

[54] **METHOD FOR OPTIMIZING THE MAKING OF A LAMINATED FIBROUS STRIP**

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[22] Filed: **June 21, 1971**

[21] Appl. No.: **155,073**

[52] U.S. Cl. **29/419**, 29/2, 29/4.5, 29/163.5 F

[51] Int. Cl. **B23p 17/00**

[58] Field of Search 29/419, 2, 4.5, 4.51, 163.5 F; 83/87, 155

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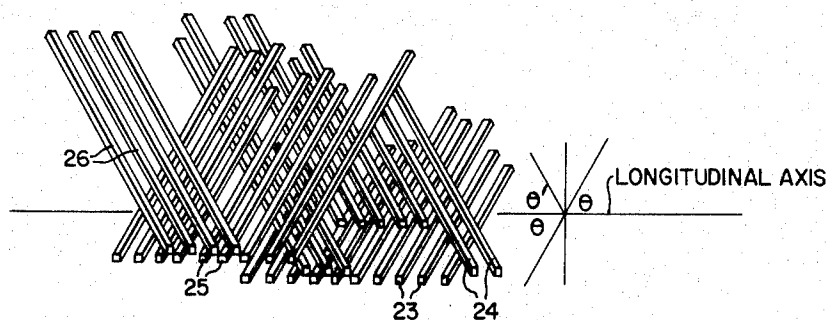
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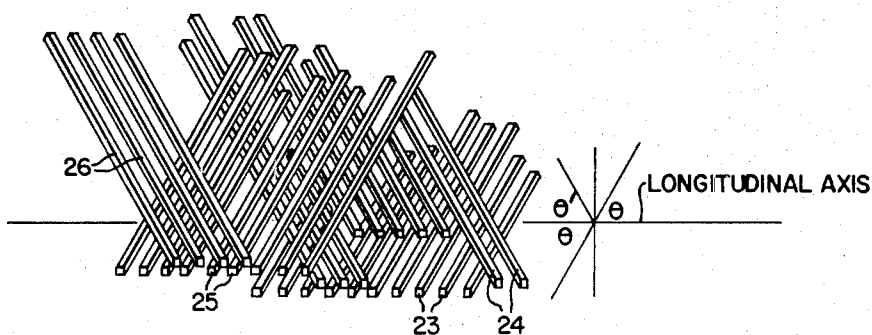
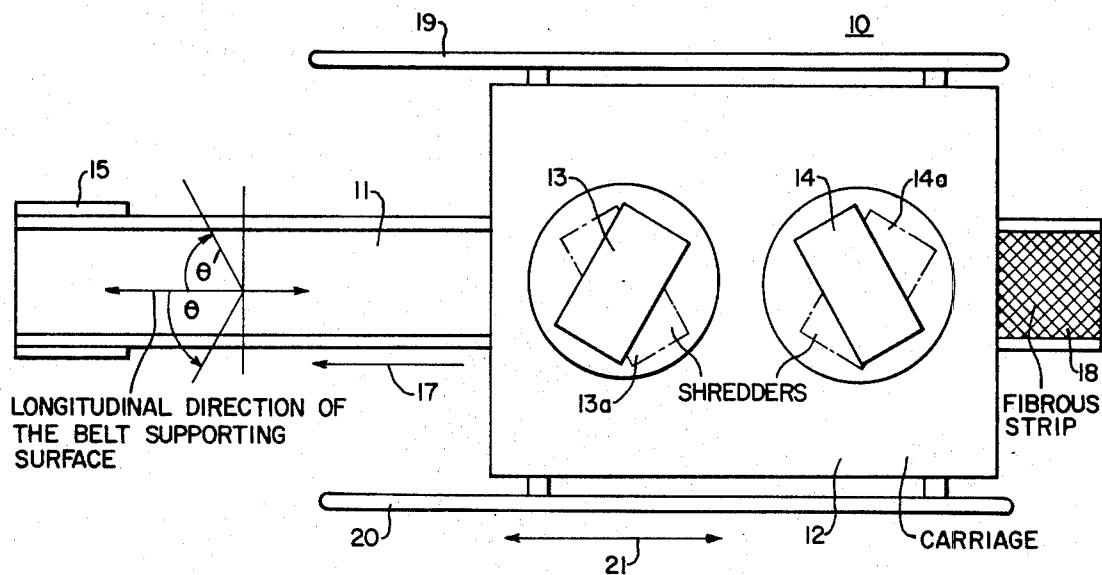
[57] **ABSTRACT**

A method for preparing a fibrous laminated strip on an elongated supporting surface, using a continuous fiber shredding apparatus having X shredders each cutting and applying P fibers/min., the strip consisting of N laminated layers of shredded metal fibers having a total weight per unit area of W gr./in², the fibers having a thickness of f_1 in., a width of f_2 in. and a density of d gr./cu. in., the fibers of each layer being disposed at an orientation angle θ from the longitudinal axis of the supporting surface; the method comprising the steps: (1) forming a layer having a weight per unit area of w gr./in² by applying P fibers/min. on the elongated supporting surface in a longitudinal direction, the fibers being disposed substantially parallel to each other and at an angle θ of between 15° and 75° from the longitudinal axis of the elongated supporting surface, the fibers being applied to the supporting surface at a traverse speed of Q in./min. and then (2) forming N layers by applying, at a speed Q , additional layers of loose thin metal fibers substantially parallel to each other within a layer, to cover the previous layer at an angle from the longitudinal axis of the elongated supporting surface alternating between θ and θ' where $\theta' = \theta$ wherein the following relationship exists:

$$Q = X[(d)(N)(P)(f_2)/(W)(\sin \theta \text{ or } \theta')].$$

6 Claims, 4 Drawing Figures





WITNESSES

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FIG. 3.

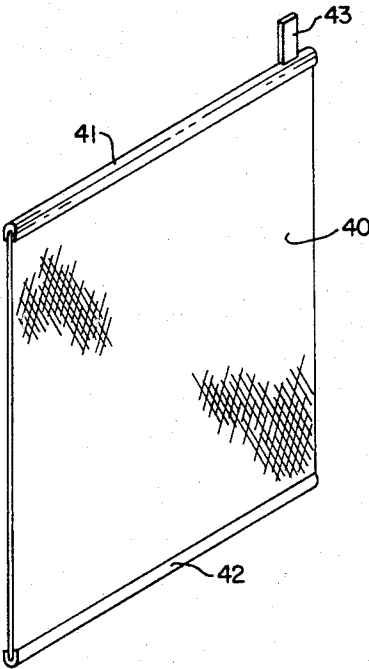
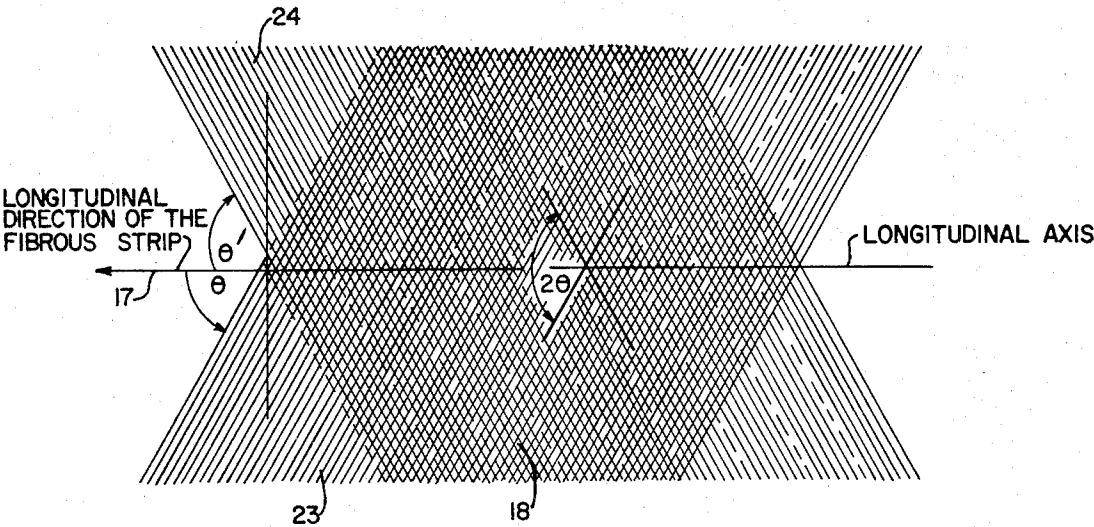


FIG. 4.

METHOD FOR OPTIMIZING THE MAKING OF A LAMINATED FIBROUS STRIP

BACKGROUND OF THE INVENTION

This invention relates to a method for producing continuous laminated fibrous structures.

Prior known procedures for making laminated fibrous structures have been dominated by manual operations. Heretofore, metal foil has been shredded by foil shredding machines into fibers which were collected in a suitable container. The fibers were then manually placed on a flat surface and "combed" into come semblance of uniform orientation. This would provide a sub-lamination. Other laminations, with fibers extending at angles to the sub-lamination, were than stacked one upon the other to yield a complete laminate. That procedure has been followed to provide, for example, laminated fibrous plaques for iron-nickel alkaline batteries.

The disadvantages of the manual procedure are well recognized and have created a demand for automatic shredding apparatus whereby a laminate of two or more layers of metal fiber may be produced in a continuous ribbon or strip. Such an automatic apparatus was disclosed in copending patent application Ser. No. 100,683, now U.S. Pat. No. 3,685,376, assigned to the assignee of this invention. However, optimization of this apparatus is highly desirable to provide a controllable method for providing optimized battery plaques of desired density, high strength and fiber orientation.

SUMMARY OF THE INVENTION

In accordance with this invention, an automatic shredding apparatus to provide laminated fibrous plaques can be controlled to produce a given desired fibrous matrix. The apparatus can include a movable belt supporting surface, and at least one metal foil shredder mounted on a movable carriage over the belt and being rotatable through or fixed at an angle θ from the longitudinal axis of the plane of the belt.

The relationships to provide the optimized laminated fibrous plaques are:

N = No. of layers

$$= \frac{(\text{given final plaque thickness}) (1 + 0.2)}{\text{fiber thickness}}$$

and

Q = Traverse speed

$$= \frac{(\text{No. of fibers cut per unit time}) (\text{fiber density})}{\text{plaque weight per unit area}}$$

$$\times \frac{(\text{No. of fiber layers}) (\text{fiber thickness}) (\text{fiber width})}{\sin \text{ of the angle of fiber orientation}}$$

These relationships provide a basic approach to a controlled and automated shredding/laminating process for the production of metal fiber matrices. Using these relationships in the method of making such matrices, our method synchronizes the three operating components into a total system for effective product control. This method attains the optimum surface area for a given fiber cross-section and a given wt./unit area of matrix, control over thickness while maintaining the optimum surface area and control over the size of the openings (pore size) of the matrix while maintaining the optimum surface area.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic plan view of one embodiment of an automatic apparatus for making a continuous strip of laminated metal fibers;

FIG. 2 is a plan view of the metal fibrous strip;

FIG. 3 is an enlarged fragmentary perspective view of the manner in which the metal fibers of the various layers are disposed; and

FIG. 4 is a perspective view of a battery plate as an example of one product for which the laminated fiber metal strip may be used.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The method of the present invention prepares an elongated strip of laminated metal fibers to a desired density using an automatic shredding apparatus, by providing the traverse speed and number of layers required. The method comprises the steps of applying on an elongated supporting surface an initial layer of loose, fine discrete metal fibers of known cross section and density disposed substantially parallel to each other, and at an angle θ of between 15° and 75° from the longitudinal axis of the supporting surface, and then applying at least one other similar layer of fibers on the initial layer and at an angle θ' , this angle preferably being in the opposite direction from the longitudinal axis of the supporting surface and equal to θ .

One embodiment of a device for performing the foregoing method is shown in FIG. 1. In FIG. 1, an automatic fiber shredding apparatus generally indicated at 10, includes a conveyor belt support 11, a movable carriage generally indicated at 12, and metal foil shredders 13 and 14. The conveyor belt in this embodiment is stationary during carriage traverse and is moved a predetermined distance in the direction of arrow 17 at the end of each right carriage traverse and each left carriage traverse. The conveyor belt 11 is disposed around and between a pair of spaced belt support rolls 15 and 16 whereby one or both of the rolls drives the belt in the longitudinal direction of the arrow 17. Thus, the upper portion of the belt provides an elongated movable support surface upon which the metal fiber strip shown as 18 is laid.

The carriage 12 extends between a pair of parallel tracks 19 and 20 which are disposed on opposite sides of the belt 11. The carriage 12 is adapted to traverse longitudinally of the belt 11 in the back and forth direction of the arrow 21. The carriage 12 is provided with means, such as a reversing drive screw for moving the carriage repetitively from one end of the tracks 19 and 20 to the other.

The shredders 13 and 14 each include a cutter head and a metal foil feed roll. The cutter head is a circular member having a plurality of spaced cutting edges extending along the outer surface of the head and from one end to the other. For each full rotation of the head, a fiber for each cutting edge will be produced. The head is mounted between a pair of journals and is driven by a motor and gear box. The foil rolls feed a strip of metal foil into the foil cutting area where the rotating cutting edges cooperate with a shear bar to cut the foil. As a result, fibers of metal are dropped upon the belt at a certain rate at spaced intervals depending on the carriage traverse speed.

The metal foil can have a thickness range of from about 0.0005 inch to about 0.0030 inch, preferably about 0.0008 to 0.0015 inches. Each filament or fiber is cut to about 0.0005 to 0.0030 inches, but preferably between about 0.0008 to 0.0015 inches wide and may have a length that is within the confines of the length of the shredder and preferably between 4 to 16 inches. As the fibers are cut by the shredders 13 and 14 they drop onto the belt 11.

When the carriage 12 moves to the left, the shredders 13 and 14 cut fibers of the metal foil which are deposited onto the belt supporting surface with the fibers from the shredder 13 forming the lowermost layer and the fibers from the shredder 14 being disposed thereon. Accordingly, the lower layer of fibers 23 as shown in FIG. 2, are disposed at an angle θ from the longitudinal axis of the supporting surface, and the fibers 24 on the next adjacent layer are disposed at an angle θ' on the opposite side of, i.e., in the opposite direction from the longitudinal axis. The fibers are preferably about 0.010 to 0.030 inches apart. As the carriage 12 approaches the end of the tracks 19 and 20, it actuates a limit switch that shuts off the shredder 13. However, the rear shredder 14 continues to operate, dropping fibers 24 on the first layer of fibers 23, until a limit switch is actuated. Thereafter, the shredders 13 and 14 are rotated to alternate positions such as shown by the dotted lines 13a and 14a in FIG. 1. Any suitable means such as a pneumatic cylinder may be provided for rotating the shredders simultaneously. Thus the shredders move between the solid line positions and the broken line positions. The angles of disposition of the shredders, θ and θ' , may vary. The orientation angle alternates, between θ' and θ where θ will equal θ' , both being an angle of less than 75° to the longitudinal direction of the belt supporting surface. Each angle being in an opposite direction from the longitudinal axis of the supporting surface.

Then the carriage 12 moves to the right, whereupon the shredder 14a becomes the lead shredder and the shredder 13a becomes the lagging shredder. As a result, two additional layers of fibers are laid upon the previous layer of fibers 23 and 24. The additional layers include a third layer of fibers 25 and a fourth layer of fibers 26 shown in FIG. 2. The third layer of fibers 25 is laid by the shredder 14a.

Each time the carriage 12 reaches the end of its travel, either to the right or left the shredders are rotated to their alternate positions as set forth above. In addition the belt 11 is advanced in the direction of the arrow 17 through a preset shift. In that manner the carriage with the shredders lay a continuous strip 18 of a fixed given number of layers of fibers. Each time the belt 11 advances a predetermined distance, the length of the strip is extended by an increment equal to the distance of advance of the belt.

As shown in FIG. 3, the initial layer 23 of fibers as provided during the first leftward movement of the shredder 13 is at angle θ from the movement 17 of the belt, with the second layer 24 of fibers, provided by the shredder 14, being disposed thereon and at an angle 2θ , i.e., $(\theta + \theta')$ to the fibers of the adjacent first layer but only at an angle θ' from the axis of the belt.

Although the laminated strip 18 may be used for various purposes, a primary use for the strip is that of a

plaque or plate for storage batteries. For that purpose the strip 18 may be cut into suitable lengths and sintered to serve as plaques 40 as shown in FIG. 4. The upper and lower edges can be reinforced by metal clips 41 and 42 and an electric contact lug 43 can be provided on the clip 41. Where the plaque 40 is to be used as a positive plate in a battery, it can be filled with oxides and/or hydrated oxides of nickel. Where the plaque 40 is to serve as the negative plate in a battery, it can be filled with a mixture of iron oxides and sulfur.

In our process, using a continuous shredding apparatus, we can sequentially combine operations to produce uniform fiber matrices of given fiber cross-section, weight, thickness, porosity and density using the equations developed below.

To control the system to produce a given fiber matrix the following relationships were used:

$$F = P / (Q \sin \theta) \quad 1$$

where:

F = Number of fibers per normal inch of supporting surface

P = Shredder speed in revolutions per minute x number of blades per shredder, i.e., fibers/minute

Q = Traverse speed in inches per minute

θ = Shredder orientation where $15^\circ \geq \theta \geq 75^\circ$ ($\sin \theta$ "normalizes" the value of F , i.e., corrects for the fact that the fibers are not laid normal (90°) to the direction of traverse of the supporting surface

The weight, w , of a matrix layer is related to the number of fibers per normal inch by the relationship:

$$w = F \times f_1 \times f_2 \times d \quad 2$$

where

w = weight of a layer in g/in²

f_1 = Fiber thickness (foil thickness) in inches

f_2 = Fiber width (shredded width) in inches

d = Solid foil density in g/in³

The weight, W , of a matrix of N layers would be:

$$W = N (F \times f_1 \times f_2 \times d) \text{ g/in}^2 \quad 3$$

The number of layers, N , for a matrix of a given final thickness, was developed empirically using the relationship:

$$N = (t_c / f_1) \times (1 + e) \quad 4$$

where:

N = Empirical number of layers for the requisite final thickness

t_c = Given final plaque thickness in inches

e = An empirical value approximately 0.20 to obtain the nearest integer of N , i.e., the value e adds about 20 percent to t_c / f_1 to compensate for plaque settlement during subsequent sintering to bond the fibers together.

The combination of expressions (1) and (3) relates the functions of the three operating components to the matrix weight, fiber cross-section, and the number of fiber layers in the matrix using a single shredder:

$$P / (Q \sin \theta) = W / (N \times f_1 \times f_2 \times d) \quad 5$$

or

$$Q = d \times (N / W) \times (P \times f_1 \times f_2) / \sin \theta \quad 6$$

Equation (6) is a generalized formula. For one layer using one shredder head it becomes:

$$Q = (d / w) \times (P \times f_1 \times f_2) / \sin \theta \quad 7$$

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If X number of shredder heads are used, the generalized formula becomes:

$$Q = X [d \times (N / W) \times P \times f_1 \times f_2] / \sin \theta \quad 8$$

Using these equations then, we provide a method for applying, on an elongated supporting surface, shredded metal fibers to form a single layer having the weight of w gr/in², where the fibers are being shredded by a single shredder at the rate of P fibers/min., the fibers having a thickness of f_1 in. a width of f_2 in. and a density of d gr/in³, the fibers being disposed substantially parallel to each other and at an angle θ of between 15° and 75° from the longitudinal axis of the elongated supporting surface. The method for obtaining this single layer having the weight w gr/in² comprises a single back and forth traversing motion between the shredder and the elongated supporting surface in the direction of the longitudinal axis of the surface at a speed of Q in./min. wherein the following relationship exists:

$$Q = P(f_1 \times f_2 \times d) / (w \times \sin \theta) \quad 7$$

We also provide a method wherein X shredders are used for applying, on an elongated supporting surface, shredded metal fibers to form a matrix of N distinct layers, the matrix having the weight of W gr/in², the fibers being shredded by each shredder at the rate of P fibers/min., the fibers having a thickness of f_1 in. a width of f_2 in. and a density of d gr/in³, the fibers in each layer being disposed substantially parallel to each other and at an angle θ of between 15° and 75° from the longitudinal axis of the elongated supporting surface. The method of obtaining this matrix having the weight of W gr/in² and N layers comprises N traversing motions between the X shredders as a group and the elongated supporting surfaces in the direction of the longitudinal axis of the surface at a speed of Q in./min., the X shredders being grouped along the longitudinal axis of the surface alternately at angles $\theta = \theta'$, which at the end of each traverse, angles θ and θ' change into angles θ' and θ respectively, wherein the following relationship exists:

$$Q = XNP (f_1 \times f_2 \times d) / (W \times \sin \theta) \quad 8$$

and the number of traverses = N/X

EXAMPLE 1

The system we used in this Example had a single stationary shredder with 18 helical cutting blades, a fixed cutting edge and a foil feeding mechanism. At recommended speeds of between 300 and 700 revolutions per minute, the shredder produced between 5,400 and 12,600 8 inch long fibers per minute. An 8 inch $\times$ 72 inch board was used as the supporting surface and was mounted below the stationary shredder on a trolley which provided for an effective reversible horizontal traverse of 48 inches at speeds up to 360 inches per minute. The shredder base swivelled in a horizontal plane to position the shredder at a selected angle, θ , to the traverse direction of the supporting surface, i.e., the longitudinal direction of the belt supporting surface of the fiber matrices to be formed.

The nickel fiber dimensions were $0.001 \times 0.00125 \times 8$ inches. Nickel density was 145.9 gr/in³. The required plaque weight was 0.61 gr/in² and the required thickness was 0.050 inches. The shredder speed and orientation angle was 510 rpm and 60° to the longitudinal direction of the belt respectively. The number of cutting blades was 18. Using expressions (4), (6) and (8),

$$N = \frac{t_e}{f_1} \times (l + e) = \frac{0.050}{0.001} \times 1.2 = 60$$

layers and

$$Q = d \frac{N}{W} \times \frac{P \times f_1 f_2}{\sin \theta} = 145.9 \frac{60}{0.61} \times \frac{[(18)(510)] \times 0.001 \times 0.00125}{0.866} = 190 \text{ in./min.}$$

Since we used only a single shredder X was equal to 1.

A suitable matrix was machine duplicated with a supporting surface traverse speed of 190 in./min. and 60 traverses of the supporting surface. The actual matrix weight was approximately 3 percent below the requisite weight of 0.61 g/in² but within the allowed weight tolerance (± 5 percent). The 60 layers provided sufficient thickness to obtain a final plaque thickness of 0.050 inches after sintering in a 1,150°C furnace to bond the fibers at points of crossover of adjacent layers.

In summary, in this Example we have disclosed a basic approach to a controlled and automated shredding/ laminating process for the production of sintered matrices with long metal fibers. We demonstrated this approach by the construction of an experimental prototype system for the production of 7 inch wide (8 sin 60°) $\times$ 36 inch sample plaques with 8 inch long nickel fibers. It is apparent that the three operating components of the prototype can be synchronized into a total system for better product control. It is also apparent that the system can be enlarged and modified, as in the two shredder moveable carriage system, all within the intent of the basic approach, for the production of wider and longer plaques at faster rates and with greater material economy.

The disclosed process does more than duplicate the required weight and requisite final plaque thickness of the manually laminated developmental battery plaques. The controllable geometry of the disclosed matrix offers the machine-laminated plaque, in addition to uniformity, complete control over the plaque porosity, percent plaque density, and the fiber surface. Thus this process offers a greater opportunity for the optimization of the battery plaque in terms of electrical output per weight, and/or surface area. For example, it is apparent from expression (3) that, without changing the plaque weight the plaque porosity can be increased and the percent plaque density can be decreased (by the proportionate increase and decrease of N and F) to provide for improved loading of the active materials.

The disclosed process for laminating fiber matrices with long fibers can be used in other applications requiring controlled porosity such as metallic filters and metallic wicks for heat pipes.

We claim:

1. In the method of preparing a laminated fibrous strip wherein a single layer of shredded metal fibers are applied on an elongated supporting surface, the single layer having the weight of w gr/in², the fibers being shredded by a single shredder at the rate of P fibers/min., the fibers having a thickness of f_1 in., a width of f_2 in. and a density of d gr/in³, the fibers being disposed substantially parallel to each other and at an angle θ of between 15° and 75° from the longitudinal axis of the elongated supporting surface, the improvement comprising the step of moving the shredder over the elongated supporting surface in a single back and forth traversing motion in the direction of the longitu-

dinal axis of the supporting surface at a speed of Q in./min., wherein the following relationship exists:

$$Q = P(f_1 \times f_2 \times d) / (w \sin \theta).$$

2. The method of preparing a laminated strip, wherein X shredders are used for applying on an elongated supporting surface shredded metal fibers which define a matrix of N distinct layers, the matrix having the weight of W gr/in², the fibers being shredded by each shredder at the rate of P fibers/min., the fibers having a thickness of f_1 in., a width of f_2 in. and a density of d gr/in³, the fibers in each layer being disposed substantially parallel to each other and at an angle θ of between 15° and 75° from the longitudinal axis of the elongated supporting surface, the improvement comprising the steps of moving the X shredders as a group over the elongated supporting surface in N traversing motions in the direction of the longitudinal axis of the supporting surface at a speed of Q in./min., the X shredders being grouped along the longitudinal axis of the surface alternately at angles $\theta = \theta'$, which at the end of each traverse angles θ and θ' change into angles θ'

and θ respectively, wherein the following relationship exists:

$$Q = XNP (f_1 \times f_2 \times d) / (W)(\sin \theta)$$

and the number of traverses = N/X .

3. The method of claim 2 wherein the fiber length is between about 4 to 16 in. the fiber thickness is between about 0.0005 to 0.0030 in. and the fiber width is between about 0.0005 to 0.0030 in.

4. The method of claim 3 wherein the elongated supporting surface is a belt movable in the longitudinal direction and the shredders are not moved in the longitudinal direction.

5. The method of claim 3 wherein the shredders are movable in the longitudinal direction and the supporting surface is not moved in the longitudinal direction.

6. The method of claim 3 wherein fibers of adjacent layers are disposed at an angle in opposite directions from the longitudinal axis of the elongated supporting surface.

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