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Short Communications

Burning behavior of aramid and FR viscose blended fabrics

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Two sets of yarns have been produced on ring spinning system. In the first set, flame-retardant viscose and meta-aramid are blended in three different ratios of 30:70, 50:50 and 70:30, and in the second set, flame-retardant viscose, nylon 66 and meta-aramid are blended in two different ratios of 30:20:50 and 50:20:30 respectively. These yarns are converted in to woven fabrics and evaluated for limiting oxygen, contact heat, radian heat and convective heat indices. One way analysis of variance (ANOVA) has been applied to find out the effect of different fibre blends on various flame and thermal properties. It is observed that there is relationship between fibre contents in the blend and flame and thermal resistant properties.

Keywords: Aramid fibres, Burning behaviour, Flame-retardant viscose, Mechanical property, Nylon 6 6, Oxygen index, Ring spinning

It is well known fact that the workers in petrochemical, foundries, hotel kitchens, fire fighting, etc have to face flame and heat hazards consistently. Flash fire is one of the most terrible hazards in these industries which is caused by the accidental release and ignition of hazardous flammable materials. The conventional clothing fabrics made from natural fibres, polyester fibres and nylon fibres can ignite and continue to burn on the body because of their flammable properties. Fabrics made of meltable fibres like polyester and nylon can lead to more serious burn injuries[1]. Fire-retardant clothing can significantly reduce the extent and severity of burn injuries as well as provide time to the wearer to get away from burning environment.

It is required that fire-retardant clothing should have low propensity for ignition from a flaming source or, if the item ignites, a slow fire spread with low heat output would be ideal. In general, thermoplastic-fibre fabrics such as nylon, polyester and polypropylene fibres fulfill some of these requirements because they shrink away from flame and if they burn, they do so with a small & slow spreading flame and ablate. However these fibres show melting and dripping problem during ignition. Beside this, one of the main requirements for flame-retardant clothing is to protect wearer from heat by providing insulation as well as high dimensional stability of the fabrics. For example, upon exposure to the heat fluxes that is expected during the course of the wearer's work, the fabric will neither shrink nor melt. If the fabrics shrink or melt, then they decompose to form char[2].

Presently aramids and flame-retardant viscose fibres are widely used in different areas of protective textiles. These fibres come in the category of heat-resistant and strong synthetic fibres. They can be used in petrochemical, aerospace and military applications. These are generally prepared by reacting an amine group and a carboxylic acid halide group. Meta-aramid polymer was produced by chemical blend of m-phenylenediamine and dicholoride of m-isophthalic acid. This fibre is characterized by medium to ultra high strength and medium to low elongation. Meta-aramid has excellent thermal resistance and good textile properties, but poor mechanical properties for high-performance fibre[3].

Inherently flame-resistant viscose fibre is produced by incorporating FR additives/fillers in the spinning dope before extrusion[4]. During burning of this fibre the flame point produces a lot of nitrous oxide, which effectively isolates the fibre flame point from oxygen, thereby showing a fire-retardant effect. This fibre does not show combustion and will instantly extinct without fire source with low smoke concentration[5].

Nylon 66 is produced using hexamethylene diamine and adipic acid, which give nylon 66 a total of 12 carbon atoms in each repeating unit. The melting point of this polymer is 268 ºC, which is high for synthetic fibres[6]. This property makes it heat and friction resistant and also the fibre exhibits high abrasion resistance and self-lubricating properties. It has high thermal stability, fire

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resistance, draw ability, good appearance and good process ability.

The selection of fibres to blend is also a function of the properties that are required for the end product. The fibres can be blended to balance protection, comfort, and durability and to reduce the cost of the fabric. The blended fabrics of two fibres have better flame retardant property than the fabric made of single fibre. Nomex/Lenzing viscose FR blended fabric can enhance the flame retardant property, improve the spinnability of yarn and reduce the cost[7].

In this study, it is aimed to produce 20 Ne yarn out of 100% meta-aramid, 100% FR viscose, 100% nylon 6, 6 and their blends on ring spinning system. These yarns are used to produce rip stop plain woven fabrics and tested for mechanical and burning behaviours.

Experimental

Yarn Spinning

Meta-aramid (M-A1), FR viscose (V1) and nylon 6 6 (N1) fibre's properties are given in Table 1. Eight different types of yarns were produced from these fibres. The blend components were first hand mixed and then fed into the blow room to have an intimate and homogeneous blend. Thereafter, the materials were processed through card, draw frame and simplex machines. Yarns were spun in to 20s count yarn having 16 TPI on a ring frame. The blend percentages along with codes are given in Table 2. The yarns so produced were tested for their physical properties (Table 3), such as tenacity following ASTM D 2256 test method and elongation by ASTM D 2256 test method using USTER Tansorapid instrument.

Fabrics

The manufactured yarns were converted into plain rip stop woven fabrics (ends/inch 80 and picks/inch 60) on rapier loom. These fabric samples were washed with hot water for the duration of 30 min to remove sizing lubricants followed by heat setting (depending upon the fibre type except FR viscose) in the laboratory curing chamber as per ISO 6330. Finally, the fabrics were evaluated using standard test methods for various mechanical and flame-retardant properties (limiting oxygen index, contact heat index, radiant heat index and convective heat index) before and washing (5 and 50 washes) as mentioned in the standard ISO 11612.

Table 1 — Fibre properties

Parameter	FR viscose	Nylon 6 6	Meta -aramid
Length, mm	51	38	51
Density, denier	1.98	1.60	2.39
Tenacity, g/tex	24.21	48.51	28.26
Elongation, %	13.78	27.46	36.25
Moisture regain, %	7.11	3.49	5.5

Table 2 — Blend percentage

Fibre	Code	Blend ratio, %
FR viscose	V1	100
Meta-aramid	M-A1	100
Nylon 6,6	N1	100
FR viscose: meta-aramid	VM-A37	30:70
FR viscose: meta-aramid	VM-A55	50:50
FR viscose: meta-aramid	VM-A73	70:30
FR viscose:nylon 66: meta-aramid	VNM-A523	50:20:30
FR viscose: nylon 6 6:meta-aramid	VNM-A325	30:20:50

Table 3 — Mechanical properties

Parameter	V1	M-A1	N1	VM-A37	VM-A55	VM-A73	VNM-A523	VNM-325
Tenacity of yarn, g/tex	13.1	23.5	26.1	19.2	16.4	14.0	25.2	28.1
Elongation of yarn, %	7.8	14.8	21.0	8.7	8.2	8.0	9.4	10.7
Weight, g/m^2	194	174	204	179	172	185	198	182
Thickness, mm	0.50	0.77	0.75	0.66	0.74	0.68	0.81	0.89
Tensile strength, N (after 5 washes)								
Warp	485	1055	1054	786	840	566	799	875
Weft	480	951	928	580	612	515	741	793
Tensile strength, N (after 50 washes)								
Warp	410	1069	1062	791	859	589	810	911
Weft	398	975	941	582	625	527	778	820
Air permeability, cc/s/cm^2	28.1	14.1	10.0	18.0	25.0	23.0	28.3	23.3
Water vapour permeability, mg/cm^2/s	10.0	8.0	9.4	9.2	11.0	10.0	11.1	9.2

Mechanical Properties

Tensile strength of fabrics was determined using Universal Testing Machine (UTM) following ISO 13934-1 test method in such a manner that specimen was gripped by two grips, vertically arranged one below the other and continuously extended at a constant rate until it is ruptured. It was performed in both the warp and filling directions ten times.

Air permeability of textiles indicates their breathability. It can be defined as the degree to which a fabric allows air to pass through its construction[8]. It was determined using WIRA Air Permeability Tester following IS: 11056-1984 test method, which indicates the amount of air passing through test specimen on the scale reading, in terms of $cc/cm^2/s$.

ISO 15496:2004 test method was followed to test water vapour permeability. The measurements determine how many grams of moisture (water vapour) passes through a square meter of fabric in 24 h. If a fabric represents low vapour permeability it would be unable to pass sufficient perspiration and this could lead to sweat accumulation in the clothing and hence discomfort.

Flame Retardant Properties

Limiting oxygen index was tested following IS: 13501: 1992 test method after conditioning in a standard atmosphere of 65±2 % relative humidity and 27±2 ^{o}C temperature. It is a preliminary test to ascertain that fabric is flame retardant or not. Samples were supported vertically in a transparent chimney with a mixture of oxygen and nitrogen flowing upward through it. The upper end of a specimen was ignited. The minimum concentration of oxygen in a mixture of oxygen and nitrogen flowing upwards in the test chimney, which would just support combustion, was measured. Following equation is used to determine limiting oxygen index (LOI) value of the fabrics:

$$\text{LOI} = \frac{[\text{O}_2]\times 100}{[\text{O}_2]+[\text{N}_2]} \quad \ldots (1)$$

where $[O_2]$ is the volumetric flow of oxygen in cm^3/s; and $[N_2]$, the corresponding volumetric flow rate of nitrogen in cm^3/s (refs 9,10).

Contact heat index was measured following ISO 12127 test method. The threshold time was determined by monitoring the temperature of the calorimeter. The higher the threshold time of a fabric, the better will be the heat protective property. A heating cylinder was heated to 500 °C and maintained at the constant temperature. A test specimen was placed on the calorimeter. The heating cylinder was lowered onto the test specimen supported by the calorimeter or, alternatively, the calorimeter with the specimen was lifted up to the heating cylinder. In either case, the operation was carried out at a constant speed. Test was carried out in an atmosphere having temperature of 20±5 °C and relative humidity of 15-80%. The test was started within 3 min after the test specimen was taken out of the conditioning atmosphere

Radiation heat index was tested using ISO 6942 test method. Fabrics were exposed to radiant heated source emitting 20 kW/m^2 heat fluxes. The heat flux density (Q, kW/m^2), was determined using the following equation:

$$Q_0 = \frac{M.C_P.R}{A.a} \quad \ldots (2)$$

where M is the mass of the copper plate in kg; C_p, the specific heat of copper 0.385 kJ/kg ˚C; R, the rate of rise of the calorimeter temperature in the linear region in ˚C/s; A, the area of the copper plate in m^2 ; and α , the absorption coefficient of the painted surface of the calorimeter.

Convective heat index test was used to compare the heat transmission through material following ISO 9151 test method. A horizontally oriented test specimen is partially restrained from moving and subjected to an incident heat flux of 80 kW/m^2 from the flame of a gas burner placed beneath it. The heat passing through the specimen is measured by means of a small copper calorimeter on top of and in contact with the specimen. The time (s) for the temperature in the calorimeter to rise 24 ± 0.2 ˚C is recorded. The heat flux density (Q, kW/m^2) is then determined from the following equation:

$$\text{Q} = \frac{M\,C_P\,R}{A} \quad \ldots (3)$$

Statistical Analysis

Experimental data was analyzed using SPSS (Version 20). One-Way ANOVA analysis was applied to compare means. The null hypothesis (Ho) indicates that there is no effect of varying fibre ratio in blend on flame-retardancy of fabric in context of limiting oxygen index, contact heat index, radiation heat transfer index and convective heat index. Null hypothesis will be rejected when the *p*-value turns out to be lower than a predetermined significance level of 0.05.

Results and Discussion

Fabric Construction Parameters

Fabric mass (g/m^2) has been evaluated following IS: 1964 standard method on GSM tester. From Table 3, it is clear that the mass of V1, N1, M-A1, VM-A37, VM-A55, VM-A73, VNM-A523 and VNM-A325 fabrics are between 172 g/m^2 and 198 g/m^2. Thickness of a fabric is one of its basic properties giving information on its warmth, heaviness or stiffness in use. IS: 7702-75 method has been followed to determine thickness of the fabrics. Thickness values of different fabrics are given in Table 3.

Experimental Results and Analysis of Mechanical Properties

Table 3 shows that the strength for both yarns and fabrics follows the similar trend. 100% meta-aramid and nylon 66 yarn and fabric show higher tensile strength. The tensile properties of fabrics mostly depend on the tensile properties of yarns[11]. FR viscose/meta-aramid blended fabrics (binary compositions) show better strength than V1 fabric. VMA55 shows better results as compared to VM-A37 and VM-A73 fabrics. The reason could be the higher thickness of VMA55, which is 0.74mm. On the contrary, FR viscose/nylon 6 6/meta-aramid blended fabrics (tertiary compositions) with ratio of 30:20:50 gives better outcomes than binary compositions (Table 3) after 5 washes. This is due to the presence of nylon 6, 6 fibres which has highest tenacity (48.51 g/tex). The polymer system of nylon is 65-85% crystalline and about 35-15% amorphous. This makes nylon a very crystalline, very well aligned or oriented polymer system, with the inter-polymer distance of about 0.3 nm[12].

It is seen that after 50 washes, strength of all the fabrics, except V1, increases. This may be due to the higher level of shrinkage in the yarn after washing. Therefore, the higher density of yarns tends to increase in the strength[13].

As per FR overall specification[14], the air permeability of the fabric should be $\geq$ 20 $cc/s/cm^2$ for comfort. The air permeability of a fabric is affected by many factors, such as fibre fineness, structural properties (shape and value of pores of the fabric), and the yarn and fabric thickness[15]. As per the results given in Table 3, V1 fabric shows highest air permeability (28.1 $cc/s/cm^2$), while M-A1 shows lowest (14.1 $cc/s/cm^2$) air permeability. Lower thickness of 100% FR viscose fabric could be the reason for higher air permeability.

In a study[14], 100% FR viscose fabric is found finer in construction than 100% modacrylic fabric, and hence is more air permeable. On the other hand, FR viscose/meta-aramid blended fabric (VM-A55) displays a better result of air permeability (25 $cc/s/cm^2$) as compared to VM-A37 and VM-A73 fabrics. As per DEBEL, M-A1 and VM-A37 fabrics do not meet the minimum requirement for air permeability. FR viscose/nylon 6 6/meta-aramid blended fabrics show good air permeability. VNM-A (50:20:30) expresses better air permeability of 28.3 $cc/s/cm^2$ as compared to VNM-A325.

According to CRPF specification[16], minimum requirement of water vapour permeability is given as 5 $mg/cm^2/s$ for nylon 66 and cotton (50:50) blended fabric, Water vapour permeability of V1 fabric is found high (10 $mg/cm^2/s$) as compared to meta-aramid 100% fabric. On the contrary, amongst blended fabrics, FR viscose/meta-aramid (50:50) blends show good results (11 $mg/cm^2/s$) even better than V1 and M-A1 fabrics. On the other hand, FR viscose/nylon 6 6/meta-aramid blended fabric (VNM-A523) shows similar value as that of VM-A55 (Table 3). Hence, it is concluded that blending of fibres improves the water vapour permeability.

Experimental Results and Analysis of Flame-retardant Properties

Fabric flammability is an important issue, especially for uniform worn during working in industries, like foundries, oil and gas. Flame-retardant clothing neither ignites nor continues to burn when it comes in contact with the flame. It not only reduces burn injury, but also provides escape time and increases chances of survival. This could mean a difference between life and death for valuable human lives. Hence, it is important to test the fabrics to evaluate their heat and flame properties like limiting oxygen index, contact heat index, radiation heat transfer index and convective heat index.

Limiting Oxygen Index

Meta-aramid fibres are made up of synthetic polymers in which repeating units containing large phenyl rings are linked together by amide groups. These amide groups (CO-NH) form strong bonds, which make the fibre resistant to solvents and heat[17]. Hence, M-A1 has highest oxygen index of 43-44 % (Table 4), while FR viscose has 26.5- 27% oxygen index. On the other hand, FR viscose/meta-aramid blended fabrics show better LOI value as compared to 100% FR viscose. These blends are evaluated with increased LOI on increasing the ratio of meta-aramid with FR viscose. Other fabrics of FR viscose, nylon 6 6 and meta-aramid have lower LOI than FR viscose/meta-aramid blended fabrics due to the presence of nylon 6 6, but these blends present better oxygen index than the fabrics V1 and N1. After 50 washes all fabrics show minimal change in LOI.

Contact Heat Index

It is clear from Table 4 that VM-A37 has the highest threshold time (8 s) for contact heat index. Aramid fibres are highly oriented rigid molecular structure and has high heat resistance. M-A1 has higher threshold time after VM-A37 fabric as compared to V1, VM-A55, VM-A73, VNM-A523 and VNM-A 325 fabrics. After 50 washes, VNM-A325 shows increased time for contact heat index. This could be due to the fact that yarns after washing exhibit higher level of shrinkage. Hence, the higher density of yarns tends to increase the time to pass heat through fabric[18].

Radiation Heat Index

M-A1 fabric shows the lowest threshold time while V1 is determined with higher threshold time (Table 4). FR viscose/meta-aramid blended fabrics show better threshold time than 100% meta-aramid fabric but lower than V1 fabric due to the presence of M-A1. On the other hand, VNM-A523 presents the highest threshold time (12.4 s). The reason could be the presence of Nylon 6 6, which is a poor conductor of heat and has a low density, thus the particles in a given volume of the material are not enough to collide and transfer heat[19,20]. All fabrics show little change in radiation heat index after 50 washes.

Convective Heat Index

As per ISO 11612, the average threshold time for heat transfer is found 4 s, which is considered suitable for protective clothing. It is clear from Table 4 that V1 shows the highest time for heat transmission, while M-A1 shows the lower threshold time than V1. On the other hand, FR viscose/meta-aramid blended fabrics (70:30) are found better among all. After 50 washes, low or no changes are seen.

Statistical Analyses

Table 5 shows the result of one way ANOVA analysis, which is applied to find out the effect of fibre ratio in different blends on limiting oxygen index, contact heat index, radiation heat index and convective heat index. The effect of fibre ratio in blend on above parameters of fabric is found significant at 5 % level. The p value is found to be lower than 0.05. The result indicates that there is a relationship between fibre content in the blend and heat and flame properties.

It is explicit from the present work that spun 100% FR viscose fabric possesses lower tensile strength and lower elongation than 100% meta-aramid and nylon 6 6 fabrics. On the other hand, FR viscose/meta-aramid and FR viscose/meta-aramid/nylon 66 blended fabrics are having better tensile property than 100% FR viscose. It is also clear from the study that meta-aramid even after having highest LOI, has shown lowest threshold time for radiation and convective heat indices. It is also revealed that FR

Table 4 — Flame-retardant properties

Test parameter	V1	N1	M-A1	VM-A37	VM-A55	VM-A73	VNM-A523	VNM-A325
Limiting oxygen index, %								
after 5 washes	26.5	21	43	46	42	39.5	30	32
after 50 washes	27	21	43	45.5	42.5	39	29.5	33
Contact heat index, s								
after 5 washes	5	6	7	8	6	6	6	6
after 50 washes	5	6	7	8	6	6	7	9
Radiation heat index, s								
after 5 washes	12.1	12.2	10.7	11	11.4	11.9	12.4	11.9
after 50 washes	12	12	10.6	11.1	11.2	11.10	12.3	11.7
Convective heat index, s								
after 5 washes	6.2	3.7	5.3	6.3	6.5	6.9	6.2	6.0
after 50 washes	6.1	3.5	5.2	6.2	6.5	6.8	6.1	6.1

Table 5 — Statistical analysis

Parameter		Sum of squares	df	Mean square	F	Sig.
LOI	Between groups	5754.118	7	822.017	5279.680	0.000
	Within groups	11.210	72	0.156		
	Total	5765.328	79			
Contact heat	Between groups	62.342	7	8.906	14.961	0.000
	Within groups	42.860	72	0.595		
	Total	105.202	79			
Radiation heat	Between groups	27.025	7	3.861	39.267	0.000
	Within groups	7.079	72	0.098		
	Total	34.104	79			
Convective heat	Between groups	70.684	7	10.098	155.549	0.000
	Within groups	4.674	72	0.065		
	Total	75.358	79			

viscose/meta-aramid blended fabric (30:70) shows better results than others. One way ANOVA indicates that there is a relationship between fibre content in the blend and thermal and flame properties

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