Abstract

Three types of fires define the thermal environment prevailing in the active workplace - routine, hazardous and emergency. Firefighters face multiple challenges during an operation, making their job risky and potentially dangerous. Turnout suits worn by the firefighters are multilayer assembles of functional fabrics comprising the outer layer (shell fabric), a middle layer (moisture barrier), an inner layer (thermal liner) and a face fabric. The purpose of fire protective clothing is to keep firefighters safe from heat and other hazards. Many investigations have been conducted to learn about and characterize the protective clothing worn by firefighters and others in similar situations. Because the outer layer is the first layer of fire protective clothing, its role and importance are higher because it protects against thermal injuries, trauma, and toxic fumes, and it must therefore have high heat resistance, thermal release rate, and mechanical properties. Properties (Protective performance, mechanical and comfort) and durability (during repeated heat exposure) of the outer layer of fire protective clothing depend on thickness, areal density, porosity, moisture content, heat flux, and air gap or microclimate thickness (distance between the fabric and copper sensor) with horizontal and vertical orientation and structure (weave design). The current level of research on the outer layer of fire protective clothing may be incapable of describing all of the required properties in a single study. As a result, a comprehensive and collective study of the outer layer is more important for improving the performance characterization of the outer layer of fire protective clothing. So, the purpose of this thesis is to a better understanding of the performance characterization of the outer layer of fire protective clothing.

The effects of heat flux intensity, pick density, and air gap between the fabric and the sensor on the outer layer of multilayered turnout suits were investigated. The material was selected because of the superior thermal protection afforded by Nomex IIIA. Benchtop experiments were developed to simulate the conditions firefighters face. Based on a three-factor and three-

level Box-Behnken model, a system equation was developed for the prediction of the protection time (t-protection). An analysis of variance was performed on the predicted values of t-protection obtained for all the experimental blocks in the design space, and the results confirmed that the system equation, along with the coefficients of linear interactive and square terms, is significant, allowing for the efficient use of the system equation in t-protection prediction. The accuracy of the system equation was checked by comparing t-protection and t*-protection which revealed a linear relationship with a high correlation coefficient (R^2 = 0.975). To analyze the effects of the independent variables on protection time, 3D surface response curves were created. The nature of the surfaces was critically analyzed by developing regression equations for the contours and the diagonals. The findings of this chapter motivate further research into the effect of repeated radiative heat exposure (low, medium, and high) on the protective performance of the outer layer of fire protective clothing.

Analysis of the effect of repeated radiative heat exposure (Low, medium and high) on the protective performance of the outer layer of fire protective clothing is more important. Four independent variables were considered: fabric material, pick density, exposure cycles and heat flux intensity. In addition to radiative protective performance (RPP), changes in the thickness, shrinkage, and mass were also tracked. An evaluation of properties was conducted at the end of each cycle to determine the effects of the heat flux (21, 42 and 63 kW/m^2), number of exposure cycles (from one to five) and effects of each attribute. Two types of fabrics were used in this study, one made with meta-aramid (Nomex® IIIA) yarns in both warp and weft (type-A fabric), and the other made with Nomex® IIIA (warp) and para-aramid (Kevlar®)(weft) (type-B fabric). Type-A fabrics displayed a greater degree of differentiation in their properties than Type-B fabrics. A regression analysis conclusively established that pick density significantly affects the performance of the outer layer of fire protective clothing.

The thermal protective performance rating (TPP) allows for the evaluation of thermal protection. Comfort levels were measured by testing the thermal resistance and water vapour transmission rate (WVTR) of a number of different of woven fabric patterns and pick density. Thermal protective performance and comfort performance are more influenced by the fabric's weaving pattern (plain, twill 2/2, twill 3/1, satin, and honeycomb), picks per inch (40, 50, and 60), ply of yarn (2-ply and 3-ply), and type of material (meta-aramid and para-aramid). Thermal protection performance (TPP) of all fabrics were evaluated in response to high levels of heat flux (80 ± 2 kW/m^2 or 2 $cal/cm^2/sec$) of radiative heat and flame exposures (50:50). When compared to other weaves with the same number of picks per inch, the TPP rating of honeycomb weave was found to be high. The TPP rating and fabric areal density are both decreased when changing from three to two yarn plies, but the percentage loss in areal density is high. Honeycomb woven fabrics had good thermal resistance when compared to fabrics with a different weaving pattern. The TPP rating and thermal resistance improved while the WVTR decreased as the number of fabric picks per inch increased across the board for the studied woven structures. The multiple linear regression equation (model) is significant for the TPP rating.

One study aimed to analysis the effects of structural configurations and thread density on the mechanical properties [bursting strength, tensile properties (breaking strength, breaking elongation and fabric assistance), tear strength and seam properties (unsewn fabric breaking strength, sewn fabric breaking strength and seam efficiency)] of the outer shell fabric used in protective clothing of firefighters. The specimen fabric produced with Nomex IIIA yarns, was woven with twill 2/2, 5 end sateen and honeycomb weaves. All samples have the same end density of 42, but the pick density was adjusted to five different levels (40, 46, 52, 58 and 64). The empirical relation between the mechanical properties of fabric and weave structure was established with the help of regression equations. The effect of pick density and weave structures on the mechanical properties of these fabrics was examined using ANOVA statistical analysis. It was observed that for the same picks per inch, weft way tensile strength, elongation and fabric assistance of honeycomb woven fabrics were better as compared to the fabrics of other patterns. At the same picks per inch, sateen woven fabrics have higher tear strength and seam performance than other weaves. The horizontal and vertical orientation of fabrics and moisture content were used to enhance the performance of fire protective clothing. Using surface response methodology, a multi-parametric experimental equation is obtained for calculating H_T and V_T for horizontal and vertical orientation respectively and creating the relationship between process parameters such as moisture content (M: 0% to 100%), heat flux (Q: 21 to 63 kW/m^2) and microclimate thickness (d: 0 to 25 mm). A good correlation coefficient (R^2 = 0.973 and 0.967 for horizontal and vertical orientation respectively) between the two sets of estimates are observed. As fabrics absorb more moisture, a water film forms around solid fibers. As a result, solid fibers cannot absorb more water, leaving free water between them. In dry materials, heat is transferred through solid fibers and air voids. Water has a higher heat conductivity than air.