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Flammability Properties of Various Layered Fabrics Assemblies[1]

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Introduction

The flammability of blended yarns, multi ply yarns and union clothes of both (cotton and polyester) has been investigated.[1)-4)] Their burning resistance (i.e., reverse of burning rate) was represented by the series and parallel model of the burning resistance of both, 100% polyester yarn and 100% cotton yarn, with their mixing ratio. According to the results of these experiments, their burning resistance was shown at the minimum point at the certain mixing ratio, and it varied depending on the quantities of the specimen. J.N.

Table 1 Details of Test Fabrics of the Vertical Flammability Test Method

Fiber Content		100% Cotton	100% Polyester	100% Wool
Construction		Plain Weave	Plain Weave	Plain Weave
Yarn Types		Staple Fiber Yarn	Filament Yarn	Staple Fiber Yarn
Yarn Number Count	Warp	40/1'S	75 d	1/52'S
	Fill	40/1'S	75 d	1/68'S
Fabric Count	Ends/cm	52	40	29
	Picks/cm	26	32	28
Thickness (cm)		0.032	0.010	0.029
Mass/Unit Area(g/m^2)		108	66	94

Table 2 Details of Test Fabrics of the MAFT Method

Fiber Content		100% Cotton	100% Polyester
Construction		Plain Weave	Plain Weave
Yarn Types		Staple Fiber Yarn	Staple Fiber Yarn
Yarn Number Count	Warp	40/1'S	40/1'S
	Fill	40/1'S	40/1'S
Fabric Count	Ends/cm	50	39
	Picks/cm	30	32
Thickness (cm)		0.033	0.027
Mass/Unit Area(g/m^2)		113	117

Apparel Administration Laboratory

1. Presented at the Annual Japan Research Assoc. for Textile End-uses Conference, Osaka, June 5, 1981 and part of paper presented at the Annual Fiber Science and Technology Conference, Tokyo, June 1−3, 1982.

Devis et al. also presented previous papers concerning this.[1),5),6)] In this paper the influences of the mixing ratio of the fabric layers, the number of layers and the different form of specimens on the flammability properties of various layered fabrics assemblies will be considered.

Materials and Method

MATERIALS. Physical properties of the fabrics were determined using the appropriate JIS Standard Test Methods (Tables 1 and 2).

SAMPLE PREPARATION. Fabrics were scoured prior to cutting specimens for physical tests and burning tests. The scourning procedures of each fabric were as follows:

a) cotton : boiled in 5% sodium hydroxide solution (liquor ratio 50 : 1) for two hours, then rinsed until neutral and dried at room temperature.
b) polyester : treated in distilled water (liquor ratio 50 : 1) at water temperature of 60°C for two hours, then rinsed and dried at room temperature.
c) wool : treated in 0.3% amylase solution (liquor ratio 50 : 1) at temperature of 40°C for two hours, then rinsed until became neutral and dried at room temperature.

FLAME RETARDANT TREATMENT. The chemical used in THPC flame-retardant treatment for the Vertical Flammability Test was tetrakis hydroxymethyl phosphonium chloride (THPC), obtained from Japan Chemical Industry Ltd. Co. The following formulations were used to prepare flame-retardant solutions for cotton:

1st Bath	THPC (95% solution)	17g
	Ethanol Amine	3g
	Water	100g
2nd Bath	Urea	15g
	Water	45g

The 1st and 2nd bath were mixed and the specimen was immersed for 30 min. at room temperature, picked up 100%, dried at 85°C for 45 min. and then cured at 140°C for 4.5 min. (Add-on : 35.1%).

Table 3 Various Layered Fabrics Assemblies of the Vertical Flammability Test Method[a)]

Number of Fabrics (N)[b)]	100% Cotton	FR[c)] Cotton	100%Polyester	100% Wool	Cotton and Wool	FR Cotton and Wool	Cotton and Polyester	FR Cotton and Polyester	Wool and Polyester
1									
2									
3									
4									

a) Each specimen was experimented 10 burnings.
b) Total number of layers of fabric.
c) Flame retardant (THPC) treated.

FLAMMABILITY MEASUREMENTS. All flammability tests were conducted at ambient temperature (between 20°C and 27°C) and relative humidity (between 60%RH and 70%RH) existing in the laboratory. Burning rate was measured with the Vertical Flammability Tester and the Mushroom Apparel Flammability Tester.

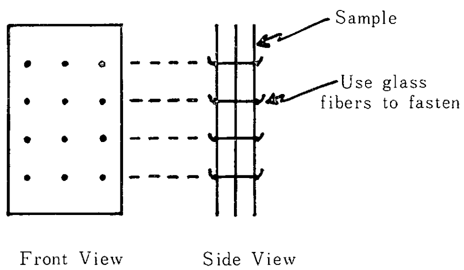
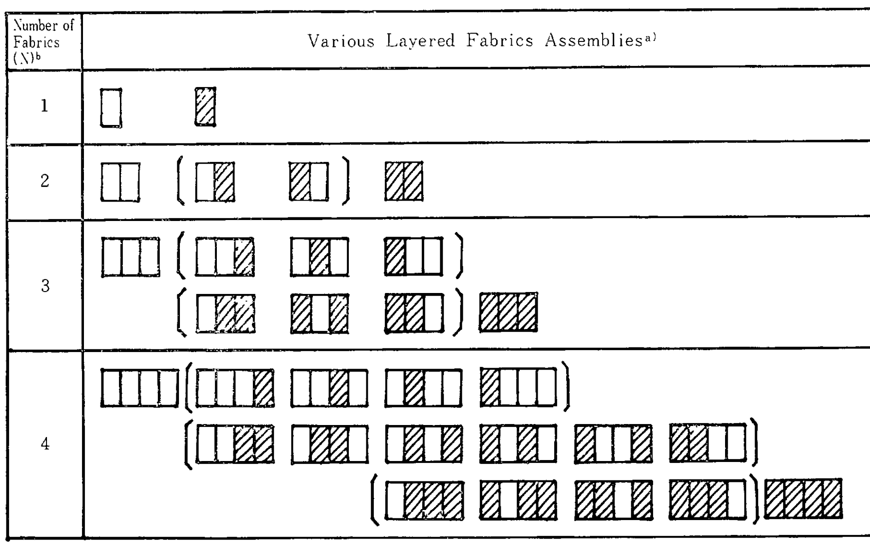


Fig. 1 Multiple layer test specimen used in rate of burning resistance testing by the Vertical Flammability Test method. The specimen was cut in 16cm X 7 cm dimension.

a) Vertical Flammability Test Method : Burning rates were determined by the JIS L-1090 C test method. Single layer specimen for the fabric assemblies, are measuring 16 cm in the warp direction and 7 cm in the fill are shown in Table 3. These were fastened with a glass fiber as shown a Fig. 1, and were controlled in the room at 65%RH and 20°C for a week, after which they were placed in a metal holder, then set in the test cabinet perpendicularly. The burning resistances, expressed as the reverse of burning rate according to the average of each of 10 burning times,



a) Each speciment was experimented 3 burnings.

b) Total number of layers of fabric, □=Single-layer of cotton; ▨=Single-layer of polyester

[ ] Presented mixing ratio of layered fabrics

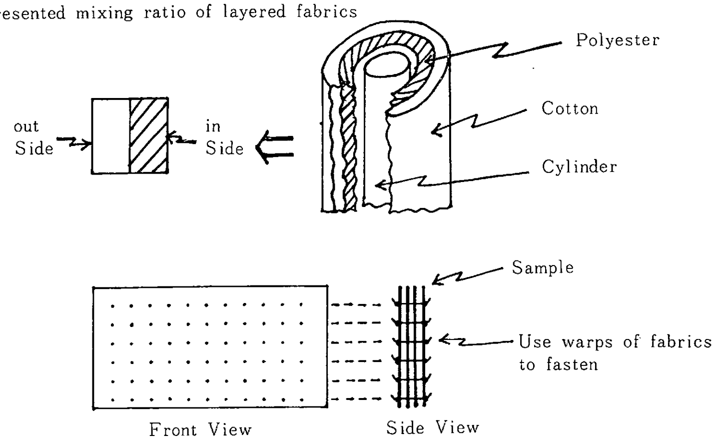


Fig. 2 Multiple layer test specimen used in rate of burning resistance testing by the Mushroom Apparel Flammability Test method. The specimen was cut in 32cm X 61cm dimension.

were used to calculate the rates. The burning was timed by starting a stop watch when the edge ignited and stopping it when the flame extinguished completely; the burning rates and the burning resistances were used to calculate the burning times and the burning length.

b) Mushroom Apparel Flammability Test Method : A sample consisted of one, two, three and four specimens from a bolt of fabric fastened with the warp yarn of the specimen as shown in Fig. 2. Single layer specimens for the fabric assemblies were cut in 32 cm X 61 cm dimensions on the test apparatus. The samples were dried in the oven at 105°C for one hour, then were cooled in the desicator for more than two hours. Burning rates were determined using the Mushroom Apparel Flammability Tester (MAFT) FL-MA model (an instrument made by Suga Co.) and were used to calculate burning areas and burning times according to the average of each of three burning times. The burning was timed by starting a stop watch when the edge of the hole was ignited and stopping it when the flame extinguished completely or halfway; burning rates and burning times were used to calculated the burning time and the burning area. The sample was folded in half, and a 6 mm hole cut on the fold 10 cm from the bottom. This was then suspended cylindrically by 4 clips at the top, and a hook was placed near the hole to position the burner, the tip of which was set at a distance of 9 mm from the hole. The length of the flame was 19 mm, the flow of methane gas was 110 ml/min. and the pressure of the methane supply was 0.1 kg/cm². The ignition time was 3 seconds and the distance between the surface of the cylinder and sample was 2 cm.

Results and Discussion

FLAMMABILITY OF VARIOUS LAYERED FABRIC ASSEMBLIES. Figure 3 shows the average of burning resistances of the fabrics as functions of the number of layers of the fabric and the burning resistance 100% cotton, 100% FR cotton, 100% polyester, and 100% wool fabrics. In general, by increasing the number of layered fabrics, the burning resistance is increased by the vertical burning method. The rating of the burning resistance of the fabrics was in order of: FR cotton > polyester > wool > cotton. Similar trends are shown in Figure 4, in which the burning resistance of the 100% cotton and 100% polyester fabrics by the MAFT method was increased, by increasing the number of layers of the fabrics. In the wool/cotton system (Fig. 5), the burning resistance at two and three layers fabric assemblies tend to be slightly decreased linearly, increasing the cotton layers fabrics content. In the wool/FR cotton system (Fig. 6), the burning resistance at two and three layered fabric assemblies tend to increase steeply linearly, by increasing the layers of the flame retardant treatment cotton. In the wool/FR cotton system the FR cotton was very effective for burning resistance of the layered fabric assemblies.

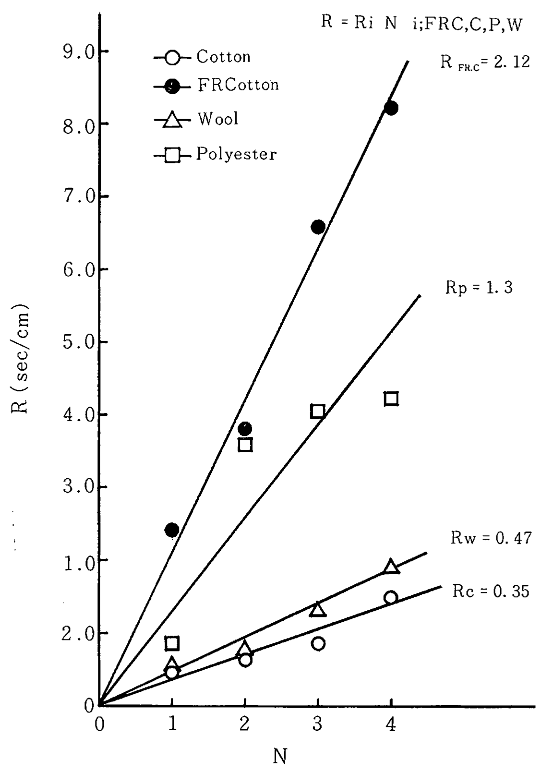


Fig. 3 Effect of the number of layers of fabric on Vertical burning resistance, R = Burning resistance; N = Total number of layers of fabric; R_i = Burning resistance of single-layer of fabric: $R_{FR.C}$ = Burning resistance of single-layer of FR cotton (2.12); R_p = Burning resistance of single-layer of polyester (1.3); R_W = Burning resistance of single-layer of wool (0.47); R_c = Burning resistance of single-layer of cotton (0.35)

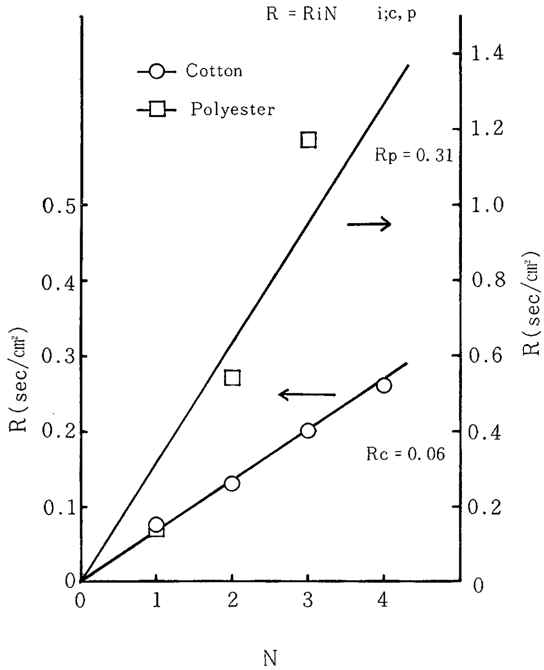


Fig. 4 Effect of the number of layers of fabric on burning resistance using the Mushroom Apparel Flammability Tester. R = Burning resistance; N = Total number of layers of fabric, R_i = Burning resistance of single-layer of fabric: R_p = Burning resistance of single-layer of polyester (0.31), R_c = Burning resistance of single-layer of cotton (0.06)

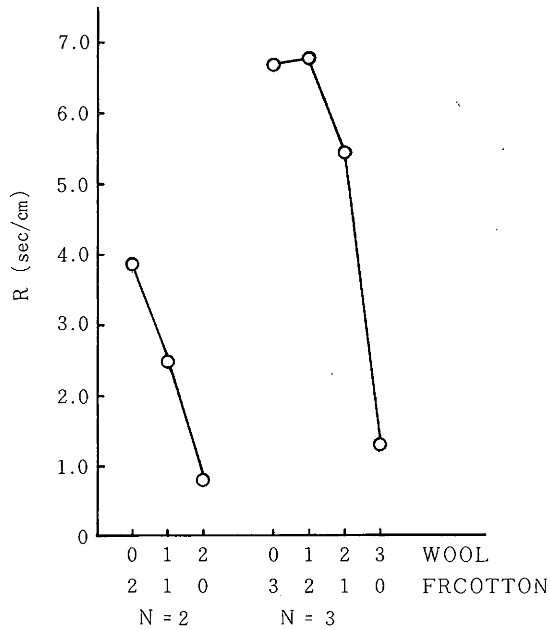


Fig. 6 Effect of the mixing ratio of fabric layers on vertical burning resistance of wool and FR cotton fabrics in 2- and 3-layered combinations; R = Burning resistance; N = Total number of layers of fabric. FR = Flame retardant (THPC) treated.

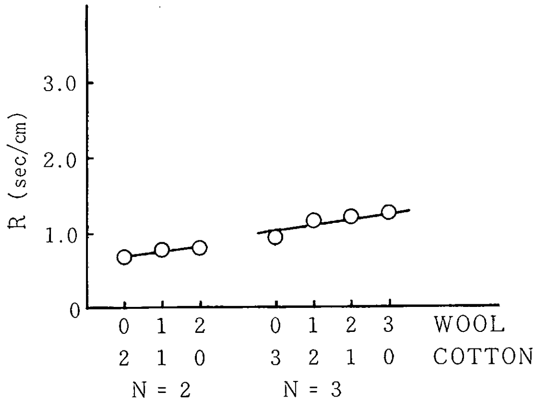


Fig. 5 Effect of the mixing ratio of fabric layers on vertical burning resistance of wool and cotton fabrics in 2- and 3-layered combinations; R = Burning resistance; N = Total number of layers of fabric

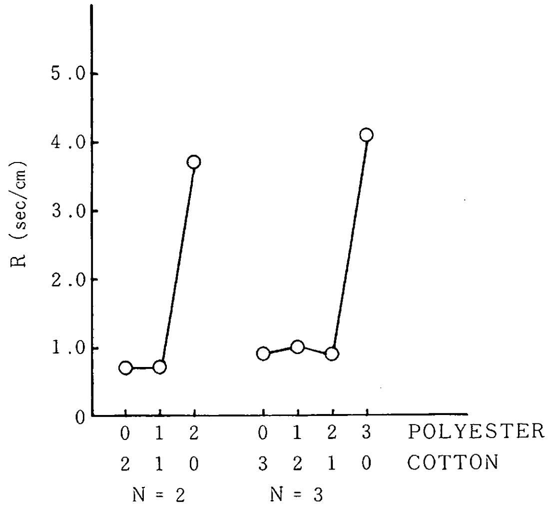


Fig. 7-a Effect of the mixing ratio of fabric layers on vertical burning resistance of polyester and cotton fabrics in 2- and 3-layerd combinations; R = Burning resistance; N = Total number of layers of fabric

In the polyester/cotton (Fig. 7-a) and polyester/wool (Fig. 8) system; their burning resistances are shown as the minimum value at 2/1 p/c and 2/1 p/w system for the three layers fabric assemblies and the burning resistance in the two layers fabric assemblies are shown as the minimum value at 1/1 p/c and 1/1 p/w system. The similar burning resistance of the polyester/cotton system of layered fabric assemblies using the vertical burning method and the MAFT method is also shown (Fig. 7-b). In the polyester/FR cotton system (Fig. 9), the values of the burning resistance are shown very larger than the p/c, and p/w system. These layered systems exhibited highly complex burning behavior, especially in thermomelting such as polvester fabrics and natural such as cotton fabrics system. Even before ignition the polyester fabric tended to melt and spread into the cotton fabric, buckling the entire system, and its burning resistance is appeared as the minimum value at the range of approximately 50%–75% polyester content.

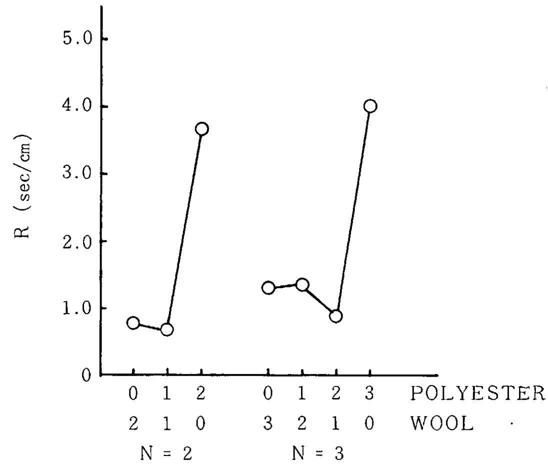


Fig. 8 Effect of the mixing ratio of fabric layers on vertical burning resistance of polyester and wool fabrics in 2- and 3-layered combinations; *R* = Burning resistance; *N* = Total number of layers of fabric

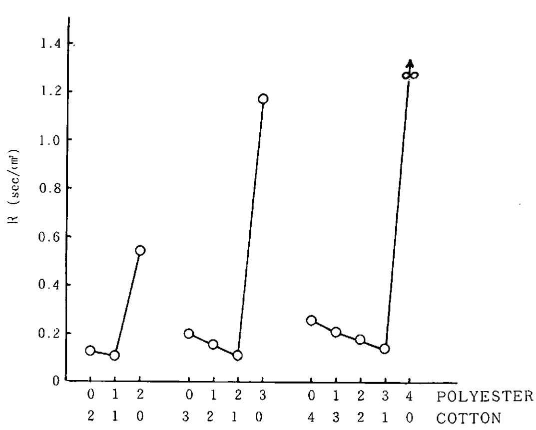


Fig. 7-b Effect of the mixing ratio of fabric layers on burning resistance of polyester and cotton fabrics in 2-, 3- and 4-layered combinations using the Mushroom Apparel Flammability Tester. *R* = Burning resistance; *N* = Total number of layers of fabric.

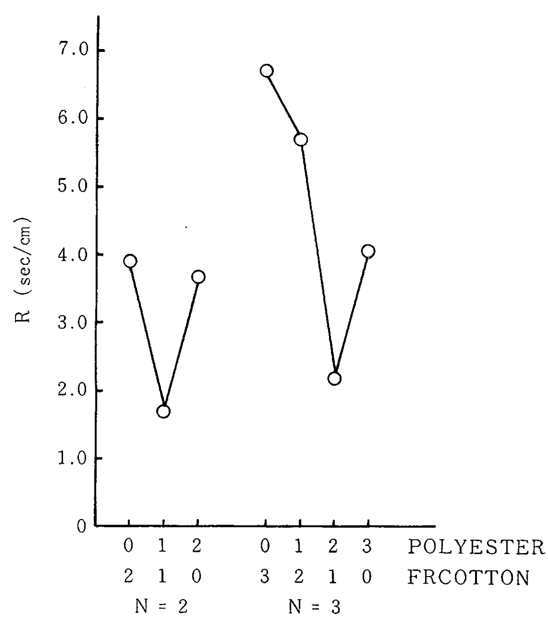


Fig. 9 Effect of the mixing ratio of fabric layers on vertical burning resistance of polyester and FR cotton fabrics in 2- and 3-layered combinations; *R* = Burning resistance; *N* = Total number of layers of fabric. FR = Flame retardant (THPC) treated.

MODEL OF BURNING RESISTANCE OF VARIOUS LAYERED FABRICS ASSEMBLIES. On the basis of the influences on the burning resistance of both the same layered fabric assemblies and the different layered fabric assemblies, the following conclusions were drawn. When the same layerd fabric assemblies were burnt, their burning resistance were approximately proportional to the number of layered fabrics. Therefore it can be expressed by the equation (1).

$$R_T = R_i\ N \tag{1}$$

Where R_i represents the burning resistance parameter (the burning resistance of one layer fabric of i) calculated from the observed values of i, and N represents the total number of layered fabrics. When the different layered fabric (wool and cotton) assemblies were burnt, their burning resistance varied linearly. The summation of the burning resistance of each layered fabric assembly can be expressed according to the same form of the equation (1) and it can be seen that

$$R_{T\cdot\perp} = (N-n)\,R_A + n\,R_B \tag{2}$$

Where R_A and R_B represent the burning resistance of the one layer fabrics of A and B respectively, N represents the total number of layered fabrics and n represents the number of layered fabrics of B. It can be said that the equation (2) was the series model of their burning resistance. The different layered fabric assemblies were burnt, and if the burning resistance of them can be predicted from equation (3), this might be taken as evidence that no interaction occurs between the two different components either of the blends, or layered systems. It can be expressed by equation (3) as follows:

$$R_{T\cdot /\!/} = NR_AR_B \,/\, nR_A\ +\ (N-n)\,R_B \tag{3}$$

It can be said that the equation (3) was the parallel model of the burning resistance of them. For instance, the burning resistance of the same layered fabric assemblies of N was $R_{T\cdot /\!/} = R_A$ when $R_A = R_B$ or $n = N$, according to equation (3). Consequently, value of $1/N$ as compared with the value of N can be calculated by equation (1). The burning resistance of the different layered fabric assemblies was inversely proportional to the mixing ratio of the two different fabrics. The parameter (X) was defined as the mixing ratio of the parallel model of the two different layered fabrics and it can be expressed by equation (4) as follows:

$$X = 4(1-n/N)n/N \tag{4}$$

The closed interval consists of all points X such that $0 \leqq X \leqq 1$. When $n = 0$ or $n = N$, then the parameter $X = 0$ and when $n = N/2$, then the parameter X was the maximal value 1. Namely the parameter X would be the maximal value 1, when the different layered fabrics were mixed in a ratio of 0.5 : 0.5. Proceeding, it was assumed that the flammability of the different layered fabric assemblies increased greatly when those fabrics were burnt and the series model of the burning resistance (equation (2)) approached the parallel model of equation (3) according to parameter X. Their burning resistance can be expressed by equation (5) as follows:

$$R_{T\cdot m} = (1-X)\,R_{T\cdot\perp} + XR_{T\cdot /\!/} \tag{5}$$

According to equation (5), the burning resistance of the same layered fabric assemblies was reduced to the burning resistance of its series model if which can be expressed by equation (2). Because, in this case, as $n = N$ or $n = 0$, then $X = 0$. In the other hand, when the burning resistance of the two different layered fabric assemblies was composed of mixing in the ratio of 0.5 : 0.5, this became the parallel model of the burning resistance expressed by equation (3). Because, in this case, if $n = N/2$ then $X = 1$. Thus, it can be provided by the parameter X of the mixing ratio that the minimum value of the burning resistance of the layered fabrics assemblies occurred when the layered fabrics assemblies were burnt. Therefore it can be assumed that equation (2) can be used when the burning resistances of the fabrics are linear, and that the equation (5) can be used when the burning resistances of the fabrics occur at the minimum value. Equations (2) and (5) have been used to calculate the burning resistances of the layered fabric assemblies for comparison with piloted burning resistance data.

The results of this calculation are shown in Figures 10 to 15 for the wool/cotton, wool/FR cotton, polyester/cotton, polyester/FR cotton and polyester/wool systems, respectively. Calculated and observed burning resistances are compared for 25/75, 33/67, 50/50, 67/33 and 75/25 of the mixing ratio of the layered fabric at each of the three different layered assembly levels (two, three and four layers of the fabric), and for the Vertical Burning Method and the MAFT Burning Method. In general, the agreement between calculated and observed datas is almost always good, except that the calculated burning resistance for 100% polyester at the two layered fabric assemblies is consistently lower than the observed one. Figure 10 shows that the burning resistance calculated by equation (2) and that observed in wool/cotton system agrees quite well for samples in the two and three layered fabric assemblies using the Vertical Burning Method. Figure 11 shows that calculated and observed burning resistance in the wool/FR cotton system agree quite well for samples in the two layered fabric assemblies, but that the observed burning resistance for 2/1 (67%/33%) and 1/2 (33%67%) wool/FR cotton are higher than that calculated in the three layered fabric assemblies field. For the polyester/cotton system (Fig. 12, 13) the observed burning resistance at two, three and four (only the MAFT method) layered fabric assemblies tend to approximate to the calculated burning resistance calculated equation (5) for the both the Vertical and the

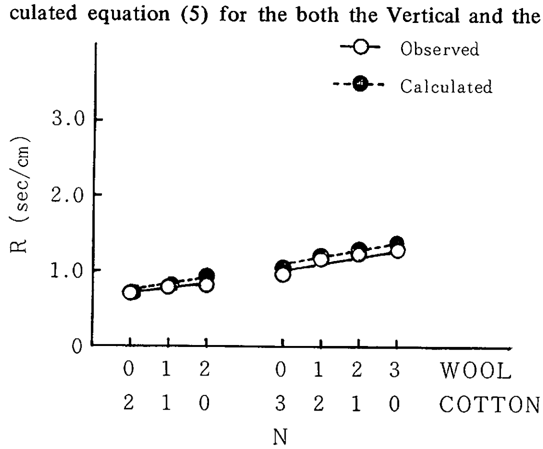


Fig. 10 Observed (——) and calculated (- - - -) vertical burning resistance for the wool and cotton system. Used equation (2) as calculated one. R = Burning resistance; N = Total number of layers of fabric.

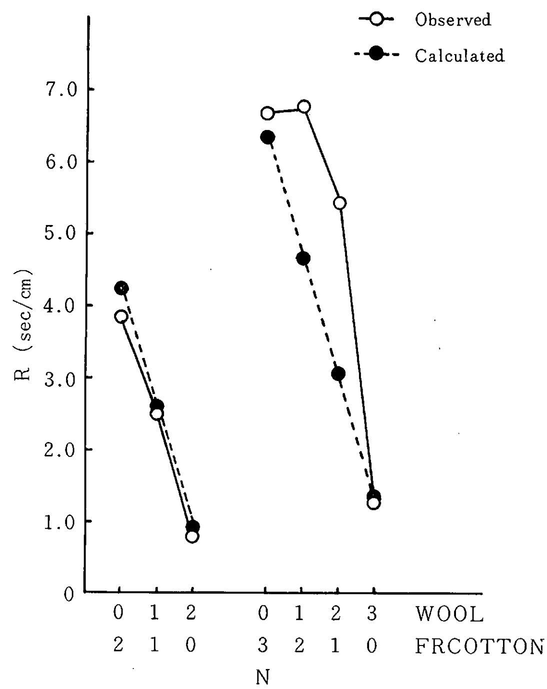


Fig. 11 Observed (——) and calculated (- - - -) vertical burning resistance for the wool and FR cotton system. Used equation (2) as calculated one. R = Burning resistance; N = Total number of layers of fabric. FR = Flame retardant (THPC) treated.

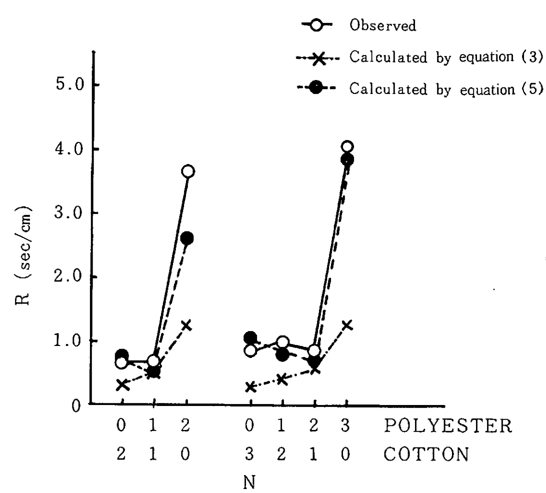


Fig. 12 Observed (——) and calculated (—— · —— = equation (3) and — — — = equation (5)) vertical burning resistance for the polyester and cotton system. R = Burning resistance; N = Total number of layers of fabric. Burning resistances calculated by equation (5) and that observed agrees quite well as compared with that calculated by equation (3).

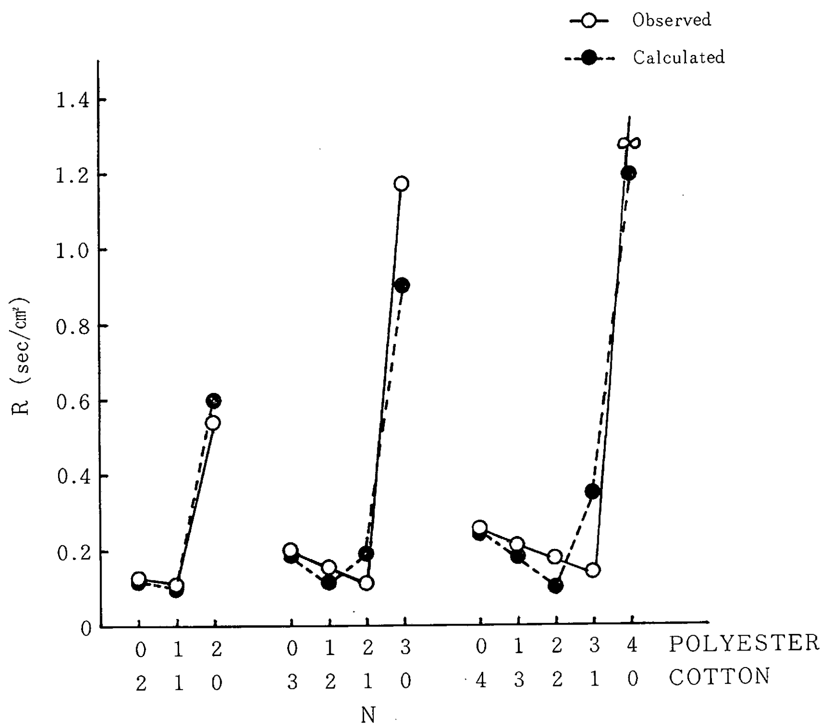


Fig. 13 Observed (——) and calculated (– – –) burning resistance using the Mushroom Apparel Flammability Tester for the polyester and cotton system, used equation (5) as calculated one. R = Burning resistance; N = Total number of layers of fabric.

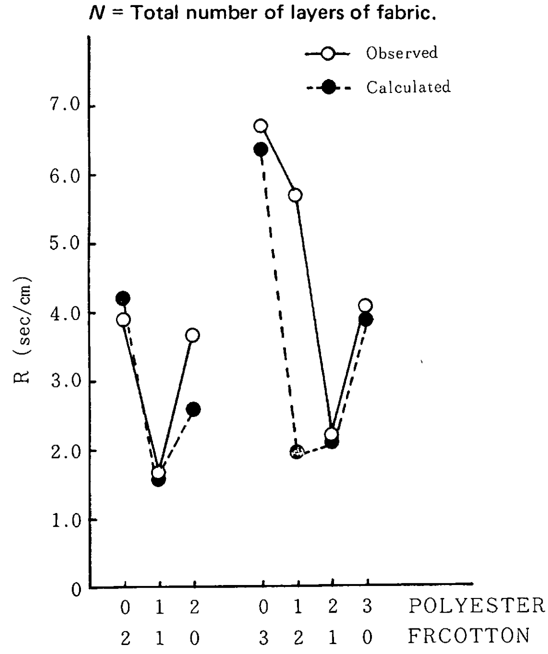


Fig. 14 Observed (——) and calculated (– – –) vertical burning resistance for the polyester and FR cotton system, used equation (5) as calculated one. R = Burning resistance; N = Total number of layers of fabric. FR = Flame retardant (THPC) treated.

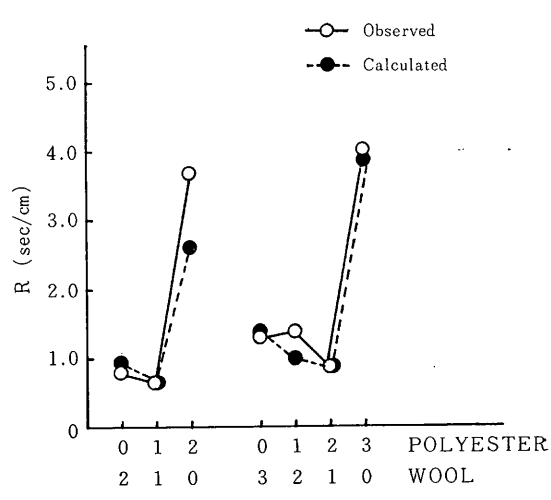


Fig. 15 Observed (——) and calculated (– – –) vertical burning resistance for the polyester and wool system, used equation (5) as calculated one. R = Burning resistance; N = Total number of layers of fabric.

MAFT Burning Methods. In the polyester/FR cotton system (Fig. 14) the burning resistance calculated by equation (5) of two and three layered fabric assemblies tend to approximate to the observed burning resistance except that the observed burning resistance in the mixing ratio of 2/1 (67%/33%) polyester/FR cotton cannot be adequately approximated by equation (5). In the polyester/wool system (Fig. 15) the burning resistance calculated by equation (5) of two and three layered fabric assemblies tend to approximate to the observed burning resistance also.

Summary and Conclusions

The purpose of this study was to investigate the influences of the mixing ratio of the fabric layers, the number of layers and different forms of samples on various layered fabrics assemblies (cotton, polyester and wool). The 100% cotton, 100% FR cotton, 100% polyester and 100% wool fabrics were tested as single, two, three and four-layer assemblies, and then the wool/cotton, wool/FR cotton, polyester/cotton, wool/FR cotton, and polyester/wool systems were tested by the direct ignition method as two and three-layer assemblies at different mixing ratios using the Vertical Flammability Tester. The polyester/cotton system was also tested the direct ignition method as two, three and four-layer assemblies at different mixing ratio using the Mushroom Apparel Flammability Tester. The conclusions were as follows:

1) As the number of natural layered fabrics such as the cotton/wool system was increased, the burning resistance was increased linearly. This can be represented by the series model of the burning resistance of a single layer of each fabric. The following equations were obtained.

$$R_{T\cdot\perp} = (N-n)\,R_A + n\,R_B$$

Where : N : total number of layers of fabric

n : number of layers of B

R_A and R_B : the burning resistance of single-layer of A and B

2) When various layered fabrics assemblies of cotton and polyester were burnt, the burning resistance when exposed to an ignition source became minimum at the specific mixing ratio (polyester content : approximately 50%–75%). This can be represented by the series and parallel model of the burning resistance of each fabric with the mixing parameter X which contributed to the parallel model of the burning resistance, when the burning resistance of both was shown at the minimum point at the specific mixing ratio.

The following equations were obtained.

$$R_{T\cdot m} = (1-X)\,R_{T\cdot\perp} + XR_{T\cdot/\!/}$$

Where : $R_{T.\perp} = (N-n)R_c + nR_p$

$R_{T./\!/} = NR_cR_p/nR_c + (N-n)R_p$

N : total number of layers of fabric

n : number of layers of polyester

R_c : burning resistance of single-layer of cotton

R_p : burning resistance of single-layer of polyester

X : mixing parameter of layered fabric assembly

3) In the polyester/cotton system, there was no difference between the forms of the burning resistances when tested by the vertical burning method and the Mushroom Apparel Flammability Test method.

ACKNOWLEDGMENTS

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Flammability Properties of Various Layered Fabrics Assemblies

重ね合わせ織物の燃焼性について

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(昭和57年9月30日受理)

各種重ね合わせ織物（綿布、ポリエステル布、毛布）の燃焼の場合、2枚，3枚，4枚重ね（ＭＡＦＴ法のみ）した場合、認意に混合した場合、試料の形状を変化した場合について重ね合わせ織物の燃焼性を垂直法およびＭＡＦＴ法（綿布，ポリエステル布）で実験した結果次の成果を得た。

1) 天然繊維織物（綿，毛）の重ね合わせの燃焼抵抗は毛布の増加と共に直線的に増大し、直列モデルで表わすことができる。

2) 綿のような天然繊維織物とポリエステルのような熱溶融性織物の重ね合わせの燃焼抵抗はある混合比の時最小となり、混合のパラメーター x を用いた直列〜並列モデルの組合わせで表わすことができる。

$$R_{T\cdot m}=(1-x)R_{T\cdot\perp}+xR_{T\cdot /\!/}$$

3) ポリエステル布と綿布の組み合わせによる重ね合わせ織物を垂直法とＭＡＦＴ法で燃焼した場合、試料の形態の相違にかかわらず、それらの燃焼抵抗は同様な形状を示した。