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SOME PROPERTIES OF FLAMEPROOF FABRICS*

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A group of five cotton and rayon fabrics were treated with seven different flame-retardant finishes. Flame resistance of the treated fabrics was determined by three different methods, before laundering and after laundering up to 14 times. Fabric strength determinations were made on the treated and untreated fabrics, before and after laundering. Several of the treatments showed good durability as affected by laundering. Commercial applications appeared to be most successful on closely woven fabrics of medium or heavy weight. In general, the treatments produced a reduction in tearing strength of the fabrics, but did not significantly affect the breaking strength.

INTRODUCTION

In recent years, decided advances have been made in the development of durable flameproofing treatments for textiles, with the work largely directed toward meeting the needs of the military services. The treatments developed have found civilian application primarily in the field of interior furnishings in the execution of large decorating contracts, such as in hotels, theaters, and ships. Flameproofed fabrics have not been offered generally to the public at the retail level and it appeared that information regarding the effects of available treatments on fabrics suitable for clothing and other home purposes would be useful.

In the present study seven different flameproofing treatments were applied to 20- to 25-yard pieces taken from one or more of five selected fabrics. The original and flameproofed fabrics were tested for flame resistance by three different methods, for breaking strength, and for tearing strength. The fabrics were also laundered repeatedly and tested by the same methods to show the durability of the flameproofing in laundering. The materials and procedures used are described, and the results obtained are discussed in this paper.

DESCRIPTION OF FABRICS

Although a wide range in fabric type was desired for the study, preliminary contact with the finishing plants disclosed that the flameproofing treatments were considered to be applicable only to smooth-surfaced cotton or rayon fabrics weighing five oz/yd^2 or more. Nevertheless, one fabric of considerably lighter weight was included for trial. A description of the fabrics selected is given in Table I. The sateen, supplied by the Army Quartermaster Corps, was included as one of the fabrics which had been employed in much of the flameproofing development work, to provide a possible basis for comparison with previously obtained data.

The commercial finishing plants were not able to obtain a satisfactory application of the flameproofing in all cases, and some of the fabrics were not returned in a treated condition. The treatments applied to the various fabrics, with the add-on as calculated from fabric weight determinations, are shown in Table II. Treatments A and B were applied by the Southern Regional Research Laboratory of the U S Department of Agriculture at New Orleans. In treatment A, applied only to the sateen, the key chemical is tetrakis (hydroxymethyl) phosphonium chloride, abbreviated to THPC (*1, 2*). Treatment B was a combination formula in which the bromoform-triallyl phosphate polymer is added to the THPC formulation, the combination being designated THPC-BAP (*3*). The next four flameproofing materials were proprietary formulas applied by commercial finishers of fabrics. The probable type of each is indicated in the table. The seventh treatment, G, was the well-known borax-boric acid water-soluble flameproofing (*4*), and was applied in the laboratory by the author. The monks cloth and rayon fabric finished with treatment E would have been unacceptable commercially. They were excessively

TABLE I
Description of base fabrics

Type	*Fiber*	*Weave*	*Color*	*Weight (oz/yd^2)*
Sateen	cotton	sateen	olive green	8.6
Monks cloth	cotton	basket	natural	8.1
Byrd cloth	cotton	twill	gray	4.8
Bengaline	rayon warp, cotton fill	warp-rib	rose	6.5
Dress fabric	rayon	novelty	blue	3.3

TABLE II
Flameproofing material and add-on, expressed as a percent of the base fabric weight

		Add-on				
Designation of flameproofing treatment	*Type of flameproofing material*	*Sateen (%)*	*Monks cloth (%)*	*Byrd cloth (%)*	*Bengaline (%)*	*Rayon (%)*
A	THPC (*1, 2*)	15	—	—	—	—
B	THPC-BAP (*3*)	14	21	17	20	18
C	resin	25	34	19	21	—
D	resin	30	31	—	—	—
E	metallic oxide-chlorinated hydrocarbon	31	143	27	26	55
F	urea-phosphate	17	28	19	28	33
G	borax-boric acid	11	16	10	17	12

stiff, spotted, and the weave was distorted. The finisher did return them, however, and they were tested for flame resistance.

The most noticeable effect of the treatments was a tendency to stiffen the fabrics, the degree ranging from slight to excessive. The degree of stiffening, as determined by inspection alone, showed a rough correlation with add-on in that treatment E, with generally heavy weightings, produced generally severe stiffening, while treatment G, with comparatively light weightings, produced lightly stiffened fabrics. Otherwise, no consistent correlation was evident, either on a fabric or a treatment basis, which suggests perhaps a considerable variation in the effectiveness on different fabrics of the softening processes used. The effect of the treatments on color was slight and entirely acceptable with the neutral shades. The blue rayon and rose bengaline were more noticeably affected, but only the rose bengaline finished with treatments B and C showed objectionable change. The colors of these fabrics were lightened and, though not unattractive, appeared faded in comparison with the original.

TABLE III
Flame resistance as determined by vertical Bunsen test

Base fabric	No. of launderings	Treatment						
		A	B	C	D	E	F	G
Sateen	0	7.6	7.8	7.6	7.3	7.0	8.0	8.7
	1	8.0	7.9	8.2	7.8	6.7	6.6	
	14	7.7	7.4	7.9	7.7	5.8		
Monks cloth	0		9.1	8.9	8.7	9.6	9.0	10.6
	1		9.4	9.5	8.9	9.5	0.0	
	14		9.4	9.7	9.0	9.3		
Byrd cloth	0		7.3	7.1		5.6	7.8	8.1
	1		7.4	7.2		5.6	0.0	
	14		6.9	6.2		4.2		
Bengaline, warp	0		8.1	8.0		7.7	8.4	9.1
	1		8.5	8.1		6.9	0.0	
	14		8.3	5.8		5.1		
Bengaline, filling	0		7.1	7.0		5.7	8.0	8.9
	1		7.5	7.3		5.1	3.4	
	14		6.8	3.8		3.4		
Blue rayon	0		7.1			6.9	8.1	8.7
	1		7.3			5.2	0.0	
	14		7.2			0.0		

Note: Values represent average length in inches of specimen remaining uncharred.

FLAME RESISTANCE

The major criterion used for the evaluation of flame resistance was the vertical Bunsen test (5, Method 5902), which is widely used and is accepted as a standard method by various officials and organizations, including the American Society for Testing Materials and the National Fire Protection Association. The test is not a reliable criterion of fabric fire hazard under all conditions of use, however, and there is continuing interest in other methods which are proposed or may be adapted to fabric application. The group of treated fabrics offered a convenient basis for some comparison of test procedures, and flame-resistance determinations were made by two other methods in addition to the usual vertical Bunsen test. One of these was a simple match test (3), devised at the Southern Regional Research Laboratory in the course of work on the development of flame-retardant treatments, and adopted as a practical laboratory criterion which gave reproducible results. The other was a radiant panel method (6) developed at the National Bureau of Standards particularly to measure the flame-spread properties of building materials used for interior finishing purposes. The latter method was of special interest because of the wide range of flame resistance over which it might prove useful.

VERTICAL BUNSEN TEST——This test consists essentially in applying a 1½″ luminous flame for 12 seconds to the lower end of a 12″ strip of fabric supported in a vertical position and clamped in a holder so that a 2″ width is exposed. Comparative flame resistance is assessed mainly on the basis of the length of the resulting charred and weakened area, which is defined as the distance from the lower end of the specimen to the end of a tear produced by raising one lower corner of the specimen to lift a prescribed weight attached to the other lower corner. The test was applied to the treated fabrics as received, and also after they had been subjected to one, three, eight and 14 launderings.

A laundering cycle judged to be reasonably comparable to home laundering was selected. It followed the procedure of the mobile laundry method for shrinkage in laundering (5, Method 5556) except that the sour was omitted and the wash load was reduced to approximately 3¼ lbs. Although little durability as affected by laundering was claimed for treatment F, it was carried through the first cycle of laundering to determine whether any flame-retardant effect might be retained. The water-soluble treatment G was not subjected to laundering. Such pressing as was required was done with a moderate hand iron.

At the selected check points in the laundering program, eight specimens (four cut in the warp direction, four in the filling direction) of most of the fabrics were tested by the vertical Bunsen method. For the bengaline throughout, and for all of the fabrics finished with treatment E, the number of specimens was doubled, inasmuch as early results indicated a possibly significant difference in flame resistance in the warp and the filling directions. All specimens were conditioned at 65% rh and 70°F. The testing was scheduled so that two specimens (or four in the special cases noted above) of each fabric at each of two of the check points were tested in a single day. The check points were selected so that, at some time during the program, each check point had been coupled with every other in tests made on the same day. This scheduling of tests was designed to permit a statistical evaluation of the possible effects of storage over the several months of the test program and of varying ambient conditions in the test room.

The results of the vertical Bunsen tests are summarized in Table III and those obtained with treatments B and E are shown graphically in Figure 1. Inasmuch as it is usually desirable that a high value indicate good performance, the results are expressed as the average length of specimen remaining uncharred, calculated by subtraction of the measured char length from the total 12″ specimen length. Only the bengaline showed a substantial difference in warp and filling values, and this appeared to result from a difference between the warp and filling yarns in weakening ahead of the flame. The warp and filling results for the other fabrics were averaged together. Consideration of the detailed data indicated that storage and the variation in conditions in the test room had no important effect on the flame resistance results. An analysis of variance was made on a suitable portion of the data and yielded a standard deviation, s, equal to 0.5 inch for a single measurement. Applying the relation $s/\sqrt{n}$ to the average of n measurements, the standard deviation for the results shown in Table III would be approximately 0.2 inch in most cases (about 0.1 inch for the

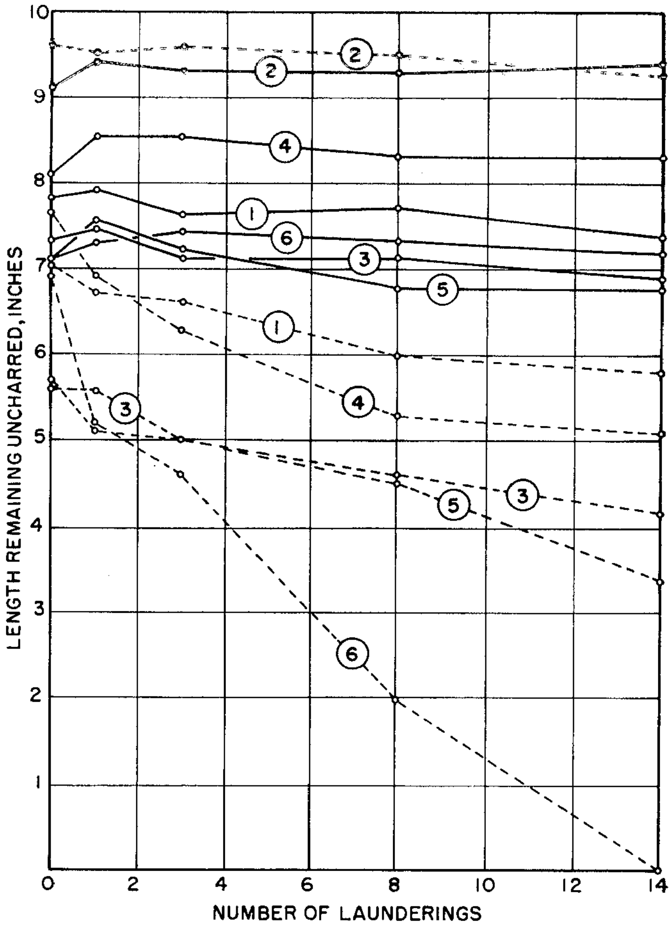

Figure 1

Relationship between flame resistance and number of launderings for treatments B (solid lines) and E (broken lines).

1—sateen
2—monks cloth
3—Byrd cloth
4—bengaline, warp
5—bengaline, filling
6—blue rayon

treatment E values except bengaline).

The results indicate that treatment G, representative of water-soluble treatments in general, provided excellent flame resistance with a lower add-on than any of the more durable treatments employed. Among the latter, treatment B was successfully applied to all of the fabrics and, with moderate add-on, provided good flame resistance which was largely retained throughout the laundering program. Treatment C also showed a fair range in application but suffered some loss in flame resistance on the bengaline and Byrd cloth after 14 launderings. Treatment D showed excellent laundering durability on the sateen and monks cloth, but its successful application was limited to those two materials. With treatment E there was, in general, a progressive reduction in flame resistance with repeated laundering, the blue rayon showing almost complete loss after 14 launderings. The slight hump in the curves for treatment B (Figure 1), indicating a small temporary increase in flame resistance with the first launderings, was characteristic of all of the treatments except E. Presumably, this reflects some shrinkage and readjustment of yarns with the first laundering which, in most instances, was soon offset by a slight loss of flame-retardant chemicals.

MATCH TEST——This test uses a strip of fabric ¼″ wide by 10″ long, which is suspended vertically in a draft-free area and ignited at the lower end wtih an ordinary match. The height of flame travel is noted visually and the results are expressed by four general classifications of flame resistance: "excellent" if the fabric does not burn after removal of the igniting flame, "good" if the burning is self-extinguished in the lower three or four inches of the strip, "fair" when the burning extends approximately halfway up the strip, and "fail" when the strip burns completely.

This match test was applied to the group of treated fabrics at the same laundering checkpoints selected for the vertical Bunsen test. Six specimens (three cut in the warp direction, three in the filling direction) were used for each test, and they were subjected to the same conditioning at 65% rh and 70°F as the specimens for the Bunsen test. Average results of these tests (averaged by assigning numbers 1 to 4 to the four classifications) are shown in Table IV.

RADIANT PANEL TEST——This method incorporates a major departure from most flame-test procedures in that the unburned portion of the specimen is heated by a controlled external radiant source rather than by flames from the burning portion, which commonly waver so severely as to obscure the progress of flame travel. This is accomplished by supporting the 6″ x 18″ specimen in front of a vertically-mounted, preheated radiant panel, with the long dimension of the specimen at an angle of 30 degrees to the vertical, the lower end being farthest from the radiant panel. The specimen is ignited at the top by means of a pilot light. Thus, the flame front travels downward and the flames rise away

TABLE IV
Results of the match test

Base fabric	*No. of laund*	*Treatment* *A*	*B*	*C*	*D*	*E*	*F*	*G*
Sateen	0	fair	*ex	ex	good	good	ex	ex
	1	fail	ex	ex	good	good	fail	
	14	fail	fair	ex	good	good		
Monks cloth	0		ex	ex	good	ex	ex	ex
	1		ex	ex	fair	ex	fail	
	14		ex	ex	fair	ex		
Byrd cloth	0		good	good		good	ex	ex
	1		good	fair		good	fail	
	14		fair	fail		fair		
Bengaline	0		ex	ex		good	good	good
	1		ex	good		good	fail	
	14		good	fair		fail		
Blue rayon	0		good			ex	ex	good
	1		fair			ex	fail	
	14		fair			fail		

*Excellent

from the unignited part of the specimen. Thermocouples placed in a stack above the upper end of the specimen furnish information on the rate at which the flames would supply heat to the unignited material under normal burning conditions. Records are kept of the time of arrival of the flame front at specified distances from the upper edge of the specimen and the test is continued until the flame has travelled the full length of the specimen or until an exposure period of 15 minutes has elapsed. Results are expressed as a flame spread index, I_s, calculated as the product of the flame spread factor (F_s) and the heat evolution factor (ΔT) by the formula

$$I_s = .23\ F_s\ \Delta T$$

where .23 is a constant obtained from the thermocouple calibration curve. Large values of I_s correspond to low flame resistance and vice versa. While building materials are usually tested with a ½″ asbestos millboard backing applied directly to the material under test, the fabric test specimens were prepared with a ½″ air space between the fabric and the millboard backing.

The test was applied to the untreated fabrics before laundering and to the treated fabrics before laundering and after 14 launderings. Four specimens of each of the untreated fabrics were tested, and from one to three specimens were used in the treated fabrics tests. In most of the tests of the treated fabrics, ignition to produce sustained flaming did not occur. However, glow appeared on some specimens and progressed varying distances, and on some a brief surface flash travelled a short distance down the specimen. In calculating flame spread index values, the flame spread factor was based on whichever of these evidences of combustion showed the most rapid progress. When no flame, flash, or glow was present, the flame spread index was based on the heat evolution factor alone. Results of the radiant panel tests, expressed as average flame spread index values, are shown in Table V. Average values of F_s and ΔT for the untreated fabrics are included, to indicate the type of data obtained.

TABLE V
Results of radiant panel test

Base fabric	No. of laund	F_s	None ΔT	I_s	Treatment: A I_s	B I_s	C I_s	D I_s	E I_s
Sateen	0	31.9	46	340	1.1	1.1	2.5	5.3	2.3
	14				3.2	14.0	13.0	16.0	17.0
Monks cloth	0	48.1	84	927		23.0	3.0	33.0	4.6
	14					32.0	32.0	48.0	19.0
Byrd cloth	0	81.3	54	1013		0.5	0.7		0.2
	14					1.4	2.8		5.7
Bengaline	0	42.1	59	569		0.8	0.2		0.4
	14					3.6	4.6		29.0
Blue rayon	0	48.9	23	260		1.2			0.2
	14					62.0			264.0

TABLE VI
Tearing strength

Base fabric	No. of laund	Fabric strength: Untreated fabric (lbs)	Fabric with treatment*: A (%)	B (%)	C (%)	D (%)	E (%)	F (%)	G (%)
Sateen	0	8.2	91	66	68	71	71	73	72
	14	6.1	75	82	93	93	123		
Monks cloth	0	10.9		82	91	101		74	9[illegible]
	14	15.4		62	62	81			
Byrd cloth	0	2.5		80	100		100	96	7
	14	4.3		51	70		107		
Bengaline	0	10.8		58	47		84	51	72
	14	11.2		61	48		83		
Blue rayon	0	3.7		97				159	95
	14	4.2		162					

*Strength expressed as % of that of the untreated fabric after the indicated number of launderings.
Note: Tongue tear method used for all fabrics except the monks cloth and bengaline, which were tested by the trapezoid method.

COMPARISON OF TEST METHODS——The free-hanging narrow specimen of the match test provided a more severe exposure than that of the vertical Bunsen test, and the two methods differed as to criterion of flame spread. In the match test, flame travel was judged by observation of the visible flame progress, while in the Bunsen test it was gauged by the progress of a subsequently measured specified degree of fabric deterioration. The match test criterion would appear more closely related to flame spread hazard although its application was less precise, since it depended on the momentary judgment of the operator, and the classifications were approximate. In view of these differences, it is not surprising that the correlation between results by the two methods varied with the treatment, and there was no limited range of char length in the Bunsen test which corresponded consistently with a given classification in the match test. With its more severe exposure the match test appeared somewhat more sensitive than the Bunsen test in indicating degrees of flame resistance.

The radiant panel test provided comparative values over a much more extended range of flame resistance than either of the other methods, covering the untreated as well as the treated fabrics. It also supplied more detailed information on flame-spread characteristics, indicating the relative contributions of the flame-spread rate and of the amount of heat evolved to the overall flame-resistance evaluation. Thus, a rapid flame spread was the primary factor in producing the relatively high index value for untreated Byrd cloth, and a low heat output accounted for the comparatively low index value of the untreated blue rayon material. Like the match test, the radiant panel test appeared to provide a more severe exposure and give a greater resolution of the degree of flame resistance than the vertical Bunsen test. The radiant panel method has not previously been applied to fabrics, however, and additional work would be necessary to support these results and establish its value for this purpose.

FABRIC STRENGTH DETERMINATIONS

The breaking and tearing strengths of the fabrics were evaluated before and after flameproofing and after laundering one, three, eight and 14 times. In breaking strength, determined by the grab method, some of the treated fabrics appeared to show a slight initial loss, but after several launderings the breaking strength was nearly that of the laundered untreated material and it was concluded that the treatments generally had no significant effect on breaking strength. The tearing strength, however, was considerably affected in most cases.

Tearing strength determinations were made with an Instron machine, using the tongue method (5, Method

5134) for the sateen, Byrd cloth, and blue rayon materials and the trapezoid method (5, Method 5136) for the monks cloth and bengaline, for which the tongue method was not well suited. The two methods do not give comparable values, but an approximate comparison of the effects of the treatments on the different fabrics may be made on a percent basis. Table VI gives tear results before laundering and after fourteen launderings, expressed as percent of the tearing strength of the untreated fabric similarly laundered.

The effect on tearing strength varied considerably with the type of fabric. With the sateen, a marked loss in initial tearing strength generally produced by the treatments, was substantially overcome by repeated laundering, although treatment A showed a reverse effect. The Monks cloth and Byrd cloth showed decidedly lower proportionate tearing strength after laundering in most cases, which reflected a considerable increase in the tearing strength of the untreated fabric with laundering, with relatively small corresponding increases for the treated samples. The bengaline suffered generally severe reductions in initial tearing strength which were not significantly altered by laundering. Although few data were obtained on the light-weight blue rayon, it would appear that treatments B, F, and G had little adverse effect on the tearing strength of this fabric.

SUMMARY

At present, the commercial application of durable flameproofing appears to be satisfactory on a fairly restricted range of materials, although wider applicability for some experimental treatments was indicated. A general tendency of the treatments to stiffen the fabric, limits acceptability of the finish for many purposes, and it appears that certain colors are modified by treatment. Some fabrics showed a considerable reduction in tearing strength with treatment, although this effect was generally not so severe as to seriously restrict consumer acceptability, in which fabric strength is probably a less critical factor than appearance. Progress in achieving durability of flame resistance as affected by laundering has been notable, however. Thus, treatment B, applied in weightings which gave a somewhat stiffened but reasonably satisfactory finish to the entire group of fabrics studied, provided flame resistance which persisted, in large part, through a considerable laundering program. Commercially applied flameproofing also showed good laundering durability on the fabrics best suited to treatment.

With regard to the three methods used to determine flame resistance, both the match test and the radiant panel test provided a more severe exposure and appeared to give a somewhat greater resolution of the degree of flame resistance than the vertical Bunsen test. The match test offers a simple, rapid means of approximate flame resistance evaluation, well suited to checking progress in the development of new treatments, but for general use as a standard method it would require more exact definition as to test procedure and interpretation of results. The radiant panel test is a more complex method but it permits evaluation over an unusual range of flame resistance on a single scale, and separate determination of the flame spread and heat evolution factors. The tests with the present group of fabrics were not sufficient, however, to establish suitability of the method for fabric work.

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