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FLAMMABILITY ANALYSIS OF MILITARY FABRICS

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Abstract:

There are many types of fabric materials used in military applications. From clothing to protective equipment, fabric analysis mostly focused on its physical properties. Still, its flammability has not been well studied, such as ease of ignition, heat release, and toxicity. This paper reports the flammability properties of fabric in military applications. The ignition time, heat release, and smoke production of six commercially available military fabrics are discussed in this article. The fabrics analysed are cotton, polyester-cotton, coated nylon, and kenaf fabric. The fabric grouping into the coated and printed fabric while cotton and kenaf were tested as a comparison. Results indicated that coated fabric (N420D and N1000D) showed higher TTI compared to printed fabric (P35C65, P35C65M, and P65C35). It is affected by heat flux, the areal density of the sample, sample mass, and the number of sample layers. Coated fabrics (N420D and N1000D) indicate higher EHC compared with other fabrics. For printed fabric, a relatively lower EHC was observed as it indicates incomplete combustion. Total heat release of the samples tested was presented as an integration of the HRR vs time curve. Coated samples show the highest values for PHRR and THR values compared to printed and cotton fabrics.

Keywords: flammability; cone calorimeter; smoke density; heat release rate.

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1. Introduction

There is large category of fabric used in military. Not limited to their multi types of uniforms, there are other military essential materials, such as individual protective equipment, tentage, metal bed folding, and firearms textiles. There are also special types of clothing that require special properties such as fire-retardant tank suits, flight suits, anti-riot suits, and EOD. Through the recent years there are growing demand for improved functionalized textile materials. The advancement covers areas of camouflage protection (Samolov et al., 2020), environmental hazard, biological, chemical and radiation and many more. Camouflage protection is still one of the main problems related to the protection of military personnel and equipment in so-called hostile environments. Military fabric consists of material used for clothing, personnel protective, shelter, field bedding, and many more. Currently Polyester/Cotton printed fabric comfortably used by Malaysian Army as combat uniform in tropical environment. Nylon-based coated fabric used as tentage fabric or combat webbing, thanks to their water resistance. Recently, natural fibre such as kenaf also used in military for armoured vehicle spall-liner application (Yahaya et al., 2016).

To improve the safety and comfort of the users, there are increasing use of flame retardant (FR) textiles, mainly in work clothing such as in firefighter apparel, bedding and military garments. However, there are concern about the toxicological and environmental effect of such chemical in the fabric finishes (Ceylan et al., 2013). Flame retardancy is one of the smart functions inserted into textile fabrics to improve user comfort (Elsayed et al., 2020). This study was one of a series of separate projects to develop new smart fabrics for military applications.

The cone calorimeter is one of the most used in polymer fire behaviour analysis. It is based on the measurement of the decreasing oxygen concentration in the combustion gases of a sample subjected to a given heat flux (in general from 10 to 100 kW/m^2) (Dewaghe et al., 2011). Although textiles were classified as thermally thin materials cone calorimeter remains a useful tool to characterize the fire performance of textile materials (El Gazi et al., 2021). There are various research work reported based on cone calorimeter analysis (White et al., 2013; Luo et al., 2014; Xu et al., 2020; Nazaré et al., 2002).

Morgan and Yip (2016) reported their findings on the effects of laundering on military uniform fabric flammability. Heat release data from cone calorimeter analysis determine the blast and fire damage properties of military fabric (Morgan & Yip, 2016). Hernandez et al. (Hernandez et al., 2018) have studied the effect of mass per unit area of polypropylene fabric by using cone calorimeter analysis. They observed the areal density affect significantly with the flammability parameters such as TTI, pHRR, or FGR after ignition).Several parameters affecting reproducibility and repeatability of the cone calorimeter data determined

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as heat flux, the temperature of ceramic backing pads and retaining grid used during sample mounting, sample weight, the density of textiles, and the relative humidity (Tata et al., 2011). Cone calorimetry has been developed for evaluating HRR and other related parameters, and it has been widely used in predicting the fire hazard of different materials as standard international testing methods (Yang & He, 2011).

In this study, we investigated the flammability properties of military fabric using cone calorimetry. This work reports an initial investigation into the use of the cone calorimeter for measuring the heat release parameters of untreated military fabrics.

2. Experimental

2.1. Fabrics

The flammability of commercially available fabric used in military applications has been investigated. Samples were conditioned at an ambient temperature and humidity for 48 h before testing. Fabrics were tested as received; no laundering or treatment was performed. Coated fabric (N420D, N1000D) used by military as tentage fabric, metal folding bed, and pack large (backpack). Fabric for military clothing usually printed in digital camouflage patterns. It consists of printed fabric made of slightly different material composition. For comparison, neat cotton and kenaf fabrics were also analysed in this study. The main properties of these samples are listed in Table 1. Kenaf properties were tested previously by Yahaya et al. (Yahaya et al., 2014). Based on ISO 8096, coated fabric is a material composed of two or more layers, at least one of which is a textile material (woven, knitted, or non-woven) and at least one of which is a substantially continuous polymeric film, bonded closely together by means of an added adhesive or by the adhesive properties of one or more of the component layers. Printing is a process of decorating textile fabrics by application of pigments, dyes, or other related materials in the form of patterns. Military fabric printed with camouflage pattern for camouflaging purposes.

Table 1: Main characteristics of fabric samples tested in this work.

Sample	Area Density (g/m^2)	Thickness (mm)	Fabric Structure
N1000D	352	0.53 (0.01)	Coated Fabric
N420D	224	0.34 (0)	Coated Fabric
P35C65	242	0.36 (0.01)	Printed Fabric
P35C65M	216	0.40 (0.01)	Printed Fabric
P65C35	238	0.46 (0.01)	Printed Fabric

2.2. Method

Cone calorimeter (FESTEC International Co., Ltd., Korea) (Figure 1) was employed to evaluate the combustion properties of fabric materials used in military according to ISO5660. The data reported in this paper includes the following measurements: heat release rate (kW/m^2); peak heat release rate (PHRR) (kW/m^2), time to PHRR (s); total heat released (THR) (MJ/m^2); average effective heat of combustion (MJ/kg); average mass loss rate. Prior to testing, all the samples were conditioned at 50% relative humidity for at least 24 h at 23 °C. The samples were tested on the standard 13mm thick low-density refractory blanket with the samples of 100 mm×100 mm which is wrapped in aluminum foil to avoid heating over the samples side. Single layer fabric was tested for most of the analysis except for multi -layer samples; it was tested at 35 kW/m^2 heat flux. Metal grids were used to prevent sample warping and to avoid big changes in burning surface area (Figure 2). The surface area of the samples, about 88 mm^2 exposed to an external heat flux. Flame-out was recorded as the flame was extinguished and testing was stopped as the flame -out time was recorded.

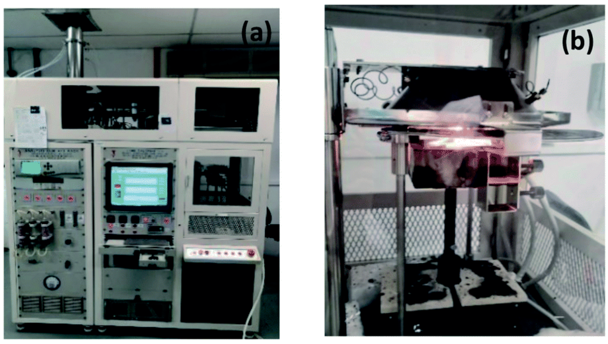

Figure 1: Cone calorimeter (Chee et al., 2020).

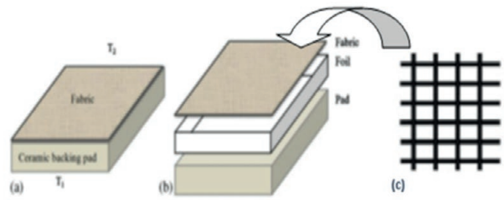

Figure 2: Sample positioned over the backing pad for the cone test (a). Sample assembly (b).(Tata et al., 2011), metal grid (c).

Heat release rate is determined based on the oxygen depletion principle, utilising the fact that heat release per unit mass of oxygen consumed is approximately independent of the type of fuel, and has a value of 13.1 MJ/kg, with an error of 5%. It is calculated from the oxygen concentration in the flue gases based on the principle that the heat released from a fuel is proportional to the oxygen consumed during combustion (Huggett, 1980). The heat release rate calculated following ISO5660 (Xu et al., 2017):

$$\dot{q}''(t) = \frac{\dot{q}'(t)}{A} = \frac{1.1c}{A}\,\frac{\Delta H_c}{r_0}\sqrt{\frac{\Delta P}{T_e}}\left[\frac{X_{O_2}^{0} - X_{O_2}(t)}{1.105 - 1.5X_{O_2}t}\right] \quad (1)$$

where

$\frac{\dot{q}'(t)}{A}$= HRR per aera (kW/m^2)

ΔH_c= heat of combustion (kJ/kg)

1:10 = ratio of oxygen to air molecular weight

r_0= stoichiometric oxygen/fuel mass ratio

ΔP= orifice meter pressure differential

T_e= absolute temperature of gas at the orifice meter

$X_{O_2}t$ = oxygen analyser reading, mole fraction of oxygen

$X^0_{O_2}$= initial value of oxygen analyser reading

Based on ISO 5660, the result generated includes parameters such as time to ignition (TTI) and peak heat release rate (PHRR). The peak of the HRR curves (PHRR) indicates the highest heat release of the test period. Total heat release (THR) is the integration of the HRR vs. time curve which is expressed in kJ/m^2. The yield of combustion gases was measured with a CO and CO_2 analyser. Smoke production was analysed by measuring how the smoke attenuated a laser beam in the exhaust duct. The attenuation is related to volume flow, resulting in a measure of smoke density called smoke extinction area (SEA) having units of m^2/s. The ranges of the paramagnetic oxygen analyser, CO analyser and CO_2 analyser were 0–25%, 0–10% and 0–1%, respectively. The gas analyser is required to be calibrated prior to testing. Basically, the analysis of cone calorimeter data is printed out form the software and graphically as shown in Figure 3.

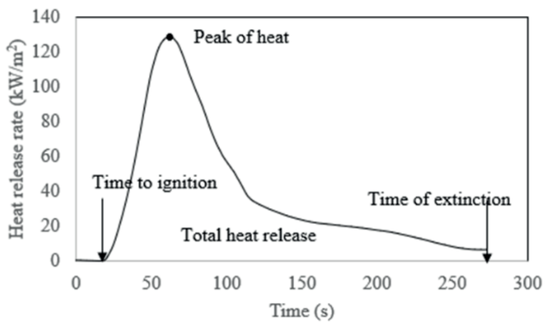

Figure 3: Typical heat release rate versus time curve based on kenaf fabric tested at 35 kW/m^2.

In the HRR vs time curve (Figure 3), after ignition time (19 s), heat release rate increases with the oxygen consumed; this means that a lot of oxygen is consumed immediately after ignition and here the peak heat release rate is then found. The PHRR is about 120 kW/m^2 and occurred around 47 s after ignition. The heat release rate then drops until the time of extinction. Data on heat release curves for neat natural fibre kenaf fabric tested at various heat flux levels are presented in Figure 4. It clearly indicates a reduction in PHRR as heat flux levels are reduced.

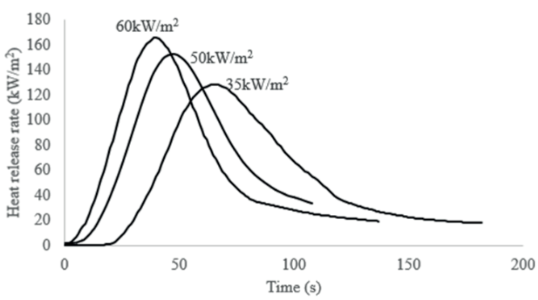

Figure 4: Heat release curves for kenaf fabric tested at various heat flux level.

3. Results and discussion

Heat flux levels for cone calorimeter analysis are normally selected based on fabric application and expected fire scenario. The heat flux of 25 kW/m^2 was applied in previous study (Godfrey et al., 2016) the 35 kW/m^2 level is often associated with a mild fire exposure, and the 50 kW/m^2 level is likewise associated with a well-developed fire. Other heat flux values used in fabric study are; 20 and 30 kW/m^2 (Bei et al., 2012); 20 to 60 kW/m^2 (based on type of fabric) (Nazaré et al., 2002), 25 to 75 kW/m^2 (El Gazi et al., 2021) and 20, 30, 50 kW/m^2 (White et al., 2013), while 85 kW/m^2 used by (Morgan et al., 2016) to analyse laundering effect of fire retardant finished military uniform. In this study, Heat flux levels of 35, 50 and 60 kW/m^2 at about 500, 700 and 750 ºC respectively. Other researchers suggested the heat flux of 35 kW/m^2 to ensure reproducible and significant data (Tata et al., 2011).

3.1. Combustion properties

The samples for cone calorimeter analysis listed in Table 1 were conducted at three heat flux levels: 35, 50 and 60 kW/m^2. The combustion properties of the samples are reported in related tables and plots. Table 2 presents the ignition-related results for cone calorimeter analysis of military fabric. Initial mass is the mass of the sample prior to testing, while mass at sustained ignition is recorded as ignition occurred. Sample mass different recorded because of process by which the solid transforms into gas phase fuel (pyrolysis) before ignition occurred.

Table 2: Ignition-related results.

Sample	Heat Flux (kW/m^2)	TTI (s)	Initial mass (g)	Mass at sustained ignition (g)
N420D	35	34.00 (5.65)	2.05 (0.07)	1.70 (0.14)
	50	15.67 (2.52)	2.20 (0.26)	1.67 (0.61)
	60	11.33 (0.58)	2.30 (0.17)	1.90 (0.20)
N1000D	35	28.00 (2.83)	3.35 (0.21)	3.20 (0)
	50	14.00 (1.00)	3.80 (0.44)	3.33 (0.23)
	60	11.00 (1.00)	3.47 (0.12)	2.97 (0.40)
P35C65	35	9.50 (0.71)	1.80 (0.57)	1.55 (0.35)
	50	5.67 (0.58)	2.07 (0.21)	1.63 (0.25)
	60	4.67 (0.58)	2.43 (0.32)	2.20 (0.26)
P35C65M	35	16.50 (0.71)	2.25 (0.21)	2.00 (0.28)
	50	7.67 (1.15)	2.43 (0.35)	1.80 (0.26)
	60	5.67 (0.58)	3.10 (1.68)	1.83 (0.05)
P65C35	35	14.50 (2.12)	2.20 (0.28)	2.00 (0.28)
	50	9.33 (2.52)	2.43 (0.23)	1.67 (0.40)
	60	7.33 (0.58)	2.43 (0.06)	2.03 (0.15)
Cotton	35	14.00 (5.00)	1.33 (0.05)	0.9 (0.36)
	50	6.67 (1.53)	1.27 (0.12)	0.97 (0.12)
	60	4.67 (1.15)	1.27 (0.06)	1.00 (0)

3.2. Time to ignition

Time to ignition (TTI) is very important factor in determining the burning behaviour of materials, such as fabrics. Shorter TTI means the easier the fabric to ignite and spread as a treat to the surrounding materials. TTI defines how quickly flaming combustion of a material will occur when exposed to a heat source. From the data shown in Table 2, we can see that TTI for some of the samples decreased as heat flux increased. Generally, coated fabric (N420D and N1000D) shows higher TTI compared to printed fabric (P35C65, P35C65M, and P65C35). Coated fabric takes about 11 to 34 s to ignite as exposed to 35 kW/m^2 heat flux. While printed fabric ignited at 7.33 to 16.50 s after being exposed to heat flux. Printed fabric shows moderate flammability in terms of ignition time when compared to cotton fabric, which takes 4.67 s to 14 s before being ignited. When exposed to heat flux, the coated materials melt first, start decomposing with the release of smoke before being ignited. Even without a fire-retardant additive, the coating material affects the flammability process of fabric. TTI of coated fabric is longer because of the longer time required for the volatile gases to escape from coated materials at the exposure side (coated surface). The TTI is roughly affected by sample weight increases. The longer TTI was observed as the initial weight of the sample as shown in Figure 5.

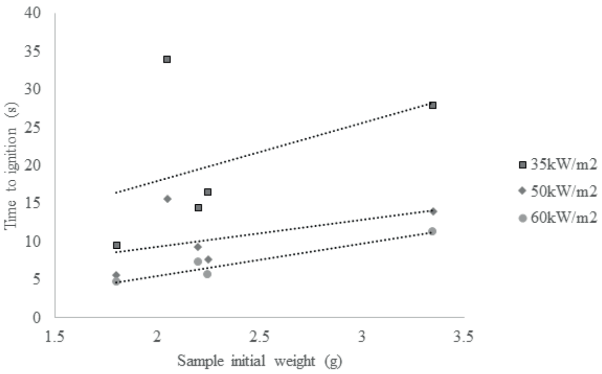

Figure 5: Time to ignition (TTI) versus initial weight of samples.

Figure 6 presents the time to ignition based on number of fabric plies tested at 35 kW/m^2 heat flux. Most of the samples take longer time to ignited as the number of fabric layers increased. Figure 7 dictate that TTI is shorter as the heat flux value increased. Similar result observed for composites materials (Fateh et al., 2017).

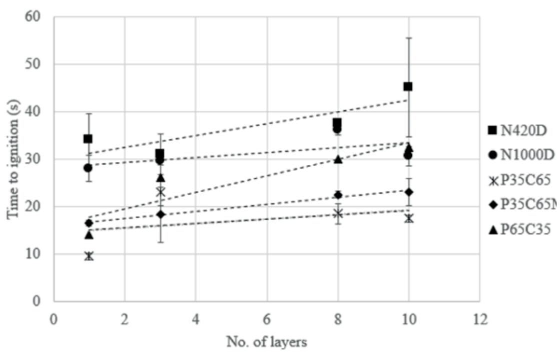

Figure 6: Time to ignition vs. number of fabric layers.

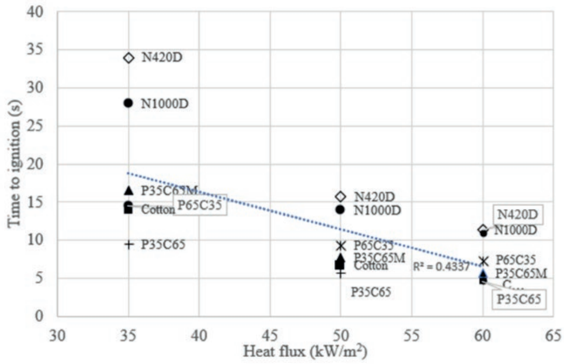

Figure 7: TTI vs. heat flux.

3.3. Heat release rate

Heat release rate (HRR) is the most important variable in characterizing the flammability of products and their consequent fire hazard (Babrauskas & Peacock, 1992). HRR is measured in terms of power or as surface area normalized HRR (kW/m^2). The HRR determination follows the ISO 5660-1, where it is important to give the imposed irradiance (heat flux) in kW m^{-2} on the cell. Normally HRR values are given as the mean HRR which is determined by dividing the total heat energy released, by the fire duration. In this study, the HRR curves of coated, printed fabrics and cotton fabric under different heat fluxes are plotted in Figure 8-Figure 10.

Sample tested burned quickly after ignition and mark a peak heat release rate (PHRR) value. Based on the plots, heat release rate increased gradually until it reaches the highest point (peak) and dropped until test ended as the flame-out occurred. Single peak observed in HRR curves for coated and printed fabric tested. The similar pattern observed for PET-cotton 65:35 as reported by Alongi et al. (Alongi et al., 2015). Based on Alongi et al., peak HRR for untreated PET−cotton (PET:cotton = 85:15) is 150 ± 1 kW/m^2 higher than recorded in this study (78.04 ± 3.76 kW/m^2). The differ due to the content of polyester in the samples. Other factor is the weight of the fabric per unit area (Kotresh et al., 2006). The average heat release rate represents the average level of heat material releases in fire. The bigger the average heat release rate is, the more violent the material burns (Bei et al., 2012).

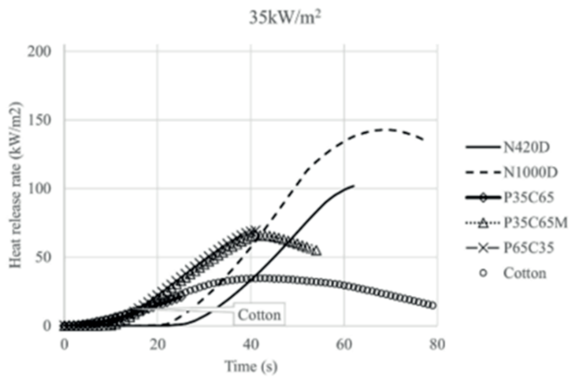

Figure 8: HRR curves at 35kW/m^2 heat flux.

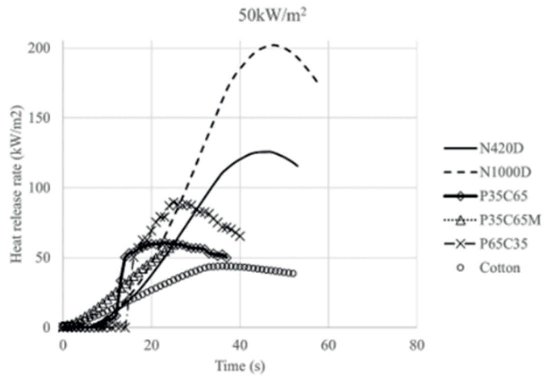

Figure 9: HRR curves at 50kW/m^2 heat flux.

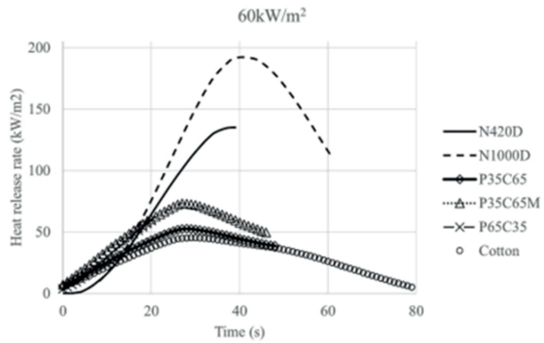

Figure 10: HRR curves at 60kW/m^2 heat flux.

Table 3 presents the cone calorimeter testing data. The effective heat of combustion (EHC) is the energy generated by combustion reactions per unit mass of fabric samples. Based on ISO 5660, it is calculated as the ratio of the total heat release rate to the mass loss. This value indicates the burning intensity of the volatile compounds in the flame.

The effective heat of combustion (ECH) of the military fabric is given in Table 3. EHC almost remains constant at all applied heat fluxes. Coated fabrics (N420D and N1000D) indicate higher EHC compared with other fabrics. For printed fabric sample CER (P35C65)- relatively lower EHC observed as it indicates incomplete combustion at the tested heat flux. Lowest EHC observed in cotton fabrics. However, the small mass of samples may affect the data accuracy as well as the presence of moisture as reported in Moinuddin et al., (Moinuddin et al., 2020) the effective heat of combustion which in turn affects the simulation outcome.

Peak heat release rates for the sample tested occurred after ignition and just before the flame-out. PHRR is the point where the material is burning most intensely and is therefore also important for the estimation of the fire cascading effect. In this study, PHRR increased with heat flux increases. The integration of the HRR vs. time curve gives the total heat release (THR) expressed in kJ/m^2. The peak HRR for coated fabrics (N420D and N1000D) samples is higher compared to other samples. The highest peak for N1000D is 170, 213 and 227 kW/m^2 for heat flux of 35, 50 and 60 kW/m^2 respectively. The peak and average heat release rates increased with increasing heat flux while the time to the initial peak decreased. Figure 12 to 14 shows the THR based on heat fluxes.

Table 3: Heat release-related results.

Sample	Heat Flux (kW/m^2)	Effective heat of combustion (MJ/kg)	PHRR (kW /m^2)	THR (MJ /m^2)	time of PHRR (s)
N420D	35	8.77 (1.01)	122.22 (9.28)	4.00 (0.71)	70.00 (4.24)
	50	6.62 (1.12)	150.42 (9.36)	5.73 (0.45)	45.33 (1.53)
	60	6.76 (2.93)	162.10 (5.04)	4.33 (2.12)	35.33 (1.52)
N1000D	35	8.62 (2.88)	170.67 (23.65)	8.25 (0.49)	65.50 (0.71)
	50	6.08 (1.66)	213.69 (21.43)	8.47 (0.38)	43.67 (1.53)
	60	7.55 (1.42)	227.59 (8.01)	8.43 (0.06)	36.00 (2.64)
P35C65	35	1.14 (0.31)	40.94 (6.36)	1.55 (0.64)	31.00 (7.07)
	50	2.69 (0.54)	62.47 (1.92)	1.97 (0.60)	23.33 (1.53)
	60	3.02 (1.52)	64.23 (2.81)	2.40 (0.44)	20.00 (1.00)
P35C65M	35	2.44 (0.13)	71.17 (5.37)	2.95 (0.07)	36.50 (0.71)
	50	5.89 (1.52)	84.46 (1.01)	1.93 (0.49)	26.33 (1.53)
	60	3.19 (0.07)	89.40 (2.98)	3.30 (0.10)	22.00 (1.73)
P65C35	35	2.57 (1.51)	78.04 (3.76)	2.90 (0.28)	37.50 (0.71)
	50	7.38 (1.08)	91.24 (1.73)	2.03 (0.12)	27.33 (3.21)
	60	4.54 (1.40)	95.09 (1.46)	2.50 (0.85)	26.67 (2.08)
Cotton	35	0.653 (0.14)	38.30 (4.73)	1.93 (0.40)	39.33 (4.93)
	50	1.91 (0.62)	47.40 (1.07)	1.63 (0.7)	29.00 (3.46)
	60	0.83 (0.17)	49.25 (1.77)	2.37 (0.12)	25.33 (5.03)

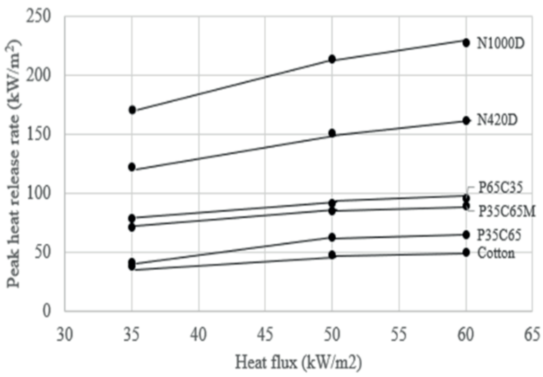

Figure 11: PHRR vs heat flux

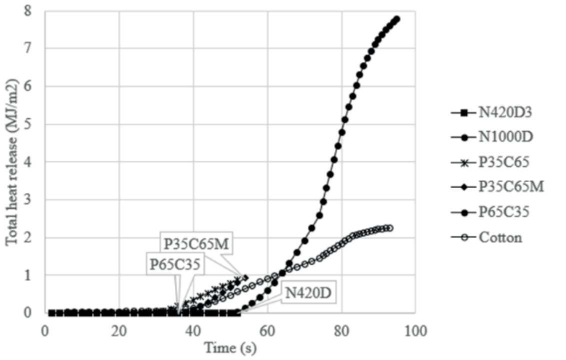

Figure 12: Total heat release of fabric tested at 35 kW/m^2.

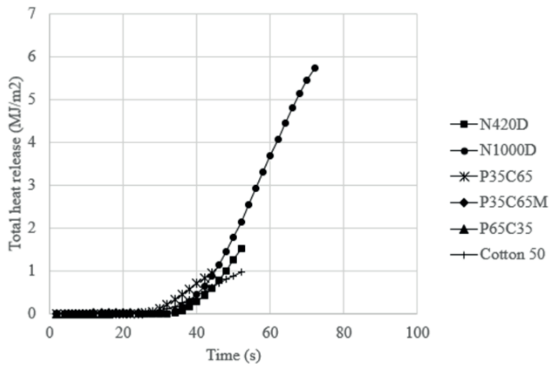

Figure 13: Total heat release of fabric tested at 50 kW/m^2.

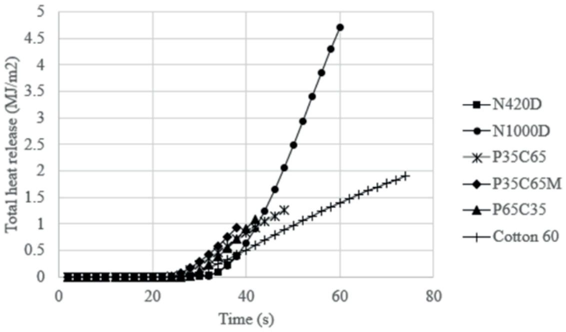

Figure 14: Total heat release of fabric tested at 60 kW/m^2.

Based on this study, THR of sample Nylon 1000D > Nylon420D > P65C35 > P35C65M > Cotton > P35C65. Polyester/cotton fabric shows higher THR compared with pure cotton fabric. This was explained as the effect of interaction between cotton, and synthetic fibres (Chen & Zhao, 2016). Four of the samples tested were made of the same material composition but were relatively different in areal density. It was found that THR of Nylon 1000D (352 g/m^2 > Nylon420D (224 g/m^2 > P35C65M (216 g/m^2) > P35C65 (242 g/m^2).

3.4. Mass loss

Mass loss rate is the rate of changes in sample mass during combustion. It shows the level of pyrolysis, volatilization, and burning of sample under constant heat flux (Xu et al., 2017). Table 4 shows the mass loss properties of the sample tested in this study. Higher mass loss rate indicates the sample is easier to burn, thus greater risk of fire. Figure 15 shows the mass loss rate of coated fabric (N1000D) tested in this study. Mass loss is roughly correlated with heat release rate because it is the rate at which the test material is degraded to produce combustible fuels. This is not significant for other samples due to the small weight of the sample tested (White et al., 2013).

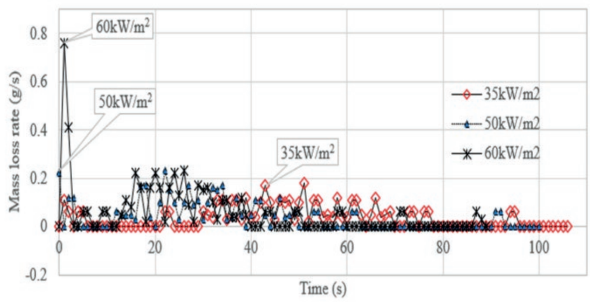

Figure 15: MLR curve of coated fabric (N1000D)-sample at various heat flux.

Table 4: Mass loss.

Sample	Heat Flux (kW/m^2)	Initial Mass (g)	MLR$_{ave}$ (g/m^{2}s)
N420D	35	2.05 (0.07)	4.78 (0.71)
	50	2.20 (0.26)	3.94 (0.59)
	60	2.30 (0.17)	5.50 (2.95)
N1000D	35	3.35 (0.21)	4.10 (0.95)
	50	3.80 (0.44)	4.51 (0.38)
	60	3.47 (0.12)	4.96 (0.83)
P35C65	35	1.80 (0.57)	2.82 (1.13)
	50	2.07 (0.21)	4.40 (0.60)
	60	2.43 (0.32)	3.82 (0.44)
P35C65M	35	2.25 (0.21)	3.14 (0.06)
	50	2.43 (0.35)	6.27 (1.27)
	60	3.10 (1.68)	3.68 (0.15)
P65C35	35	2.20 (0.28)	2.89 (1.57)
	50	2.43 (0.23)	6.75 (0.07)
	60	2.43 (0.06)	6.22 (2.53)
Cotton	35	1.33 (0.05)	1.69 (0.51)
	50	1.27 (0.12)	3.51 (1.61)
	60	1.27 (0.06)	1.87 (0.25)

3.5. Smoke production

Burning textiles and toxic fumes generated in confined spaces, for example in armoured vehicles, are one of the threats to military personnel (Grover et al., 2014). Table 5 presents the smoke production rate of fabric samples at heat flux, respectively. Specific extinction area (SEA) and total smoke production (TSP) are the two parameters that determine the smoke production of fabric. SEA is defined as the ratio of the extinction area of smoke to the mass loss of the specimen associated with the production of that smoke (ISO5660). This parameter reflects the quantity of smoke during the combustion process of the fabrics tested. It varies as a function of time during the test; therefore, the average SEA values used in this study. Figure 16 presents the average SEA versus the average HRR. The SEA value for most of the fabric samples generally changes linearly with the average HRR. This observation indicates that the smoke produced is strongly related to the heat release rate (Mouritz et al., 2006).

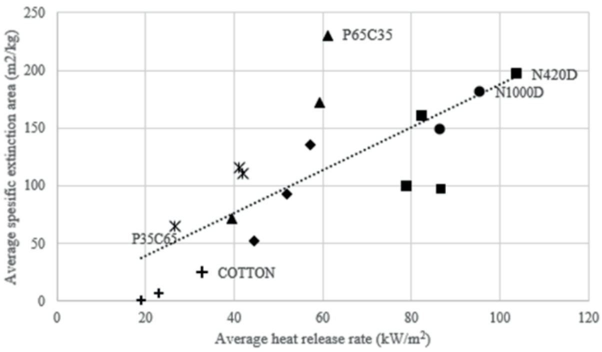

Figure 16: Average SEA vs. average HRR.

Total smoke production from military fabric is reported in Table 5. Sample N1000D was observed as mostly producing smoke compared to other fabric. Printed fabric produced total smoke release between 57.1 to 68.53 m^2/m^2, which is higher than cotton fabric. The low weight of the sample may affect the accuracy of this data as cone calorimeter primary design for heavier samples (White et al., 2013).

Table 5: Smoke related result.

Sample	Heat Flux (kW/m^2)	SEA (m^2/kg)	Time of Peak SEA (s)	Total Smoke Release (m^2/m^2)
N420D	35	99.35 (73.00)	63.50 (6.00)	38.90 (24.00)
	50	96.87 (35)	39.67 (5.00)	52.90 (32.00)
	60	159.81 (105.00)	27.00 (4.00)	65.50 (8.00)
N1000D	35	148.29 (2.00)	45.50 (9.00)	139.95 (22.00)
	50	181.05 (31.00)	24.00 (5.00)	148.3 (32.00)
	60	196.45 (51.00)	25.67 (6.00)	159.03 (12.00)
CER	35	65.62 (23.62)	15.50 (0.71)	57.10 (10.00)
	50	111.40 (18.4)	11.67 (2.89)	62.80 (17.00)
	60	116.11 (55.00)	10.67 (1)	65.56 (3.00)
FAW	35	52.05 (21.00)	25.5 (6)	48.30 (1.00)
	50	135.49 (29.00)	17.00 (4.00)	37.00 (1.00)
	60	92.74 (1.00)	14.33 (1.00)	60.80 (3.00)
FAP	35	70.99 (45.00)	24.00 (4.00)	48.45 (1.00)
	50	230.61 (39.00)	17.33 (2.00)	56.37 (6.00)
	60	171.94 (70.00)	17.00(1.00)	68.53 (4.00)
Cotton	35	0	14 (5.00)	0
	50	24.13 (9.00)	27.33 (26.00)	20.73 (1.00)
	60	6.06 (4.00)	46.33 (53.00)	21.00 (17.00)

4. Conclusion

In the present work, cone calorimeter analysis has been made to determine the flammability characteristics of military fabrics. It consists of types of coated, printed, and untreated cotton fabric. Flame ignition results indicated that TTI reduced as heat flux levels and sample mass increased. Printed fabric ignites faster than coated fabric due to coating material decomposition. Higher heat-related properties (EHC, PHRR and THR) observed for coated fabric. Its major challenge in obtaining reproducible and reliable cone calorimetric data for these low density and thermally thin materials was overcome by varying different testing parameters such as sample weight, heat flux, and grid type. Flammability analysis of military fabric is vital to ensure user safety during training and operation.

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References

Alongi, J., Tata, J., Carosio, F., Rosace, G., Frache, A., & Camino, G. (2015). A Comparative Analysis of Nanoparticle Adsorption as Fire-Protection Approach for Fabrics. *Polymers*, *7*(1), 47–68. https://doi.org/10.3390/polym7010047

Babrauskas, V., & Peacock, R. D. (1992). Heat Release Rate: The Single Most Important Variable in Fire Hazard. *Fire Safety Journal*, *18*, 255–272. https://doi.org/10.1016/0379-7112(92)90019-9

Bei, P., Liwei, C., & Chang, L. (2012). *International Symposium on Safety Science and Engineering in China, An Experimental Study on the Burning Behavior of Fabric used Indoor*. *43*, 257–261. https://doi.org/10.1016/j.proeng.2012.08.044

Ceylan, Ö., Alongi, J., Landuyt, L. Van, Frache, A., & Clerck, K. De. (2013). Combustion characteristics of cellulosic loose fibres. *Fire and Materials*, *37*, 482–490. https://doi.org/10.1002/fam.2147

Chee, S. S., Jawaid, M., Alothman, O. Y., & Yahaya, R. (2020). Thermo-oxidative stability and flammability properties of bamboo/kenaf/nanoclay/epoxy hybrid nanocomposites. *RSC Advances*, *10*(37), 21686–21697. https://doi.org/10.1039/d0ra02126a

Chen, Q., & Zhao, T. (2016). The thermal decomposition and heat release properties of the nylon/cotton, polyester/cotton and Nomex/cotton blend fabrics. *Textile Research Journal*, *86*(17), 1859–1868. https://doi.org/10.1177/0040517515617423

Dewaghe, C., Lew, C. Y., Claes, M., Belgium, S. A., & Dubois, P. (2011). Fire-retardant applications of polymer-carbon nanotubes composites: Improved barrier effect and synergism. In *Polymer-Carbon Nanotube Composites: Preparation, Properties and Applications*. Woodhead Publishing Limited. 718-745. https://doi.org/10.1533/9780857091390.3.718

El Gazi, M., Sonnier, R., Giraud, S., Batistella, M., Basak, S., Dumazert, L., Hajj, R., & El Hage, R. (2021). Fire behavior of thermally thin materials in cone calorimeter. *Polymers*, *13*(8). https://doi.org/10.3390/polym13081297

Elsayed, E. M., Attia, N. F., & Alshehri, L. A. (2020). Innovative Flame Retardant and Antibacterial Fabrics Coating Based on Inorganic Nanotubes. *Chemistry Select*, *5*(10), 2961–2965. https://doi.org/10.1002/slct.201904182

Fateh, T., Kahanji, C., Joseph, P., & Rogaume, T. (2017). A study of the effect of thickness on the thermal degradation and flammability characteristics of some composite materials using a cone calorimeter. *Journal of Fire Sciences*, *35*(6), 547–564. https://doi.org/10.1177/0734904117713690

Godfrey, T., Auerbach, M., Proulx, G., Yip, P., & Grady, M. (2016). Modeling exposures of a nylon-cotton fabric to high radiant heat flux. *Journal of Engineered Fibers and Fabrics*, *11*(3), 55–63. https://doi.org/10.1177/155892501601100308

Grover, T., Khandual, A., & Luximon, A. (2014). Fire protection: Flammability and textile fibres. *Colourage*, *61*(5), 39-45+48.

Hernandez, N., Sonnier, R., & Giraud, S. (2018). Influence of grammage on heat release rate of polypropylene fabrics. *Journal of Fire Sciences*, *36*(1), 30–46. https://doi.org/10.1177/0734904117738928

Huggett, C. (1980). Estimation of rate of heat release by means of oxygen consumption measurements. *Fire and Materials*, *4*(2), 61–65. https://doi.org/10.1002/fam.810040202

Kotresh, T. M., Indushekar, R., Subbulakshmi, M. S., Vijayalakshmi, S. N., Prasad, A. K., & Agrawal, A. K (2006). Evaluation of Commercial Flame Retardant Polyester Curtain Fabrics in the Cone Calorimeter. *Journal of Industrial Textiles, 36*, 47-58. https://doi.org/10.1177/1528083706064379

Luo, S. L., Zhang, H. L., Zhan, Z. C., Mao, B. H., Jiang, Z. J., & Yan, Y. R. (2014). Investigation of flammable behavior of nylon 6 fabrics with and without spandex using cone calorimeter test and vertical burning test. *Advanced Materials Research*, *852*, 644–647. https://doi.org/10.4028/www.scientific.net/AMR.852.644

Moinuddin, K., Razzaque, Q. S., & Thomas, A. (2020). Numerical simulation of coupled pyrolysis and combustion reactions with directly measured fire properties. *Polymers*, *12*(9), 2075. https://doi.org/10.3390/POLYM12092075

Morgan, A. B., & Yip, P. W. (2016). Effects of laundering on military uniform fabric flammability. *Fire and Materials*, *40*, 599–611. https://doi.org/10.1002/fam.2313

Mouritz, A. P., Mathys, Z., & Gibson, A. G. (2006). Heat release of polymer composites in fire. *Composites Part A: Applied Science and Manufacturing*, *37*(7), 1040–1054. https://doi.org/10.1016/j.compositesa.2005.01.030

Nazaré, S., Kandola, B., & Horrocks, A. R. (2002). Use of cone calorimetry to quantify the burning hazard of apparel fabrics. *Fire and Materials*, *26*(4–5), 191–199. https://doi.org/10.1002/fam.796

Samolov, A. D., Simić, D. M., Fidanovski, B. Z., Obradović, V. M., Tomić, L. D., & Knežević, D. M. (2020). Improvement of VIS and IR camouflage properties by impregnating cotton fabric with PVB/IF-WS2. *Defence Technology*, *17*(6), 2050-2056. https://doi.org/10.1016/j.dt.2020.10.008

Tata, J., Alongi, J., Carosio, F., & Frache, A. (2011). Optimization of the procedure to burn textile fabrics by cone calorimeter: Part I.Combustion behavior of polyester. *Fire and Materials*, *35*(6) 397–409. https://doi.org/10.1002/fam.1061

White, R.H., Nam, S., Parikh, D.V. (2013). Cone calorimeter evaluation of two flame retardant cotton fabrics. *Fire and Materials*, *37*, 46–57. https://doi.org/10.1002/fam.2111

Xu, D., Wang, S., Wang, Y., Liu, Y., Dong, C., Jiang, Z., & Zhu, P. (2020). Preparation and mechanism of flame-retardant cotton fabric with phosphoramidate siloxane polymer through multistep coating. *Polymers*, *12*(7), 1538. https://doi.org/10.3390/polym12071538

Xu, Q., Chen, L., Harries, K. A., & Li, X. (2017). Combustion performance of engineered bamboo from cone calorimeter tests. *European Journal of Wood and Wood Products*, *75*(2), 161–173. https://doi.org/10.1007/s00107-016-1074-6

Yahaya, R., Sapuan, S., Jawaid, M., Leman, Z., & Zainudin, E. (2014). Mechanical performance of woven kenaf-Kevlar hybrid composites. *Journal of Reinforced Plastics and Composites*, *33*, 2242–2254. https://doi.org/10.1177/0731684414559864

Yahaya, R., Sapuan, S. M., Jawaid, M., Leman, Z., & Zainudin, E. S. (2016). Effect of fibre orientations on the mechanical properties of kenaf–aramid hybrid composites for spall-liner application. *Defence Technology*, *12*(1), 52-58. https://doi.org/10.1016/j.dt.2015.08.005

Yang, C .Q., & He, Q. (2011). Applications of micro-scale combustion calorimetry to the studies of cotton and nylon fabrics treated with organophosphorus flame retardants. *Journal of Analytical and Applied Pyrolysis, 91*(1), 125–133. https://doi.org/10.1016/j.jaap.2011.01.012