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An Analysis Of Selecting Personal Protective Equipment Clothing Used In Foundries

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AN ANALYSIS OF SELECTING PERSONAL PROTECTIVE EQUIPMENT
CLOTHING USED IN FOUNDRIES

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Abstract

A foundry is a type of factory that deals with producing metal casting. The metals are casted in to shape by being melted into liquid and is then poured into the mold. Personal protective equipment (PPE) is worn to protect the worker from the hazard that engineering control cannot protect the worker from. A Private company wanted to evaluate their current PPE clothing to understand how well they protect a worker against molten metal splash PPE clothing was tested using the American Standard for Testing Material (ASTM) standard F955-07 entitled "Evaluating Heat Transfer through Materials for Protective Clothing upon Contact with Molten Substances." The ASTM standard F955-07 evaluates the protection of the PPE clothing by their visual appears and calculating the total heat energy through the fabric after molten metal impact. The visual examination evaluates extent of fabric damage by five different categories(charring, shrinkage, metal adherence, and break out/ perforation).The total heat energy is calculated to determine if the PPE clothing will protective a worker from a 2nd degree burn if splashed with molten metal. Twenty six different clothing was used for this experiment of those twenty-six, twenty-one was tested with molten iron and the other five was tested with molten brass. An examination of their results was completed to determine how well the private company was protecting their workers, and if personal protective clothing manufactured for protection from molten metal splash provides the best protection for foundry workers. Results found that majority of the clothing used in the foundries did not protect the worker from attaining a second degree burn, and the PPE clothing manufactured to protect against molten metal provides the best protection against molten metal splash.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ASTM	American Standard for Testing Material
PPE	Personal Protective Equipment
EHOS	Environmental Health & Occupational Safety
OSHA	Occupational Safety & Health Administration

INTRODUCTION

A Foundry is a type of factory that deals with producing metal casting. The process to produce metal castings includes, preparing a mold cast, then melt and pour the metal into the mold. Once the metal has cooled in the mold, it is then removed and finished. There are many different possible risk and hazard that foundry employees are exposed to. A possible risk is breathing in silica, wood, and metal dust. These particles can cause damage to an employee's respiratory system causing chronic lung disease. Employees in foundries are also at risk for heat related illness because the furnaces are heated between 300-1600 °C (600-3000 °F), which is required to melt the metal. The elevated heated from the furnace causes the temperature to increase in the environment. The molten metal produced can cause potential risk to the employees through possible explosion or splash.

The major hazards that are focused on in this study were heat stress and molten metal splash. Heat stress is caused when you body is unable to regulate the body temperature. When your body temperature increases because of the outside environment, the body cools itself down, mainly by sweating to reduce the core temperature. The evaporation of the sweats causes a coolant sensation to cool the body temperature down. When you work strenuously wearing heavy clothing it will impede the evaporation process, your body is not able to cool efficiently. This causes heat related diseases, such as heat cramps, heat exhaustion, and heat stroke

Molten metal splash is also a concern because it burns to the worker's skin. When splashed with molten metal, workers will often receive a second-degree burn, which is when the epidermis and dermis is damaged. This usually causes pain and swelling. Third degree burn is also common type of burn which is when all layers of the skin is damaged and vital skin sensors are destroyed.

To protect the employee, hazard controls are put in place. The hazard control includes elimination/substitution, engineering controls, administrative controls, and personal protective equipment. Since molten metal is needed to produce the product, it cannot be eliminated or substituted. Engineering controls are designs and modifications made to plant equipment and ventilation that reduces the source of exposure. When elimination or engineering controls are not efficient enough to protect from a hazard, administrative controls are put in place. Administrative controls include rules, policies, and work practices. There are a variety of different administrative controls that are used in foundries, including mandatory water breaks to prevent dehydration, also good housekeeping practice to decrease the amount of dust in the air.

The last hazard control used is Personal Protective equipment (PPE). PPE is worn to protect the employee from the hazard that the other controls cannot protect the employee from. PPE is the last barrier between the employee and the hazard; this is the reason why PPE should be used with other controls. PPE can cause stress to the employee, which can increase the employee rate of accident. This is why other controls are implemented before PPE is used.

Occupational Safety & Health Administration (OSHA) 29CFR 1910.132 only requires that the type of PPE clothing that is chosen, will be based on what hazards are present or likely to be present while the employee is working, and what hazard is a necessity (OSHA 29CFR 1910.132). The problem arises because majority of the clothing worn in foundries are not manufactured for protection against molten metal, because majority of the operation do not handle molten metal. This is why when choosing PPE clothing for workers who work in theses operation, molten metal protection is not considered. This is because; most PPE clothing made for protection against molten metal is heavy and decrease flexibility, to complete operation.

This is significant because when accidents happen workers who are not wearing proper PPE clothing that protect from molten metal splash, will mostly likely become injured. In 2010, an accident at a steel production foundry caused several injuries and fatalities. The OSHA accident reports stated that the worker lacked proper PPE, and that better PPE may have saved the lives of those who died. As stated before, most work done in foundries does not involve molten metal. This is why workers wear cotton flame retardant (FR) clothing. When workers handle molten metal, aluminum based clothing is worn with cotton clothing underneath. Cotton based clothing is favored because it is more comfortable to wear and because of their dexterity when in awkward positions. The workers that were injured in the steel foundry were wearing cotton-based clothing, and were working on operation not handling molten metal (Lester, 2011).

In 2013, 81 reports were submitted to the Aluminum Association of incidents of molten aluminum spilled or splashed. The cause of theses incidents range from ranging from explosions to spills in various phases of production. Out of the 81 reported 22 were minor injuries, none were series or fatal. Over the past 4 years there has been no reports fatalities, even though the number reports went up. It was also reported that the proper

PPE that were worn either prevented an injury or decreased the severity of the injury. Although these statistics represent the aluminum industry, other molten metal industry with thermal risk will yield similar results if proper PPE clothing is worn during accidents (Summary Report on Molten Metal Incidents, 2013).

Although wearing the proper PPE clothing is a major factor in protecting worker from molten metal splash, a bigger issue is worker compliance with safety regulation. Workers are resistant to wearing clothing that is not comfortable or convenient if they do not have to. Clothing manufactured for molten metal protection is uncomfortable to wear especial in foundries hot environment. The clothing are not breathable and do not provide any type of ventilation. The clothing is also heavy to wear and make it difficult for workers to carrier out tasks. This is the reason why worker who do not handle molten metal do not wear PPE clothing that protects from molten metal splash. That is why finding lighter weight PPE clothing that protects the worker from molten metal splash is important.

Since PPE is the last barrier between the hazard and the employee, it is import to make sure the equipment is efficient. The American Society for Testing Material (ASTM) standard F955-07 is used to test how well personal protective clothing (PPE clothing) used in foundries responds to molten metal. A private company wanted to evaluate how well the clothing that they use in their facility protects their worker from molten metal splash. The company wanted to ensure that all employees are protected from molten metal splash, regardless of job task. A variety of different types of PPE clothing are used in the company's facilities. The majority of clothing worn in foundries is not manufactured for protection from molten metal splash, since only a small portion of a foundry's operation involves handling of molten metal. Most of the clothing that is used in the facilities is cotton based and treated with flame retardant chemicals. Flame retardant (FR) clothing is manufactured to self-extinguish upon the removal of an ignition source, not for the prevention of a burn from molten metal impacted. Most PPE clothing is created to protect the worker from a specific hazard.

With the collaboration with this company, we tested their PPE clothing using the ASTM standard F955-07. An analysis was done on the results of the test to determine if the currently used types of Personal Protective clothing worn in different areas of the foundry provide the best protection against molten metal splash. We also wanted to determine if any of the clothing not manufactured for protection against molten metal splash may provide some protection and how it compared to clothing manufactured specifically for molten metal protection.

A survey was also sent out through the American Foundry Society (AFS) to their members who are Environmental health & Occupational Safety (EHOS) professional who currently work at a foundry. The survey was issued to gain information on what type of PPE clothing are being used in foundries across the United States.

BACKGROUND

Heat Stress

When working in high thermal environments the workers may be at risk for heat stress.   To maintain thermal homeostasis when working in a hot environment, equilibrium must be made between heat production and emission. Heat stress occurs when the body is not able to cool the body temperature by sweating. This usually happens when the environment extremely hot, something is blocking the evaporation of sweat, or lack of appropriate hydration. The major heat diseases that we are concerned about are heat cramps, heat exhaustion, and heat stroke. Heat cramps happen when the body loses salt through sweating, which causes muscles to have painful cramps Heat exhaustion is caused when too much salt and water is lost due to excessive sweating. The most severe of the disease is heat stroke. Heat stroke happens when the body temperature rises to critical levels, which can cause for death or permanent damage (Heat Stress, 2015).

When PPE clothing is worn in a hot environment, the thermal properties of the clothing can affect the heat exchange. The clothing causes reduction of heat transfer from the environment to the skin (Holmér, 1995). Heat is transported through clothing by conduction and evaporation. Convection is what transfers heat from clothing and environment. The amount clothing has on affects if the wear is strained by heat. A study found that wearing full protective clothing from head to toe, reduce the physiological strain a person could tolerate when in a thermally extensive environment and the core temperature increases. When a worker is partially protected, the face, neck, and hands are exposed, the core temperature stay within normal range. (Montain,1994)

A recent study evaluated the heat strain caused by heat stress, of fire fighters in Japan that wore either aluminized or non-aluminized PPE. A questionnaire was administered to firefighters in two major cities of japan. The goal was obtain information on the firefighter activities, physical strain, work environment, and the mobility of firefighters when wearing PPE clothing. In city A, the firefighters wore aluminized PPE clothing and were under higher heat strain than city B fire fighter who wore non-aluminized clothing. The firefighters in city A stated that the aluminized PPE was very poor at ventilating and mobility. The time when both cities fire fighters received the most heat strain was in August between 2pm and 3pm. Both cities fire fighter when PPE clothing was worn experienced limited movement (Son, Lee, & Tochihara, 2013).

Skin Burn Structure

The American Burn Association reports that 486,000 burns are treated annually, of which 40,000 burn victims were hospitalized, including 30,000 that were treated at burn centers across the US for more server burns (Burn Incidence and treatment in the United States, 2015). 20% to 30% of burn hospitalizations are due to workplace exposure (Burn Injury, 2008). Occupational burn injuries are caused by exposure to open flames, chemicals, or materials that are heated at high temperatures. The type of burn that usually occurs in a foundry is contact burn. A contact burn is attained when the skin comes in contact with a heated object that is extremely hot or the contact is abnormally long. Contact burns tend to be deep dermal or full thickness (ABC of burns:

Pathophysiology and types of burns, 2004). Four percent of burns in the US are contact burns (Burn Incidence and treatment in the United States, 2015).

The classification of a burn injury is based on the thickness of the skin involved. First-degree burns are also called superficial burns, and involve only the most outer layer of skin. This type of burn usually cause swelling, redness, heals quickly on its own, and is the least serious of the burn injuries. Second-degree burns are also known as partial-thickness burns, and affect both the epidermis and part of the dermis. These burns can be painful and will cause the burned skin to blister. This type of burn may also cause scaring or disfigurement and has an increased risk of infection. Third-degree burns are called the full-thickness burns, with damage extending down through the epidermis, dermis, and into the hypodermis, or subcutaneous tissue. This type of burn will affect underlying bone, nerves, tendons and other structures. Third degree burns are the most life threatening, because of the high risk of infection and possible damage to some vital organ and artery's (Parmet, 2003).

There are many different factors that contribute to how quickly a burn patient will recover from their injury. There are some factors that can be clearly observed by the health care professionals such as the total body surface area (TBSA) or percent of body surfaced burned. Another factor is the type of burn that includes partial thickness burn (2st degree burn) or full thickness burn (3rd degree). These two factors added together can help the health care profession to estimate the length of treatment (Helm & Walker, 1992).

Pain is also an indicator on how serve a burn is. The stimulation of pain depends on the instantaneous rates in which reaction are occurring, rather than the amount or the extent of damage done (Stoll & Greene 1959). When the skin is exposed to heat it usually takes 2 to 60 seconds to stimulate pain. This depends on the intensity of the heat and initial skin temperature (Buettner, 1951). The damage of epidermis depends on the temperature and the time at which the dermis is held at the temperature. Once the temperature surpasses 51^{o}C it will not require much time to destroy the epidermis and cause irreversible damage (Moritz & Henriques, 1947). When a burn victim feels no pain that is a sign that the nerves that vital sensory nerves that the skin contains were destroyed.

In addition to the injury and lost days of work, the financial cost to a foundry can be large when a foundry worker is burned by molten metal. A study examined the cost of 16 burned victims. The 16 burned patients received their wounds from molten metal while working in a foundry. The total percent of the body burned of the 16 patients on average 2.7% of body was burned. Out of all 16 only one was admitted to a hospital after accident. The other 15 burn patients did not get a referral to the hospital on average 17 days after the incident. The amount of days that the patient lost at work on average was 69 days. All medical bills were covered by worker compensation but the researchers could only attain data from 10 patient. Workers compensation spent on average 7,595 on medical bills. Money spent on disability on 2,759. Since most the burn was full thickness (third degree burns) skin graft were needed, 100% of the skin graft took. This study concluded that if the patient were admitted to the hospital and their injury were recognized sooner it would have reduced the amount of time out of work and the medical and disability cost (Hoyt, Kahn, & Mccrad, 1981).

Personal Protective Clothing (PPE clothing)

Personal protective clothing (PPE clothing) in foundries is used to eliminate or decrease burns when exposed to molten metal. There are many different types of clothing used to protect against molten metal splashes, including wool, cotton, rayon, aluminum, and leather. The fabrics that are needed to protect the worker from molten metal depend on the metal, temperature, density, size of droplet and reactivity. When choosing a fabric for molten metal protection the safety officer considers the flowing: 1) will the metal cause the fabric to ignite, 2) will the metal burrow through the fabric and char, and 3) will the metal stick onto fabric. (Horrocks , 2005).

There is very little research data concerning the best choice in protective fabrics used in foundries. During the 1980s, the choices of material available to protect against molten metal were cotton, wool and aluminized rayon, wool, leather and asbestos. Jaynes (1986) conducted a study of variety of different fabric against 1500g of different metals. He found that wool was better at protecting against molten aluminum than fire retardant (FR) cotton but not as protective as aluminum fabric against steel. FR cotton was found to protect against molten iron and steel but not against molten aluminum. His study also found when the amount of molten metal was lessened to 1000g, a burn would not be received(Jaynes, 1986).

Benisek (1986) found that cotton that was untreated provided better protection for molten aluminum than some FR treated cotton because of the metal would adhere to fabric. It was found that when organ-bromine compound was combined with organ-phosphorous, would strop metal from adhering to FR treatment cotton. (Benisek, Edmondson, & Phillips, 1986)

Fabric structure is important on how well the clothing will protect the worker. Thicker heavy weight fabrics provide better protection than thin fabrics. The construction of the thread is also vital on how well fabric will with stands molten metal. Tightly packed thread provides better protection than loosely packed thread. Heavy fabric with loose thread will still provide protection but is not as protective as tightly woven heavy fabric. Research has also found that two-layer fabric will provide better protection than a single layer fabric of same weight and thickness. (Mehta, 1980)

Even though majority of the worker in foundries do not handle molten metal they are exposed to radiant heat. A study evaluated how PPE clothing responds against low radiant heat over time. The study found the thicker fabric provided great protection, but also found that layered clothing provides better protection. The reason is because layered fabric traps dead air in-between fabrics, which helps reduce the heat transfer. (Song et al., 2011).

The most studied type of clothing used against molten metal splashes is aluminum. Aluminized PPE clothing is widely used throughout iron and steel plants. When aluminum is used as PPE clothing it is combined with many different types of fabric such as asbestos, wool, and rayon. Aluminum is woven with or placed above other fabrics to allow the wearer to be comfortable and also to create more breathable clothing. When aluminum serves as the outer layer it provides thermal protection. When fabric is layered under aluminized fabric the heat flux can be reduced because the air trapped between the fabrics acts as an insulator (Wren, Scott, & Bates, 1977). The layered fabric helps reduce heat transfer when exposed to flames (Benisek, Edmondson, & Phillips, 1979).

When the weight and the density of a fabric is increase so will the amount of molten metal the fabric will withstand. The fabric surface should be smooth so the metal will not get trapped in the fabric and also to eliminate conduction, the smoother the fabric the better protected you are (Jin, Park, Hong, & Yoon, 2014). Aluminized fabric was found to protect better against molten iron than non-aluminized fabrics (Barker &Yener, 1981).

EXPERIMENTAL PROCEDURES

The American Standard for Testing Material (ASTM) standard F955-07 entitled "Evaluating Heat Transfer through Materials for Protective Clothing upon Contact with Molten Substances" was used to complete this experiment. The standard set by ASTM to assess molten iron impact, is when 1 kg (2.2 lbs.) ± 0.1 kg of molten iron is melted at a minimum temperature of 1538º C (2800 ºF), and poured onto sample fabric. The standard set by ASTM to assesses molten brass impact, is when 1 kg. (2.2 lbs.) ± 0.1 kg of molten brass is melted at a minimum temperature of 1150º C (2100 ºF), when poured onto sample fabric. The molten iron or brass is held in a crucible. The crucible is rotated on a plan that comes to a firm stop 12 inches above the calorimeter board. Both type's molten metal then lands on fabric attached to the calorimeter board. The calorimeter board is horizontally slanted at 70^0angle (ASTM 955-07). (Figure 2)

Each type of molten metal was held in an induction furnace that was constantly at a temperature of around 52 ºC (125 ºF). The molten metal was then placed in to a preheated ladle. The weight of the molten metal in the ladle was determined with an electronic balance. The weight of the molten metal in the ladle was kept at 1 kg. ± 0.1 kg. After the molten metal is poured into the ladle, the molten metal is left in the ladle for 20 seconds to maintain constant metal impact temperature. The ladle containing the molten metal is placed on the ladle holder and splashed on to the fabric that was placed on the calorimeter board. The fabric is held on the board by clips along the upper edges (ASTM 955-07).

Visual Examination

The visual appearance of the fabric is examined after the fabric is splashed with molten metal. The fabric is tested with t-shirt backing and was rated in four categories. The categories that were included are charring, shrinkage, metal adherence, and break out/ perforation. This rating system described in table 1.

The visual examination of charring is defined as if the fabric becomes scorched, charred, or burned after molten metal impact. Shrinkage is defined how much the fabric will wrinkle when impacted with molten iron. The goal of PPE clothing is to have minimum amount of charring, shrinkage during and after the fabric is being exposed to molten metal. Metal adherence is when the metal sticks to the fabric it was poured on. Break out evaluates how much of the fabric is destroyed in relations to the size, number of holes created, and penetration of molten metal through the fabric. The goal is to have PPE clothing to have no metal adherence or breakout. The visual examination categories are each rated by levels one through five, 1 representing best response to 5 being the worst response (ASTM 955-07).

Table 1
Grading System Used to Evaluate Fabric Damage

The fabric samples were evaluated visually for charring, shrinkage, adherence and breakout to provide an indication of the extent of damage to the outer impacted layer. Five grades were used in evaluating the extent of charring as listed below

	Charring - fabric becomes scorched, charring, or burned
1	slight scorching, fabric had small brown areas
2	slight charring, fabric was mostly brown in impacted area
3	moderate charring, fabric was mostly black in impacted area
4	charred, fabric was black and brittle, cracked when bent
5	severely charred, large holes or cracks, very brittle
	Shrinkage- fabric will wrinkle
1	no shrinkage
2	slight shrinkage
3	moderate shrinkage
4	significant shrinkage
5	extensive shrinkage
	Metal Adherence- metal sticks to the fabric
1	none
2	small amount of metal adhered to face or back of the fabric
3	a moderate amount of metal adhered to face or back of the fabric
4	substantial adherence of the metal to face or back of the fabric
5	large amount of adherence of metal to face or back of the fabric
	Break Out/ Perforation -how much of the fabric is destroyed in relations to the size, number of holes created, and penetration of molten metal through the fabric
1	none
2	slight, small holes impacted area
3	moderate, holes in fabric
4	metal penetration through the fabric, some metal retained on the fabric
5	heavy perforation, the fabric exhibited gaping holes or large cracks or substantial

Heat Transfer Data Collection and Interpretation

Using ASTM standard F955-07 the refectory board contained two copper disks that were 4 cm (1.57 inch) diameter; 1/16-inch thick .The first copper disk was located at the top of the board where the metal would impact. The second disk was located 4 inches below the first disk. The placement of the calorimeter and thermocouple is illustrated figure3. The experimental setup illustrating the crucible and experimental fabric placement is shown in Figures 4 and 5. Inserted in the back of the calorimeter is a single 30-gauge iron/constantan Type j thermocouple. High precision digital data acquisition system was use to record the thermos couple output from the calorimeter. Each calorimeters temperature rise was plotted for 45 seconds for all fabric/metal combination.

The formula below was used to calculate the total heat energy that flowed through the fabric each time step:

$$Q = \frac{m \times C_P \times (Temp_{final} - Temp_{initial})}{Area}$$

where:
Q = heat energy (J/cm2),
m = mass of copper slug (g),
Cp = average heat capacity of copper during the temperature rise (J/gºC),
Tempfinal = final temperature of calorimeter at timefinal (ºC),
Tempinitial = initial temperature of calorimeter at timeinitial (ºC),
Area = area of copper calorimeter.

The heat energy curve will be compared to Stoll Curve. The survival of the epidermis is dependent on time and temperature when heat is applied to skin. The Stoll curve is a standard that was developed to serve as a baseline to determine if a fabric provides thermal protection. The Stoll curve was created by the US Military to create a thermal protection rating for fabric. The military observed the interaction between pain and blister effects on the human skin. The Stoll curve represents the amount of energy that a person can receive as a function of time before they would receive a 2nd degree burn. This standard was set to see the severity of a burn and if it will be less than 2nd degree burn. The baseline was created by measuring the amount of heat absorbed by a person before receive a 2nd degree burn on human subject. A second-degree burn is usually defined as a point in which a blister has formed. A blister will form when the epidermis is destroyed and separates from the remaining skin (dermis). The equation for the Stoll curve as stated before is the amount of energy absorbed by unit surface as a function of time. Figure represents a range of heat either high or lover over period of time either short or long. The temperature in the figure represents delta the change in temperature over a period time not the actual temperature (ASTM 955-07).

The Stoll curve is calculated from the following formula:

Stoll Curve (J/cm2) = 5.0204 x $tj^{0.290}$ tj represents the time after molten metal impact.

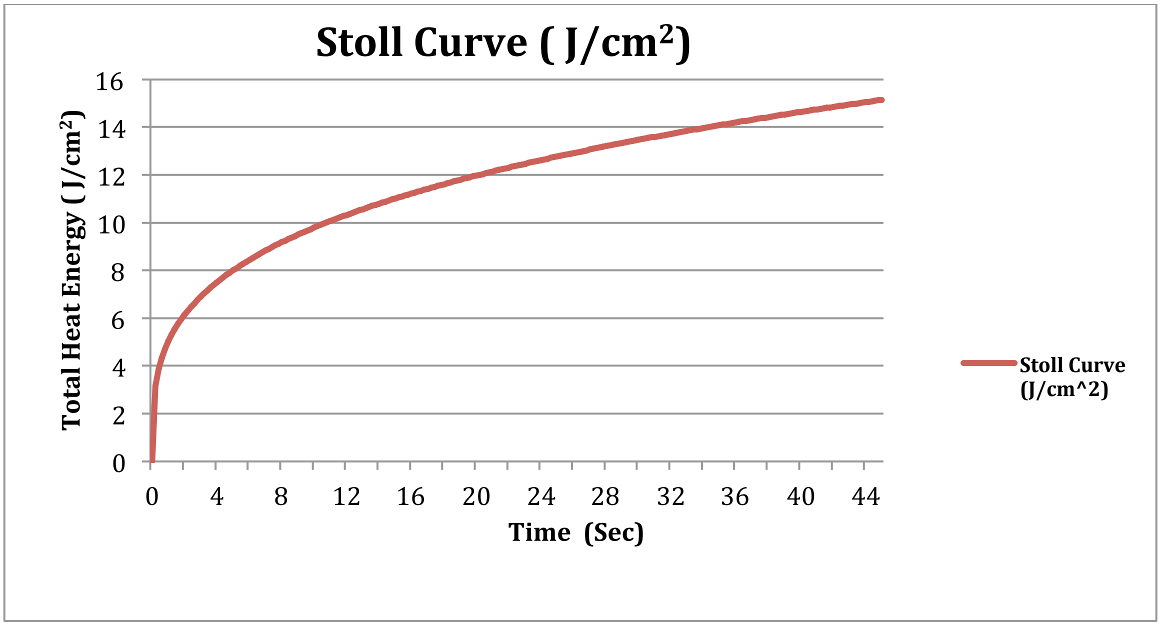

Figure 1: The Stoll curve represent the amount of energy absorbed by unit surface as a function of time.

Survey

A questionaire was developed consisting of 15 questions that would gather the demographic of the occupational workers, what type of PPE clothing they use in their foundry, if they test the PPE clothing that they use, and what are their major concerns when it comes to PPE clothing.

The questionaire was distributed to Environmental health & Occupational Safety (EHOS) professional who work in foundries. Theses types of workers were chosen because they have the responsibility at foundries to chose the PPE clothing for the workers.The questionaire sent with the assistance of the American Foundry society. All members who received the questionairre were active members.

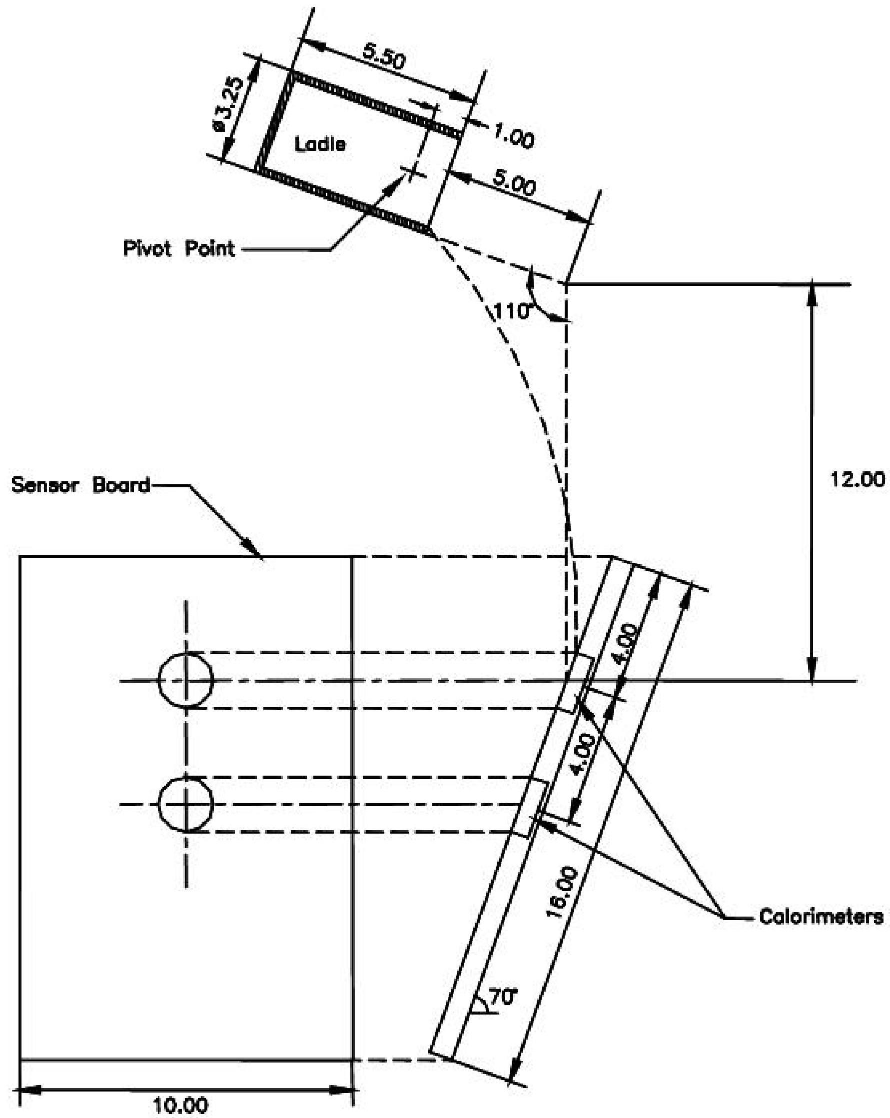

Figure 2. Molten Metal Impact Apparatus Illustrating Ladle and Calorimeter Orientation.

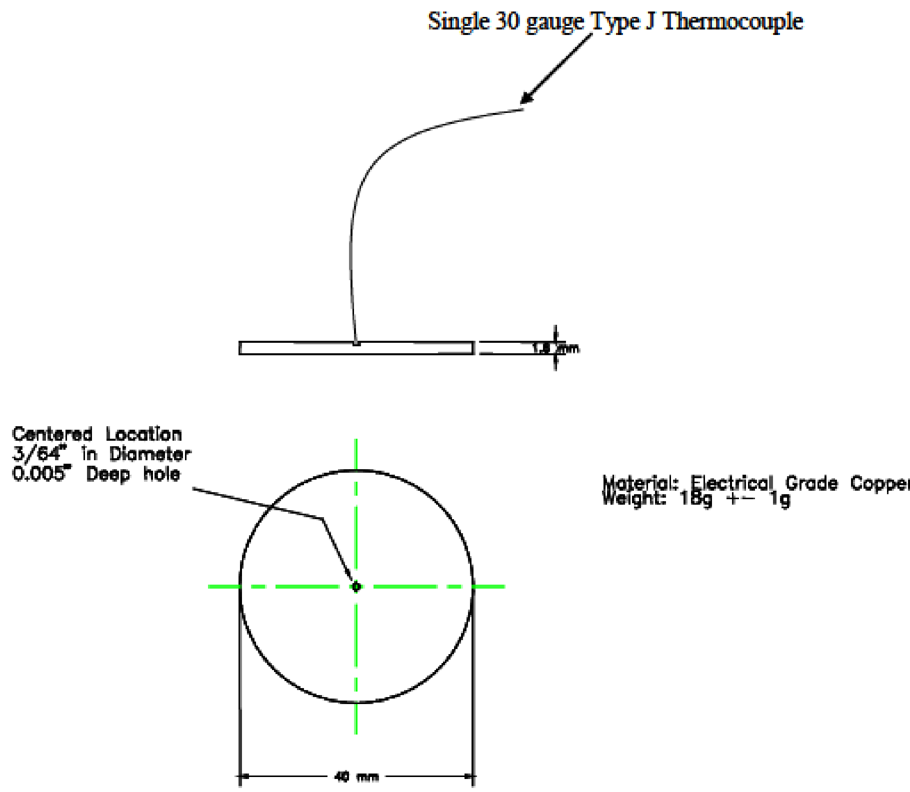

Figure 3: Schematic of 4.0 cm (1.57 in) Diameter Copper Calorimeter

Figure 4: Splash Test Apparatus Illustrating Cup Position and Copper Calorimeters in Refractory Plate

Figure 5: Splash Test Apparatus Illustrating Cup in Splash Position and Test Fabric.

RESULTS

This project evaluated twenty-six different Personal Protective Equipment (PPE) clothing used in foundries. The goal was to determine how well the PPE clothing that is currently used in the private company protects against molten metal splash. The American Standard for Testing Material (ASTM) standard F955-07 was used to assess the PPE clothing. Each PPE clothing that was tested three times except for Carbon X® Nit Hood, Leather Chaps (Split Cowhide Kevlar sewn)-WELDA, and 11 oz. Cloth Jacket (cape) Steel Grip Woven Kevlar with snap on leather apron-Tilman over 6 oz. cotton work shirt which were only tested twice because the limited amount of fabric. Twenty-one types of clothing were tested with molten iron and the other five types were tested with molten brass. The clothing was evaluated visually for charring; shrinkage, adherence and breakout to provide an indication of the extent of damage to the outer impacted layer (Table II, &Table IX). The PPE clothing was also evaluated by calculating the total heat energy that flowed through the fabric for each time step. The total heat energy curve was compared to the Stoll Curve to determine if the clothing will cause a second-degree burn if splashed with molten metal (Table X-XI)

Visual Examination

Chi- Square test was used for the qualitative analysis to compare the visual results (charring, perforation, shrinkage, and adherence) of each of the items based on if the PPE clothing was manufactured to protect against molten iron splash. The visual results for charring showed that PPE clothing manufactured for protection against molten iron were significantly different than PPE clothing that is not manufactured for protection against molten metal (P-value= .022). Among products manufactured for protection against molten iron 10% demonstrated slight charring, and fabric was mostly brown at impacted area (grade 2), 40% showed moderate charring, and fabric was mostly black in impacted area (grade 3), 60% showed charring, and fabric was black and brittle, cracked when bent (grade 4). While PPE clothing not manufactured for protection against molten metal, 60% showed moderate charring, and fabric was mostly black in impacted area (grade 3), 14.6% received a grade of (3.5) which means the fabric was moderately charred and brittle in some areas, and 68.4% showed charring, and fabric was black and brittle, cracks when bent (grade 4). (Table II)

100% of clothing tested with molten iron did not have any shrinkage (Table III).The chi- square analyzes of adherence results found that PPE clothing made for protection against molten metal were significantly different than PPE clothing that are not made for protection against molten metal when splashed with molten iron (P-value= 0.043). PPE clothing that were manufactured for Molten Metal, 90% showed no adherence (grade 1), 5% showed small specks of metal on the fabric (grade 1.5), 5% showed moderate amount of metal adherence to face or back of the fabric (grade 2). While PPE clothing that was not made for protection against PPE 63.4% showed no adherence (grade 1), 9.8% small specks of metal appeared on fabric (grade1.1), 24.4% showed small amount of metal adherence to face or back of the fabric (grading 1.5), and

2.4 % showed small amount of metal adherence, to face or back of the fabric (grade 2). (Table IV)

A chi- square test was done to analysis the results of the perforation. What was found was that PPE clothing made for protection against molten metal were significantly different than PPE clothing that is not made for protection against molten metal when splashed with molten iron (P-value=.024). Among materials manufactured for molten metal use, 83.3% showed no perforation (grade 1), 16.7% showed slight perforation with small holes (grade 2.5). While materials that were not manufactured for molten metal use 81.4% showed no perforation (grade 1), 2.3% a few tiny holes small holes (grade 1.1), 2.3% moderate amount of tiny holes (grade 1.2), 4.7% had a few small holes in the fabric (grade 1.5), 9.3% showed heavy perforation, the fabric exhibited gaping holes or large cracks (grade 4). (Table V)

A Chi- Square test was performed to analysis the qualitative the visual results (charring, perforation, shrinkage, and adherence). A comparison was mad between each of the clothing based on if the PPE clothing was manufactured to protect against molten brass splashes. The visual results for charring showed that PPE clothing manufactured for protection against molten brass were significantly different than PPE clothing that is not manufactured for protection against molten metal (The P-value<0.0001). Among materials manufactured for molten metal use 71.4% moderate charring, fabric was mostly black in impacted area (grade 3). 15.4% charred, fabric was black and brittle, cracked when bent (grade 4), 46.2% severely charred, large holes or cracks, very brittle (grade 5.) While PPE clothing not manufactured for protection against molten metal 100% were severely charred, with large holes or cracks (grade 5). (Table VI)

The chi- square results of the shrinkage found that PPE clothing made for protection against molten metal were significantly different than PPE clothing that is not made for protection against molten metal when splashed with molten Brass (P-value=.011) Among materials manufactured for molten metal use, 28.6% had no shrinkage (grade1), 42.9% slight shrinkage (grade 2)28.6% moderate shrinkage (grade 3). While PPE clothing not manufactured for protection against molten metal 100% had no shrinkage at all (grade 1). (Table VII)

The chi- square results of the adherence found that PPE clothing made for protection against molten metal were significantly different than PPE clothing that is not made for protection against molten metal when splashed with molten Brass (P-value=. 269) Among materials manufactured for molten metal use, 71.4 % no metal stock to the fabric (grade1) and 28.6% had moderate amount of metal adhered to the face or back of the fabric (grade 3). While PPE clothing not manufactured for protection against molten metal 100% had no metal stick to the fabric (grade 1). (Table VIII)

The chi- square results of the breakout found that PPE clothing made for protection against molten metal were significantly different than PPE clothing that is not made for protection against molten metal when splashed with molten Brass (P-value=<.00001) Among materials manufactured for molten metal use, 71.4% had no breakout (grade1), 28.6% slight, small holes in metal impact area (grade 2). While PPE clothing not manufactured for protection against molten metal 16.7% had metal penetrate through the fabric, some metal retained on the fabric(grade 4) 83.3% heavy perforation, the fabric exhibited gaping holes or large cracks or substantial (grade 5). (Table IX)

Heat transfer data collection and Interpretation

A chi-square test was done to compare 2nd degree burn results based on if they were manufactured for protection against molten metal or not. It was found that there was a significant different between clothing manufactured for molten metal protection and clothing not manufactured for protection against molten metal when splashed with molten iron (P-value=. 003 N=61). The clothing manufactured for protection against molten metal 70% did not receive a 2nd degree burn when splashed with molten iron. Compared to 29.3 % of clothing not manufactured for molten metal protection received 2nd degree burns when splashed with molten iron.(Table XI)

A chi-square test was also performed to compare the 2nd degree burn results based on if they were manufactured for protection against molten metal or not when splashed with molten brass. It was found that there was a significant different between clothing manufactured for molten metal protection and clothing not manufactured for protection against molten metal when splashed with molten brass (P-value=.009 N=14). 75% of the clothing manufactured for protection against molten metal did not receive a 2nd degree burn compared 100% of clothing not manufactured against molten metal protection that did received a second degree burn. (Table X)

An analysis was done to see if there was a correlation between if the PPE clothing world received a second-degree burn and the grade that was given in each category. A weak positive relationship between weather the PPE clothing received a second-degree burn and the grade for each visual categories was found (charring r (71)=. 39 p=. 00052, shrinkage (71)=. 29 p=. 0108, adherence (71)=. 21p=. 07135, breakout r (71)=. 21p=0.0725)

Survey

A survey was issued through the American Foundry Society (AFS). They sent the survey to Environmental health occupational professional that currently works at foundries and are members of AFS. 47 professional were sent emails and only 14 responded. Of the 14 respondents 75% works with iron, 25% works with steel, and 25% works with Brass-Copper. The operation that they work in 64.3% work in manual, 14.3% works in automated, and 21.4% combination of manual and automated facilities. Only 57.15% of the respondents test their PPE clothing they use and 37.5% say they follow ASTM standard when they test. The major concern from the foundry personnel was heat stress. Only 10 of the PPE clothing listed by the EHOS profession were tested by us, and out of that 10 only 3 would protect against a second-degree burn.

Table II
Charring Visual Rating of Fabrics Exposed to Molten Iron Rating of Outer (Impacted) Layer

Test Material	Run 1	Run 2	Run 3
9 oz. Greens - Magid Glove	4	4	4
10.9 oz. Quantum Coveralls	4	4	4
Quantum Pants	3	3.5	3.5
9 oz. Greens Westex	4	3.5	4
9 oz. greens -Westex over Carbon X®	4	4	4
12 oz. FR green Jacket - Magid Glove	3.5	3	3
9 oz. FR Green Jacket Magid Glove	4	4	4
11 oz. CarbonX® Jacket	3	3	3
14.4 oz. Norfab-900 Carbon Kevlarv-Intertex	3	3	3
9 oz. UltaSof®t FR Navy Jacket	4	4	4
7oz UltraSoft® FR work shirt Westext over cotton long sleeve T shirt	4	4	4
9oz FR Green Jacket over 7 oz. UltraSoft® FR work shirt Westex	4	4	4
7 oz. UltraSoft® FR work shirt Westex over 7.7 oz. Carbon X® long sleeve shirt	4	4	4
CarbonX® nit hood	3.5	3.5	-
BodyShield pants- leather cover*	3	3	3
BodyShield pants- without leather cover*	4	4	4
BodyShield jacket*	4	4	4
7.7 oz. Aluminized Norfab-900 Carbon Kevlar-Intertex*	4	4	4
17oz Aluminized Carbon Kevlar*	3	3	3
7 oz Aluminized Para Aramid PBI Fabric Gentex® Dual Mirror® Aluminized Fabric*	4	4	4
Leather Chaps (Split Cowhide Kevlar sewn)-WELDA*	2	2	-

* Manufactured for molten metal Protection

Table III
Shrinkage Visual Rating of Fabrics Exposed to Molten Iron Rating of Outer (Impacted) Layer

Test Material	Run 1	Run 2	Run 3
9 oz. Greens - Magid Glove	1	1	1
10.9 oz. Quantum Coveralls	1	1	1
Quantum Pants	1	1	1
9 oz. Greens Westex	1	1	1
9 oz. greens -Westex over Carbon X®	1	1	1
12 oz. FR green Jacket - Magid Glove	1	1	1
9 oz. FR Green Jacket Magid Glove	1	1	1
11 oz. CarbonX® Jacket	1	1	1
14.4 oz. Norfab-900 Carbon Kevlarv-Intertex	1	1	1
9 oz. UltaSof®t FR Navy Jacket	1	1	1
7oz UltraSoft® FR work shirt Westext over cotton long sleeve T shirt	1	1	1
9oz FR Green Jacket over 7 oz. UltraSoft® FR work shirt Westex	1	1	1
7 oz. UltraSoft® FR work shirt Westex over 7.7 oz. Carbon X® long sleeve shirt	1	1	1
CarbonX® nit hood	1	1	-
BodyShield pants- leather cover*	1	1	1
BodyShield pants- without leather cover*	1	1	1
BodyShield jacket*	1	1	1
7.7 oz. Aluminized Norfab-900 Carbon Kevlar-Intertex*	1	1	1
17oz Aluminized Carbon Kevlar*	1	1	1
7 oz Aluminized Para Aramid PBI Fabric Gentex® Dual Mirror® Aluminized Fabric*	1	1	1
Leather Chaps (Split Cowhide Kevlar sewn)-WELDA*	1	1	-

* Manufactured for molten metal Protection

Table IV
Adherence Visual Rating of Fabrics Exposed to Molten Iron Rating of Outer (Impacted) Layer

Test Material	Run 1	Run 2	Run 3
9 oz. Greens - Magid Glove	1	1.1	1.1
10.9 oz. Quantum Coveralls	1	1	1
Quantum Pants	1	1	1
9 oz. Greens Westex	1	1.1	1
9 oz. greens -Westex over Carbon X®	1.1	1	1.5
12 oz. FR green Jacket - Magid Glove	1	1	1
9 oz. FR Green Jacket Magid Glove	1	1	1
11 oz. CarbonX® Jacket	2	1	1.5
14.4 oz. Norfab-900 Carbon Kevlarv-Intertex	1.5	1.5	1.5
9 oz. UltaSof®t FR Navy Jacket	1	1	1
7oz UltraSoft® FR work shirt Westext over cotton long sleeve T shirt	1.5	1.5	1
9oz FR Green Jacket over 7 oz. UltraSoft® FR work shirt Westex	1	1	1
7 oz. UltraSoft® FR work shirt Westex over 7.7 oz. Carbon X® long sleeve shirt	1	1.5	1
CarbonX® nit hood	1.5	1.5	-
BodyShield pants- leather cover*	1	1	1
BodyShield pants- without leather cover*	1	1	1
BodyShield jacket*	1	1	1
7.7 oz. Aluminized Norfab-900 Carbon Kevlar-Intertex*	1	1	2
17oz Aluminized Carbon Kevlar*	1	1	1
7 oz Aluminized Para Aramid PBI Fabric Gentex® Dual Mirror® Aluminized Fabric*	1	1	1.5
Leather Chaps (Split Cowhide Kevlar sewn)-WELDA*	1	1	-

* Manufactured for molten metal Protection

Table V
Break out Visual Rating of Fabrics Exposed to Molten Iron Rating of Outer (Impacted) Layer

Test Material	Run 1	Run 2	Run 3
9 oz. Greens - Magid Glove	1	1	1
10.9 oz. Quantum Coveralls	1.1	1.2	4
Quantum Pants	1.5	1.5	4
9 oz. Greens Westex	1	1	1
9 oz. greens -Westex over Carbon X®	1	1	1
12 oz. FR green Jacket - Magid Glove	1	1	1
9 oz. FR Green Jacket Magid Glove	1	1	1
11 oz. CarbonX® Jacket	1	1	1
14.4 oz. Norfab-900 Carbon Kevlarv-Intertex	1	1	1
9 oz. UltaSof®t FR Navy Jacket	1	1	1
7oz UltraSoft® FR work shirt Westext over cotton long sleeve T shirt	1	1	1
9oz FR Green Jacket over 7 oz. UltraSoft® FR work shirt Westex	1	1	1
7 oz. UltraSoft® FR work shirt Westex over 7.7 oz. Carbon X® long sleeve shirt	1	1	1
CarbonX® nit hood	1	1	-
BodyShield pants- leather cover*	1	1	1
BodyShield pants- without leather cover*	1	1	1
BodyShield jacket*	1	1	1
7.7 oz. Aluminized Norfab-900 Carbon Kevlar-Intertex*	1	1	1
17oz Aluminized Carbon Kevlar*	1	1	1
7 oz Aluminized Para Aramid PBI Fabric Gentex® Dual Mirror® Aluminized Fabric*	2.5	2.5	2.5
Leather Chaps (Split Cowhide Kevlar sewn)-WELDA*	1	1	-

* Manufactured for molten metal Protection

Table VI
Charring Visual Rating of Fabrics Exposed to Molten Brass Rating of Outer (Impacted) Layer

Test Material	Run 1	Run 2	Run 3
6 oz. Cotton work shirt over 7.7 oz. Carbon X® shirt	5	5	5
Cotton T-Shirt over 7.7 oz. Carbon X®	5	5	5
Leather Jacket (Cape)-Radnor over Leather apron snap on over 6 oz. Cotton work shirt*	3	3	3
Leather Apron Tilman 3124 over 6 oz. cotton work shirt*	3	3	3
11 oz. Cloth Jacket (cape) Steel Grip Woven Kevlar with snap on leather apron-Tilman over 6 oz. cotton work shirt*	4	4	-

* Manufactured for molten metal Protection

Table VII
Shrinkage Visual Rating of Fabrics Exposed to Molten Brass Rating of Outer (Impacted) Layer

Test Material	Run 1	Run 2	Run 3
6 oz. Cotton work shirt over 7.7 oz. Carbon X® shirt	1	1	1
Cotton T-Shirt over 7.7 oz. Carbon X®	1	1	1
Leather Jacket (Cape)-Radnor over Leather apron snap on over 6 oz. Cotton work shirt*	2	3	2
Leather Apron Tilman 3124 over 6 oz. cotton work shirt*	2	3	2
11 oz. Cloth Jacket (cape) Steel Grip Woven Kevlar with snap on leather apron-Tilman over 6 oz. cotton work shirt*	1	1	-

* Manufactured for molten metal Protection

Table VIII
Adherence Visual Rating of Fabrics Exposed to Molten Brass Rating of Outer (Impacted) Layer

Test Material	Run 1	Run 2	Run 3
6 oz. Cotton work shirt over 7.7 oz. Carbon X® shirt	1	1	1
Cotton T-Shirt over 7.7 oz. Carbon X®	1	1	1
Leather Jacket (Cape)-Radnor over Leather apron snap on over 6 oz. Cotton work shirt*	1	1	1
Leather Apron Tilman 3124 over 6 oz. cotton work shirt*	1	1	1
11 oz. Cloth Jacket (cape) Steel Grip Woven Kevlar with snap on leather apron-Tilman over 6 oz. cotton work shirt*	3	3	-

* Manufactured for molten metal Protection

Table IX
Break out Visual Rating of Fabrics Exposed to Molten Brass Rating of Outer (Impacted) Layer

Test Material	Run 1	Run 2	Run 3
6 oz. Cotton work shirt over 7.7 oz. Carbon X® shirt	5	4	5
Cotton T-Shirt over 7.7 oz. Carbon X®	5	5	5
Leather Jacket (Cape)-Radnor over Leather apron snap on over 6 oz. Cotton work shirt*	1	1	1
Leather Apron Tilman 3124 over 6 oz. cotton work shirt*	1	1	1
11 oz. Cloth Jacket (cape) Steel Grip Woven Kevlar with snap on leather apron-Tilman over 6 oz. cotton work shirt*	2	2	-

* Manufactured for molten metal Protection

Table X
Time to Second Degree Burn According to the Stoll Curve after Impact with Molten Brass

Test Material	Run 1	Run 2	Run 3
6 oz. Cotton work shirt over 7.7 oz. Carbon X® shirt	1.8	0.6	1.2
Cotton T-Shirt over 7.7 oz. Carbon X®	0.8	0.4	0.4
Leather Jacket (Cape)-Radnor over Leather apron snap on over 6 oz. Cotton work shirt*	15.2	2.4	-
Leather Apron Tilman 3124 over 6 oz. cotton work shirt*	No Burn	No Burn	No Burn
11 oz. Cloth Jacket (cape) Steel Grip Woven Kevlar with snap on leather apron-Tilman over 6 oz. cotton work shirt*	No Burn	No Burn	No Burn

* Manufactured for molten metal Protection

Table XI
Time to Second Degree Burn According to the Stoll Curve after Impact with Molten Iron

Test Material	Run 1	Run 2	Run 3
9 oz. Greens - Magid Glove	0.6	0.8	0.6
10.9 oz. Quantum Coveralls	No Burn	No Burn	No Burn
Quantum Pants	1.2	No Burn	No Burn
9 oz. Greens Westex	No Burn	0.6	0.6
9 oz. greens -Westex over Carbon X®	No Burn	No Burn	No Burn
12 oz. FR green Jacket - Magid Glove	0.4	0.6	0.6
9 oz. FR Green Jacket Magid Glove	0.4	3.2	0.6
11 oz. CarbonX® Jacket	No Burn	2.2	3.2
14.4 oz. Norfab-900 Carbon Kevlarv-Intertex	No Burn	3.6	1.4
9 oz. UltaSof®t FR Navy Jacket	1.2	1	1
7oz UltraSoft® FR work shirt Westext over cotton long sleeve T shirt	0.4	0.6	0.6
9oz FR Green Jacket over 7 oz. UltraSoft® FR work shirt Westex	2	No Burn	1.8
7 oz. UltraSoft® FR work shirt Westex over 7.7 oz. Carbon X® long sleeve shirt	0.6	1.2	0.8
CarbonX® nit hood	1.6	3.6	-
BodyShield pants- leather cover*	No Burn	No Burn	No Burn
BodyShield pants- without leather cover*	No Burn	No Burn	No Burn
BodyShield jacket*	No Burn	No Burn	No Burn
7.7 oz. Aluminized Norfab-900 Carbon Kevlar-Intertex*	2.2	2.8	1.4
17oz Aluminized Carbon Kevlar*	No Burn	No Burn	No Burn
7 oz Aluminized Para Aramid PBI Fabric Gentex® Dual Mirror® Aluminized Fabric*	2	2.2	1.6
Leather Chaps (Split Cowhide Kevlar sewn)-WELDA*	No Burn	No Burn	-

* Manufactured for molten metal Protection

DISCUSSION

An evaluation of private company personal protective equipment (PPE) clothing was done. We examined how resistant their PPE clothing is to molten metal splash to determine if PPE clothing manufactured for protection against molten metal was more protective than PPE clothing that is not. We also wanted to find a lighter weight PPE clothing for workers who are working in operation that do not handle molten metal, but also protects them from molten metal. It was found that majority of the clothing used in the foundries did not protect the worker from attaining a second degree burn, and the PPE clothing manufactured to protect against molten metal provides the best protection against molten metal splash. We also found lighter weight PPE clothing that would protect the worker from a second degree burn.

The visuals examination results showed that there was a significant difference between PPE clothing manufactured for protect and non-manufactured for all four visual categories (charring, perforation, shrinkage, adherence) when splashed with ether iron or brass. No correlation was found between the levels received between each category. What was found was when two of the fabrics, 6 oz. Cotton work shirt over 7.7 oz. Carbon X® shirt and Cotton T-Shirt over 7.7 oz. Carbon X® , that was tested with brass received a level of 5 for charring also received a level 5 for breakout. This is understandable because level 5 for charring is when the fabric is severely charred, and large holes or cracks form, the fabric becomes very brittle which allow for large holes to form and molten brass to get through to the skin.

A significant difference was found between PPE clothing manufactured for protection against molten metal PPE clothing not manufactured for molten metal protection. The result yielded that clothing that was splashed with either molten brass or iron that are manufactured for molten metal protection you are less likely to receive a 2nd degree burn than clothing that is not. The PPE clothing that are manufactured for molten metal protection, when a burn would accrue after molten iron or brass splash, it would take longer to receive a 2^{nd} degree burn. On average, PPE clothing manufactured for molten iron protection that was burned it would take 2.03 second to receive a second degree burn versus only 1.28 seconds for clothing not manufactured for protection against molten metal when splashed with molten iron. The average of the PPE clothing manufactured for protection against molten metal that was tested with molten brass was 2.4 seconds versus .866 for clothing no manufactured for protection against molten metal protection when tested with molten brass.

As stated in the literature above studies have found that layered fabric increases the protection from molten metal, this was also seen in our some of our results. We found that 9 oz. Greens -Westex when tested with molten iron would receive a second degree, but when carbon X was added under the 9 oz. Greens –Westex (9 oz greens -Westex over Carbon X) the combination together wound prevent a second-degree burn. The other fabrics that was layered and tested with molten iron did not yield the same results (7oz UltraSoft® FR work shirt Westex over cotton long sleeve T shirt, 9oz FR Green Jacket over 7 oz. UltraSoft® FR work shirt Westex, 7 oz. UltraSoft® FR work shirt Westex over 7.7 oz. Carbon X long sleeve shirt). This may because the other combination were made of light weight and thin fabric that could not with stand the molten iron or the fibers that they were made with had low melting points.

The layered fabrics that were tested with molten brass only 2 out of 5 would protect against molten brass splash. Leather Apron Tilman 3124 over 6 oz. cotton work shirt , and Leather Jacket (Cape)-Radnor over Leather apron snap on over 6 oz. Cotton work shirt, were the two PPE clothing that would protect from molten brass splash. This may be due to that the PPE clothing that was layered on top of the combination was manufactured for protection against molten metal. Compared to to11 oz. Cloth Jacket (cape) Steel Grip Woven Kevlar with snap on leather apron-Tilman over 6 oz. cotton work shirt which would receive a 2nd degree burn if splashed with molten brass. In this clothing combination the PPE clothing that was manufactured for molten metal protection was underneath clothing that was not made for molten metal protection.

Previous work found that fabric that weighted more provided better protection against molten metal splash. This was true with the aluminized fabrics tested. The 17oz Aluminized Carbon Kevlar, which was the heavyset aluminized fabric, tested was found to protect against molten iron splash compared to the other aluminized fabric tested. The other two aluminized fabrics would receive a 2nd degree burn if worn but it took 7.7 oz./ sq. yd. Aluminized Norafab 900 Carbon Kevlar longer to received a second degree burn than the 7oz ALUMINIZED PBI/KEVLAR® KNIT when splash with molten iron. This was not seen in all PPE in different weight, both. 9 oz. FR green Jacket and 12 oz. FR Green would receive a 2nd degree burn when splashed with molten iron. Also the time it would take to get a second-degree burn with both fabrics was similar.

All PPE clothing that was treated with a Flame Retardant chemical would receive a 2nd degree burn if splashed with molten metal. This could be because of the type of FR chemical used to treat the fabric, since we know from previous research some chemicals will make the metal adhere. It can also be because all the clothing tested was not manufactured to protect against molten metal. The FR treated fabrics used were also lightweight.

Past studies have shown that when aluminized based PPE clothing provide the best protection for against molten iron. Our results do not support this augment, two out of three of the aluminized PPE clothing received a second-degree burn when splashed with molten. As stated before this may be due to the fact that the two aluminized fabrics that would receive a second degree burn were light weight and the aluminized fabric that would not receive a second degree burn if worn was heaver.

Majority of the survey respondents did not test the PPE clothing before they use them. We also found that the major concern was heat stress, which is why it is important to find lighter weight material to protect the workers from molten metal. We received few responses from the survey sent to EHOS professional. We also had limited selection of EHOS professional that work in foundries, since we only used members of the AFS. To have more respondent the survey should be given at a conference when people will be included to stop. Conferences are also places were professional voice their concerns, so we will get a better insight of what the major problem are with PPE in foundries. The Global Foundry Sourcing Conference is large conferences were we might find willing participants.

CONCLUSION

This study evaluated how well the current Personal Protective Equipment clothing used by a private company protects against molten metal splash. The study wanted to find lighter weight PPE clothing that would protect the worker no matter if they were handling molten metal or not. The study found that 65.4 % of the clothing tested did not protect against molten metal splash. Which says that majority of the clothing should not be worn when employees are working with or around molten metal. The findings show that PPE clothing manufactured for protection against provides better protection than material that was not. The study also found if PPE clothing that is manufactured for protection against molten metal received 2nd degree burn it would take longer to receive that a burn compared to PPE clothing not manufactured for molten metal protection. Which shows that clothing manufactured for molten metal protection is more resistant to molten metal splash.

The study did find PPE clothing that is light weight and that would protect against 2nd degree burns from molten iron in the facilities which include: 10.9 oz. Quantum Coveralls 9 oz. greens -Westex over Carbon X, Body Shield Pants with Leather cover, Body Shield Pants without Leather cover, Body Shield Jacket, and Leather Chaps (Split Cowhide Kevlar sewn)-WELDA. Lightweight PPE clothing was also found for the private company brass facility to uses which include; Leather Apron Tilman 3124 over 6 oz. cotton work shirt and Leather Jacket (Cape)-Radnor over Leather apron snap on over

6 oz. cotton work shirt. This was all suggested to the private company. The private company used this information to take out any clothing that would not protect their workers from molten metal splash.

Using correct PPE clothing when working in hazards job, is vital to an employee survival. When the correct PPE is warren it can reduce the severity of the injury caused by molten metal. Analyzing PPE clothing will help employer chose the best PPE clothing that will protect their workers. Future application of this study should include a larger sample size of PPE clothing from different companies. Since different foundries use different clothing we should evaluate how well they are protecting their worker incase of an accident. Evaluation should also be done on what combination of layering of clothing works best when trying to protect against molten metal splash. To better evaluate which clothing is best to use, heat stress monitoring should be done while clothing is being worn, since the major concern of workers in foundries is heat found in the survey.

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