When personnel are routinely exposed to splash hazards, the threat is different. A splash hazard will generally lead to a localized exposure in which the thermal energy is concentrated at a particular point on the PPE. Although minimizing the cross-plane thermal conductivity and thereby reducing the amount of heat transferred through the PPE remains a high priority, designing PPE that can eliminate the threat by rapidly shedding the spilled material or by rapidly transferring the heat away from the point of contact by in-plane conduction are alternative ways of reducing the possibility that a splash hazard will result in injury.

A fabric's ability to rapidly shed spills is reflected in pour testing and Stoll curve comparison tests. However, these widely used assessments of PPE effectiveness do not quantify a fabric's ability to transfer heat away from a localized spill in the plane of the fabric. Recent analytical studies [10] in which a splash hazard is modeled as a point source have shown the importance of considering the ratio of a material's cross-plane thermal conductivity to its in-plane thermal conductivity when designing PPE to guard against splash hazards. Figure 4 shows the results of a simulated Stoll curve comparison test in which the in-plane thermal conductivity, k_{i-p}, of a fabric is increased relative to its cross-plane thermal conductivity, k_{c-p}. PPE constructed using an isotropic fabric ($k_{i-p}/ k_{c-p}= 1$) fails the Stoll curve comparison test, while PPE constructed using an orthotropic fabric ($k_{i-p}/ k_{c-p}\neq 1$) passes the Stoll curve comparison test.

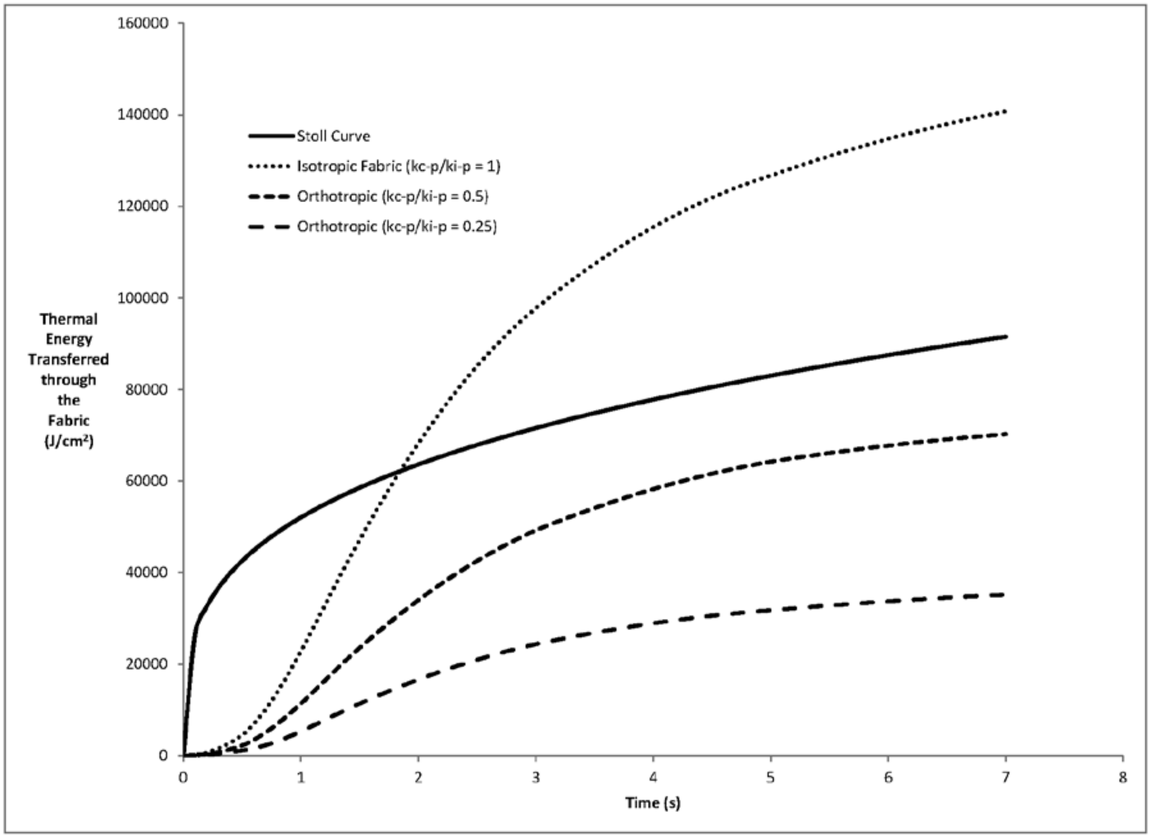

Figure 4. This figure shows the results from a simulated Stoll curve comparison test that indicate PPE constructed using an orthotropic fabric will pass the test while PPE constructed using isotropic fabric will fail the test.

Presently, research and development is underway in an effort to extend the capabilities of the portable testing platform to allow the measurement of in-plane heat transfer in addition to cross-plane heat transfer. The proposed extended functionality will allow thorough and rigorous testing of PPE based on orthotropic materials—materials whose cross-plane and in-plane thermal conductivities differ. The ability to determine the optimal thermal conductivity ratio will result in PPE that is tailored to protect against the actual splash hazards seen in a facility while allowing the greatest amount of flexibility and comfort.

Summary and Conclusions

PPE designed to protect against a generic hazard is over-designed, and over-designed PPE is less flexible and less comfortable to wear. When employees are issued PPE that is uncomfortable and restricts movement, employees will frequently fail to comply with regulations regarding the use of the PPE. Failure to use or improper use of PPE is frequently cited as the cause of workplace injuries. Therefore, providing decision-makers with the information and tools needed to verify the ability of PPE to guard against the specific splash hazards routinely encountered in their facilities will lead to the selection of PPE that will receive higher levels of compliant use, which will lead to more informed choices and greater levels of comfort and safety.

Over the past year, Chapman Innovations has collaborated with the Department of

Mechanical Engineering at Brigham Young University to develop a first-generation portable testing platform able to measure a protective fabric's ability to guard against splashes of molten substances and hot liquids. This innovative device is portable, so testing is being performed onsite where safety managers and employees can observe firsthand how different protective fabrics compare when exposed to actual hazards.

Presently, research and development is underway in an effort to extend the capabilities of the portable testing platform to allow the measurement of in-plane heat transfer in addition to cross-plane heat transfer. The ability to determine the optimal thermal conductivity ratio will result in PPE that is tailored to protect against the actual splash hazards seen in a facility while allowing the greatest amount of flexibility and comfort. It is anticipated that such custom-designed PPE will protect personnel and receive higher levels of complaint use, which will significantly increase workplace safety.

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