Technical Communication

Heat Release Characteristics of the basic materials used for flying clothing

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ABSTRACT

The fabrics used for overalls and anti-G suits are chosen so as to meet the requirements of tropical climate along with other functional utility parameters. The conventional textiles may meet most of the functional requirements but their heat release characteristics in case of an accidental fire also need to be considered. In this study an attempt has been made to assess the heat release characteristics of the clothing assembly worn by aircrew. Using the cone calorimeter test facility the present study evaluates different flying clothing assemblies consisting of overall flying Mk-II, anti-G suit Mk-II, flame retardant overall with anti-G suit Mk-IV. The results of this study indicate the advantages of flame retardant clothing assembly over the conventional clothing in terms of lower heat release.

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Flying imposes considerable physiological demand and aircrew are provided with specialized clothing to protect them against aviation stresses. The minimum protective equipment worn by aircrew include overalls, anti-G-suit, aircrew helmet, gloves and boots. Thus textiles are the major component of this protective equipment. The quality of this protective clothing is critical not only for flight safety but also for protection against unforeseen fire hazards.

The fabrics used for overalls and anti-G suits are chosen so as to meet the requirements of tropical climate along with other utility parameters such as durability and comfort. Hence these textiles are tested for porosity, flexibility, texture, weight and behaviour towards heat exchanges (1). The conventional textiles may meet all funtional requirements but they are highly flammable. Currently the trend both in the civilian and military sector is to go in for the flame retardant (FR) protective clothing. A FR fabric is defined as one which does not propagate the flame although it may burn or char when subjected to any form of heat. A considerable amount of research work is in progress to develop flame retardant synthetic fibre which can be used without discomfort. In protective clothing it is desirable to have low propensity to ignition from a flaming source or if it ignites it should have low heat output.

Every textile fibre burns differently and during this process it decomposes. Textile fibre can be divided into two classes based on their relative ignitability (2). Fibre that char when ignited such as viscose, cotton, wool and fibre that melts when ignited such as polyesters, polypropylene and so on. The dripping molten polymers adhere to skin and aggravate burn injuries. The decomposition of cellulosic material produces levaglycosan and this further decomposes into flammable volatile products that propagate the flame. In contrast fibres like polyester, soften, melt and undergo pyrolysis. A pyrolysis temperature is the temperature at which chemical degradation takes place by heat in absence of air. Pyrolysis is the essential first step in combustion of polymers. The combustion temperature is the temperature at which chemical decompostion takes place by combination with oxygen, producing heat and light.

It is evident that no single laboratory test can determine the potential burning character and hazard of

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a particular textile. The flammability of clothing material is usually assessed by tests such as char length and the Limiting Oxygen Index (LOI) test (3). LOI is defined as the minimum oxygen concentration which permits the entire length of the specimen to burn. These test performed on smaller strips fail to provide any information of the potential heat release property of the burning fabric. Better understanding of the phenomena governing fire initiation and growth has led to development of Heat Release Rate (HRR) test method which can predict the real scale burning behaviour of the materials. HRR is defined as the amount of energy that a material produces while burning. In the present study the assessment of the heat release characteristics of the clothing assembly worn by the aircrew is done using the cone calorimeter test facility. HRR and other data generated from cone calorimeter testing is used to evaluate fire hazards related to the textile material used for fabrication of flying clothing.

Materials and Methods

This study evaluates the three commonly used flying clothing assemblies worn by fighter aircrew.

(a) **Flying overalls Mk-II with anti-G-suit Mk-II :** Currently aircrew are using flying overall Mk-II fabricated out of flammable 60/40 polyester/cotton blended in mockleno weave. Anti-G-suit Mk-II is cut away type consisting of outer material of flammable heavy duty nylon fabric. The bladder is made of natural rubber which is also a highly inflammable material.

(b) **Flying overalls Mk-II with anti- G suit Mk-IV:** Anti-G-suit Mk-IV has been developed specifically for use in aircrafts such as LCA, MiG 29 and Mirage. The outer cover is made of flammable nylon fabric and bladder system is fabricated with flame retardant neoprene coated fabric.

(c) **Flame retardant (FR) overalls with anti-G-suit Mk-IV:** FR overalls is made of FR materials mixture/ blend of 70/30 FR viscose/P-84 or equivalent material. FR overalls were also evaluated for thermal stress and it was found that it was not significant (4) as compared to flying overall Mk-II.

The cone calorimeter is the instrument used for fire testing of the above mentioned three flying clothing assemblies. This is a most significant instrument to evaluate fire related properties of the material as it directly measures (5), time to ignition, Heat Release Rate (HRR), Mass loss rate, Smoke release rate, effective heat of combustion and Rate of toxic gas release. The above mentioned data obtained can be used for comparison to real scale tests. This instrument operates on oxygen consumption calorimeter.

Table I : Cone Calorimeter run data

Material Name	AGS Mk II: Nylon, Natural Rubber, Nylon Overall Mk II : Polyester/cotton
Specimen thickness	2.00mm
Specimen initial mass	24.28 g
Time to ignition	23 secs
Total heat evolved	61.5 MJ/m^2
Total oxygen consumed	41.6 g
Heat release rate	Average : 157.79 k W/m2
Effective heat of combustion	Average : 28.55 MJ/Kg
CO yield	Average : 0.0504 Kg/Kg
Mass loss rate	Average : 0.049 g/s
CO_2 yield	Average : 2.88 Kg/Kg
Specific extinction	Average : 541.69 m^2 / Kg

Measurement of concentration of the oxygen in exhaust duct and volumetric flow of air gives the rate of oxygen consumption from which HRR is calculated by data acquisition unit. Test samples are cut to the desired size of 10cm x 10cm and wrapped in aluminium foil. The wrapped specimen are secured in the sample pan and placed on the loaded platform and its mass along with all its other measurements is recorded. The prepared samples are exposed to calibrated heat flux of 50 KW/m^2. The data thus obtained is recorded and analysed.

Results

Cone calorimeter test runs were carried for the above mentioned flying clothing assemblies. Test data is obtained in form of a computer print out by the data acquisition system. The relevant results of the flying clothing assembly consisting of flying overalls Mk II and anti-G suit Mk II are compiled in Table I. Important parameters average during the period from ignition upto 4 minutes is given in Table II.

The Cone Calorimeter run data for flying clothing assembly consisting of anti-G-Suit Mk-IV and flying overalls Mk-II is compiled in Table III. Average of these parameters from ignition time upto 4 minutes is given in Table-IV.

Table II: Parameters during the period from ignition upto 4 minutes

Average during period from ignition to ignition plus	1 min	2 min	3 min	4 min
Heat release rate (k W/m^2)	378.0	340.8	278.2	227.8
Effective heat of combustion (MJ/kg)	26.4	29.1	28.9	29.1
Mass loss rate (g/s)	0.123	0.103	0.086	0.070
Specific extinction area (m^2/kg)	624.6	697.9	648.2	617.6
Carbon monoxide yield (kg/kg)	0.0242	0.0477	0.0484	0.0501
Carbon dioxide (kg/kg)	1.74	2.43	2.56	2.71

Table III : Cone Calorimeter run data

Material Name	AGS Mk IV: Nylon, Neoprene coated fabric, Nylon Overall Mk II : Polyester / cotton
Specimen thickness	2.00 mm
Specimen initial mass	13.35 g
Time to ignition	32 secs
Total heat evolved	22.7 MJ/m^2
Total oxygen consumed	15.6 g
Heat release rate	Average : 145.5 k W/m2
Effective heat of combustion	Average : 19.16 MJ/Kg
CO yield	Average : 0.0576 Kg/Kg
Mass loss rate	Average : 0.068 g/s
CO_2 yield	Average : 2.10 Kg/Kg
Specific extinction	Average : 566.54 m^2 / Kg

Table IV: Parameters from ignition time upto 4 minutes

Average during period from ignition to ignition plus	1 min	2 min	3 min	4 min
Heat release rate (k W/m^2)	231.4	178.2	127.3	114.5
Effective heat of combustion (MJ/kg)	18.6	19.3	18.5	18.3
Mass loss rate (g/s)	0.109	0.083	0.061	0.056
Specific extinction area (m^2/kg)	669.3	597.3	538.6	523.0
Carbon monoxide yield (kg/kg)	0.0355	0.0545	0.0582	0.0597
Carbon dioxide (kg/kg)	1.42	1.97	2.08	2.10

Table V : Cone Calorimeter Run Data

Material Name	**AGS Mk IV: Nylon, Neoprene coated fabric, Nylon FR Overalls**
Specimen thickness	2.00 mm
Specimen initial mass	13.93 g
Time to ignition	26 secs
Total heat evolved	21.4 MJ/m^2
Total oxygen consumed	14.6 g
Heat release rate	Average : 113.13 k W/m2
Effective heat of combustion	Average : 16.87 MJ/Kg
CO yield	Average : 0.0461 Kg/Kg
Mass loss rate	Average : 0.059 g/s
CO_2 yield	Average : 1.83 Kg/Kg
Specific extinction	Average : 519.96 m^2 / Kg

Table VI: Period from ignition to ignition plus

Average during period from ignition to ignition plus	**1 min**	**2 min**	**3 min**	**4 min**
Heat release rate (k W/m^2)	212.8	161.9	117.9	101.1
Effective heat of combustion (MJ/kg)	17.4	17.9	17.1	16.4
Mass loss rate (g/s)	0.104	0.080	0.061	0.055
Specific extinction area (m^2/kg)	641.9	597.9	528.8	495.7
Carbon monoxide yield (kg/kg)	0.0280	0.0460	0.0461	0.0472
Carbon dioxide (kg/kg)	1.32	1.71	1.82	1.84

Data for flying clothing assembly consisting of anti-G-Suit Mk-IV and FR overalls is given in Table V. Average of these important parameters from ignition time upto 4 minutes is given in Table VI.

Discussions

The measurements of the cone calorimeter run have the following important parameters:

(a) **Ignition time:** A measure of how easily a material can be ignited.

(b) **Time to peak HRR:** A measure of the speed of fire growth.

(c) **Peak HRR:** A measure of how large a fire will result from a burning material.

(d) **Effective heat of combustion :** A measure of the amount of heat released from a burning material per unit of sample burned.

(e) **Specific extinction:** A measure of smoke production of the material.

Heat is the energy output of any fire and it is logical to use parameters such as total heat release, peak heat release and HRR to quantify the fire. HRR is the key indicator of real scale fire performance as most other variables such as smoke, toxic gases and other fire hazard variable tend to increase with increasing HRR. High HRR thus indicates high threat to life. HRR from a cigarette lighter is about 50 W/m^2 and that from a waste paper basket fire is about 20-50 KW/m^2. Heat of combustion is defined as the energy generated in combustion process per unit mass of the material vapourised (6). Burning characteristics of commonly used synthetic and natural fibres are given in Table VII (7).

Materials evaluated in this study include flying clothing assemblies which are already in use and the recently introduced anti-G-suit Mk IV and FR overalls. The results of this study provide the necessary data which give assessment of material's individual contribution to overall fire hazard. Table VIII gives the comparative assessment of heat release parameters of three different flying clothing assemblies tested.

Table VII : Thermal Transition Temperature And Limiting Oxygen Index (LIO) of Some Fibre

Fibre	Tm°C (melting)	Tpr°C (pyrolysis)	Tc°C (combustion)	H Kjg^{-1}	LIO %
Nylon	215	431	450	39	21-22
Polyester	250-255	400-477	480	24	21-22
Acrylic	>320	290	>250	32	19
Cotton	--	350	350	19	18-20
Viscose	-	350	420	19	18-19

Table VIII

Parameters	Flying overalls Mk II AGS Mk II	Flying overalls Mk II AGS Mk IV	FR overalls AGS Mk IV
HRR k W/m^2	646.73	318.21	289.40
HRR (kW/m^2) - average	157.79	145.50	113.13
Effective heat of combustion MJ/kg	28.55	19.16	16.87
Mass loss rate g/s	0.049	0.068	0.059
Specific extinction area m^2/kg	541.69	566.54	519.96
CO yield kg/kg	0.0504	0.0576	0.0461
CO_2 yield kg/kg	2.88	2.10	1.83

It is evident from the comparative data that flying clothing assembly with FR overalls and anti-G-suit MK IV gives least HRR, yields least amount of toxic gases and also has least effective heat of combustion thus providing better survival chances in case of fire accidents. The results of the study indicate the advantages of FR clothing over the conventional clothings.

The ignition time in case of FR overall and anti-G suit Mk IV is 26 sec compared to 32 sec with flying overall Mk II and anti-G-suit Mk IV (Table V and Table III) appears to be not in conformity with the expected results. Though ignition time is one of the indicators of the ease of ignition but what is more important is the heat released by the burning assembly of material i.e., HRR, which is lower for FR overalls and anti-G-suit Mk IV assembly vis-a-vis the other two assemblies considered in the Study. HRR (Peak and Average) values reflect this trend. In all three sample assemblies considered, the overall fabric forms the bottom layer while the top layers pertain to the anti-G-suit. Ignition, being a surface phenomenon, is governed by the material on the top layer and the material at the bottom layer (i.e., the overall fabric of the FR or Non-FR quality) do not influence the ignition time; however, the bottom layer influences the total heat released as is seen from the results. The observed difference in ignition time may be attributed to possible variation in the sample and the way the applied heat travels through the assembly (the analysis of which is beyond the scope of this paper).

Heat release characteristics of the individual components of the flying clothing assembly such as overall fabric material, bladder material also need to be studied individually which shall be taken up in our future studies. The present study was taken up only to have the comparative assessment of heat release parameters of the three different flying clothing assemblies. The equipment (Cone Calorimeter) used to measure the heat release characteristics is a highly reliable and in this study just one sample of each test material has been taken. The results of the study clearly indicate the advantages of FR clothing over the conventional clothing.

Conclusion

In this study the newly introduced FR clothing are comparatively evaluated to the currently used flying clothings. The results clearly indicate the usefulness of FR materials for fabrication of flying clothing. Recent awareness regarding the FR characteristics of textile materials has led to search for more efficient FR textiles. The currently used anti-G-suit Mk IV has bladder system made of neoprene coated nylon fabric. Further work is in progress to develop polyurethane coat fabric having still better FR characteristics The property of flame retardancy does not adversely impair the thermal response of the fabric. The FR overalls can be used advantageously to provide additional protection during fire hazards. Anti-G-suit Mk IV though developed for new generation fighter aircrafts can be made compatable for other MiG aircrafts with added advantage of protection against fire hazard.

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