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EFFECT OF THE RAW MATERIAL COMPOSITION OF FABRICS ON THE LIMITING OXYGEN INDEX (LOI)

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16. Abstract

The raw material composition of fabrics is one of the most important factors for LOI value. LOI value was determined in samples of varying composition composed of cellulose, protein, and synthetic fibers and their mixtures, based on ASTM D 2863-76. Cellulose fibers and their mixtures exhibited the lowest value, while synthetic fibers had the highest LOI value.

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EFFECT OF THE RAW MATERIAL COMPOSITION OF FABRICS ON THE LIMITING OXYGEN INDEX (LOI)

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1. Introduction

The Limiting Oxygen Index (LOI) is the minimum concentration of oxygen in combination with nitrogen which a sample of fabric consumes at room temperature when burning for three minutes or a distance of 50 mm. In the literature, various synonyms are used for the LOI: Critical Oxygen Index (COI) or just Oxygen Index (OI). We shall express the LOI in accordance with ASTM D 2863-76 [2], using the formula /151*

$$n\ (\%) = \frac{(O_2)}{(O_2 + N_2)} \cdot 100$$

where n is the LOI expressed in percent, (O_2) is the volumetric flow of oxygen (ml/sec), and (N_2) is the volumetric flow of nitrogen (ml/sec). ASTM D 2863-76 does not differ from ASTM D 2863-70, which was the first standard in this area. Likewise, the International Standards Organization (ISO)defines LOI [3], but instead of room temperature as the operating temperature, it prescribes execution at a temperature of 296.15±2 K. The French standard T 51-071 [4] likewise specifies the combustion time, but it differs from the ASTM standard, with the condition that the fabric sample burn a distance of 100 mm. Many authors use "temperature index", defined here as flammability or combustion, which is the temperature at which the LOI value reaches 20.8 [5].

2. Fabric Samples

In order to carry out the investigation, we used samples of natural and chemical raw materials and combinations of these. On an in-

*Numbers in the margin indicate pagination in the foreign text.

dustrial scale, the washing phases were among the favored phases studied, while the thermoset phase was studied for the synthetic samples.

In order to select the samples, we limited the density of the fabric to 140 g/cm^2 and excluded the significance of the weave (here, we chose samples of various raw-material composition in a linear weave)

We divided the samples available into three groups or series:

1) a source of cellulose and cellulose mixtures
2) a source of natural p-otein and protein mixtures
3) a synthetic source and synthetic mixtures.

Examples in the first series are designated in the tables by Cl, C2, C3, etc., examples in the second series by B1, B2, B3, etc., and examples in the third series by S1, S2, S3, etc.

With samples in mixtures, we first used two-component ones. The raw-material composition of the entire sample is given in the tables. Combinations such as cellulose and synthetic are presented in two tables, in the tables for the C and S series, and for this reason the identification is given as a note.

For both groups, the effect of the second component was taken into consideration, the effect of the synthetic upon the C and S series in order for us to readily establish the contribution of the cellulose raw material present.

3. Procedure /152

We ignited the sample (set in a frame) continuously from above in an oxygen and nitrogen atmosphere, and we dteermined the minimum amount of oxygen needed for the sample to burn three minutes or to burn through a distance of 50 mm. The analysis was done at room temperature or at an optional temperature of up to 400°C.

4. Equipment

We used a Stanton Redcroft apparatus to carry out the analysis, models FTA and HFTA.

The FTA model is made up of three major parts:

- a device to which steel piping for the oxygen and nitrogen gas are connected through a two-level reducing valve (inlet pressure 1.5-2.1 bars)

- a meter system for the oxygen, which analyzes the gas mixture and determines the oxygen concentration in it. A Servome oxygen analyzer [6] was used for the analysis, which established changes in the magnetic field which makes the oxygen a paramagnetic gas

- a test column with a holder for the sample. The column is a 310-mm-high glass cylinder with a diameter of 95 mm; the gas mixture passes through a porous bottom.

The HFTA model is a variety of the FTA model and serves to obtain the LOI at high temperatures (up to 400°C). The model is made up of an automatic temperature regulator and a special column with a heater and heating connections.

5. Performing the Analysis

Execution of the analysis on the FTA model: We placed a holder with a sample (40 X 100 mm) in the test column, equalized the oxygen concentration, blew the mixture through the column for 30 sec at a flow rate of 4±1 cm/sec (at 750 bars and 273.15 K), and with a special lighter ignited the sample. The sample had to burn at least 3 min or burn through a length of 50 mm. We calculated the LOI to scale.

Execution on the HFTA model: The method of measurement was the same as with the FTA, but we heated the column and the preheating chamber for the gas mixture to room temperature.

We determined each LOI for tem samples along the warp and ten samples along the woof, if the raw-material composition of the warp was different from that of the woof.

6. Measurements and Analysis of the Measurement

We carried out the measurements in accordance with the instructions of ASTM D 2863-76. We used a flame (25 mm) from a propane-butane mixture [7] for ignition. ASTM D 2863-76 does not specify the time the samples are to be in contact with the flame (ignition time). Because we determined the effect of the ignition time in the preliminary measurements, we carried out the measurements for 5 sec of contact with the flame [8].

Because the moisture of the samples is not specified in the ASTM standard (although the standard was foreseen for determining LOI for synthetic sheets, whose moisture content is independent of the surroundings), we carried out the measurements on climatized samples (65±2% rel. humid. at 20 C). The results of the measurments for the climatized samples are presented in the following tables.

For samples whose warp and woof were of the same raw material composition, we determined the LOI on the warp. Experimentally determined differences between warp and woof were minimal. For samples whose raw material composition along the warp differed from that of the woof, we also measured the LOI on the woof.

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TABLE 1. EFFECT OF CELLULOSE COMPONENTS IN SAMPLES ON LOI

Sample	Raw Material Composition (%)		LOI warp	LOI woof	Remarks
C1	cotton	100	19.2		Weak flame, burns uniformly along width, sample smoulders
C2	viscose	100	17.8		Burns very uniformly along width
C3	triacetate thread	100	18.6		Burns perpendicular to strips
C4	PES cotton	53 47	15.6	16.6	Burns uniformly, thick smoke arises
C5	PAC cotton polinose thread	51 25 24	18.7	17.7	Burns uniformly, burns out in a dark cloud
C6	viscose PA 6 thread	80 40	18.0	18.4	Burns perpendicular to strips

TABLE 1 (cont.d)

Sample	Raw Material Composition (%)	LOI warp	LOI woof	Remarks
C7	PES thread 48 viscose 43 silk 9	17.0	17.8	Burns uniformly, produces thick smoke
C8	triacetate thread 67 PA 6 thread 33	17.1		Burns very uniformly

Notes: In C1, C2, C3, and C8, the raw-material composition of the warp and woof is the same, but it is different in the other samples.

C4:	warp	PES	100%
	woof	cotton	100%
C5:	warp	cotton	100%
	woof	PAC	68%
		polinose thread	32%
C6:	warp	viscose	100%
	woof	PA 6	100%
C7:	warp	PES	48%
		viscose	52%
	woof	PES	48
		viscose	43
		silk	9

Analysis of Table 1

The results of determining LOI in climatized samples of cellulose origin and mixtures are presented in this table. The difference between the lowest and highest values is 3.6 (19.2-15.6).

Of the samples with pure raw materials, 100% cotton has the highest LOI value (19.2), and the viscose sample has the lowest (17.8). The viscose sample is thus the most flammable.

In the mixed samples, the effect of a second component is evident. The PES-cotton mixture (C4) has a much lower LOI (15.6) than cotton along (19.2). The PES component makes the LOI value smaller.

In sample C5, 51% PAC is included with cotton and polinose thread. The LOI value (18.7) is lower than the LOI for cotton alone. With the addition of 40% PA 6 to viscose, LOI increases by 0.2. The difference is small but unexpected, although practically all the mixtures have a lower LOI than the single components. Sample C7 is a three-component mixture and has a lower LOI than viscosee by itself.

The mixture of triacetate and PA is more flammable than triacetate alone (18.6).

All the samples in the C series have an LOI under 20 and therefore are defined as flammable. All the mixtures in the table have a lower LOI than components of cellulose origin. The LOI for the woof (PAC/polinose thread) of sample C5 has a lower value. The woof is more flammable or combustible than the warp, which is cotton alone. The LOI of sample C7 is interesting, in having a higher value for the woof (17.8) than for the warp (17.0). The woof is a three-component mixture containing silk (9%).

TABLE 2. EFFECT OF PROTEIN COMPONENTS IN SAMPLES ON LOI

Sample	Raw Material Composition (%)	LOI warp	LOI woof	Remarks
B1	wool 100	24.0		Burns perpendicular to strips
B2	silk 100	27.0		Burns perpendicular to strips, produces soot
B3	PES 55 wool 45	20.1		Burns uniformly, produces thick, black smoke
B4	wool 92 PA 8 thread 8	21.4	21.2	Burns perpendicular to strips, produces very rare smoke
B5	wool 84 PA 6 thread 16	22.5	20.6	Burns uniformly
B6	PES thread 48 viscose 43 silk 9	17.0	17.8	Burns uniformly, produces thick smoke

Notes: In B1, B2, and B3, the raw-material composition of warp and woof is the same: in the remaining samples, it is different. /154

B4:	warp	wool	85%
		PA 6	15%
	woof	wool	100%
B5:	warp	PA 6	100%
	woof	wool	100%
B6:	warp	PES	48%
		viscose	52%
	woof	viscose	43%
		silk	9%

Analysis of Table 2

Results and indicated interrelationships of climatized samples of natural protein origin and mixtures of the remaining synthetics polymers are included in this table. All the samples in the series except for B6 have higher LOI's than the samples in the preceding series, where cellulose samples were included in the mixtures. The difference between the lowest and highest values in the B series is from 17 to 24.

With a single-component sample, wool and silk, LOI decreases. Both samples have a higher LOI than the samples in series B. Silk has the highest LOI, amounting to 27. which means that it is barely flammable. The LOI is 24.0 for the woolen sample.

All the mixtures have a lower LOI than the single components do; 55% PES component in a mixture with wool reduces the LOI to 20.1. The mixture is more flammable than wool alone.

In sample B4, 8% PA 6 is in the wool, but in B5, it is 16% PA 8. In the first example (8% PA), the LOI decreases to 21.4, but in the second, it is reduced to 20.6. The reduction is not linear. The mixture with more PA 6 is more flammable.

The three-component sample has the lowest LOI value in the series [17]. The protein component in the sample is only 9%. The PES component increases the rise in flammability, which is, as a result of the framework (viscose!), much more flammable.

The LOI values along the woof are higher in several samples; in others, it is lower than along the warp. In B4, where the LOI along the woof is lower, it is wool. The difference is minor. In B8, the protein fiber is in the woof and therefore the LOI is higher than in the warp.

TABLE 3. EFFECT OF SYNTHETIC COMPONENTS IN SAMPLES ON LOI

Sample	Raw Material Composition (%)		LOI warp	LOI woof	Remarks
S1	PES thread	100	31.2		Burns non-uniformly, drops melt and burn
S2	PA 6 thread	100	27.4		Burns very rapidly, drops melt
S3	PA 6.6 thread PA 6	58 42	30.3	30.3	Sample twists up, melts, burns without smoke
S4	PAC cut thread	100	17.1		Burns uniformly, melts in the form of beads
S5	PES cut thread cotton	53 47	15.6	16.6	Burns uniformly, gives off black smoke
S6	PES cut thread wool	55 45	20.1		Burns uniformly, gives off thick black smoke
S7	PES viscose silk	48 43 9	17.0	17.8	Burns uniformly, gives off thick smoke
S8	viscose PA 6	60 40	18.0	18.4	Burns perpendicular to strips
S9	wool PA 6	92 8	21.4	21.2	Burns perpendicular to strips, gives off rare smoke
S10	wool PA 6	84 16	22.5	20.6	Burns uniformly
S11	triacetate thread PA 6	67 33	17.1		Burns uniformly
S12	PAC cotton polinose thread	51 25 24	18.7	17.7	Burns uniformly, burns out in the form of a net

<u>Notes:</u> In S1, S2, S4, S6, and S11, the raw material compositions of the warp and woof are the same; they are different in the rest.

S3	warp	PA 6 100%			
	woof	PA 6.6 100%			
S5 = Č4		see Table 1			
S7 = C7 = B6		see Tables 1 and 2			
			S8 = C6	see Table 1	
			S9 = B4	see Table 2	
			S10 = B5	see Table 2	
			S12 = C5	see Table 1	

Analysis of Table 3

In the table, the LOI's are determined in accordance with ASTM D 2863-76. The climatized samples (at 65±2% rel. humid. and 20±2°C) are synthetic polymers and mixtures of synthetic with natural and artificial fibers.

In the S series, LOI along the warp is from a low of 15.6 to a /155 high of 30.3. The differences is 14.7 in all. The raw-material composition affected the different LOI values.

PES, PA, and PAC were single-component samples.

Sample S3 had the highest LOI value, which was 30.3. PA 6 and PA 6.6 (58%) were in this mixture. The next highest value was for PES at 30.3. This value was very high and higher than the data for PES in the literature. LOI was 27.1 for PA 6 alone, which is very high here, and this sample is very flammable. The lowest LOI value of the single components was PAC thread, which was the most flammable of all the synthetic samples presented. All the mixtures have lower LOI's than do the single components (except for S12). With a mixture of 47% cotton with PES, LOI is reduced to 15.6. This is a very great difference. The mixture is much more flammable, due to the effect of framework! A mixture of wool (45%) with PES actually also effects a reduction in LOI, but not to the same degree as does cotton.

Sample S7 has the lowest LOI value among the mixtures. A mixture with raw material of cellulose origin has a lower LOI than a mixture of protein fibers. In sample S8 in which 60% viscose is mixed with 40% PA, LOI is 18.0, which is much lower than for PA itself. In samples S9 and S10, there is 8 to 18% PA in wool. The sample with more PA has the lower LOI. A mixture of triacetate and PA is very readily flammable, but the LOI is 17.1, the single lowest value in the series. The difference between PA alone and in a mixture is considerable, and triacetate has a great effect on this.

Sample S12 is composed of three raw materials. The mixture has a higher LOI than does PAC alone. The woof is as expected, but the LOI's here are in the same relationship as for cotton and PAC.

7. Classification of Fabric Samples with Respect to LOI

On the basis of the results and analyses of the contribution of the raw-material composition in the sample to the LOI, we classified the samples in all the series (C, B, and S) in order, indicating an increase in the perpendicular direction in fire resistance or slight flammability or combustibility.

TABLE 4

Number	Sample Designation	Raw Material Composition of Sample of Density 60-140 g/m^2
1	C4, S5	PES/cotton
2	C7, S7, B6	PES/viscose/silk
3 & 4	C8, S11, S4	triacetate/PA 6/PAC
5	C2	viscose
6	C6, S8	viscose/PA 6
7	C3	triacetate
8	C5, S12	PAC/cotton/polinose thread
9	C1	cotton
10	B3, S6	PES/wool
11	B5, S10	wool/PA 6
12	B4, S9	wool/ PA 6
13	B1	wool
14	B2	silk
15	S2	PA 6
16	S3	PA 6.6/PA 6
17	S1	PES

8. Summary

- The raw material composition of the fabric samples affects the LOI.

- Pure cellulose samples have a higher LOI than do mixtures.

- The LOI is below 20 for cellulose samples and their mixtures, which means that they are readily flammable.

- Mixtures with wool are more flammable than wool alone.

- A large amount of PA in mixtures with wool causes a greater increase in flammability.

- Synthetic samples have the highest LOI values (PES, PA 6, and PA 6.6/PA 6) and therefore fall among the least flammable fibers.

- Synthetic samples melt and twist up along the ignition path.

- PAC mixed with synthetic samples: LOI is below 20 and therefore PAC is determined to be readily flammable.

- PES and PA 6 mixtures with cellulose or protein fibers have /156
a lower LOI value than synthetic-only samples.

- PA mixtures with wool have a higher LOI than do PA mixtures with cellulose.

From the sample classification with respect to LOI, it follows that:

Cellulose samples in a mixture are readily flammable; the LOI values are below 20.

The LOI for PAC is also below 20.

Protein samples in mixtures are less flammable than cellulose samples.

Mixtures of protein fibers with other fibers are more flammable than are protein components alone.

Synthetic samples (PES, PA 6, PA 6.6/PA 6) are barely flammable.

The LOI is highest among all the samples analyzed.

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