United States Patent [19]
Nicely

[11] **3,727,292**
[45] **Apr. 17, 1973**

[54] METHOD OF FABRICATING A NON-WOVEN SHEET FROM EXTRUDED METAL FILAMENTS

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[73] Assignee: **Monsanto Company**, St. Louis, Mo.
[22] Filed: **Dec. 9, 1969**
[21] Appl. No.: **883,540**

[52] **U.S. Cl.**......................**29/419**, 161/170, 29/187, 29/527.7, 29/DIG. 47, 264/176 F
[51] **Int. Cl.**..**B23p 17/00**
[58] **Field of Search**..........................29/527.7, 527.6, 29/527.5, 419, 527.1, DIG. 47, 187; 164/283, 70; 161/170; 264/176 F

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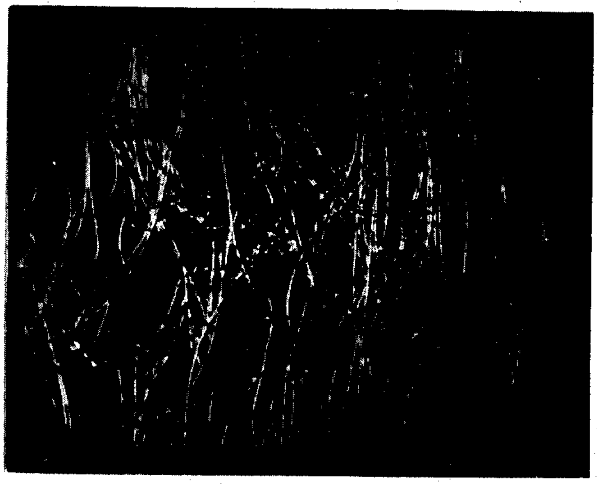
[57] ABSTRACT

A non-woven unitary metallic sheet is fabricated by extruding a molten stream from a metallic melt into an atmosphere which reacts to form a film about the periphery of the stream. The film serves to stabilize the stream against surface tension-induced disruptions pending solidification. The stream is collected as a non-woven fibrous mass, compressed into sheet like form and given physical integrity by binding substantially all or selected adjacent fibers together.

10 Claims, 11 Drawing Figures



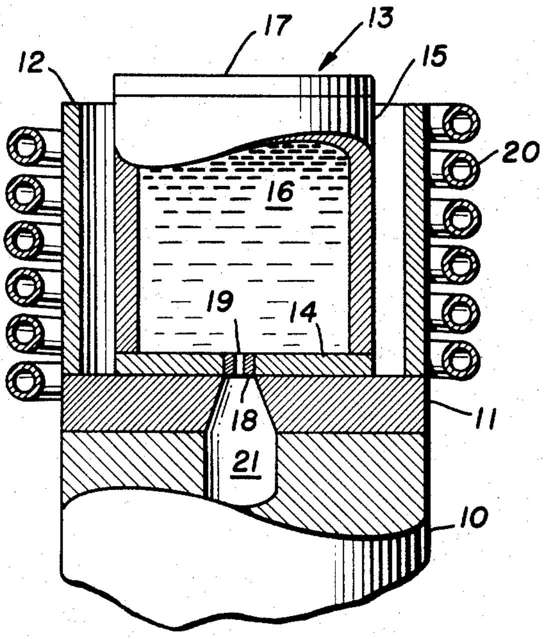

17
13
12
15
20
16
19
14
18
11
21
10

FIG. 1.

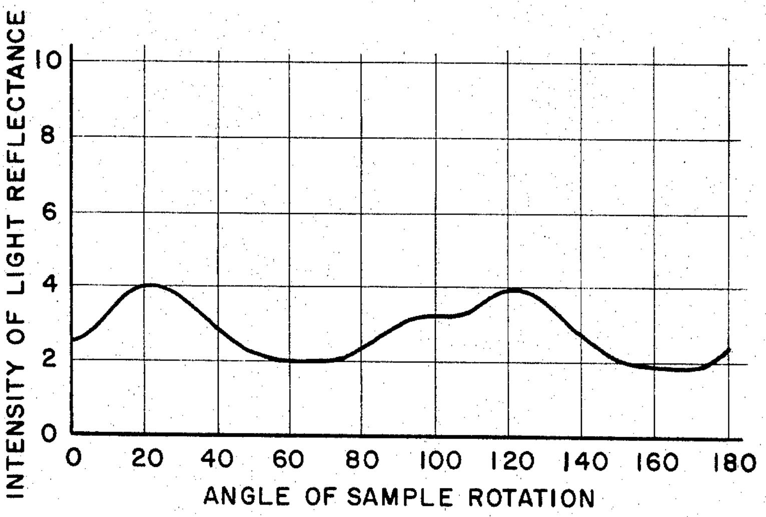

INTENSITY OF LIGHT REFLECTANCE
10
8
6
4
2
0
0
20
40
60
80
100
120
140
160
180
ANGLE OF SAMPLE ROTATION

FIG. 5.

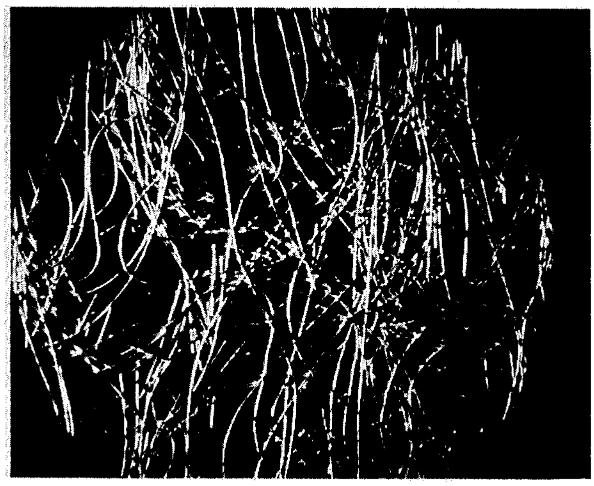


FIG. 2.

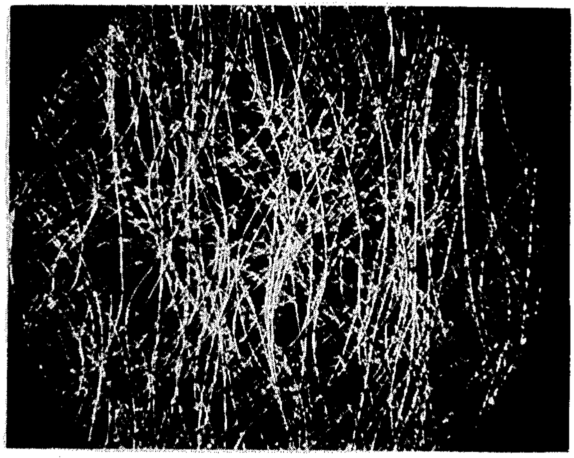


FIG. 3.

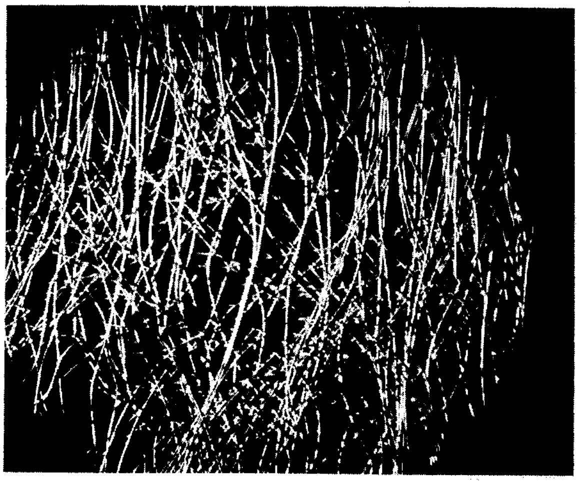


FIG. 4.

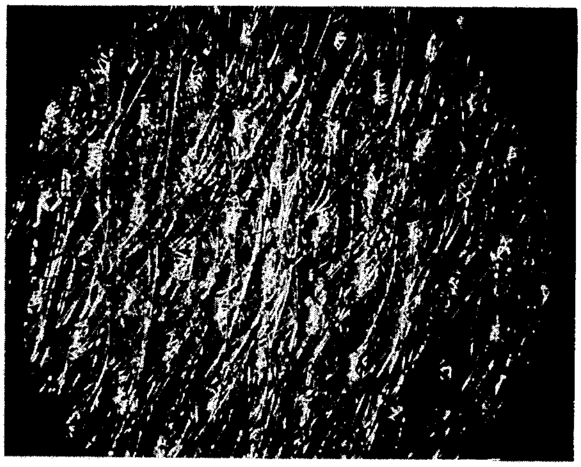


FIG. 6.

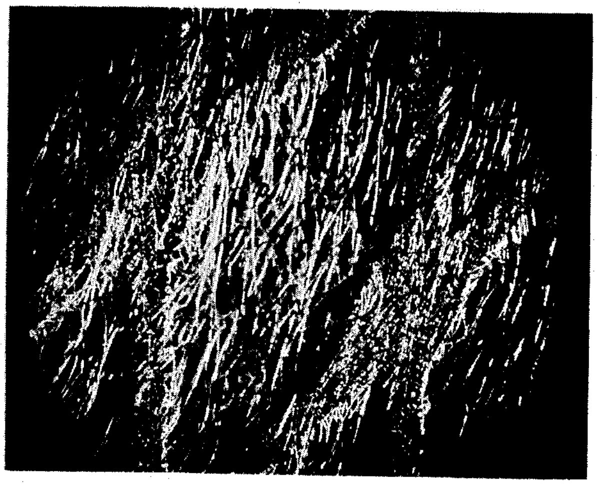


FIG. 7.

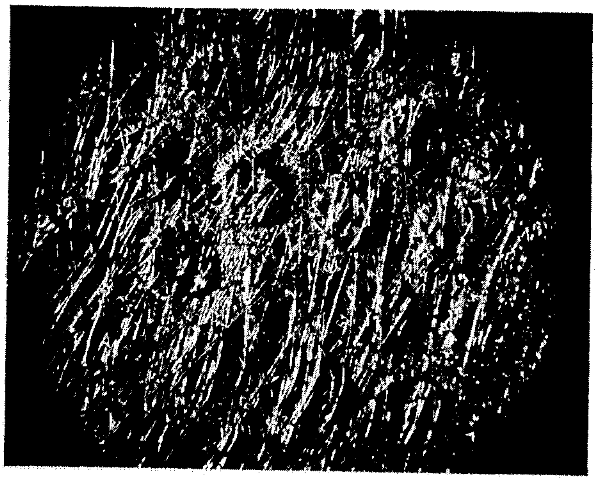


FIG. 8.

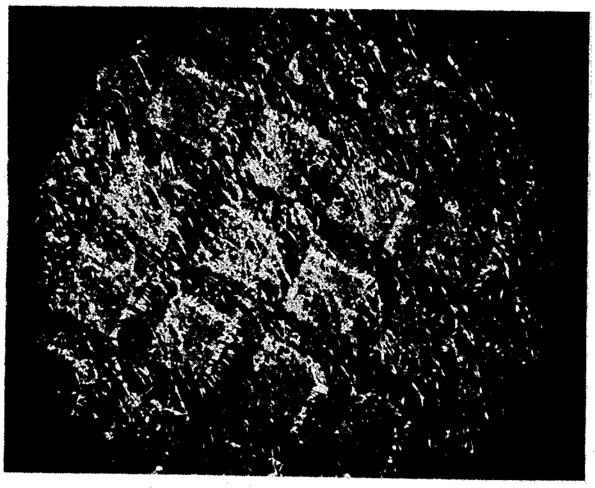


FIG. 9.

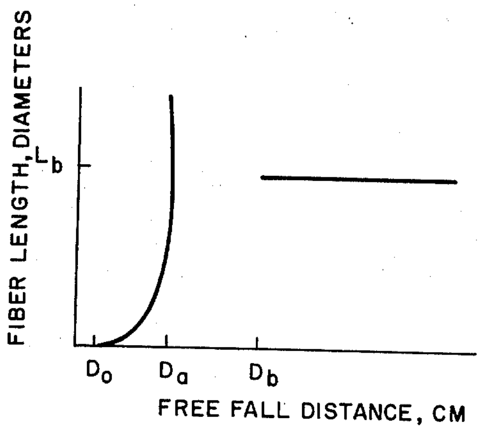


FIG. 11.

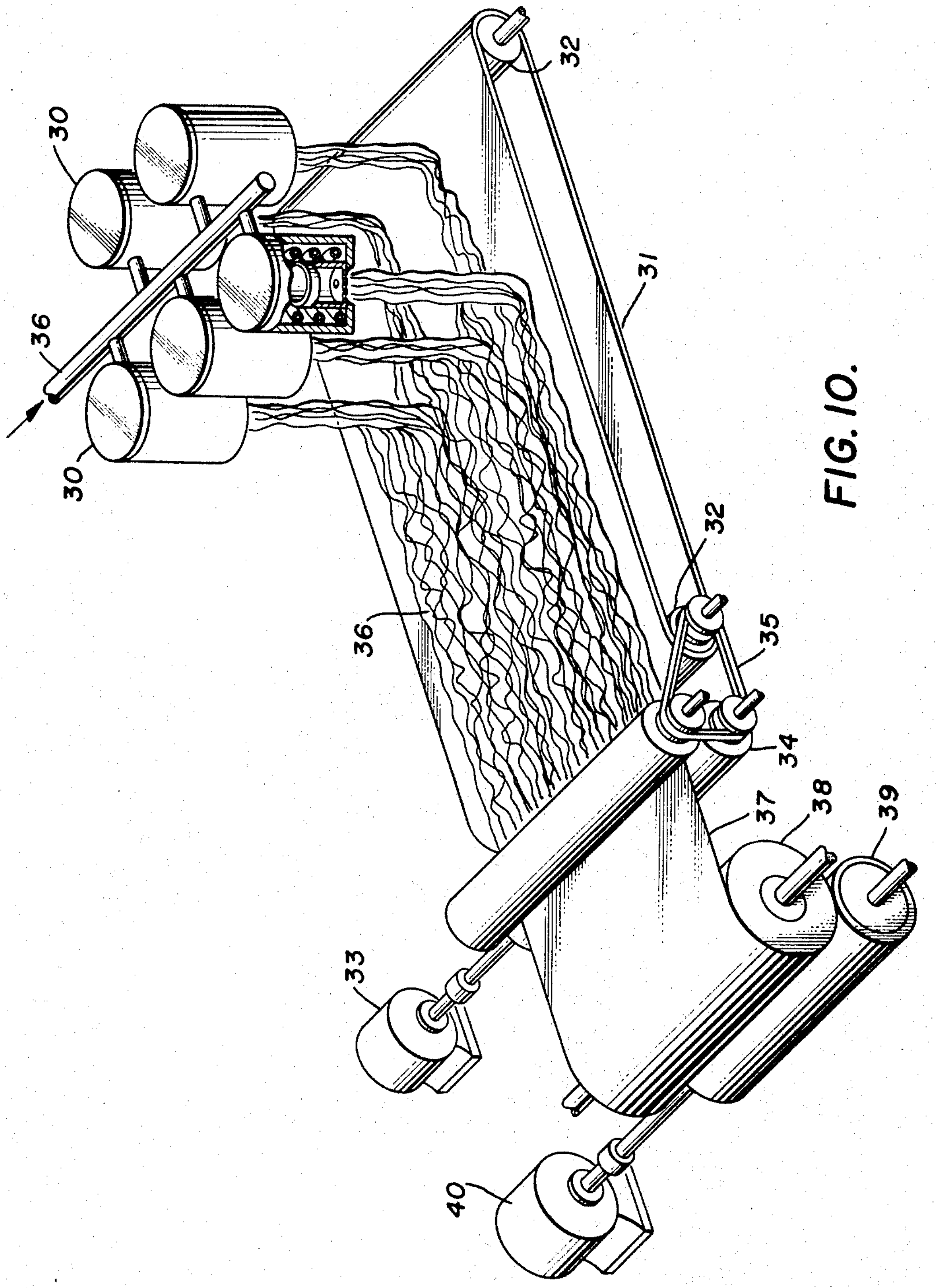


FIG. 10.

METHOD OF FABRICATING A NON-WOVEN SHEET FROM EXTRUDED METAL FILAMENTS

CROSS-REFERENCES TO RELATED INVENTIONS

This invention is related to commonly assigned and concurrently filed application Ser. No. 883,543, filed on Dec. 9, 1969 of D. C. Nicely, now abandoned. Other related and commonly assigned applications are Ser. No. 829,216 filed June 2, 1969 of S. A. Dunn, R. E. Cunningham, and L. F. Rakestraw, now Pat. No. 3,658,979; Ser. No. 883,266, filed on Oct. 2, 1969 of W. J. Privott, Jr. and R. E. Cunningham; and Ser. No. 863,311, filed on Oct. 2, 1969 of W. J. Privott, Jr. and R. E. Cunningham.

FIELD OF THE INVENTION

This invention relates to a method of preparing non-woven unitary metallic sheets directly from a metallic melt.

BACKGROUND OF THE INVENTION

Metal fibers have commonly been used for many years in such familiar forms as scouring pads and metal wool insulation structures. In recent years, however, particular attention has been directed to new and promising applications of fine diameter metallic fibers, i.e. diameters of 20 mils or less. By borrowing a technique employed in the paper making industry, metallurgists have developed fine diameter metal fibers as a new group of engineering materials available for use in varied applications such as, for example, in composites, sound absorption, and vibration damping. The paper making technique called "felting" provides a production method for forming simple and complex porous shapes with metallic fibers.

In felting, a suspension or slurry of metal fiber generally not longer than one centimeter in length is a liquid, such as glycerine, is deposited on a porous master. The liquid is then drawn away through the master, leaving a mass of fiber on the master surface. The form or shape of the mass may be preserved by imparting stability or rigidity thereto through mechanical interlocking or bonding processes.

One particular advantageous fine diameter metal fiber form is a sheet or web which has use, for example, as a composite, a boundary layer in aerodynamic applications, a filter, resistance heaters, composite reinforcements, or as a battery plate. Some of the qualities appropriate for the above uses are uniformity of tensile strength in all directions, uniformity of fiber distribution, and smoothness of the sheet surface. The last quality is particularly needed in aerodynamic and battery applications which are detrimentally affected by nap or unbonded ends of metal fiber protruding outward from the sheet surface. Metallic sheets presently utilized are characterized by a large number of unbonded ends which either protrude or have a tendency to protrude from the sheet surface thereby disrupting smooth airflow and causing possible short circuits in aerodynamic and battery applications, respectively.

Although some metallic sheets are made with metallic wools formed by shaving processes, fabrication heretofore has been generally accomplished by the above described felting process.

It has been found (as disclosed hereinafter) in the fabrication of metallic sheets that it is 11, 1965 and the references copending application Ser. No. 829,216 to utilize "low viscosity melt spinning processes" as described and claimed in U. S. Pat. No. 3,216,076 to Alber et al, issued on Nov. 829,216. The above references which are incorporated by way of reference herein disclose processes by which filamentary material may be spun directly from melts having low viscosity-surface tension ratios. Ordinarily, when a stream is extruded from a melt which has a low viscosity relative to its surface tension (consistent units being used), the stream continuity is disrupted prior to solidification. The metals, alloys thereof, and intermetallic compounds are included in this class of materials whose melts have low viscosity-surface tension ratios. Metals, for example, have a viscosity-surface tension ratio on the order of 1×10^{-5}. Thus, in direct cooperation with the low viscosity melt spinning processes, non-woven metallic sheets may be fabricated quickly and economically without having to use a slurry.

The term metallic filament as opposed to metallic fiber means a fine diameter metallic wire of very long or essentially continuous length. On the other hand, the term metallic fiber is defined as a fine diameter short metallic wire or staple. Other terms such as filamentary form, fibrous material, and fibrous mass are descriptive of the form of the solidified metallic stream and the article made with the stream.

Although the patent to Alber and copending application Ser. No. 829,216 are incorporated herein by way of reference, it is thought to be necessary to briefly discuss some of the important fundamentals of low viscosity melt spinning in order to promote a more complete understanding of the present invention.

It is known that initially upon emerging from an orifice, a stream extruded from a melt having a low viscosity-surface tension ratio assumes or tends to assume an essentially cylindrical shape which, as stated hereinbefore, remains intact until, at a point beyond the orifice, the stream breaks up into shot. It is thought that breakup is initiated by minor vibrations inherent in the spinning processes which give rise to very small variations in the surface configuration. Because enlarged portions of the stream are adjacent to narrower portions, surface tension-induced pressure differentials exist therebetween. When the molten material has a low viscosity, the liquid in the smaller portions being substantially uninhibited by viscosity tends to flow into the enlarged portions, causing still greater variations in the surface configuration. The growth of the variations, called Rayleigh waves, continues until the stream breaks up.

The elapsed time between the issuance of a molten stream and breakup is much shorter in duration than the time required for the stream to solidify. Therefore, it is necessary to stabilize the stream pending solidification. The aforementioned Alber et al patent and copending application Ser. No. 829,216 teach stream stabilization by passing the stream into an atmosphere which forms a "stabilizing" film about the periphery thereof. The term "stabilizing film" defines a film strong enough to prevent further growth of variations in stream configuration due to surface tension.

Briefly stated in accordance with the present invention, metallic sheets are provided by extruding a molten free falling stream from a metallic melt and forming a stabilizing film (insoluble in the melt) about the periphery of the molten stream. The stabilizing film serves to prevent or inhibit the growth of continuity-disruptive waves in the stream until the stream is solidified into filamentary form. The stream is next collected as a non-woven fibrous mass downstream of a point "D_o" upstream of which attending stream deceleration causes attainment of a non-fibrous mass. The non-woven fibrous mass may be given either a random or preferred orientation as desired. Then, the fibrous mass is compressed into a flat sheet and provided with physical integrity by binding substantially all or selected adjacent fibers together.

The present invention has been found to be particularly useful in the fabrication of a metallic sheet as described and claimed in the concurrently filed application Ser. No. 883,543. Therein is described a metallic sheet which is constructed from essentially continuous metallic filaments thereby providing the sheet with an essentially nap-free surface and with increased strength. Such a sheet attains a number of advantages (1) the number of filament ends per unit area which may protrude through the sheet surface is very small; (2) the continuous length coupled with the small diameter adds flexibility, increased strength, and manipulative characteristics not obtainable by sheets comprised of shorter fibers; and (3) though filament securing or fastening may be done as desired, it is not necessary to do so with as greater a frequency to preserve the physical integrity of the metallic sheet of the present invention as with those of the prior art.

BRIEF DESCRIPTION OF THE DRAWINGS

The features of the present invention which are desired to be protected are pointed out with particularity in the appending claims. The invention itself, together with further objects and advantages thereof, may be best understood with reference to the following description taken in connection with the appending drawings in which:

FIG. **1** is a cross-section of a typical low viscosity melt spinning apparatus.

FIG. **2** is a photograph of a magnified view of a metallic sheet utilizing short lengths of metallic fiber.

FIG. **3** is a photograph of a magnified view of a metallic sheet utilizing metallic fibers having large aspect ratios.

FIG. **4** is a photograph of a metallic sheet wherein the metallic fibers are orientated in preferred directions.

FIG. **5** is a chart showing the reflected light intensity characteristics of the metallic sheet of FIG. **4**.

FIGS. **6–9** are photographs of metallic sheets having varied bonding patterns.

FIG. **10** is a perspective view of a spinning assembly which may be utilized to practice the present invention.

FIG. **11** is a graph illustrating fiber length as a function of the distance from extrusion point to collection point.

DESCRIPTION

It is perhaps useful and illuminating to initially describe a typical low viscosity melt spinning apparatus. FIG. **1** illustrates pedestal **10** supporting a shelf member **11** which in turn supports a susceptor **12** and crucible assembly **13**. Crucible assembly **13** comprises a base member **14** and cylindrical wall **15** positioned on base member **14**. Base **14** and cylindrical wall **15** define a container for low viscosity melt **16**. Cover **17** is secured to the top of cylindrical wall **15** by appropriate means not shown. Base member **14** defines an opening in which a spinning orifice insert **18** contains an orifice **19**. A helically arranged inductor coil **20** encircles susceptor **19**.

In operation, a charge of metal is placed in crucible assembly **13** and heated until molten through the action of inductor coil **20**. Melt **16** is then forced through orifice **19** at a selected extrusion velocity by appropriate means such as, for example, gaseous pressure above melt **16** in crucible assembly **13**. The molten stream then enters into a stabilizing atmosphere zone contained in chamber **21** wherein the reactive component of the stabilizing atmosphere forms a stabilizing film about the periphery of the molten stream thereby preventing breakup due to surface tension effects pending solidification.

For descriptive and photographic purposes an alloy of approximately 61.1wt. % lead- 38.1 wt. % tin was selected herein as the material for metallic sheet fabrication. The alloy chosen, however, is not to be construed as a limitation since any material included in the definition of metallic is equally suitable.

To more completely describe the advantages of the present invention, it is thought to be necessary to illustrate the important features of the non-woven unitary metallic sheets as described and claimed in application Ser. No. 883,543. Although metallic sheets made of fibers of any desired lengths may be fabricated through the practice of the present invention, it has been found to be particularly convenient to utilize a method in accordance with the present invention in the fabrication of the metallic sheets of the above application.

To clearly compare such a metallic sheet made of short fiber staple to one made with essentially continuous filaments, a section of each type sheet was magnified about 4.3 times. FIG. **2** provides a photographic view of a metallic sheet section comprising a larger number of fibers averaging about 2.5 inches long and having a cross-sectional diameter of 4.7 mils. The average aspect ratio is approximately 532. In contrast thereto, the photograph of FIG. **3** illustrates a metallic sheet made of essentially continuous filaments having an aspect ratio of approximately 1.9×10^5.

In each sheet, the fibers and filaments follow a curvilinear or loopy path and cross at many points. When the sheet of FIG. **3** is held flat or planar as depicted, the paths of the filaments are essentially coplanar. It is evident from a cursory examination of FIG. **2** that the metallic sheet therein has many unbonded fiber ends. As stated hereinbefore, unbonded ends protruding through the surface of a metallic sheet have a deleterious effect upon many applications for which the sheet has been fabricated.

In stark contrast to the sheet of FIG. **2**, the metallic sheet of FIG. **3** has essentially no unbonded fiber ends.

The surface of the sheet in FIG. **3** presents a smooth, nap-free surface due to the utilization of essentially continuous filaments. Further, the filaments also have an essentially random orientation in that the segments thereof have no preferred directions. Random orientation is desired in many applications such as, for example, when uniform strength in all directions is needed.

Random orientation may be easily demonstrated by various comparative light measurements. One well known comparative light measurement is performed by obliquely illuminating the sheet with a light source, rotating the sheet through 360°, and measuring the intensity of the reflected light reflected at a constant angle to the sheet. A photometer may be utilized to measure the intensities and further to cause an ink inscriber to deflect laterally across a moving sheet of graph paper as the light intensity varies. A sheet having random orientation causes little variation in light intensity which results in the inscriber tracing a substantially straight path on the graph paper. On the other hand, a preferred or ordered orientation in a metallic sheet under the above test results in substantial lateral deflection or deflections of the inscriber path.

It may be more convenient to determine filament orientation by measuring the ultimate tensile strength of a metallic sheet in various directions. When a sheet has essentially random distribution of filaments, the metallic sheet exhibits an essentially uniform ultimate tensile strength in all directions, i.e. essentially isotropic ultimate tensile strength. In contrast thereto, a metallic sheet having an ordered distribution therein exhibits a marked change in tensile strength between the preferred direction and a direction transverse to the preferred direction.

FIG. **4** and the accompanying light intensity chart of FIG. **5** illustrate a metallic sheet wherein the filaments lie in two predominant directions. It is difficult to visually identify the two directions in FIG. **4**, but the reproduced chart of FIG. **5** clearly shows two peaks in light intensity, one at about 20° and a second at about 120°C. The peaks represent the predominant directions in which the filaments lie and the angular difference (i.e., 100°) indicated the relative orientation therebetween.

Thus, it is seen from the ensuing discussion that a nonwoven metallic sheet fabricated in accordance wth the present invention may be given isotropic or anistropic strength characteristics as desired through orientation of the filaments. Added tensile strength is also provided through utilization of a continuous filament or filaments for the sheet construction.

It has been noted that some aerodynamic, battery, and other related applications do not require the degree of surface smoothness provided by essentially continuous metallic filaments but still require the sheet surface to have a smoothness heretofore not attained by the metallic sheets and webs of the prior art. A practical upper limit to the number of unbonded ends which may exist in the sheet surface for the above applications is considered to be about one end/cm². The number of unbonded ends in a sheet, however, is not a simple function but depends upon several sheet parameters and can be stated as

$$Ne = (8W/\pi\rho d^3\alpha) \qquad (1)$$

where

Ne = the number of ends/cm²

W = the sheet weight/cm², gms/cm²

ρ = the fiber density, gm/cm³

d = the average fiber cross-sectional diameter, cm.

α = the aspect ratio, fiber length in cm/ fiber diameter in cm

It is evident that the number of fiber ends for any given sheet is inversely proportional to the aspect ratio. Thus, for example, when it is desired to fabricate a sheet weighing 7.36 gms/cm² utilizing metallic fibers having an average cross-sectional diameter of **20** mils and a density of 15 gms/cm³, it is necessary that the aspect ratio be not less than 1×10^4 in order that the number of fiber ends not exceed one per square centimeter of the sheet surface. It is noteworthy that the values employed for the fiber diameter and the fiber density are also considered to be upper limits which also results in a large sheet weight. Larger values thereof result in a unwieldy, relatively inflexible sheet, when using fibers having aspect ratios near 1×10^4.

From the ensuing discussion, it should be understood that it is desirable and preferable to utilize metallic fibers having an aspect ratio from 1×10^4 to 1×10^6 and above in the construction of the nap-free metallic sheets as described in copending application 883,543. Smaller values of aspect ratio increase the number of unbonded ends beyond that which has been deemed appropriate in the hereinbefore enumerated metallic sheet applications.

There are varied techniques which may be utilized to ensure the physical integrity of the metallic sheet such as, for example, cold welding, sintering, mechanical interlocking, or application of bonding thermoplastic resins. Because of its simplicity, cold welding is the preferred technique of securing the filament segments of the metallic sheet. Briefly, cold welding is an actual bonding of the filaments at points of contact through application of pressure. In FIG. 3, the entire sheet was subjected to a pressure of 15,000 psig. At filament cross-overs, diffusion occurred across the interfaces resulting in a weld of the filament segments.

Bonding may also be attained by raising the temperature of the metallic sheet to a point below its melting point in a reduced atmosphere. Diffusion will occur at the various filament cross-overs again resulting in a bond. This technique called sintering may also be used in conjunction with cold-welding and/or mechanical interlocking.

A sheet secured mechanically is not bonded but is rather interlocked through intimate contact between segments of the filament at cross-overs. Ordinarily, the segments are kinked together through the application of pressure. The strength of mechanical interlocking may be increased when the filament surface is rough.

Some metallic materials are not readily secured through bonding processes due to the presence of stable surface oxides. It may be desirable to utilize materials such as certain bonding thermoplastic resins to promote the physical integrity of the sheet. It should be understood, however, that any adherence technique may be employed which satisfactorily preserves the physical integrity of the metallic sheet. Therefore, the terms "binding," "secured", and "securing," as used herein in reference to adherence of filament segments are defined to include bonding, mechanical interlocking, or any other technique which may be employed to join segments.

It is not necessary that the filament segments be bonded at each cross-over of the metallic sheet. For example, FIGS. **6** through **9** illustrate metallic sheets which have been "pattern-bonded" by cold welding. That is, by applying pressure at selected areas or points repetitiously along the surface of the sheet, a patterned configuration is obtained.

In the sheet illustrated in FIG. **6**, pressure has been applied so as to bond filament segments located at discrete pointlike areas which are arranged in a plurality of rows and columns. This arrangement may be contrasted to the "diamond" pattern of FIG. **7**. In the latter, pressure has been applied so as to bond segments at cross-overs arranged in two sets of obliquely intersecting rows.

Through the application of pressure to selected areas of a sheet, essentially all of the cross-over points therein are bonded. This gives an embossed appearance to a sheet as illustrated by the rectangular and circular waffle-like configuration of FIGS. **8** and **9** respectively.

The metallic sheet illustrated in the photograph of FIG. **2** was fabricated in accordance with my present invention. The sheet is composed of a 61.9 wt. lead-38.1 tin alloy. The lead-tin composition of the sheet is solely for descriptive purposes as any material included in the definition of metallic is equally suitable. Though the sheet structure is discussed in greater detail hereinafter, it should be noted that the lead-tin fibers are essentially randomly distributed and intersect at many points called "cross-overs". Because the sheet is comprised of independent fibers, physical integrity is maintained by bonds between fibers at essentially all of the cross-overs.

Though other stabilizing film compositions are equally suitable, it is convenient to utilize lead oxide as a stabilizing film in the fabrication and collection of a fibrous mass of the above alloy by the inviscid spinning processes. Thus, the lead-tin alloy is extruded into an oxidizing atmosphere such as air. The oxide film formed about the periphery of the stream is insoluble therein and serves to inhibit or prevent surface tension-induced disruptions.

Broadly stated, a process according to the present invention includes collecting the spun metallic filaments after solidification with an appropriately positioned collecting means and simultaneously causing the filament to form a desired orientation on the surface of the collecting means. The simplest mode of collection is accomplished by positioning a collecting member having a flat surface normal to and in the path of the falling filaments.

The flat surface is positioned below a point "D_o" measured from the origin of the molten stream. The point D_o can be found experimentally by moving the collecting surface up and down along the path of the stream until the stream collects into a fibrous mass as opposed to a non-fibrous mass. The term "collecting" however, is used generically to describe any appropriate means of gathering the fiber into a mass.

After positioning the collecting surface at a selected level below D_o, it is then desirable to distribute the fibrous non-woven mass over the surface. In the simplest mode, the above may be accomplished by oscillating or otherwise moving the collecting surface across the stream. The type of distribution depends primarily upon the relative movement between the collecting surface and stream. For example, a random motion of the collecting surface across the stream results in a random distribution of the fibrous material. Conversely, a repetitive motion results in the fibrous material being oriented largely in one particular direction hereinafter known as "preferred direction".

More complex modes of distribution may be used. For example, a plurality of air jets directed at the stream below D_o may be utilized to distribute the fibrous material over a collecting surface such as conveyor belt. The motion of the fibrous material due to the aerodynamics of free-fall and air jets coupled with the conveyor belt motion may be varied as desired to give random or preferred distribution.

The next step in the fabrication of a metallic sheet is the attainment of the sheet-like shape. Through the application of pressure, the mass is compressed until it is essentially planar, i.e., has a small thickness compared to width and length thereof. The thickness of the sheet is on the order of the cross-sectional diameter of the fibers. The pressure may be applied simultaneously to the entire mass or in continuous fashion as in the case of the fibrous mass when conveyed through the nip of pressure rollers.

FIG. **10** illustrates an apparatus which may be utilized in accordance with the present invention to fabricate a metallic sheet. Therein a plurality of spinning assemblies **30** similar to that illustrated in FIG. **1** are positioned above a conveyor belt **31** which moves about rollers **32**. Belt **31** is driven by variable speed motor **33** through pressure rollers **34** and chain **35**.

In operation, the molten metallic material is extruded under the pressure of an inert gas supplied by pipe **36** through one or more orifices in spinning assemblies **32**. The fibers are stabilized as described hereinbefore and are randomly collected upon the surface of conveyor belt **31**. The randomness of the fibers may be caused by a plurality of air aspirators, or as shown in FIG. **10**, by an "overfeed" of the fibers to belt **31**. Over feed may be accomplished by moving belt **31** at a velocity which is less than the velocity at which the fibers are impinging upon the surface thereof.

The fibrous mass **36** is then carried to and between pressure rollers **34** which may have either smooth or patterned surfaces. Bonding of the fibers is thus effected at the fiber cross-over points which are placed under pressure. The metallic sheet **37** is then wound upon surface driven take-up roll **38** driven by drive roll **39** through variable speed motor **40**.

To achieve a sheet having fibers predominantly aligned in the machine direction by the above apparatus, the differential in velocity between that of the fibers and the collection surface of belt **31** is decreased.

Copending application Ser. No. 863,311 incorporated by way of reference herein discloses that continuous filaments are obtainable only when the solidified portion of the stream is interrupted intermediate a pair of points "D_a" and "D_b". The former may be defined as a point upstream of which attending deceleration causes disruptions in the stream continuity; the latter may be defined as a point upstream of which the stream must be decelerated to avoid repeated tensile breaking. Reference is now made to FIG. **11** which is a graph of the relationship between stream free-fall distance and fiber length. The horizontal axis represents free-fall distance in centimeters while the vertical axis represents fiber length measured in fiber diameters, i.e. aspect ratio. As seen from curve **40**, the fiber length becomes continuous between D_a and D_b. Thus, to form metallic sheets of continuous filaments with an apparatus such as that illustrated in FIG. **10**, it is necessary to ensure that the filaments are decelerated above or impinged against the surface of the conveyor belt a distance beneath the orifice breater than D_a but smaller than D_b.

On the other hand, it may be desirable to fabricate metallic sheets of short fibers or staple. Copending application Ser. No. 863,266 incorporated by way of reference herein discloses a method by which fibers of predetermined lengths may be formed directly from the melt. Briefly, it is stated therein that an interruption or deceleration of the stream above the point D_a but below the point D_o causes the formation of staple. As seen in FIG. **11**, the fiber lengths increase in length as the point of deceleration or interruption approaches D_a. It should be understood, however, that in both the continuous and staple processes that the relative positions are influenced by a number of controllable factors discussed in detail in the aforementioned application Ser. Nos. 863,266 and (E-NC-**83**).

Still another technique of fabricating metallic sheets in accordance with the present invention is the collection of the fibers below the distance D_b beneath the orifice. FIG. **11** illustrates that a fiber which free-falls a distance D_b without experiencing sufficient deceleration will break into fibers of essentially equal lengths. Thus, for example, by positioning the conveyor belt of the apparatus depicted in FIG. **10**, a distance beneath the orifice greater than D_b, a mass of essentially equal lengths of fiber is obtained. The lengths of the fibers depends primarily upon a number of characteristics such as fiber density, fiber diameter, and the molten fiber tensile strength near the orifice.

For a more detailed understanding of the present invention, reference is now made to the following examples of metallic sheets made in accordance with the present invention.

EXAMPLE I

A melt spinning apparatus comprising a crucible having an extrusion orifice was used to produce several metallic filaments having aspect ratios greater than 1×10^5. The extrusion orifice had a cross-sectional diameter of 6 mils. An alloy composition of 61.9 weight percent lead and 38.1 weight percent tin at a melt temperature of 350°C under a pressure of 20 psig was spun into an atmosphere of air and collected on a paper board sheet held horizontally under the spinning head. Two single filaments having a diameter of 3.4 mils were collected and placed in a crossed position with respect to each on the paper board sheet. The filaments on the paper board sheet were subjected to 15,000 psig. platen pressure at room temperature. The filaments were found to be bonded at the cross-over point. The ultimate tensile strength of the filaments was 2,936 psi. The single bond strength was 47.9 percent of the ultimate tensile strength of the filaments.

EXAMPLE II

Using the apparatus and alloy composition of Example I, a metallic sheet was fabricated by collecting a substantially continuous filament having a diameter of about 3.1 mils. The collection surface was moved up and down the molten jet until substantially continuous filaments were observed to collect. The surface was then manipulated so as to yield a fibrous sheet-like mass having the randomly dispersed filaments throughout. The sheet was bonded as described in Example I. Subsequent to bonding the sheet was photographed at a magnification of about 4.3 X to enable visual counting of the number of filament ends. A section of the photograph is shown by FIG. **3**. In an area of 3 square inches, there were three filament ends. This is equivalent to 432 ends per square yard of web.

The average aspect ratio of the filaments comprising the sheet is from equation 1

$$Ne = (8W/\pi d^3 \rho \alpha)$$

$$\alpha = [8(.053)]/[\mathrm{b}a(.155)(.0079)^3(9.22)]$$

$$\alpha = 1.91 \times 10^5$$

where

$Ne = 0.155$ ends/cm^2
$W = 0.053$ gms/cm^2
$d = 0.0079$ cm
ρ 9.22 gms/cc

Subsequent to photographing the sheet, two sample strips measuring 1.0 inch by 5.125 inches were cut from the web for evaluation by a tensile strength tester. The two samples were taken at 90° to each other to correspond to the "machine direction" (M. D.) and the "transverse direction" (T. D.) as if the web had been collected upon a continuously moving conveyor surface. The measured physical properties of this web are tabulated in Table I under the heading "Example **2**".

EXAMPLE III

Using the apparatus and alloy composition of Example I, a metallic sheet was fabricated by collecting substantially continuous filaments having a diameter of about 3.1 mils. The collection surface was moved up and down the molten jet until substantially continuous filaments were observed to collect upon the collecting surface. The surface was then manipulated so as to yield a fibrous sheet-like mass having the filaments predominantly orientated in two directions as depicted in FIG. **4** and the accompanying chart of FIG. **5**. The sheet was bonded as described in Example I. Subsequent to bonding the sheet was photographed at a magnification of about 4.3 X to enable the visual counting of the number of filament ends. In an area of 3 square inches there were 15 filament ends. This is equivalent to 2160 ends per square yard of sheet.

The average aspect ratio of the filaments comprising the sheet was calculated as in Example II from equation 1 to be

$$\alpha = [8(.041)]/[\mathrm{b}b(.775)(.0079)^3(9.22)]$$

$$\alpha = 2.94 \times 10^4$$

As in Example II, sample strips were taken and evaluated to determine the sheet properties in the machine and transverse directions thereof. The sheet physical properties are tabulated in Table I under the heading "Example III". The large difference between strip tenacity in the machine direction and in the transverse direction is indicative of the predominant filament orientation in the machine direction.

EXAMPLE IV

Using the apparatus and alloy composition of Example I, a metallic sheet comprised of low aspect ratio fibers was produced. The fibers were collected by moving the collecting surface upward along the molten stream until short fibers were observed to impinge upon the surface. The surface was then manipulated so as to yield a fibrous sheet-like mass having randomly dispersed fibers throughout. The mass was compressed and bonded as described in Example I. Subsequent to bonding, the sheet was photographed at a magnification of about 4.3 X. FIG. **5** depicts a section of the photograph and illustrates a larger number of fiber ends.

The average aspect ratio was calculated from the average fiber length, 2.5 inches, and average cross-sectional diameter, 4.7 mils. The aspect ratio was found to be about 532.

As in Example II, two sample strips were taken from the sheet for evaluation of the sheet properties in the machine and transverse directions thereof. The sheet physical properties are tabulated in Table I under the heading "Example IV". It may be seen that strip tenacity is abruptly lower than those tabulated for Examples II and III. This indicates the reduced strength of a sheet fabricated from low aspect ratio fibers as compared to sheets made of high aspect ratio or continuous filaments.

TABLE I

	Examples		
	II	III	IV
web thickness (mils)	**6.5**	**7.0**	**10.0**
web density (gms/cm^3)	**3.18**	**2.32**	**2.13**
nominal web weight (oz/yd^2)	**15.44**	**12.15**	**15.93**
strip tenacity (oz/in/yd^2)			
M.D.	**2.58**	**3.15**	**1.55**
T.D.	**2.26**	**2.30**	**1.60**
elongation at break (%)			
M.D.	**4.75**	**2.8**	**3.25**
T.D.	**3.50**	**2.4**	**2.2**
web volume occupied by fiber %	**34.5**	**25.1**	**23.1**

EXAMPLE V

A metallic sheet was fabricated as described in Example II except that a thin plate having a rectangular grid pattern was laid on top of the fibrous sheet-like mass during compressing and bonding. The resulting sheet has a waffle-like embossed configuration as depicted in FIG. **9**. It was observed that the filaments were bonded at essentially all of the cross-over points within the rectangular compressed areas.

While the invention has been set forth with respect to certain embodiments and specific examples thereof, many modifications and changes will occur to those skilled in the art. Accordingly, the appended claims are meant to cover all such modifications and changes which fall within the true spirit of the present invention.

I claim:

1. A method for making a porous, non-woven metallic sheet comprising the steps of

a. extruding a molten stream from a metallic melt into an atmosphere forming a stabilizing film about the periphery of the molten stream and suppresses surface tension-induced disruptions in the molten stream;

b. collecting the stream on a collecting surface as a solidified non-woven fibrous mass downstream of a point D_o upstream of which attending stream deceleration causes attainment of a non-fibrous mass; and

c. compressing the mass into a sheet and binding together a plurality of fibers in the sheet causing the sheet to have physical integrity.

2. The method of claim **1** in which the physical integrity of the sheet is provided by binding the fibrous material at essentially all of the cross-over points.

3. The method of claim **2** in which the sheet is cold-weld bonded.

4. The method of claim **1** in which the physical integrity of the sheet is provided by binding the fibrous material at essentially all of the cross-over points within selected areas of the sheet.

5. The method of claim **1** in which compressing and binding are done simultaneously.

6. The method of claim **1** in which the stream is collected intermediate D_o and a point D_a upstream of which attending stream deceleration results in the formation of fiber, D_a being downstream of D_o.

7. The method of claim **1** in which the stream is collected intermediate a point D_a upstream of which attending stream deceleration results in the formation of fiber and a point D_b upstream of which attending stream deceleration results in the formation of essentially continuous filaments, the points D_a and D_b being downstream of D_o.

8. The method of claim **1** in which the stream is collected below a point D_b at which the tensile strength of the stream is insufficient to support the weight of the stream resulting in breakage of the stream into fibers having essentially the same lengths.

9. The method of claim **1** in which the stream is collected as a non-woven fibrous mass having random distribution.

10. The method of claim **1** in which the stream is collected as a non-woven fibrous mass having preferred distribution.

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