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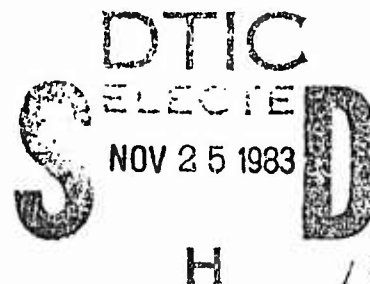
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RESEARCH AND DEVELOPMENT REPORT

TEXTILE SERIES - REPORT NO. 70



CORRUGATED FIBROUS WEBS AS INSULATION FILLERS

by
E. R. FREDERICK
Mellon Institute
Pittsburgh, Pa.



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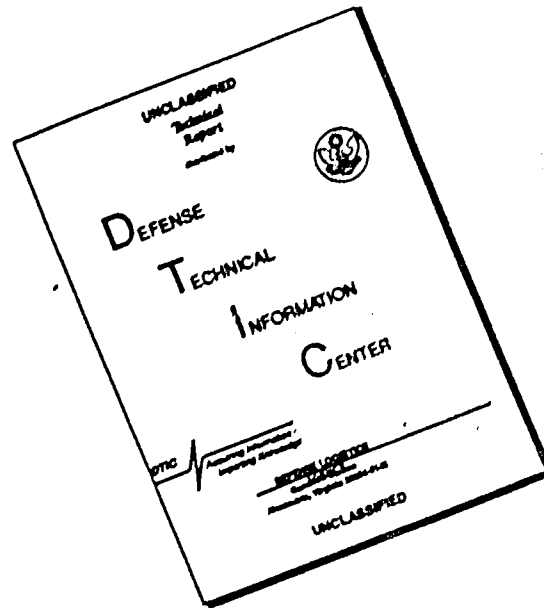
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FOREWORD

An appreciable portion of the weight of cold climate insulating clothing lies in the insulation layers which provide the thickness essential for warmth. Since the weight of most textile structures increases with thickness, the possibility of producing low weight insulating layers is quite limited. Studies have shown that it is the dead air space trapped by the fibers rather than the fibers themselves which provides the insulation. Means therefore have been sought for trapping more air in a given mass of fibers and thus providing more efficient insulation.

Bulk fiber masses such as loose wool and cotton and also feathers and down furnish the high thickness/weight ratio needed for lightweight insulation. However, these materials lack the compressional resistance required in those clothing areas where heavy pressures (3 lbs/sq.in.) are applied, viz., in the seat area or along the long surfaces of the body. An important aspect of the work on the Quartermaster Corps insulating material project has been concerned with the modification of the orientation of bulk fiber masses to increase their resistance to compression without altering their space filling capacity.

Described in this report is the development of a laboratory method for achieving increase in compressional resilience of bulk fibrous materials by reorienting the fibrous mass from a predominantly horizontal to a vertical configuration. This is achieved by bending or buckling the fibrous mass so that the plane of the fibers lies perpendicular to the plane of the batting itself. Laboratory tests have demonstrated the superiority of this type of "corrugated batting." At the present time, pilot plant equipment is being developed in which fibrous webs may be simultaneously corrugated and quilted for use in linings and other clothing and equipage items.

This report was prepared by Mr. E. R. Frederick, who is the project leader of the Quartermaster contract on insulating materials

at Mellon Institute. The assistance of Mr. Norris Parbre, formerly of the Quartermaster Textile Materials Engineering Laboratory, and Mr. Henry A. Sinski, present project leader on the filling materials project, is gratefully acknowledged. Acknowledgement is also made of the help of Mr. Gerald Winston and Mr. John Medernach for the preparation of the graphical material and Dr. Oscar Mandel for his editorial assistance.

March 1952

S. J. KENNEDY
Research Director
for
Textiles, Clothing and Footwear

1. - INTRODUCTION

The Mellon Institute project on Garment Filling Materials was initiated by the Office of the Quartermaster General to develop an improved batting type of insulation interliner for use in cold climate clothing and possibly for sleeping bags. The best available low density material at the time of the project's inception was characterized by good insulating properties but poor wear resistance. Laboratory evaluation for simulated wear properties of insulation fillers, although not correlated thoroughly with field service data, soon demonstrated that practically all experimental materials were superior to this material.

In the same studies, modifications in fiber- and batt-form were found to yield fillers of increased compression resistance as well as improvements in other features giving superior insulation properties. Confirmation of these findings prompted a concentrated study of the experimental fibrous materials and of methods to improve the batt structures. Thus, while the initial concern was for durability of interliner materials, the program came to be broadened to include an investigation of the configuration of fibers, their compression resistance, and their overall insulation efficiency. One development stemming from these studies is the corrugation process -- a fiber web forming technique by which any fiber mass may be converted into a geometric form which provides high compressional resistance and overall insulation properties.

II. GARMENT INSULATION FILLERS

Clothing provides insulation primarily because it traps air. For conventional fibrous types of insulation, particularly for those of the same fiber-size and type, the insulation efficiency may usually be considered to be approximately proportional to the thickness. This interdependence of thickness and insulation values is especially significant in military cold climate clothing. The severe wear and/or excessive constant compressive loads applied to a Service garment frequently leads to appreciable temporary or permanent reduction in thickness and consequently in insulation value. Resistance to compression, therefore, is one of the important requirements of an efficient, cold climate garment interliner.

III. FIBER AND FIBER FORMS

The stress-strain properties of fibers are important in estimating fiber resiliency. The latter property is a measure

of the fiber's effectiveness in an interliner, particularly when prepared by the conventional laminated web process. But the influence of fiber- and batt-form is so important that a less resilient fiber in an improved form may actually surpass in insulation effectiveness an extremely resilient fiber formed in a less effective manner.

The influence of the properties of a particular fiber on insulation efficiency, furthermore, is more significant than can be explained on a basis of resiliency alone. Fiber diameter and fiber shape affect thermal conductivity and compression resistance. For optimum insulation properties, it is ordinarily advantageous to select fibers possessing the most resilient properties and to blend mixtures of highly crimped fibers to achieve a structure wherein the interstices are such that a very low coefficient of thermal conductivity is afforded.

The value of crimped over straight filaments in improving loftiness of fibrous battings has been demonstrated and further improvement in compressional resiliency has been attained through the use of "helix-shaped" fibers.

IV. CONVENTIONAL BATT STRUCTURE

The most common fibrous insulation structure consists of superimposed carded- or garnetted-fibrous webs. Even though more uniform properties are achieved by cross lapping the webs, the fibers remain essentially in a position normal with respect to the forces applied during actual use. In such a form the fibers behave in the manner of a beam -- if the mechanics of fiber structure are compared with structural members. Since a beam is subject to greater deflection than a column of the same size and material, it becomes apparent that fibers in insulation fillers should be oriented, for optimum compression resistance, in a direction parallel to the direction of applied compressive forces. The "snow-fall" or random mat processes, for example, can be expected to allow, on the average, about one-third of the fibers to become oriented essentially in a direction along which axial compression dominates. Actually, such processes are employed commercially, and the orientation so attained has in some instances been retained effectively by fixing the structural configuration by means of elastomeric or resinous binders.

Under certain conditions, for instance by the addition of heat-sensitive fibers, it is possible to achieve simultaneous random distribution, curling, and interlocking of fibers in a batting. Applying a heat treatment to these fibers causes them to shrink, curl, and bind to the other ingredients. Such preparations exhibit resiliency properties similar to those provided by randomly oriented and bonded fillers.

Finishing techniques are also applicable for improving insulation properties. Binders serve to retard fiber motion. The type of binder affects durability properties particularly when the finish is or becomes embrittled under conditions of service. Similarly, anti-lubricants, which also inhibit fiber motion, serve to maintain fiber structure and improve compressional resiliency.

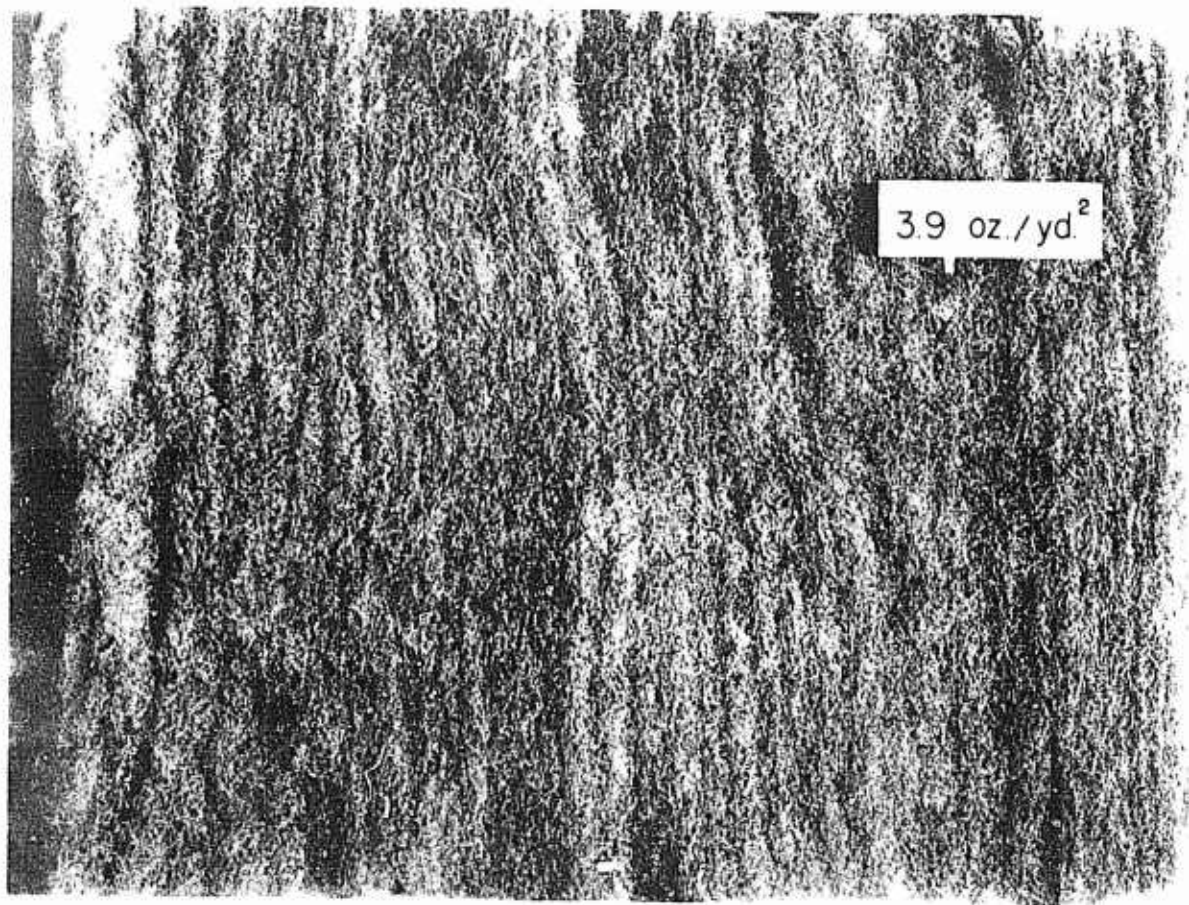
None of the fibrous batt structures referred to, with or without improved fiber shapes or finishes, offer the type of improvement in insulation properties that are ultimately possible. More satisfactory fiber alignment for specific axial loading, however, is provided in pile constructions. Wool pile fabrics act as an effective insulation under low pressure, because the inherent resiliency of the wool gives a relatively high thickness. Under high pressure, however, the pile flattens. While this effect can be offset to a certain extent by not cutting the loops (as in the frieze), the weight of the backing fabric and the pile yarns is responsible for a relatively high weight per unit area. Corrugated fibrous batts offer a possibility of achieving high resiliency with lower weight materials.

V. CORRUGATED FIBROUS WEB BATTINGS

In an attempt to overcome the deficiencies inherent in conventional fabrics while retaining or even improving the advantages of the pile construction, the mechanics of fabric construction as applied to insulation properties was thoroughly studied. This work culminated in the development of the corrugated fibrous web type of insulation batting, a sample of which in very low density form is depicted in Figure 1. The process involves four important operations, two of which are commonly conducted in ordinary commercial practice. (1) The preparation of corrugated fibrous web batting employs first an orienting process of the card or garnet type. (2) The fibrous web so prepared is then buckled. The buckling action is conducted in such a manner that the web takes on the appearance of corrugations. These corrugations, for garment insulation applications, stand

VERY LOW DENSITY CORRUGATED WOOL FILLER

Top View



End View

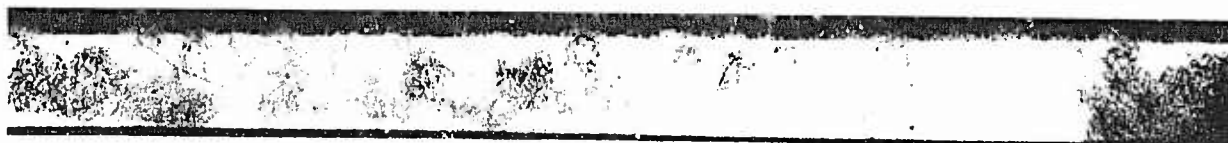


FIG. 1

approximately $3/8$ to $1/2$ inches in height. (3) The next operation consists of a condensing technique in which the buckled or corrugated web is "closed" to the desired density. (4) The last step in the process then involves a conventional quilting technique. Operation (3) can be accomplished by means of double layer belt assemblies and is not unusual. Only the corrugating operation (2) introduces a new forming procedure. Corrugating processes have been applied commercially to various materials other than fibers, and the textile processors undoubtedly will develop for themselves a practical fiber forming practice. However, the methods used to prepare corrugated battings in this laboratory are presented below for appraisal.

A. Pleating Techniques

1. The Laboratory Pleater.

The experimental, hand operated pleating device used for preparing large size samples is reproduced in Figure 2. The operation of this rather hastily constructed equipment is given as follows:

A web or lamination of webs to be corrugated is placed under the corrugating unit in such a manner that the end of the mat extends to the bar (A) which is free to move under the glass plate (B) and initially is positioned just under the edge of the glass plate. The eccentric (C) carrying the arm (D) and blade (E) is then turned in a clockwise rotation to move about three-fourths of an inch length of the web toward the bar (A). The resistance to movements offered by the bar (A) causes the web to buckle and form the first pleat. Having thus formed the first pleat it is then maintained between one of the metal straps (F) and the bar (A). The second pleat is formed in the same manner. Each complete turn of the crank causes the blade (E) to push forward about three-fourths of an inch, lift, and return to the initial point of contact. The second pleat, as the first, is maintained in position between the straps (F). After the third pleat is formed, the strap (F) nearest the bar (A) is removed, the pleat that it held is maintained between the bar (A) and successive pleats and the strap (F); and the formed corrugated batting is retained under the glass plate. Thus, the processing continues with each new pleat being held temporarily until moved under the plate (B) by a new pleat. The straps are repeatedly moved to hold each new and previous pleat in position.

The application of a water spray to the web prior to pleating or to the formed corrugated batting serves to soften natural fibers and facilitate the operation. During the drying operation, these fibers retain the shape in which they were positioned. Some semi-

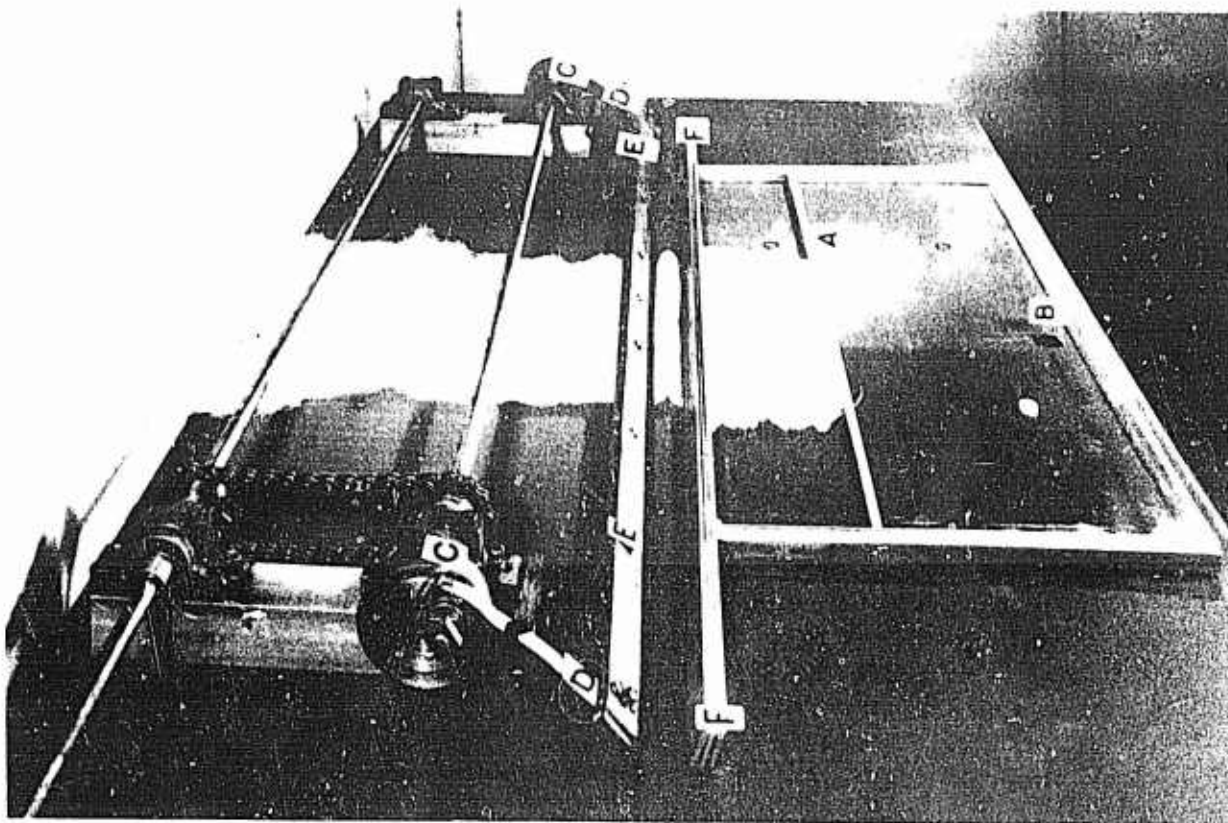


FIG. 2

THE LABORATORY PLEATER

synthetic fibers, particularly acetate rayon and regenerated cellulose have also been successfully formed in this manner. When nylon is formed, a steam treatment with the temperature raised to a point exceeding the previous setting condition is necessary to effect retention of the corrugated construction. Softening and bonding with the accompanying fixation of the corrugated structure has been achieved through the use of a dilute aqueous dispersion of an elastomer or resin.

Several experimental corrugated fibrous web battings were prepared by the technique referred to above using four superimposed webs formed on a sample card. The four layers of web were employed in order that the number of corrugating operations could be reduced.

This simplifying practice was required in order not to delay the evaluation program. Actually, it should be feasible to carry out the operation commercially on single webs and thereby obtain a batting of greater utility.

This laboratory corrugating unit was prepared and used to expedite the fabrication of samples for evaluation. It is not necessarily a pattern suggested for commercial corrugating, for the temporary features of the equipment introduced certain conditions which were not ideal for forming the best corrugated structure.

2. Commercial Pleating Machines.

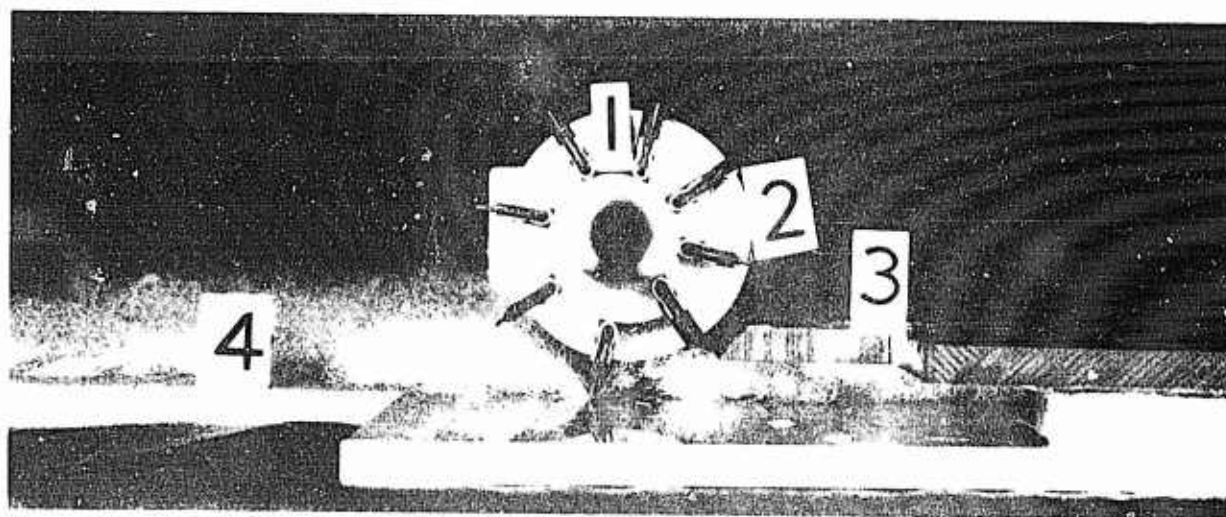
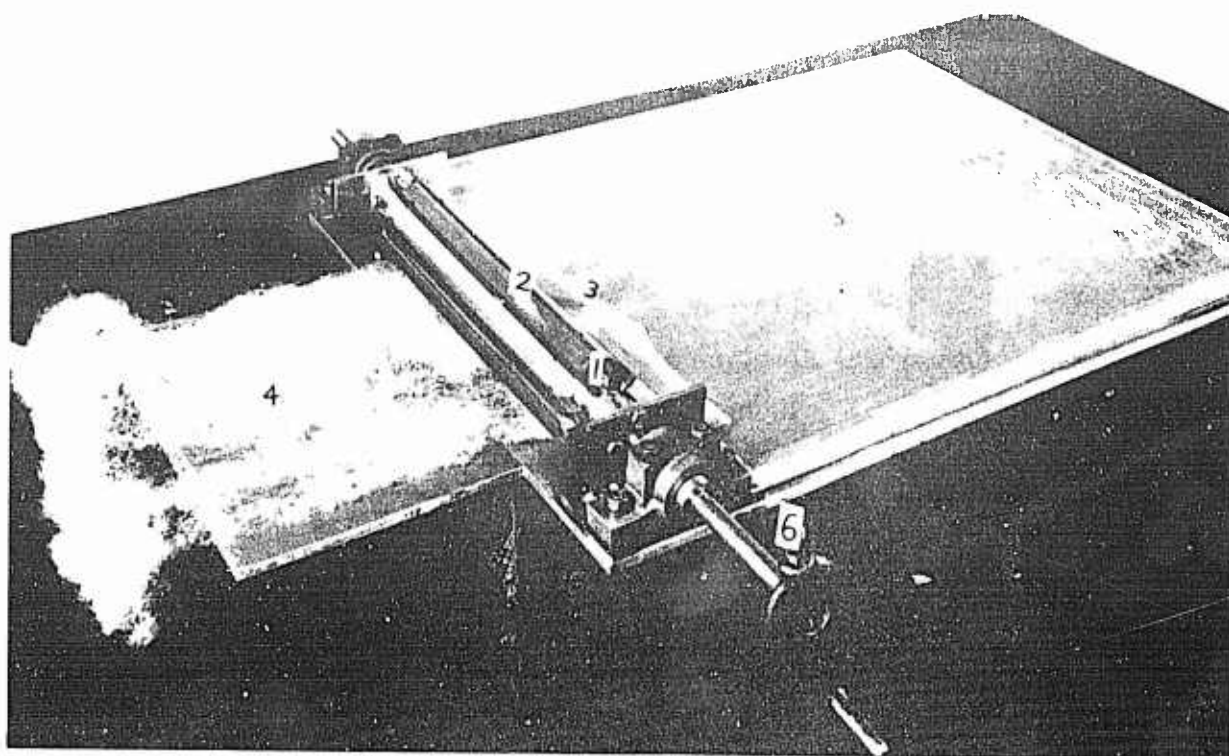
Commercial pleating equipment is available for use on fabrics. Several varieties are manufactured and, with certain refinements and other modifications, they would seem to be applicable for corrugating fibrous webs. No use of the commercial pleaters for corrugating fibrous webs has been made so far, but the comments received from a representative of the Chandler Machine Company suggest confidence in the utility of such a device for rapidly corrugating a delicate fibrous web structure.

B. The Fibrous Web Crimper

The limiting features of the pleating operation -- especially the apparent need for using paper over the web during commercial pleating and the difficulty of obtaining the card rate of speed -- gave rise to the consideration of other corrugating methods. The most promising corrugating technique evolved from these studies has been the web crimper.

A laboratory model of the crimper is reproduced in Figure 3. It consists of a blade roll assembly and base and top plates. As depicted, the blades in the blade roll assembly are positioned in slots equidistantly located around the roll in such a manner that the blade (windshield wiper) tips touch the web at $3/4$ " intervals. After each blade sweeps across the plate and forms a web as a corrugation, it recedes into the slot until flush with the roll surface. The corrugation is made by the moving blade and the resistance of the plain web to motion. The resistance is provided by the previously formed corrugated web, or initially by a bar placed on the first section of web passed through the crimper. Experiments also indicate that a canvas belt over the base plate or serving as a base plate offers sufficient resistance in itself to cause the web to buckle

THE FIBROUS WEB CRIMPER



End View

FIG. 3

and form a corrugation. The position of the blade in the slot is controlled by the stationary cam pictured in the photograph as No. 1. It will be noted that as the web (No. 4) is received from the doffer of the carding machine, it is picked up by the blade, the blade making contact with and carrying the web as it sweeps across the plate. Since the roll turns in a counter clockwise direction, this blade continues to make contact with the web until it moves into the slot provided by the cam. At the point where the blade recedes into the slot the formed corrugation passes under the top plate (No. 3), where it is retained to offer resistance for forming succeeding corrugations, and where it slides freely between the plates by the force being applied as the result of the building up of such corrugations. The next blade then moves to the point of contact with the web and the operation is repeated. Since the distance between blades at the points of contact with the base plate is about $3/4$ ", each corrugation is $3/8$ " in height. This distance also represents the spacing between the top and the base plate. For each revolution of the roll, 6 inches ($8 \times 3/4$ ") of web from the doffer is corrugated. Thus, with the web being provided at about 48 ft. per minute, the roll must be rotated at about 96 rpm.

In practice the equipment has operated exactly as indicated when carded cotton, nylon or wool web was used as feed. Ordinarily, however, particularly at speeds approaching 96 rpm., the fibers tend to adhere sufficiently to the blades and/or slot to cause the formed web to pass through the space between the top plate and the roller. Not until the top plate was vibrated could this difficulty be avoided. With one end stationary the end nearest the roll was vibrated through an arc of about $1/4$ ". It seems that the difficulty might also be avoided through the use of canvas belts -- one placed immediately over the base plate and the other above this, and separated by the thickness ($3/8$ ") of the formed bat. Since these belts travel at just sufficient speed to permit suitable web crimping without allowing the formed corrugation to condense significantly just after forming, they should prevent the formed web from riding over the roll in the manner described above. The treating of the corrugated web may be carried out just beyond this first belt assembly in a section of separated plates, while the condensing of the formed and/or treated web can be accomplished by another set of double layer conveyer belts.

This principle of forming corrugated web appears, from limited observations, to be quite sound. Further development, however, is needed to carry the operation to a point of commercial usefulness.

C. Carding Corrugating

Another corrugating process involving the use of the card alone has been considered. This method of corrugating fibrous webs may be more readily adaptable to commercial operation than those techniques previously described, particularly when relatively thick (1.5 inch) battings are desired. The technique requires that the speed of the take-off apron of the carding machine be reduced to permit the doffer comb to build up the web in the form of corrugations. In the ordinary operation of a carding machine, the periodic motion of the combs produces the corrugations, but the sweep of the comb is relatively great and the webs are straightened or even stretched as a result of the excessive take-off apron speed. By means of relatively minor modifications, it may be possible to carry out the entire course of operations required for forming corrugated fibrous battings directly on the carding or garnetting equipment.

D. Variations in Composition and Structure of Corrugated Battings

1. Fiber Treatment

In preparing corrugated battings it is usually advantageous or even necessary to apply a finish to the fibrous web. Softening of the fiber facilitates the shaping of the web, and frequently the treatment may actually serve to fix the corrugated structure. Resinous and elastomeric dispersions as well as water and steam have been used to this end in preparing corrugated fibrous fillers. The moistening or steaming of most natural fibers provides a condition for temporarily setting the structure. The steam pressure treatment of nylon and of certain other thermoplastic fibers is effective in holding and maintaining the batt structure until more severe conditions of exposure are encountered. Resinous and elastomeric finishes applied to either natural or synthetic fibers perform as a fixative, a binder, or both.

2. Fiber Additives

It is evident that coarse, stiff, crimped fibers impart good compression resistance. The inclusion of fine fibers, however, causes the area of contact between individual fibers to be lessened and increases the resistance to heat flow. In the corrugated form, similarly, fiber properties are instrumental in determining filler characteristics. However, in the new forming process it is possible to add to a web of the preferred size and type of fibers coarse, stiff, uncrimped filaments in their continuous form, and thereby achieve all the advantages of the stiff fiber. Preferably, the stiffening fibers are included in a

corrugated filler by spacing continuous monofilaments across, superimposed on, and in the same direction as the web of selected fibers just prior to the buckling operation. The greater stiffness of the added filaments together with their method of orientation in the corrugated form provides a batting of unusual compression resistance and accompanying high overall insulation efficiency.

3. Wave Pattern and Durability

Before corrugated fibrous web battings were evaluated for simulated wear resistance, concern was expressed about the possible separation of the pleats during use. In an effort to inhibit degradation of this nature, the additional application of a wave pattern on the finished corrugated filler was considered. The effectiveness of the wave pattern in reducing pleat separation is based on mechanical principles wherein the forces applied transversely to the waved corrugated structure are counter-acted by the greater resistance to movement offered by this arrangement of the pleated fibrous webs. Presumably, similar advantages can be achieved by performing the quilting operation at an angle of about 45 degrees rather than 90 degrees to the direction of the ridges in a straight corrugated batting. Actually, however, experimental straight corrugated interliners (quilted in a 5 inch box pattern between nylon facing fabrics) have displayed no significant separation after 20,000 cycles of flexing on the simulated wear tester. Their behavior in actual use in clothing is still to be determined.

VI. PROPERTIES OF CORRUGATED FIBROUS WEB FILLERS

The properties of experimental corrugated fibrous web fillers have been compared in laboratory testing with conventional laminated and pile fabrics. Inasmuch as low density is of primary importance, the corrugated samples have usually been prepared at about one ounce per square foot (before quilting). This is the weight of some laminated and randomly oriented fiber fillers that have been considered for use in military equipage and is lower than for wool pile. Comparison of the overall insulation properties of these pile fabrics with the light weight corrugated battings formed from the same fibers as woven fabrics is favorable to the corrugated material.

In an examination of about 150 experimental and commercial insulation fillers for overall insulation properties, the laboratory corrugated

samples were shown to be most efficient. The corrugated structure provides high resistance to compression at low density, and also shows thermal conductivity properties which are no greater and may be even less than those found for fillers prepared in the conventional pile- or laminated web-structure. Furthermore, these advantages for the new fill construction are maintained after simulated wear testing.

The compression resistance properties of laminated web, corrugated web, and pile battings prepared from wool fibers are compared in Figure 4. Both the laminated web and corrugated web fillers were formed at approximately the same density in the laboratory from an F-1 grade wool supplied by the Albany Felt Company. The laminated wool batting, naturally, is quite thick under low pressure, but both the corrugated and pile preparations are far superior in retaining their thickness as the applied pressure is increased. Actually, the corrugated web sample is the thickest under 0.05 pounds per square inch pressure, even though the pile fabric is almost 50 per cent heavier. Since the quilting operation reduces the initial thickness of loose fillers, the initial advantage in thickness displayed by the laminated web battings is not a factor when the batting is fabricated as a garment interliner.

In Figure 5, the effect of somewhat higher compressive loads on the thickness of quilted, laminated webs, and corrugated webs is shown. The corrugated wool batting (B-1) is superior in compression resistance, even after having been subjected to 5000 cycles of flexing, to the conventional type filler before the flex treatment. These same differences are displayed graphically in Figure 6, comparing the compressional properties of the following cotton battings: laminates of garnetted web, random mat, and corrugated random mat. These curves again indicate the superiority of the corrugated structure, and it is particularly noteworthy that the simulated wear test again has had least destructive influence on the new form of insulation filler.

The compression resistance, over a range of relatively high pressures, for a corrugated wool, a low density pile fabric and a fibrous glass filler is compared in Figure 7. Throughout the range of loading (above 1 pound pressure), the corrugated sample is at least twice as thick as the fibrous glass batting. Furthermore, in spite of its higher density, the pile fabric performs little or no better, compression-wise, than the corrugated web preparation.

The comparative cushioning properties of corrugated rubberized wool and a commercial foamed rubber are given in Figure 8. A shoddy

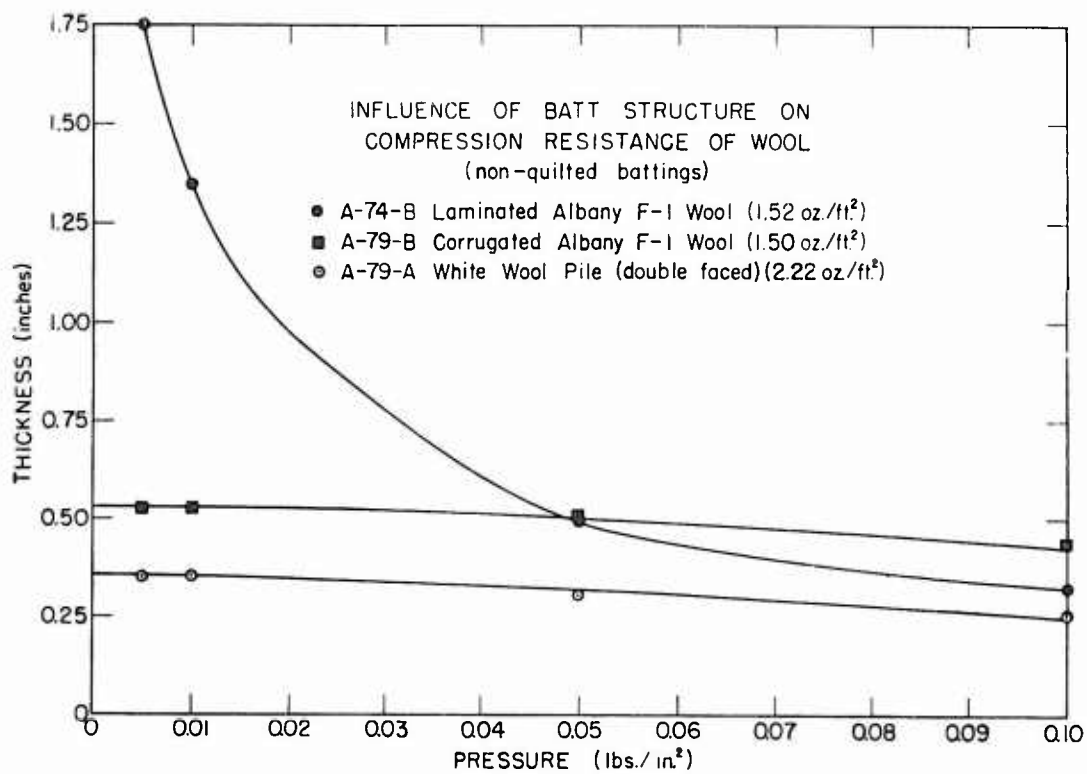


FIG. 4

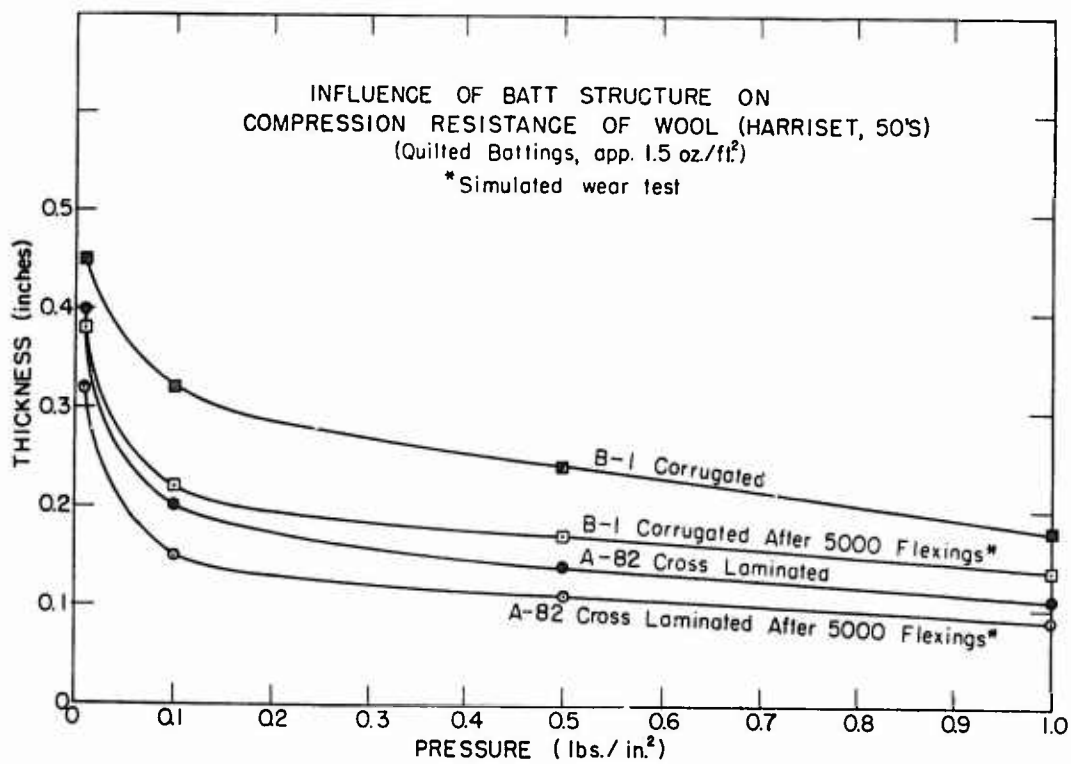


FIG. 5

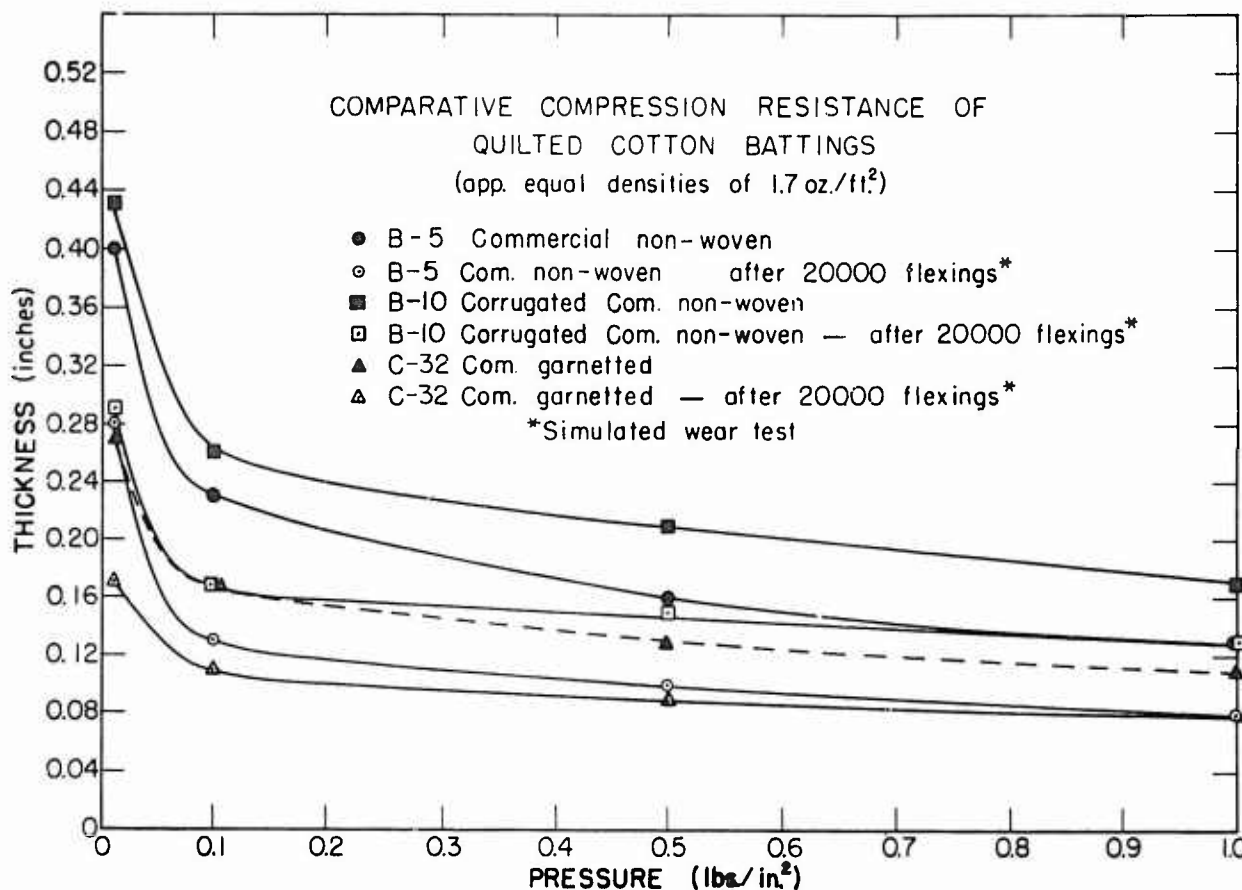


FIG. 6

COMPARATIVE COMPRESSION RESISTANCE OF
QUILTED COTTON BATTINGS

wool was used in preparing each of the corrugated samples and the rubber add-on amounted to 20 per cent on a weight basis. The elastomer employed in this instance served only to fix the fibers in the web prior to forming and did not bond together the pleats in the improved insulation structure. These curves again indicate that for equivalent weights the corrugated structure is superior to the uncorrugated sponge rubber.

The foregoing results clearly demonstrate the superior compression resistance of the experimental corrugated web structures. These findings are important only if thickness and insulation efficiency are directly proportional. Insulation efficiency may be expressed as being equivalent directly to thickness and inversely to the coefficient of thermal conductivity and density. With the density of the battings maintained at a constant value, and the improved thickness properties of corrugated battings demonstrated, only the influence of structure on thermal conductivity remains to be considered. In none of the experimental corrugated fibrous web battings has the coefficient of thermal conductivity

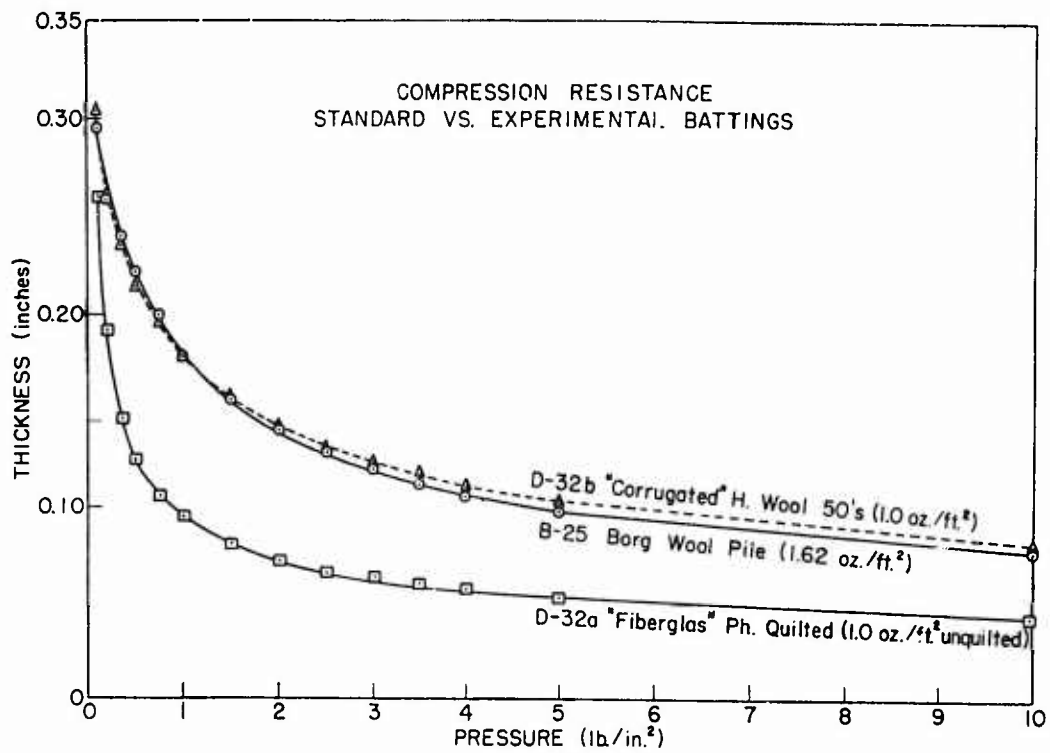


FIG. 7

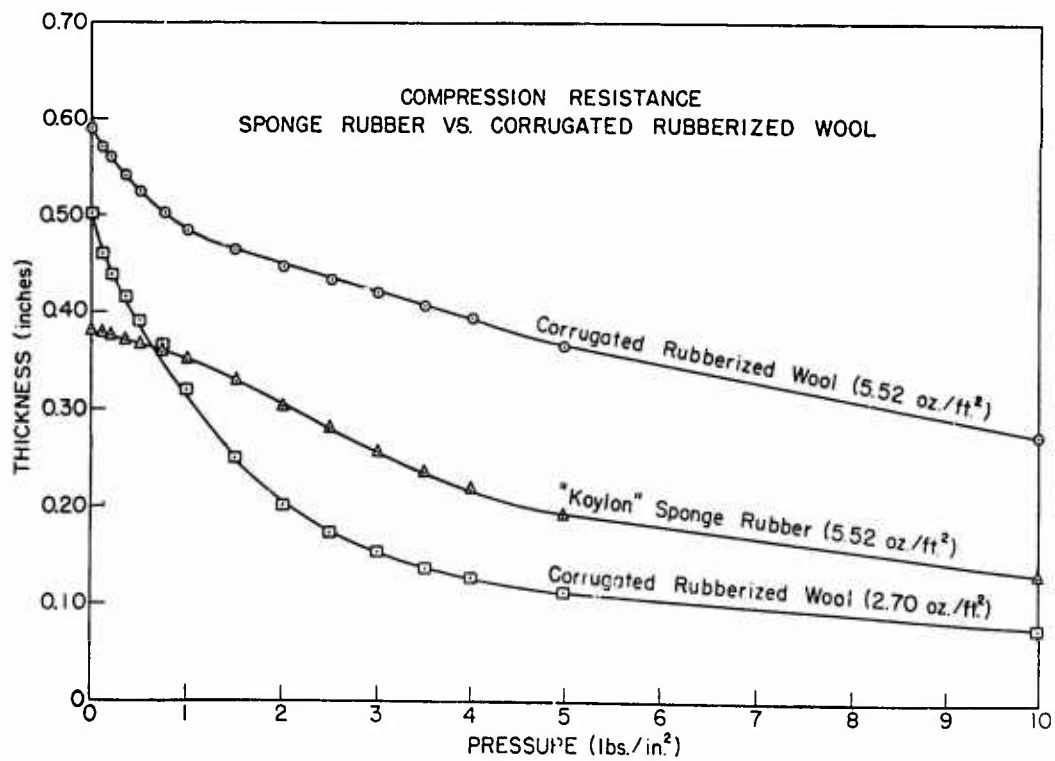


FIG. 8

been found to be greater than that determined for conventional laminated web battings of the same fiber. In fact, as is indicated in Table I, the relative coefficient of thermal conductivity for corrugated web battings is equal to or less than that value determined on other forms of fibrous insulation fillers of the same ingredients.

TABLE I

Effect of Batt Form on Thermal Conductivity
(Battings Subjected to 5000 Cycles of Flexing)
Under 0.01 psi pressure

<u>Interliner</u>	Relative Thermal Conductivity Coefficient	
	$K = \frac{\text{BTU}}{\text{hr, } ^\circ\text{F, ft}^2} \text{ per inch thickness}$	
Wool, Albany Felt F-1, corrugated	0.35	
W. Wool Pile, double faced	0.37	
H. Wool (50's), corrugated	0.39	
H. Wool (50's), plus elastomer, corrugated	0.41	
H. Wool (50's), cross laminated	0.41	
Wool, Albany Felt F-1, Cross laminated	0.42	

The results of laundering tests (Table II) also indicate that corrugated fillers perform better or no less satisfactorily than ordinary insulation materials. The shrinkage (decrease in width and length) of various experimental and commercial fillers after three mobile launderings is given as follows:

TABLE II

<u>Sample No.</u>	<u>Composition-Construction</u>	Shrinkage (%) after 3 launderings	
		<u>Warp</u>	<u>Fill</u>
A-82	Harrisat Wool 50's (laminated carded webs)	13.3	16.7
B-1	Harrisat Wool 50's (corrugated carded webs)	3.3	8.3
C-31	W. Wool Pile (woven)	7.2	8.3
B-25	"Borg" Wool Pile Nylon Back (knitted)	6.3	6.7

VII. CONCLUSIONS

In the laboratory, experimentally formed corrugated fibrous web fillers have displayed outstanding compressional resiliency properties. When formed in this manner, any fiber may be expected to provide a level of compression resistance which is superior to that offered by the same fiber in conventional form. Abrasion properties are not adversely affected and thermal conductivity characteristics may actually be improved by this fiber orientation process. As a result, the overall insulation properties of corrugated fibrous web fillers are maintained at a level which appears to be optimum for the fiber used.

The corrugating operation should not be difficult to adapt to commercial practice. Potentially, the process offers a means of producing improved insulation fillers in quantity and on conventional equipment with relatively minor modifications and/or attachments.

All these facts considered, it is suggested that the corrugating technique, which presents a possibility of converting less satisfactory fibers into an improved insulation filler, be seriously investigated by the American Textile industry as a commercial method for preparing fibrous fillers.