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Insulating Characteristics of Battings

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ABSTRACT

Fiber battings are becoming increasingly important for their uses as insulation. This paper reports the results of an investigation of the influence of thickness, applied pressure, bulk density and fiber type on insulation parameters such as Clo and Warmth Factor. The specific Clo value of 3.4 Clo per inch for battings falls between specific Clo values for fabrics and fabric-foam laminates. Warmth Factor, for a given batting weight, increased with thickness; and for a given thickness level, decreased with weight. Neither fiber type, within the limited range investigated, nor batting density had a significant influence on the intrinsic insulation of the battings.

KEY WORD INDEX

Battings
Clo
Heat Transfer
Insulation
Thermal Properties
Warmth Factor

BATTINGS are a relatively new class of textile material which is expanding in importance and use in our textile economy. Since battings are made from fiber stock without spinning, weaving or knitting, their rate of production is high and their cost low. While the stress-strain properties of the battings are such that they cannot be used for many textile applications in which mechanical properties are important, they are excellent for applications requiring insulation.

One of the critical properties of battings, with regard to insulation characteristics, is compressibility. Battings are much more compressible than conventional textile structures. Since insulation, under most conditions, is proportional to thickness, it is likely that under some use conditions battings may not provide sufficient insulation. In addition, it is possible that under very high compression, significant differences may be found among different fibers used as battings, since conduction through the fiber substance itself may become more important. Also, the relative compressibility of different fibrous battings will vary because of inherent variations in the stress response characteristics of the fibers. Thus it is possible that battings made from one type of fiber may maintain a greater thickness under equivalent pressure conditions than battings from another type and provide more insulation.

The purpose of this study is to evaluate the relative insulating characteristics of battings, most of them of different polyester fibers, which vary in weight and initial thickness. Analysis consists of characterizing the insulation in terms of both fiber composition and level of compression. Relationships among the variables are analyzed for significant trends and the data are expressed in terms of useful insulation parameters.

Experimental Procedure

Materials

Sixteen commercial battings consisting of seven fiber types were investigated: two types of Dacron (one having a higher resin content than the other); one type each of Kodel, Vycron, Fortrel and nylon, and one blend of 70% viscose, 15% nylon and 15% polyester. A description of the battings in terms of weight, low-pressure thickness and fiber composition is given in Table I.

Equipment

A Cenco-Fitch unit (*1*) with modifications and circuitry as described below was used for the insulation measurements. The unit (Fig. 1) consists of two main parts: a heat source and a heat receiver. The heat source is essentially a metallic vessel which contains a liquid maintained at a constant temperature. Mineral oil was selected for this study rather than water to reduce the moisture load into the atmosphere of the conditioned room in which the tests were conducted. Accessories placed in the mineral oil consisted of a 200-watt immersion heater, a thermostat control and a stirrer. A variable resistor (maximum capacity 100 ohms) and relay were introduced into the circuit of the heater and ther-

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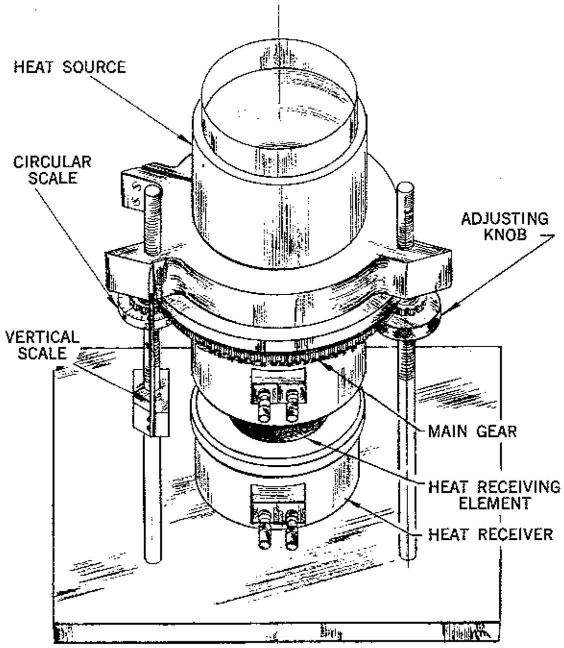

Fig. 1—Modified Cenco-Fitch unit.

mostat (Fig. 2). This arrangement provides a stable temperature which was maintained at 64C.

The heat-receiving element consists of a solid, cylindrical copper block, 1.75 inches in diameter, 0.975 inches in height and 340 grams in weight. The block is mounted in the center of the heat receiver and is surrounded on all sides and the bottom by insulating material, leaving the top flat surface, with an area of 0.00159 square meters, exposed to the heat source.

The heat source is maintained in position above the heat receiver by an annular ring attached to a main gear, affixed to and just under the annular ring. This main gear is meshed with and supported by three small gears mounted on three vertical threaded rods, spaced at angles of 120° around the heat receiver and source. The bottoms of these threaded rods are permanently attached to a wood platform on which all of the equipment is mounted. By rotating the small gears which have knurled knobs attached to them for this purpose, it is possible to move the heat source up or down to adjust the distance between the bottom of the heat source and the top of the heat-receiving element in the heat receiver.

One of the knobs has a smooth (rather than a knurled) periphery. An equal-interval scale engraved on its periphery forms an accurate thickness-measuring system when used in conjunction with a fixed scale mounted vertically beside it. This vertical scale is graduated into 56 equal divisions spaced 0.025 inches apart. The circular knob has 20 evenly spaced divisions engraved on its periphery. One complete rotation of the circular knob is equivalent to one space of the vertical scale or 0.025 inches. Therefore, each division of the circular knob is 1/20th of 0.025 inches or 0.00125 inches.

When the bottom of the heat source is just in contact with the top of the heat receiver, the lower edge of the graduated knob is coplanar with the zero division marking on the vertical scale, and the zero graduation of the circular knob coincides with the zero division on the vertical scale. A potentiometer constantly monitors the temperature gradient between the heat source and heat receiver by means of the differential circuit (Fig. 3).

Operating Procedure

To make a measurement on the Cenco-Fitch, the potentiometer, the immersion heater and the stirrer are switched on. The heat receiver is removed from under the heat source and located a sufficient distance from the heat source so that the copper block will be maintained at the ambient temperature of the conditioned room (70F and 65% RH).

After temperature equilibrium is reached, as shown by the millivolt reading on the potentiometer remaining constant for several minutes, a test may be started. The heat source is raised by rotating one of the knurled knobs, so that the thickness indicated by the vertical scale is approximately 0.1 inches greater than the thickness at which the test is to be conducted. The heat receiver is placed under the heat source and the sample is inserted between the two. The source is then lowered by means of the knurled knobs until the desired thickness for the measurements is indicated by the vertical scale and graduated circular knob. The lower surface of the heat

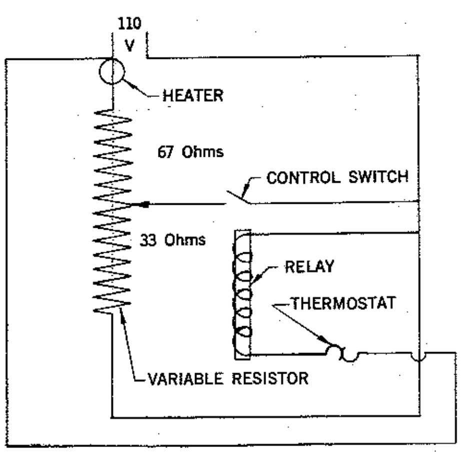

Fig. 2—Heat control circuit for Cenco-Fitch.

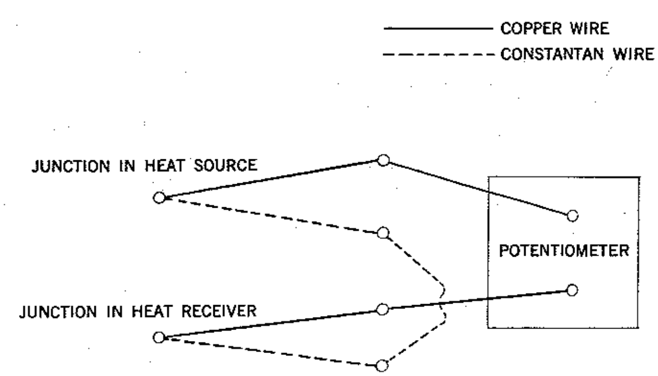

Fig. 3—Wiring arrangement for temperature measurement.

source must be in contact with the upper surface of the batting.

For most of the battings evaluated in this study, 30 minutes was found to be sufficient time for the evaluation of insulation at any thickness level. The millivolt value at the beginning and at the end of the test, and also the duration of the test in minutes, are read from the potentiometer.

Methods For Computing Thermal Conductance

A graphical or a log-difference method may be used for computing thermal conductance of the battings. The graphical method is more accurate, but somewhat more time consuming. The log-difference method may be used when preliminary evaluations reveal that a plot of the time *vs.* millivolt values obtained from the potentiometer yield the expected straight-line relationship on semi-log graph paper. On the assumption that the plotted points for zero time and 30 minutes do fall on the best straight line, we subtract from the log of the millivolts corresponding to zero time, the log of the millivolts corresponding to 30 minutes to obtain Δlog mv. This value divided into 30 (for a 30-minute test) gives the slope of the minutes versus log millivolt line. Then using the equation for conductance from reference (*1*) we obtain:

$$C = \frac{(2.303)(M)(S)}{(60)(m)(A)}$$

where

C is conductance in cal/m² sec °C

2.303 is the conversion factor from natural logs to common logs

M is mass of heat receiver = 340 grams

S is specific heat of heat receiver = 0.093 Cal/g °C

m is slope of time (minutes) versus log millivolt line = 30/Δlog mv

A is area of heat receiver = 0.00159 m²

60 is conversion factor = sec/min

$$\text{Thus } C = \frac{(2.303)(340)(0.093)}{(60)(30/\Delta \log mv)(0.00159)}$$

$$\text{or } C = \frac{763}{(30/\Delta \log mv)} = 25.4\ (\Delta \log mv)^{*}$$

Since the measurements of thickness in this study were based on inches, to be consistent with industrial practice, the above equation for conductance was modified to allow direct substitution of the English unit measurement in the equation for conductivity:

* For a 30-minute test

Table I—Description of Battings

Sample Number	Weight (oz/yd²)	Fiber Composition	Thickness at .01 psi
1	1.47	Dacron	0.23
2	2.53	Dacron	0.32
3	3.38	Dacron	0.29
4	5.05	Dacron	0.37
5	1.44	Kodel	0.20
6	2.53	Kodel	0.28
7	3.38	Kodel	0.27
8	1.47	Vycron	0.15
9	2.53	Vycron	0.23
10	1.53	Fortrel	0.20
11	2.48	Fortrel	0.27
12	3.06	Dacron (30% Resin)	0.35
13	1.63	70% Viscose + 15% Nylon + 15% Polyester	0.20
14	2.30	70% Viscose + 15% Nylon + 15% Polyester	0.17
15	2.30	Nylon	0.21
16	3.06	Nylon	0.30

Note: All battings contain approximately 17% resin except Sample No. 12.

Table II—Intrinsic Clo Values of Experimental Battings

Sample Number	Weight oz/yd²	Fiber Composition	Intrinsic Clo At Inches 0.05	0.10	0.15	0.20	0.25	0.30	0.40
1	1.47	Dacron	.22	.36	.47	.66	—	—	—
2	2.53	Dacron	—	.36	.48	.63	.77	—	—
3	3.38	Dacron	—	—	.49	.66	.80	.93	—
4	5.05	Dacron	—	.33	—	—	.78	.93	1.51
5	1.44	Kodel	.21	.36	.47	.63	—	—	—
6	2.53	Kodel	—	—	.48	.63	.77	.90	—
7	3.38	Kodel	—	—	.48	.62	.80	.95	—
8	1.47	Vycron	.23	.36	.49	.66	—	—	—
9	2.53	Vycron	.24	.37	.47	.65	—	—	—
10	1.53	Fortrel	.21	.34	.47	.67	—	—	—
11	2.48	Fortrel	—	.34	.51	.64	.81	—	—
12	3.06	Dacron (Resin 30%)	.21	.31	—	.63	—	.97	—
13	1.63	70% Viscose + 15% Nylon + 15% Polyester	.21	.33	.47	.62	—	—	—
14	2.30	70% Viscose + 15% Nylon + 15% Polyester	—	.39	.47	.65	.78	—	—
15	2.30	Nylon	.21	.33	.48	.65	—	—	—
16	3.06	Nylon	.19	.34	.47	.65	—	—	—

Table III—Statistical Analysis of Differences in Specific Clo as a Function of Thickness

Thickness	Specific Clo (Average Clo/inch)	D.F.*	Calculated "t"	Significance of Difference
0.05	4.26	20	99.1	Significant
0.10	3.48	25	14.1	Significant
0.15	3.19	27	0.0528	Not significant
0.20	3.22	20	0.1650	Not significant
0.25	3.15	10	0.57	
0.30	3.12			

Grand Average = 3.40 Clo/inch
* Degree of Freedom = $N_1 + N_2 - 2$

Table IV—Pressure and Insulation Values of the Battings at Given Thickness Levels

Sample Number	Weight oz/yd²	Pressure (psi) to Compress to Given Thickness 0.10 in	0.15 in	0.20 in	Intrinsic Clo at Given Thickness 0.10 in	0.15 in	0.20 in
5	1.44	0.068	0.023	0.010	0.36	0.47	0.63
1	1.47	0.120	0.050	0.018	0.36	0.47	0.66
10	1.53	0.095	0.035	0.010	0.34	0.47	0.67
13	1.63	0.114	0.028	0.010	0.33	0.47	0.62
15	2.30	0.123	0.054	0.017	0.33	0.48	0.65
9	2.53	0.148	0.053	0.020	0.37	0.47	0.65

K = CL, where

$$K = \text{thermal conductivity}\left(\frac{\text{cal} \quad \text{cm}}{\text{m}^2 \text{ sec } ^\circ\text{C}}\right)$$

$$C = \text{conductance}\left(\frac{\text{cal}}{\text{m}^2 \text{ sec } ^\circ\text{C}}\right)$$

L = batting thickness (inches)

$$K = \frac{763}{(30/\triangle \log \text{mv})} \times L \times 2.54$$

$$K = \frac{1938}{(30/\triangle \log \text{mv})} \times L$$

$$= 64.5\ (\triangle \log \text{mv})\ L$$

Some conversion factors used for Conductance and specific Insulation are given below:

$$\frac{\text{cal}}{\text{m}^2 \text{ sec } ^\circ\text{C}} \times 3.6 = \frac{\text{Kcal}}{\text{m}^2 \text{ hr } ^\circ\text{C}}$$

$$\frac{\text{cal}}{\text{m}^2 \text{ sec } ^\circ\text{C}} \times 0.74 = \frac{\text{BTU}}{\text{ft}^2 \text{ hr } ^\circ\text{F}}$$

$$\frac{\text{cal}}{\text{m}^2 \text{ sec } ^\circ\text{C}} = \frac{1.544}{\text{Clo}}$$

$$\text{Clo} = \frac{5.56}{\text{Kcal/m}^2 \text{ hr } ^\circ\text{C}}$$

Results And Discussion

The results of this study are presented as resistances to heat transfer or insulation, in preference to conductances, since battings are used as insulating materials where the level of warmth and comfort provided is a major consideration. Normally, resistances are directly additive and, as a consequence, are more easily characterized in multilayer systems. One of the most useful units of thermal resistance or insulation in the Clo unit first proposed in 1941 by Gagge, Burton and Bazzet (*2*). They defined Clo as, "the amount of insulation necessary to maintain in comfort a sitting, resting subject in a normally ventilated room (air movement 20 ft/min) at a temperature of 70F and a humidity of air which is less than 50%." Clo may be directly converted to physical units of thermal resistance or thermal conductance.

$$\text{Thus} \quad \text{Clo} = \frac{5.56}{\text{KCal/m}^2 \text{ hr } ^\circ\text{C}}$$

For this study Clo is used in the form of either "intrinsic Clo" which is Clo at a given thickness or "specific Clo" which is Clo per inch thickness.

Insulation As A Function Of Thickness

The Clo values computed for each of the battings at each thickness level are shown in Table II. The spread of Clo values for all the samples ranged from a low of 0.19 to a high of 1.51. At a given thickness, the spread of Clo values was relatively small, despite the differences in fiber composition and weight of the battings.

For example, at a thickness level of 0.15 inches, the Clo values range from a low of 0.47 to a high of 0.51.

The most obvious conclusion to be drawn from the data in Table II is that Clo values increase as the thickness of the battings increases. This is consistent with the observation made by Monego and others (*3*) on fabrics, foams and laminates: that insulation shows a linear relationship with thickness.

To test the hypothesis of linearity, the test results shown in Table II were adjusted to a unit thickness basis. The value of specific Clo (Clo/inch) of the battings ranged from a low of 3.00 to a high of 4.72. The overall average value was 3.4 Clo/inch, and the standard deviation was 0.704 Clo/inch. There is a difference in level of specific Clo which depends on the thickness of the battings at which measurements were made. The specific Clo appears to decrease as the thickness of the battings increases.

An analysis was made using Student's "t" test to determine whether these differences are significant. A summary of the statistical data is given in Table III. It may be noted in Table III that the differences in specific Clo were significant at the 95% level of probability for battings at thickness levels of 0.05 and 0.10 inches, and 0.10 and 0.15 inches. However, the differences were not significant for battings at thickness levels of 0.15 and 0.20 inches; 0.20 and 0.25 inches; and 0.25 and 0.30 inches. Thus, the specific Clo values are significantly higher for thinner samples. For the thinner samples, the thermal resistance of the instrument (bare plate value) may assume greater significance in interpreting specific Clo values. However, the bare plate value of approximately 0.02 Clo for the Cenco-Fitch is less than 10% of the intrinsic Clo values found for the thinner samples and did not influence the significance of the differences noted for these samples. For the thicker samples the bare plate value ranged from 1 to 3% of the measured values and would not significantly influence the results noted.

The data in Table II plotted in Fig. 4 show the nature of the relationship between intrinsic Clo and thickness. The individual test values are grouped in vertical arrays showing the range in Clo at the fixed thickness levels at which the measurements were made. The center line on the graph was drawn with a slope of 3.4 Clo/inch, which is the grand average of the specific Clos of all the samples. The other two lines represent upper and lower 10% limits of the slope line. With a few exceptions, all of the test values fell within these 10% limits. The relative positions of the range lines confirm the previous observation regarding the higher specific Clo of the thinner samples and the lower specific Clo of the thicker samples.

Effect Of Pressure On Insulation

To show the relationship between pressure and insulation, six battings,

Table V—Insulation in Terms of Clo/Inch as a Function of Fiber Type

Sample Number	Fiber Composition	Weight oz/yd²	Clo/Inch*	Grand Average
1	Dacron	1.47	3.59	
2	Dacron	2.53	3.25	
3	Dacron	3.38	3.21	
4	Dacron	5.05	3.32	
12	Dacron (30% Resin)	3.06	3.41	3.36
5	Kodel	1.44	3.52	
6	Kodel	2.53	3.11	
7	Kodel	3.38	3.17	3.27
8	Vycron	1.47	3.68	
9	Vycron	2.53	3.69	3.69
10	Fortrel	1.53	3.55	
11	Fortrel	2.48	3.30	3.43
13	70% Viscose + 15% Nylon + 15% Polyester	1.63	3.44	
14	70% Viscose + 15% Nylon + 15% Polyester	2.30	3.34	3.39
15	Nylon	2.30	3.48	
16	Nylon	3.06	3.41	3.45

* Values of Clo/inch for each sample represent the average value obtained for all thickness levels at which measurements were made.

having different fiber compositions and weights per square yard, were selected at random. From pressure-thickness curves obtained on an Instron machine, pressures were selected corresponding to three of the thicknesses under which the insulation measurements were made. These measurements are tabulated (Table IV) in the sequence of increasing batting weight along with corresponding intrinsic Clo values. While at a given thickness the insulation is relatively constant and independent of fiber type and batting weight, the pressure required to produce this thickness is strongly dependent on fiber type and batting weight. This is particularly true at the relatively higher pressures required to compress the battings to a thickness of 0.10 inches. Accordingly, a major criterion for the selection of battings should be compressibility rather than insulation. It can be assumed that for a given thickness, insulation will be relatively constant regardless of the weight or fiber composition, but that the pressure required to produce this thickness can vary markedly depending upon weight and fiber type. Because of the small number of samples evaluated in this portion of the study no specific conclusions were reached on the influence of fiber type on compressibility.

Insulation As A Function Of Fiber Type

Table V shows insulation in terms of Clo/inch as a function of fiber type. The grand average specific Clo for the Dacron battings was 3.36, Kodel 3.27, Vycron 3.69, Fortrel 3.43, viscose, nylon and polyester blends 3.39 and nylon 3.45. These variations are not statistically significant. It is concluded, therefore, that insulation in terms of specific Clo is not a function of the different fiber types used in this study. In five out of six classes of fiber type, the battings of lowest weight had higher values of specific Clo. However, as the weight of the battings increased, the difference in specific Clo was not apparent.

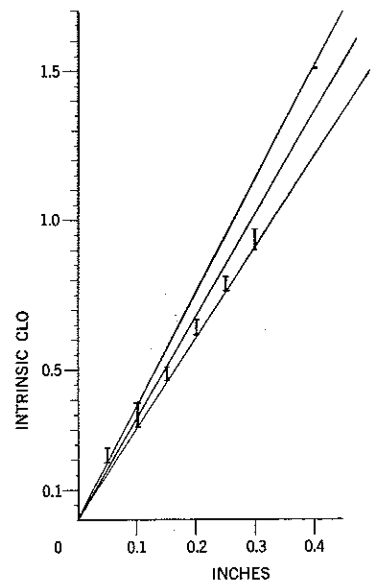

Fig. 4—Relationship between intrinsic Clo and thickness.

Effect Of Bulk Density On Insulation

To determine the effect of bulk density on insulation, comparisons were made based on computed bulk densities for battings of equivalent thickness at the time of measurement. thickness levels were computed from The densities in g/cm³ at the various the equation:

$$D = 0.00133\ W/G$$

where D = density in g/cm³
W = weight in oz/yd²
G = thickness in inches

These values are shown in Table VI. The relationship between thermal resistance in intrinsic Clo and density in g/cm³ at different thickness levels is plotted in Fig. 5.

It can be seen that the insulation varies very little through threefold increases in density of battings. There appears to be a tendency for the thermal resistance to be lower at the low and high densities for some thickness levels. This behavior has been noted by Finck (*4*). A statistical comparison of insulation values at 0.02 g/cm³ and 0.033 g/cm³ of the battings measured at a thickness of 0.1 inches showed no significant difference. Apparently, the optimum values in these curves are not the result of any predictable phenomenon. The increase in insulation with increase in thickness, regardless of density level, is apparent from Fig. 5.

Warmth Factor

A useful parameter with which to work in making comparisons among different batting types is the Warmth Factor. The Warmth Factor is defined as the insulation per unit of surface density of the fabric. For this study, Warmth Factor was computed as:

$$\text{Warmth Factor} = \frac{\text{Intrinsic Clo}}{\text{oz/yd}^2 \text{ of the Batting}}$$

The results of the Warmth Factor computations are shown in Table VII. For a given fiber, as batting thickness increases, Warmth Factor increases; as batting weight increases, Warmth Fac-

Table VI—Density-Thickness Relationship of the Experimental Battings at Various Thickness Levels

Sample Number	Weight oz/yd²	Fiber Composition	Bulk Density (g/cm³) at Inches						
			0.05	0.10	0.15	0.20	0.25	0.30	0.40
1	1.47	Dacron	.039	.019	.013	.010	—	—	—
2	2.53	Dacron	.068	.034	.023	.017	.014	—	—
3	3.38	Dacron	.091	.045	.030	.023	.018	.015	—
4	5.05	Dacron	.135	.068	.045	.034	.027	.023	.017
5	1.44	Kodel	.039	.019	.013	.010	—	—	—
6	2.53	Kodel	.068	.034	.023	.017	.014	.012	—
7	3.38	Kodel	.091	.045	.032	.022	.018	.015	—
8	1.47	Vycron	.039	.020	.013	.010	—	—	—
9	2.53	Vycron	.068	.034	.023	.017	—	—	—
10	1.53	Fortrel	.041	.021	.014	.010	—	—	—
11	2.48	Fortrel	.067	.033	.022	.016	.013	—	—
12	3.06	Dacron (Resin 30%)	.082	.041	.027	.021	.016	.014	—
13	1.63	70% Viscose + 15% Nylon + 15% Polyester	.044	.022	.015	.011	—	—	—
14	2.30	70% Viscose + 15% Nylon + 15% Polyester	.062	.031	.021	.015	.012	—	—
15	2.30	Nylon	.062	.031	.021	.015	.012	—	—
16	3.06	Nylon	.082	.041	.027	.021	.016	.014	—

Table VII—Warmth Factor of the Experimental Battings at Various Thickness Levels

Sample Number	Weight oz/yd²	Fiber Composition	Warmth Factor (%) at Inches 0.05	0.10	0.15	0.20	0.25	0.30	0.40
1	1.47	Dacron	.146	.245	.319	.449	—	—	—
2	2.53	Dacron	—	.142	.190	.249	.304	—	—
3	3.38	Dacron	—	—	.145	.195	.237	.275	—
4	5.05	Dacron	—	.065	—	—	.154	.184	.299
5	1.44	Kodel	.146	.250	.326	.438	—	—	—
6	2.53	Kodel	—	—	.190	.249	.304	.356	—
7	3.38	Kodel	—	—	.142	.186	.237	.281	—
8	1.47	Vycron	.156	.245	.333	.449	—	—	—
9	2.53	Vycron	.095	.146	.186	.257	—	—	—
10	1.53	Fortrel	.138	.222	.307	.438	—	—	—
11	2.48	Fortrel	—	.137	.206	.258	.327	—	—
12	3.06	Dacron (Resin 30%)	.069	.101	—	.206	—	.317	—
13	1.63	70% Viscose + 15% Nylon + 15% Polyester	.129	.202	.288	.380	—	—	—
14	2.30	70% Viscose + 15% Nylon + 15% Polyester	—	.170	.204	.283	.339	—	—
15	2.30	Nylon	.091	.143	.209	.282	—	—	—
16	3.06	Nylon	.062	.111	.154	.212	—	—	—

tor decreases. Both of these observations follow directly from the basic fact that thickness is the predominant factor governing insulation of battings regardless of fiber type, weight or bulk density.

Conclusions

The overall conclusions reached in this study follow the patterns of insulation behavior of other classes of fibrous materials when evaluated using the Cenco-Fitch apparatus. The findings cannot be generalized for all types of battings nor for all conditions of pressure. However, within the range of fiber types evaluated and over the pressure range of measurements, the following specific conclusions may be made.

- Batting thickness is the predominant factor governing insulation. Insulation increases linearly with thickness over a measured range of 0.05 to 0.40 inches. For practically all the battings tested, this linear relationship holds within an error of ±10 percent.
- The relationship between insulattion and thickness permits the prediction of insulation values at various pressures using the equation:

$$\text{Clo} = 3.4 \times (\text{Thickness of batting expressed in inches})$$

This value of 3.4 is designated as specific Clo and has the units Clo/inch. Data obtained from the literature indicate that this value of 3.4 falls between the specific Clo of 3.02 for fabric and of 3.68 for fabric laminated to foam.

- Within the range of fiber types evaluated, there were no significant differences in specific insulation which could be attributed to fiber type. Regardless of fiber type or weight, increased pressure resulted in reduced insulation values; conversely the greatest insulation values were obtained at the lowest levels of pressure.
- Despite a threefold increase in density of the battings with applied pressure, the specific insulation values did not vary significantly with the increase in fiber-to-air ratio at the higher densities.
- Warmth Factor (insulation per unit weight) increases with thickness, decreases with increase in fabric weight, and is not influenced by fiber type.

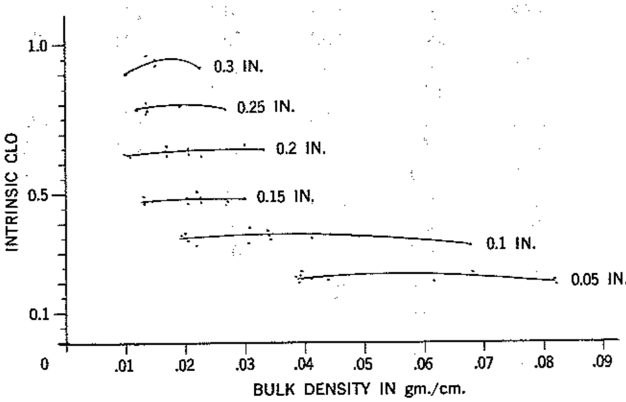

Fig. 5—Relationship between bulk density and intrinsic Clo.

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