HIGH STRENGTH GLASS FIBER TAPES AND WEBBINGS FOR HIGH TEMPERATURE PRESSURE PACKED DECELERATOR APPLICATIONS

E. S. Cobb, Jr.
Owens-Corning Fiberglas Corporation

INTRODUCTION

With the development of new weapons systems requiring high temperature materials, and in consideration of the development of recovery systems where materials can experience aerodynamic heating resulting from air friction at high velocity, a need is created for textile structures with greatly improved temperature resistance, particularly for use as decelerator materials. Nylon and polyester fiber webbings, tapes and ribbons which are presently being used for Air Force applications have a limited safe usable temperature of 250°F and 350°F respectively. Presently there is a need for textile materials having a temperature resistance of at least 500°F for extended periods of time.

One manner in which this problem can be solved is the development of glass fiber webbings, tapes and ribbons which can be fabricated in a manner which would make them suitable for decelerators which must undergo high temperature exposure.

It is well understood that glass fibers have the basic strength characteristics and temperature resistance which would make them suitable for this application. However, their inherent properties of limited flexural endurance and abrasion resistance require that special processing techniques be developed which would make them totally suitable for this application.

One of the major commercial applications which has been developed and utilizes the high temperature characteristics of glass fiber is glass fiber filter bags which operate continuously at 500°F to 600°F and undergo a considerable degree of flexing. In developing glass fabrics so that they would be suitable for this strenuous application, it was necessary to evaluate the application very specifically and to develop special techniques to make glass fibers function in an optimum manner; however, it was only with the knowledge that the glass fibers had the basic temperature requirements to be suitable for this application that the development of high temperature glass fabric filtration systems was undertaken. Some of the technology which had been worked out for this application formed the background of information for the development of high temperature webbings, tapes and ribbons for decelerator applications. Much of the information gained from this latter development has broadened our general knowledge of the utilization of the high temperature characteristics of glass fibers.

With the previously mentioned need and the confidence that glass fibers could be developed so that they would be suitable for high temperature decelerator applications, the Air Force initiated a research program with the Owens-Corning Fiberglas Corporation with the following primary objectives:

A. To develop, fabricate, and evaluate woven glass fiber webbings, tapes, and ribbons which will meet the requirements of high temperature (500°F for 5 hours) pressure packed decelerators without any appreciable loss of strength.

1. Webbings

Item 1 - 1" wide, 3000 lbs. minimum breaking strength
Item 2 - 2" wide, 5000 lbs. minimum breaking strength

2. Tapes

Item 3 - 5/8" wide, 500 lbs. minimum breaking strength
Item 4 - 2" wide, 2000 lbs. minimum breaking strength

3. Ribbon

Item 5 - 2" wide, 1500 lbs. minimum breaking strength

In designing the webbings, an attempt was made to develop a 1" wide glass webbing (Item 6) with the highest breaking strength possible (6500 lbs. is desired.)

B. To develop methods of seaming or joining the material developed under Objective A with an 80 percent seam efficiency as the target.

Prior to undertaking the major development phases of this program certain assumptions were made as to types of materials to be used for this program. These assumptions were based both on some initial tests of glass fiber structure as well as past knowledge which had been gained from the development of other glass fiber applications which had requirements similar to at least one or more of the requirements needed for this Air Force application. It was quickly established that meeting the pure tensile strength requirements outlined in the objectives would not be one of the problems of this effort and that actually there are many forms of glass fabrics which are presently in commercial use which are essentially unaffected in this property when exposed to 500°F for a period of 5 hours. With these facts in mind, the major effort on this program immediately centered around the developing of a method which would allow the retention of these high strength and high temperature resistant properties after certain flex conditions. It also indicated the need of developing a testing technique which would allow the evaluation of various candidate materials in a simulated high temperature pressure packed decelerator.

Because of data gathered from other developments, it was decided that the finer filament glass fiber would be used. An ECDE 150's fiber which has an average filament diameter of .00025" was selected as the base material to be used. For numerous reasons, it was also determined that we would not attempt to apply a high temperature finish to the basic fiber but to use it in its standard form with a starch sizing material on it and then to impart a high temperature finish onto the woven structure.

For purposes of initial evaluation, Dow Corning ET 4327 silicone lubricant was selected as a fabric finishing material. This material is commercially available and is commonly used as a high temperature finish for glass fabrics. Actually in the end this compound was found to be best for this development.

TEST METHOD DEVELOPMENT

As has been previously mentioned, it was established that the proper performance of glass fibers in this high temperature decelerator application was more than a function of initial tensile strength and a resistance of 500°F for a period of 5 hours and that it would be necessary to develop some means of establishing the performance characteristics of candidate glass fiber woven structures. With this fact in mind and with some knowledge of pressure packing techniques, a system was developed whereby candidate materials were subjected to heat, pressure, and folds simultaneously. As can be seen in Figure 1, four basic fold conditions were selected. Although these four conditions do not necessarily take into consideration the many contortions which a textile structure undergoes during pressure packaging, they were considered adequate for the evaluation of candidate materials for this application. Candidate materials after being folded were then taken and placed in a press as can be seen in Figure 2 and subjected to 250 psi at 500°F for a period of 5 hours. After specimens were conditioned in a hot press, they were then taken and tested for tensile strength, and all data was then compared back to a control sample which had not undergone any conditioning. This simulated pressure packaging conditioning cycle not only gave us good data as to the effect of these conditions on tensile strength but also allowed us to observe the flexibility and the recovery of the material which had been pressed.

Figure 1

Test Specimen Preparation for
Simulated Pressure Packaging Conditioning

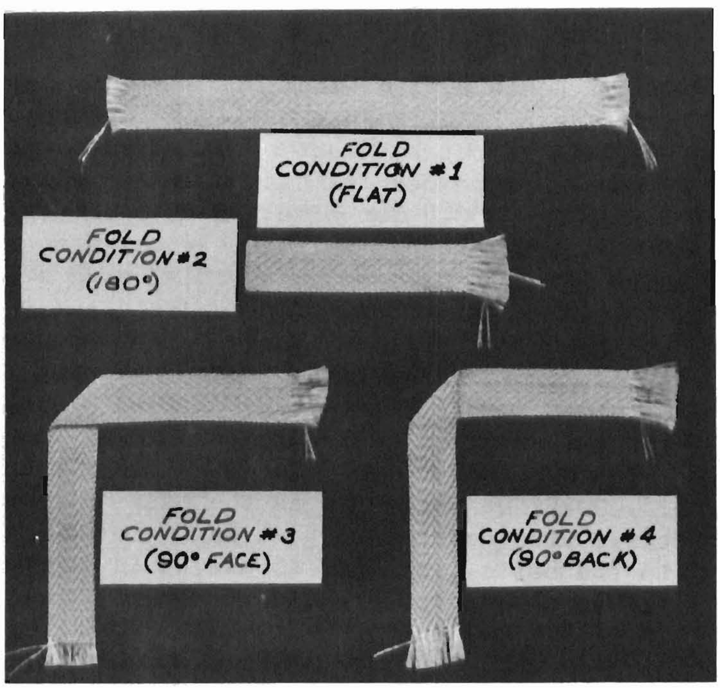
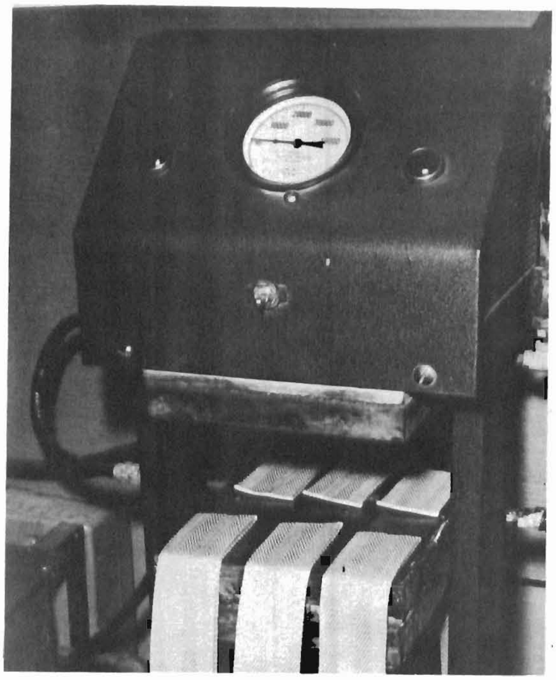
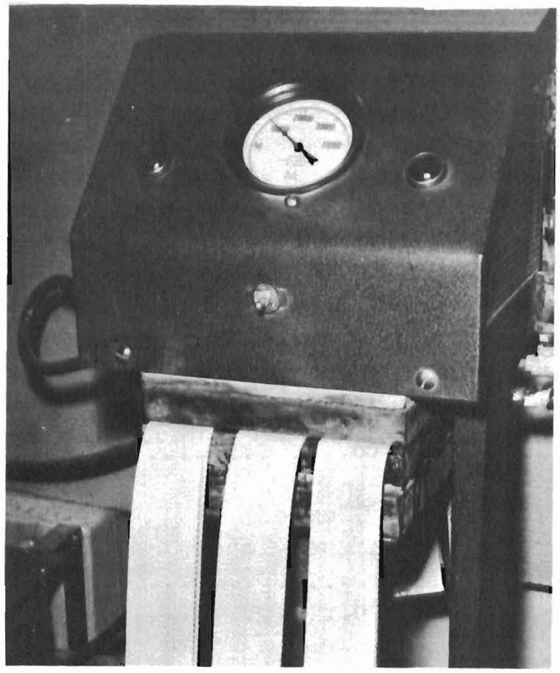


Figure 2

Test Specimen Condition for Simulated Pressure Packaging



Loading the Press
For Fold Condition II



Actual Conditioning
For 500° F at 250 PSI

OPERATIONAL CHARACTERISTICS

When this study was originally proposed, it was strongly felt that the factor which had limited the use of glass fibers in high temperature decelerator applications had been the limited flexural endurance and abrasion resistance either before or after exposure to high temperatures for an extended period of time. As a solution to this problem, it was then proposed that the tapes, webbings and ribbons be subjected to a high temperature heat cleaning operation by which the organic material originally placed on the basic fiber is almost entirely removed and the weave becomes completely set or crimped. Upon completion of the heat cleaning cycle, a high temperature resistant and lubricating finish is then applied to the structure. It was known that this heat setting and refinishing operation would reduce the tensile strength of the woven structure by approximately 30 percent; however, it was felt that the strength reduction could be anticipated and compensated for in the original design of the woven structures. In order to obtain operational characteristics of two basic forms of glass fiber materials, greige goods tapes and tapes which had been heat cleaned and finished were prepared for simulated pressure packing conditioning and then tested for tensile strength retention. For purposes of this initial study, a 12 1/2 percent solution of Dow Corning Silicone ET 4327 was used as the high temperature finishing material for the heat cleaned specimens.

As can be seen in Figure 3, the results of this evaluation are very interesting, and some very positive conclusions as to the use of glass fibers in this application can be drawn.

Figure 3

Strength Retention after Pressure and/or Heat Conditioning
Greige Tape versus Heat Cleaned and Finished Tape

Summary of Results

Sample Number and Property	Control	Fold Conditions (See Figure 1)			
		I	II	III	IV
Breaking Strength.....Lbs.					
Greige Tape:					
Hot..................	991	882	580	781	733
Cold..................	-	997	889	983	1004
Heat Cleaned And Finished Tape:					
Hot..................	859	888	724	773	846
Cold..................	-	800	646	866	800

Explanation:

Hot Condition: Samples were tested at room temperature after exposure to 500°F for 5 hours at 250 psi pressure.

Cold Condition: Same as Hot Condition except exposure was at room temperature.

In analyzing the results of this evaluation, the following conclusions were drawn:

1. In the case of the heat cleaned and finished material, even though it had approximately 20 percent less tensile strength before it was subjected to the heat and pressure conditioning cycle, its lowest value was higher than the greige goods tape exposed to similar conditions. In the case of pressure packed decelerators which may be subjected to 500°F for 5 hours, the heat cleaned and finished material would perform in a superior manner.

2. The effect of heat in the end application must be considered when establishing a cure cycle for the finishing material. In the case of the heat cleaned and finished material, when they were conditioned under both pressure and heat, the values were greater than when they were conditioned under just pressure at room temperature. In the case of the greige goods tapes, the values were considerably higher when they were conditioned under just pressure alone at room temperature. These values dropped considerably when they were conditioned under both pressure and heat.

3. It was observed during this study that the heat cleaned and finished specimens were much more flexible after removal from a hot press. This indicates that in the case of the rapid opening of a decelerator, they would perform in a superior manner.

Actually, when we review these values, we could say that a glass fiber woven structure which had been heat cleaned and finished in the above manner would perform satisfactorily in this application within the limitation of its lowest tensile value, which is only 16 percent reduction from its original control strength. However, when we take into consideration that an additional 20 percent reduction in strength was necessary in order to put the structure in this condition, it was felt by the contractor that certain modifications could be made in the heat-treating cycle which would allow us to have both a higher initial tensile strength and higher performance characteristics.

After a considerable bit of experimentation as to methods of heat treating the tapes, a system of partial heat cleaning and caramelization was developed and established to be a satisfactory method of heat treating glass textile structures for this application prior to the application of a high temperature silicone finish. This partial heat cleaning process actually reduced the ignition loss of the starch finish which had been placed on the yarn during its forming from approximately 1.9 percent to a range of 0.75 percent to 1.0 percent. Caramelization of the starch size converts it chemically to a material which offers a high degree of protection for the glass fibers. It is of major significance that this process not only does not lower the basic strength of the structure, but there was instances in which the tensile strength was actually increased by as high as 10 percent. Briefly, this process was accomplished by continuously pulling the tape or webbing through an oven which was operating at approximately 1000°F. As the tapes were withdrawn from the heat zone, a 12.5 percent solution of ET 4327 silicone was applied with a padder, and the tape was then processed through drying and curing towers. This basic process with the exception of our producing a partially heat cleaned and partially heat set fabric is similar to the standard glass fabric finishing process known as Coronizing*. Because the various tapes and webbings had different thicknesses and densities, control of the product's ignition loss was obtained by altering the heat cleaning oven temperature and the speed at which the material was processed through it. In observing this process, it was noted that the optimum running condition showed the tapes coming out of the oven just prior to being heated to the flash point of the organic sizing material which was on the yarn. Actually any slight increase in heat exposure ignites the material which lowers the ignition loss and reduces the tensile strength by approximately 50 percent. This effect is consistent with past experience on the development of high temperature glass fabric finishing processes. At such time as any quantity of materials are to be processed in this manner, much consideration should be given to further developing process controls.

The best way to illustrate the suitability of this process for the manufacture of high temperature-resistant materials for decelerators is to show the tensile values of the various structures which were developed during this project. You will note from the data in Figure 4 that in all cases there was actually a tensile strength gain after the material had been partially heat cleaned or caramelized

* Registered trademark of Owens-Corning Fiberglas Corporation

and treated with a high temperature silicone finish and that, after the material had been exposed to simulated pressure packaging conditioning, the tensile values in only a few instances actually dropped back below the value of the greige goods material. With this process developed, it was now possible to design the tapes, webbings, and ribbons specified in the objectives of this program without compensating for any tensile strength loss which would result from a heat cleaning and finishing operation. Needless to say, in consideration of the space and weight limitations which are generally placed on pressure packed decelerator devices, this becomes a strong advantage.

Figure 4

Tensile Values of Tapes & Webbings Developed for AF 33(616)7441
(Before and After Exposure to simulated high temperature Pressure Packaging)

Specimen Condition	Breaking Strength (Lbs.)					
	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6
A. Greige	3419	7496	634	2639	1558	7864
B. Heat Treated & Finished	4262	7824	694	2824	1642	8660
After Exposure to:						
1. 500°F for 5 Hours	3987	7756	620	2614	1755	7864
*2. Fold Condition I Hot	4204	7884	647	2801	1743	7158
*3. Fold Condition II Hot	3781	7054	603	2493	1350	7428
*4. Fold Condition III Hot	4204	7902	590	2703	1357	8042
C. % Strength Retention of Greige Goods (A) at weakest point	111	94	93	94	87	91
D. % Strength Retention of Heat Treated and Finished Goods (B) at weakest point	89	90	85	88	82	83
*See Figures 1 & 2						

OPTIMUM YARN CONSTRUCTIONS

Previous experience in the weaving of high strength webbings, tapes, and ribbons from glass fibers points out that the more standard yarn constructions are not necessarily optimum for this application. Filament breakage and subsequent loss of tensile strength has been a major problem and results from the abusive action of the heavier webbing and tape looms on the glass filaments and the extreme fiber bending necessary to obtain the desired constructions, particularly in the case of the multi-layer webbings. As previously mentioned, an ECDE 150's fiber having a filament diameter of 23 to 27.9 hundred thousandths of an inch was selected as a base yarn to work with instead of the more conventional ECG 150's fiber which has a 35 to 39.9 hundred thousandths of an inch filament diameter. Previous data show that this finer filament fiber has one of the highest degrees of flexibility and its denier equivalent is such that yarns having the necessary tensile strength for this application could be properly constructed with a minimum number of plies. In order to develop a series of yarn constructions which would be optimum for this application, yarns of essentially equivalent deniers were constructed, varying the amount of twist. It was readily determined that the higher twist yarns give a construction which shows a significant increase in yarn abrasion resistance on laboratory yarn testing equipment and that the breaking strength of the higher twist yarns was not substantially affected. For purposes of this contract, yarns used were twisted and plied to a degree which would be considered maximum twist, but not to a degree at which the filaments would tend to lose proper orientation and thereby give the finished yarn construction a loopy appearance. This point can readily be determined, for as soon as improper orientation is reached the yarns lose tensile strength.

WEAVE DESIGN EVALUATION

In an effort to obtain an optimum fabric construction for glass fibers in this application, a series of eight tapes were woven and finished and then tested for tensile strength retention after exposure to simulated pressure packaging conditioning. Although the width of these eight sample tapes were identical, the tensile strengths ranged from 600 to 1000 pounds. Thus it became necessary to reduce the strength data to grams per denier so that the constructions could be compared. On this basis, a Three Point Herringbone weave, using heavier yarns in the warp, showed superior properties after all tests. At its weakest point, it still retained 91 percent of finished tensile strength. This can be compared with the least satisfactory construction which only retained 72 percent of its tensile strength at its weakest point. The Three Point Herringbone weave was then used for all single layer structures as specified in the objectives of this program. Another criterion which was used in the optimizing of this weave design was that the heaviest warp yarn possible should be used, but that it was also necessary to produce a tape which was stable and would maintain proper orientation during all phases of processing.

Initially it was felt that the data gathered on the tape weaving evaluations could be extrapolated and that the design specification for the multi-layer webbing structures could be quickly settled upon. However, when the Three Point Herringbone weave was woven in a double layer with an adequate number of picks to produce a stable, non-shifting structure, the tensile strength efficiencies of the yarns were reduced drastically. The webbing was a stiff structure lacking what was considered the required flexibility for this application. As a result of this evaluation, it then became necessary to change the webbing structures for Items 1 and 2 to an Interlocking Weave which does not have a binder thread and allows the warp yarns to remain more parallel.

Further weaving trials were conducted with the multi-layers of the Interlocking Weave design in order to meet the specific requirements of Item 6 (1" wide, 6500 pounds tensile strength). However, after several trials with this weave design, it was determined impractical to obtain this strength in a 1" web of this construction. It was then necessary to design a 2-Ply Fabric having a large number of stuffer ends in order to meet the requirements.

One important point in the weaving of these heavy structures is that, in order to obtain the maximum strength in the woven material, it is absolutely necessary to maintain a uniform tension in both the warping and weaving operations. As there is a very low elongation in the glass yarns, any differential in tension of yarns going into the loom will result in improper orientation of the warp yarns. This leads to a subsequent reduction in tensile strength in the woven structure.

SEAMING AND JOINING STUDIES

In an effort to establish an optimum method of joining the tapes, webbings, and ribbons developed during this study, a survey was made, and pointed out that very little data have been developed on the joining of glass fiber material of these tensile strengths, and that present applications of glass fabrics do not necessarily require a high seam efficiency. Only two threads have the temperature requirements and were considered in this work, the first being HT-1 sewing threads. Several seams were sewn with HT-1 threads. It was found to be a thread which sewed efficiently on conventional type machines. However, because of thread elongation, the stitches tended to bite into and abrade the glass fiber tapes. It was felt that this material, having been put under tension in the sewing operation, tended to work against and subsequently break down the seam strengths of the tapes and webbings.

The second candidate sewing materials were standard glass fiber sewing threads. Although these threads are somewhat difficult to work with on the sewing machine, it was found that with a certain amount of care and proper adjustment of the sewing machines, satisfactory seams could be fabricated. A series of stitch patterns were sewn. From these it was determined that the best seam design for the single layer tapes is simply a series of staggered seams with parallel stitching. Other seam designs involving a diamond pattern or a series of stitches which were sewn width-wise in the tape tended to shear the sewn material at the point where the seam crossed the tape. This gave a much lower seam efficiency.

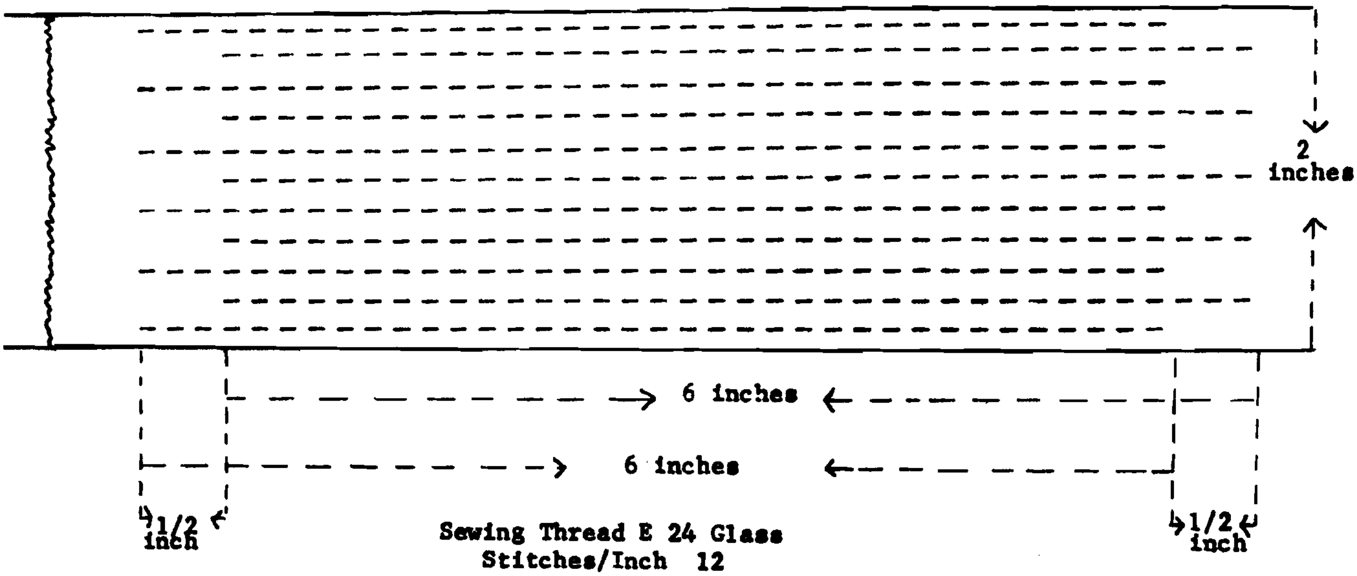
Generally, as far as the sewing of the heavier webbing structures, this same type of staggered, parallel stitch pattern appeared to be the best approach; however, in the thicker and more compressible webbing structures, it was determined that a limited amount of diamond stitching could be placed into the seam structure to improve the efficiency of that seam.

A series of seams were sewn on all the items developed in this study. Four out of six structures produced a seam efficiency of 90 percent or better. Two of the one-inch width, high tensile webbings had seam efficiencies of 70 percent and 60 percent. However based on this work, it is believed that recommendations can be developed which would lead to the fabrication of seams having at least 80 percent seam efficiency for these two structures.

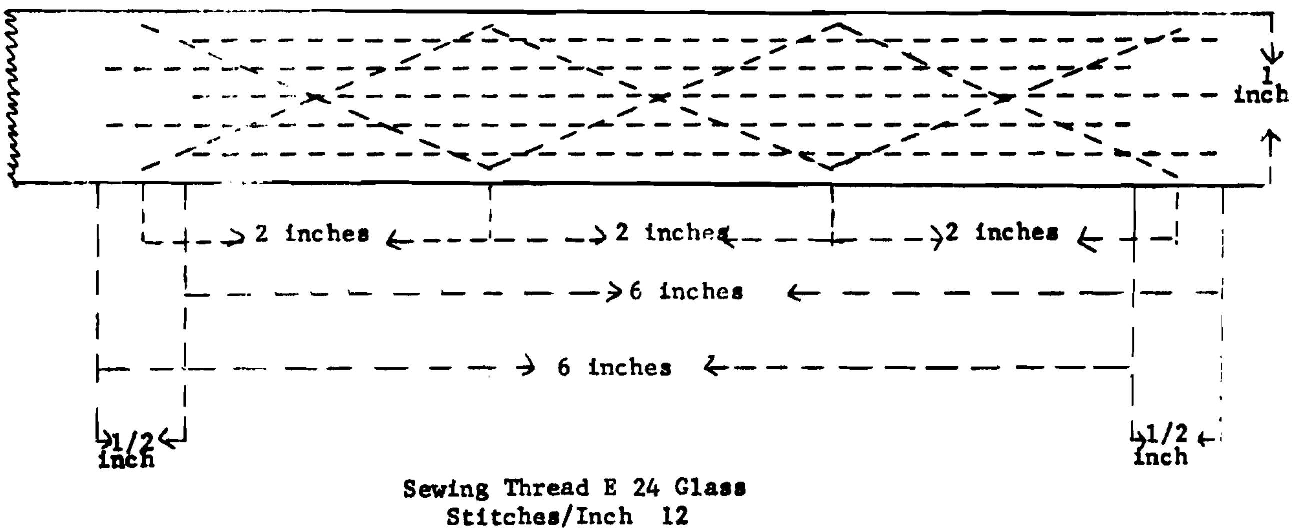
Figure 5 shows the two types of stitch patterns which were determined to be optimum for the single layer tape structures and multi-layer webbing structures.

Figure 5

Stitching Patterns



(A)
Parallel Stitching With Staggered Seams



(B)
Same as (A) Except With Diamond Pattern Added
(Used only on Thick Webbing when added strength is needed)

CONCLUSION

A basic method of fabricating glass fiber textile structures that should operate satisfactorily in pressure packed decelerators which must undergo thermal exposure to 500°F for a period of 5 hours has been developed. However, the complete success of these glass fiber materials will require further work in order to process them into operable decelerators, but if the basic properties of the fiber are considered, and previously developed handling techniques are followed this complete success should be attainable. Under further sponsorship of the Air Force, the Owens-Corning Fiberglas Corporation is continuing its effort to develop improved higher temperature glass fiber textile structures for Air Force applications. In this advanced development program, not only upgrading of the finishing techniques of existing glass fibers is being considered, but effort is also being placed on the evaluation of new glass fibers which will have greatly improved high temperature characteristics in their basic fiber state.