Modeling Exposures of a Nylon-Cotton Fabric to High Radiant Heat Flux

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ABSTRACT
American soldiers and marines involved in the recent conflicts in Iraq and Afghanistan have suffered increased incidence of burn injury, often as a direct result of exposure to improvised explosive devices. In this work, a one dimensional numerical pyrolysis model for transient heat conduction, incorporating material transformations described by chemical kinetics, is used to investigate the response of the standard 230 g/m^2 Army Combat Uniform (ACU) fabric to high radiant heat fluxes in short duration thermal protection tests and long duration cone calorimeter tests. Thermal protection tests are performed using a Thermal Barrier Test Apparatus--an automated device, incorporating a closed-loop controlled IR radiant heat source, automated water cooled shutter, a fabric sample holder, an adjustable stage with a water cooled Schmidt-Boelter heat flux gauge and a PC based data acquisition system. Cone calorimeter tests are performed on fabric specimens at an exposure heat flux of 25 kW/m^2. In thermal protection tests involving exposures of 90 kW/m^2 for five seconds and 77 kW/m^2 for four seconds, modeling indicated that desorption and evaporation of moisture content has an important effect, but melting of the nylon component and material decomposition had insignificant effects on the heat flux transmitted through the fabric back face. Modeling results for cone testing exhibited good agreement for time to ignition and duration of flaming combustion.

Keywords: cone calorimeter, pyrolysis models, textile fabrics, thermal protection tests

INTRODUCTION
Due to the recent increased incidence of burn injury, providing dismounted soldiers with protection against battlefield flame and thermal hazards has been made a high priority. The standard Army Combat Uniform (ACU) fabric is woven using blended yarns of 50% nylon staple - 50 % cotton fiber. While the fabric provides for a durable and comfortable combat uniform, when caused to burn it is not self-extinguishing, and is therefore not considered flame resistant in the conventional sense of the term's usage in protective clothing. Nonetheless, it is of interest here to investigate its thermal performance characteristics in order to understand conditions under which it may provide sufficient protection. In addition, efforts are underway to develop surface treatments for the ACU fabric through which its flame resistance can be improved; a better fundamental understanding of the base fabric performance is of value.

For a garment to provide flame and thermal protection, both flammability characteristics and thermal barrier performance are important. Ultimately, garment performance is evaluated through testing against flame engulfment conditions on an instrumented standing manikin according to the ASTM F 1930 test method [1]. Prior to that, bench level fabric swatch tests are used to characterize fabric performance. Fabric burning behavior and flammability are evaluated using the Vertical Flame Test (ASTM D 6413 [2]); fabrics that are determined to be self-extinguishing are considered candidates for flame resistant garments. The thermal protection, or thermal barrier performance, of a fabric can be evaluated by bench top tests that expose the outside surface of the fabric to a heat source and measure the heat flux transmitted on the back side of the fabric. A standard version of a thermal protection test, commonly referred to as the Thermal Protective Performance test, is described by ISO 17492 [3]; the fabric swatch is exposed a heat flux of 80 kW/m^2 delivered by a combination of burners and quartz lamps for a sufficient time to produce a theoretical second degree skin burn, as determined by the temperature rise of a copper calorimeter behind the fabric sample. A variety of other instruments and methods are used to evaluate thermal protection of fabrics.

In this work, we use a radiant heat source based device developed for the Army by Physical Sciences Inc., Andover, MA [4] which we refer to as the Thermal Barrier Test Apparatus (TBTA). A key advantage of the TBTA is the ability to test at specific exposure conditions over a range of heat flux levels and exposure durations. The TBTA is an automated device, incorporating a closed-loop controlled IR radiant heat source, automated water cooled shutter, a fabric sample holder, an adjustable stage with a water cooled Schmidt-Boelter heat flux gauge and a water cooled copper block with a mounting location for a second sensor of a design normally used in ASTM F 1930 testing, and a PC based data acquisition system. The stage may be positioned in contact with the back face of the fabric, or set to a prescribed air gap distance. In a thermal protection test, the TBTA exposes the surface of a fabric swatch to a square wave radiant heat flux and measures the heat flux transmitted behind the fabric to the water-cooled sensor. The transmitted heat flux time history is then analyzed using a skin burn injury model to determine the likely severity of injury that would result to human skin protected by the fabric layer.

In the ASTM F 1930 test, one such burn injury model is used to estimate hypothetical injuries based on time series data from 122 sensor locations on the instrumented manikin. The details of the model are described in reference [1]; essential aspects are summarized in the following. ASTM F 1930 adopts the Heriques [5] kinetic approach to thermal injury where a damage rate function is assumed in Arrhenius relation form. The damage rate function is integrated to evaluate the damage state at particular points in the skin tissue; the damage state variable Ω is calibrated such that the value one corresponds to the onset of injury. A standard one dimensional heat conduction equation is used to describe the transient temperature distribution in the tissue, where the heat flux time series data is treated as a surface boundary condition; the calculated skin temperatures are subsequently used to evaluate the damage state. In this work, burn injuries will be predicted for the experimental and simulated thermal protection tests using a version of the ASTM F 1930 burn injury model implemented at the US Army Natick Soldier RD&E Center Ouellette Thermal Test Facility.

The cone calorimeter [6] is widely used to investigate the fire behavior of materials and quantitatively measure aspects of the combustion process. The instrument exposes the top face of a material specimen to a controlled radiant heat flux from a cone shaped radiant electrical heater in the presence of an ignition source until flaming combustion occurs and the specimen ultimately burns out. The oxygen concentration in the exhaust gases is monitored and oxygen consumption calorimetry is used to determine the heat release rate during burning. The specimen holder is supported on a load cell so that the mass-loss rate of the specimen is also obtained. Generally the method is used on material specimens between 6 mm and 50 mm thick but some investigators have begun to apply the method to better understand the combustion process in fabrics [7]. In this work, the cone calorimeter will be used to investigate the response of the nylon-cotton fabric under high radiant heat flux where flaming combustion of the fabric results.

Recent work done in modeling the behavior of fabrics and protective garments in flame and thermal testing has emphasized the thermal protection aspect [8-10]. The fabrics studied have been inherently flame resistant, so fabric ignition has not been considered, and the changes to the fabric induced by the exposure are captured to a limited extent by the use of temperature dependent thermo-physical properties. Torvi and co-workers [8, 9] used the apparent heat capacity approach to model the thermo-chemical reactions involved in desorption and evaporation of water from the fabric and the thermal decomposition of the fibers. Song et al. [10] incorporated temperature dependent fabric thermal conductivity and volumetric heat capacity in their model; property values were determined by applying a parameter estimation method to data from flame test exposures of fabric samples during which surface temperature and back-face heat flux were recorded. Similar to these previous works, the models developed here treat the transient through-the-thickness conduction of heat in the fabric, where the fabric is considered a one dimensional composite slab. The approach in the present work differs in that the individual components making up the fabric are permitted to undergo transformations or reactions, where the reaction rates are governed by chemical kinetics with appropriate exo- or endothermic contributions to the energy balance. Models will be developed for two types of test scenarios: a thermal protection test in the TBTA and a flammability test in a cone calorimeter.

The presence of air gaps between the heat exposed fabric and the human skin or underlying fabric layers has a strong effect on the thermal protection provided. The ASTM F 1930 standing manikin garment test accommodates these air gaps naturally as they develop from the draping of the garment fabric on the human form. Kim et al. [11] have shown that in such tests there is general agreement between patterns of predicted burn injuries and air gap distributions, where burn severity increases as the air gap decreases. Due to the importance of air gaps in thermal protection, the previously discussed works [8-10] included their treatment, and later work has been aimed at improving heat transfer models for air gaps in bench level tests [12]. In this paper, the focus is on development of models for the fabric layer itself; for that purpose modeling and test configurations do not include air gaps.

MODEL DEVELOPMENT

In this work, we adopt the Therma-Kin computational tool; for a detailed description of Therma-Kin, the reader is directed to Ref. [13]. The one dimensional version of Therma-Kin used here was originally developed to model bench-scale fire calorimeter tests of materials [6]. A brief summary of essential aspects follows: The computational tool treats one dimensional transient through-the-thickness conduction of heat and transfer of mass (only gaseous components are considered mobile) in a layered slab-like object. Boundary conditions on the object include time-dependent radiative and convective heat fluxes with possible in-depth absorption of radiation. Each layer of the object may consist of a mixture of components. Optical properties and temperature-dependent thermo-physical properties are assigned for each component and a set of reactions involving the components are specified and described by means of chemical kinetics. The effective thermal conductivity and gas transport coefficient for a material layer are calculated from component properties by interpolation between bounds for a theoretical parallel and series arrangement of components based on an adjustable parameter. Emissivity and absorption coefficients for a material layer are calculated by volume averaging of the component properties. In the sections that follow, the development of the parameters needed to characterize the nylon-cotton blend fabric is described.

Components and Reactions

Components of the fabric in the initial state include nylon 66 fiber, cotton fiber, air, and absorbed liquid water. During heating of the fabric, components experience a variety of transformations: the water desorbs and evaporates as water vapor, the nylon solid melts to a liquid, and, ultimately, the cotton and molten nylon decompose into gases and residual chars. If the fabric experiences a cooling phase, the nylon liquid will crystallize and re-solidify. In this work, these basic transformations are incorporated in the simplest manner possible within the Therma-Kin framework. Each transformation is treated as a first order reaction with Arrhenius behavior assumed for the rate constant, and a limiting temperature. The limiting temperature is usually used as a lower limit to eliminate unnecessary calculations at temperatures where rate constants are nearly zero. An upper limit temperature is used to facilitate the re-solidification transformation of nylon. The following five reactions are used in the model:

$$water \rightarrow water\ vapor$$
$$nylon \rightarrow nylon\ melt$$
$$nylon\ melt \rightarrow nylon$$
$$nylon\ melt \rightarrow 0.88\ nyl\ gas + 0.12\ nyl\ char$$
$$cotton \rightarrow 0.85\ cot\ \ gas + 0.15\ cot\ \ char$$

In the rest of this paper, the above reactions will be referred to as reactions 1 through 5, in the order they are listed above. For reactions 4 and 5, simultaneous TGA-DSC (TA Instruments SDT Q600) was used to quantify kinetic parameters, heats of thermal decomposition, and stoichiometric coefficients. Samples were run in Nitrogen at heating rates of 3 K min^{-1}, 10 K min^{-1} and 30 K min^{-1}. Reaction rate constants were calculated by numerical differentiation of mass loss data, following the procedure described by Stoliarov et al. [14]. Kinetic parameters for nylon melting were roughly estimated from characteristic temperatures and temperature ranges in DSC using the method given by Staggs [15] for first order kinetics. The heat of reaction 1 (desorption and evaporation of liquid water from the fabric), was selected based on information in the book by Morton and Hearle [16].

The Arrhenius equation is written as,

$$k(T) = A \exp\left(-\frac{E}{RT}\right), \tag{1}$$

where R is the gas constant (=8.314 J mol^{-1} K^{-1}) and the temperature dependence of the reaction rate constant k is determined by the values of two kinetic parameters: pre-exponential factor A and activation energy E. The kinetic parameters, heats of reaction, h, and limit temperatures, T, for the five reactions are given in *Table I*, where a negative heat of reaction indicates that the reaction is endothermic, and limit temperatures are lower limits when shown with a parenthetic “L” and upper limits when shown with a parenthetic “U.”

TABLE I. Kinetic and thermodynamic parameters.

Reaction	A, s^{-1}	E, J mol^{-1}	h, J kg^{-1}	limit T, K
1	4.80×10^{3}	3.57×10^{4}	-3.0×10^{6}	298 (L)
2	2.94×10^{66}	6.96×10^{5}	-8.0×10^{4}	515 (L)
3	6.0×10^{5}	4.0×10^{3}	5.0×10^{4}	508 (U)
4	2.47×10^{11}	1.85×10^{5}	-4.0×10^{5}	573 (L)
5	2.65×10^{13}	1.82×10^{5}	-2.0×10^{5}	493 (L)

The upper limit temperature assigned for reaction 3 (re-solidification of nylon) is chosen to be lower than the lower limit temperature of reaction 2 (melting of nylon) to ensure that reactions 2 and 3 are not active simultaneously. It should be noted that the reaction kinetics are not realistic for reaction 3 due to the restriction in Therma-Kin that all reaction rate constants exhibit Arrhenius temperature dependence. The parameters chosen for reaction 3 result in rapid re-solidification of liquid nylon in the fabric when temperature falls below 508 K. The heat of fusion of nylon fibers was quantified for both melting and solidification by conventional DSC using cyclic ramping (increasing temperature / decreasing temperature). Differences between the melting and solidification heats are presumed due to the lower degree of crystallinity in the re-solidified nylon versus the as-manufactured state.

For lack of information, thermo-physical properties of residual chars of cotton and nylon are assumed to be equal to the properties of cotton and nylon in the original state. Gases produced in the thermal decomposition reactions were assumed to have the properties of propane. Furthermore, due to the high surface to volume ratio of textile fibers, it is assumed that the residence time of gases within the fibers may be neglected, i.e., gases move rapidly to the fiber surface and diffuse through the surrounding air. As such, the mass diffusivity of all components was modeled as the diffusivity of CO_2 in air.

Optical Properties

Therma-Kin treats objects as gray bodies. Since the nylon cotton (nyco) fabric is not a gray body, it is necessary to determine an average gray body emissivity corresponding to the radiation spectra to which it will be exposed. The nyco fabric is printed with the Army's Universal Camouflage Pattern (UCP) consisting of the colors Foliage Green, Desert Sand, and Urban Gray; for short wavelengths the reflectivities of the three colors can be quite different, but for wavelengths of one micron and longer differences are small. Reflectivity values for the Foliage Green color, the predominant color in UCP, were used to calculate average emissivities corresponding to the TBTA and cone calorimeter radiant source exposures, where the bank of quartz lamps in the TBTA were treated as a 2300 K blackbody radiator, and the cone heater was treated as a 870 K blackbody radiator. For each case, the average emissivity was calculated by summing weighted emissivity values for half micron wavelength bands, where the weights consist of the fraction of total emissive power contained in that band for the given spectra. The average emissivity was found to be 0.55 for the TBTA and 0.76 for the cone calorimeter. To achieve the correct average emissivity for the fabric slab in the model, each "solid" component (i.e., nylon, cotton, and air) is assigned the desired end value for the emissivity of the fabric. It should be noted that in the Therma-Kin framework, the air contained in a porous fabric must be treated as a solid; gases are mobile.

The nyco fabric is a tightly woven wind resistant poplin construction. Torvi [17] reported transmissivities of 0.6 % or less for flame resistant fabrics (Nomex® IIIA and Kevlar®/PBI) over wavelengths of 2.5 to 17 microns; it was assumed in this work that transmittance effects for the wind resistant nyco fabric may be neglected after a trial calculation indicated that varying transmittance from 0.5 % to vanishingly small values (i.e., by adjusting the absorption coefficient) had no substantive effect on results, but the algorithm used for in-depth absorption of radiant heat lead to noise in the numerical simulation. As such, in this work radiant heat is assumed absorbed at the fabric surface.

The emissivity of the nylon and cotton residual char is assumed to be higher than that of original material. For the TBTA exposure, 0.8 is used and for the cone calorimeter, 0.9 is used.

Thermal Conductivity

The thermal conductivity of the nylon-cotton fabric is determined over a range of temperatures from measurements on pads of multiple fabric layers in a Rapid-k heat flow meter apparatus using a procedure similar to that described by Lawson and Pinder [18]. The effective thermal conductivity of a fabric layer is considered to be linearly dependent on temperature, and it is assumed that the fiber and air components conduct heat in parallel. Using a linear fit to the known conductivity of air, the thermal conductivity of the fibers may be calculated from the following,

$$k_e = k_a V_a + k_f (V_n + V_c) \quad (2)$$

where V denotes the volume fraction of particular components; k denotes thermal conductivity; subscripts a, n, and c refer to the air, nylon, and cotton components; subscript e refers to an *effective* property of the composite fabric; and subscript *f* refers to a property of the *fiber* where no difference may be ascribed based on the fiber type (i.e., cotton versus nylon). Both nylon and cotton components are assigned the thermal conductivity k_f. The volume fraction of air in the fabric was found to be 0.66 as calculated from areal density measurements and thickness measurements of fabric pads under prescribed pressure. The measured fabric thermal conductivity and the component values determined as described by the foregoing are exhibited in *Figure 1*. Note that the measured properties have been linearly extrapolated to higher temperatures.

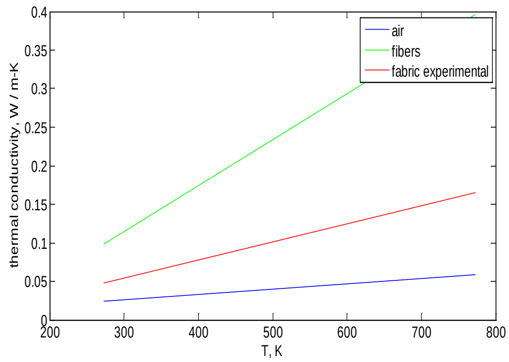

FIGURE 1. Temperature dependence of fiber and air thermal conductivities used in model.

Heat Capacity

The heat capacities of nylon and cotton fibers are modeled as linearly dependent on temperature based on measurements made using the Modulated DSC technique. The samples tested were an Invista® nylon 66 and raw cotton. Using the form $c = p_0 + p_1 T$, where T is in degrees K, and the heat capacity c is in J kg^{-1} K^{-1}, parameter values are given in *Table* II.

TABLE II. Heat capacity parameter values.

fiber type	p_0, J/kg-K	p_1, J kg^{-1} K^{-2}
nylon	467.4725	3.5476
cotton	-626.2873	4.7979

The heat capacity of air entrapped in the porous fabric requires special treatment. As mentioned previously, it is necessary to treat air as a solid without the large temperature induced change in density that occurs in a gas. To achieve correct behavior in the *volumetric* heat capacity (i.e., the product ρc) an artificial heat capacity inversely dependent on temperature is used.

Conditions and Object Structure

For the TBTA test, the flux level and shutter opening and closing times are set to produce a desired square wave exposure. The sensor stage is set to be in contact with the back face of the fabric test specimen.

The Therma-Kin object structure and boundary conditions used to model the TBTA thermal protection test are exhibited in *Figure 2*. The object consists of two layers: the top layer is the 0.6 mm thick fabric specimen, the bottom layer is a 3 mm thick copper slab. The copper layer is intended to model the copper-jacketed Schmidt-Boelter heat flux sensor that will be in contact with the back face of the fabric during TBTA tests. The back face of the copper slab has a convection boundary condition to model the effect of the cooling water circulated to the sensor. The "transmitted" heat flux is determined in the modeling results by numerical differentiation of the predicted spatial temperature distribution in the copper slab. A convection boundary condition is applied to the top face of the fabric to treat natural convection occurring between the heated fabric surface and surrounding air. A square wave radiant heat flux is applied to the top surface of the fabric with the desired flux level and duration.

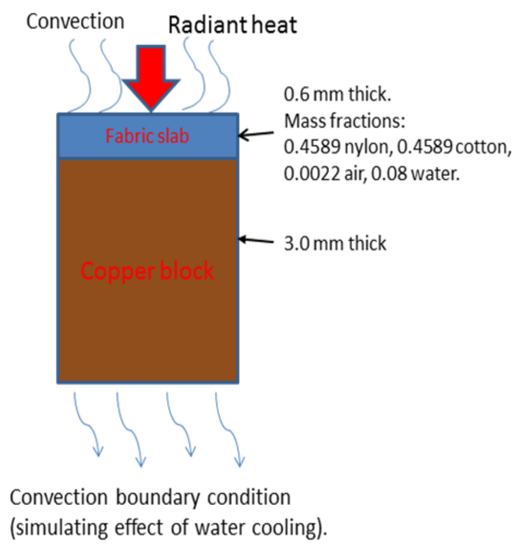

FIGURE 2. Object structure for simulation of test in TBTA.

In this work, the cone calorimeter tests are run at an incident heat flux of 25 kW m^{-2}. In the sample holder, the fabric is backed by aluminum foil and supported on an insulating ceramic wool (Kaowool^{TM}) blanket. For the cone test simulation, the fabric layer was modeled as supported by a 13 mm thick ceramic wool layer with an insulated back-face boundary condition, as exhibited in *Figure 3*. It should be noted that flaming combustion is modeled as an additional heat flux on the sample of 16 kW m^{-2}. Ignition is assumed to occur at a mass flux of 0.5×10^{-3} kg m^{-2} s^{-1}.

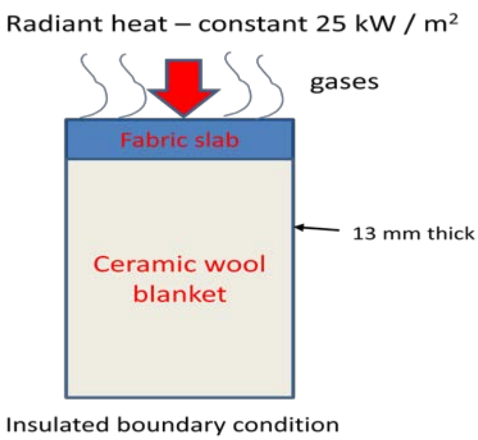

FIGURE 3. Object structure for simulation of flammability test in cone calorimeter.

RESULTS AND DISCUSSION

Experimental and modeling results for a thermal protection tests are exhibited in *Figure 4 and Figure 5*. In *Figure 4*, the fabric swatch is exposed to a square wave heat flux pulse of nominal intensity 90 kW m^{-2} and five seconds in duration in the TBTA. The heat flux transmitted through the back face of the fabric is measured by a Schmidt-Boelter gauge in contact with the back of the fabric specimen. The two experimental replicates shown agree well with modeling results for initial moisture contents of 0.04 and 0.08 mass fractions during the heating phase. Modeling results under predict flux slightly during the cooling phase. TGA results on nyco fabric specimens under normal indoor conditions in our laboratory indicate that initial moisture content is between 0.03 and 0.05 mass fraction.

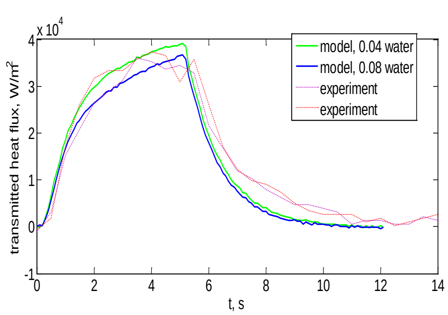

FIGURE 4. Thermal protection test in TBTA, 90 kW/m^2 incident heat flux, 5 s duration. Solid blue line – model, high moisture. Solid green line – model, moderate moisture. Lines with symbols – experiments.

In *Figure 5*, the fabric swatch is exposed to a square wave heat flux pulse of nominal intensity 77 kW m^{-2} and four seconds in duration in the TBTA. For this case, modeling results slightly over predict peak transmitted heat flux.

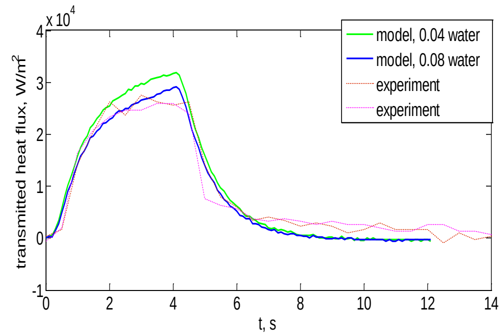

FIGURE 5. Thermal protection test in TBTA, 77 kW/m^2 incident heat flux, 4 s duration. Solid blue line – model, high moisture. Solid green line – model, moderate moisture. Dotted lines – experiments.

Desorption and evaporation of moisture in the fabric requires a significant amount of heat energy. As such, simulation results indicate moisture content has an important effect on the heat flux transmitted through the fabric back face, as can be seen in the modeling results in *Figures 4* and *5*, where a simulated fabric with high moisture content is seen to transmit a somewhat lower back face heat flux. The experiments in the present work, conducted without controlled environmental conditions and specimen conditioning, cannot provide corroboration for the predicted moisture effect; an extensive experimental study under a wide range of controlled humidity and associated equilibrium fabric moisture content would be of great value.

Agreement between the measured and predicted transmitted heat flux is best during the early portion of the radiant heat exposure, the first one and a half seconds or so. This may be expected since during this early period fabric temperature is still relatively low. As a result, fabric thermal conductivity is acting within the temperature range over which characterization measurements had been made, and temperatures are too low for much in the way of thermally driven changes to occur. In the later stages of heating the fabric may be expected to exhibit more complex behavior and agreement with the present simulations is less compelling. Further refinement of the model, supported by extensive corroborating experiments, is needed to improve the accuracy of the predicted transmitted heat flux during the late heating period.

Modeling results show that melting of the nylon component in the fabric does not significantly affect the back face transmitted heat flux for the conditions considered here (i.e., water-cooled sensor in contact with fabric back face). Results for a fabric where nylon melting has been suppressed are compared with the case where melting is permitted in *Figure 6*. In these results the fabric is given low initial moisture content, 0.02, to promote difference between the melting and non-melting cases.

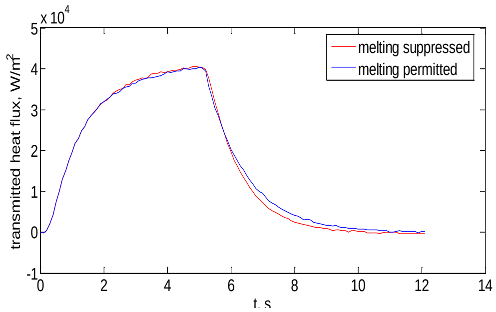

FIGURE 6. Thermal protection test in TBTA, 90 kW/m^2 incident heat flux, 5 s duration. Solid blue line – model, low moisture, nylon melting permitted. Solid red line – model, low moisture, nylon melting surpressed.

The conditions selected for the thermal protection tests are in the range normally dealt with for single layer protective clothing: for example, the standard test performed to evaluate garments, ASTM F 1930, requires a four second long exposure with an average heat flux of 84 kW m^{-2}. Such conditions simulate a flash fire. The modeling results for the four and five second exposures indicate thermal decomposition of cotton and nylon did not affect transmitted heat flux. Examination of mass flux results showed that decomposition of nylon was insignificant and peak mass fluxes for cotton ranged from 1 to 1.6 × 10^{-5} kg m^{-2} s^{-1}.

A skin burn injury model [1] was used to quantify the hypothetical injury that would result from the transmitted heat flux in the thermal protection test. For the 77 kW m^{-2}, four second experimental exposures, moderate partial thickness 2nd degree burns were predicted, with the tissue predicted to be burned to a depth of 253 and 312 microns. For the transmitted heat fluxes obtained from the thermal protection test model, partial thickness 2nd degree burns were also predicted, but tissue burn depths were somewhat deeper, 312 and 445 microns for assumed fabric moisture contents of 0.08 and 0.04 mass fractions, respectively. The deeper injury predictions are consistent with the higher heat fluxes seen in the modeling results as exhibited in *Figure 5*.

Cone calorimeter tests were performed at an incident heat flux of 25 kW/m^2. In the sample holder, the fabric is backed by aluminum foil and supported on an insulating ceramic wool (Kaowool^{TM}) blanket. For the cone test simulation, the fabric layer was modeled as supported by a 13 mm thick ceramic wool layer with an insulated back-face boundary condition. It should be noted that flaming combustion is modeled as an additional heat flux on the sample of 16 kW/m^2. Ignition is assumed to occur at a mass flux of 5×10^{-4} kg/m^2-s.

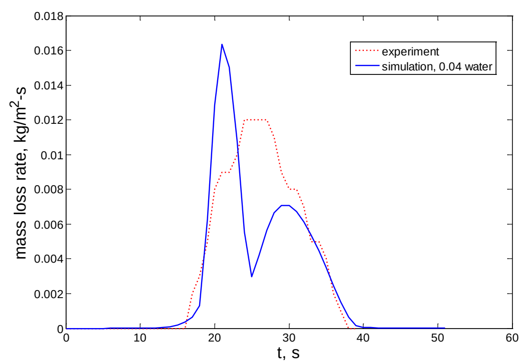

FIGURE 7. Cone calorimeter test, 25 kW/m^2 incident heat flux. Solid blue line – model, moderate moisture. Dashed red line – typical experimental results.

The modeling results for mass loss rate (*Figure 7*) are seen to be separated into two peaks, the earlier peak consisting of cotton and the later more gradual peak consisting of nylon. This behavior is not seen in the experimental results. A partial explanation may be the oversimplified decomposition reaction assumed in the model, where cotton is taken as decomposing in a single step, whereas TGA experiments indicate a second slower decomposition step occurring. It should be noted that the fabric specimens buckled up toward the cone heater somewhat during the exposure and therefore did not experience a spatially and temporally uniform radiant exposure. Time to ignition is 15 s in the simulation in agreement with the experimental results; the total duration of flaming combustion is also captured by the simulation.

CONCLUSION

A one dimensional numerical pyrolysis model has been used to investigate the response of a 230 g/m^2 50/50 nylon-cotton blend fabric to high radiant heat fluxes in bench level thermal protection and flammability tests. The fabric is treated as a composite slab where the individual constituents are permitted to undergo transformations or reactions, with reaction rates governed by chemical kinetics and appropriate exo- or endothermic contributions to the energy balance. The models for two scenarios, a thermal protection test and a flammability (cone calorimeter) test, were compared to experimental results. Good agreement was obtained for the thermal protections tests at two different exposure intensity levels and agreement was fair for the cone test with good reproduction of time to ignition. The simulation results indicate that, for thermal protection tests desorption and evaporation of moisture play an important role but other forms of material transformation do not significantly affect the nylon-cotton fabric's protective function as evidenced by the transmission of heat to a sensor in contact with the back face of the fabric.

ACKNOWLEDGMENT

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