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(54) Title: NONWOVEN INSULATION MATERIAL

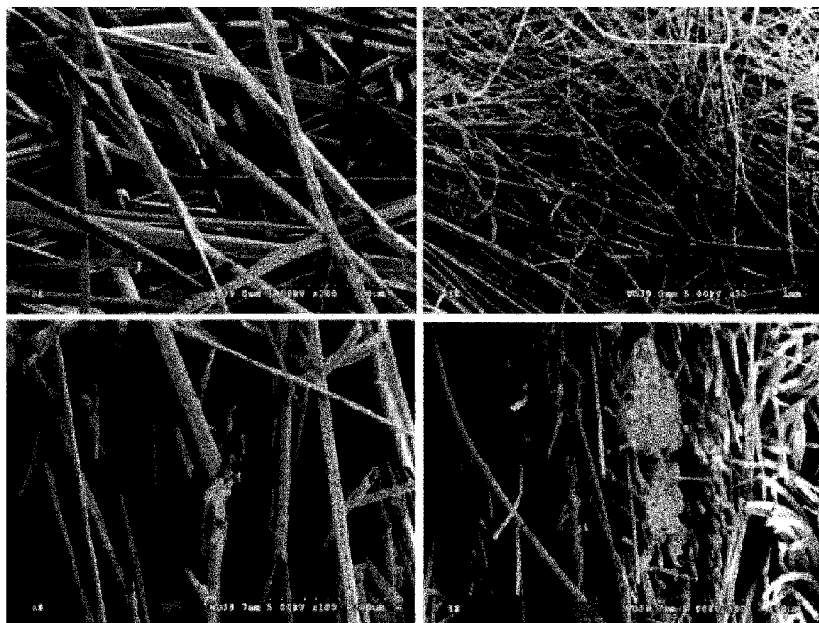


FIG. 3

(57) Abstract: A nonwoven material is provided. The nonwoven material includes hollow plant fibers having a mean length L_1 and a second fibrous material, the hollow plant fibers and the second fibrous material are mixed substantially homogeneously and are thermally bonded together. The hollow plant fibers originate from harvested hollow plant fibers having an initial mean length L_0 , wherein the ratio $L_1:L_0$ is from 0.5 to 1.



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NONWOVEN INSULATION MATERIAL

FIELD

The technical field generally relates to nonwoven materials, and more particularly to nonwoven materials including plant-based fibers which can be used in thermal or acoustic insulation.

BACKGROUND

Having access to effective thermal insulation has always been desirable in many industries, such as the transportation, construction, and textile industries. Furthermore, the density of living spaces being in constant increase, with many living units fitting into a single building, the people inhabiting these spaces have high expectations for sound insulation. It is therefore also desirable to have access to effective acoustic insulation, notably in the transportation and construction industries.

The insulation materials are sometimes made of fibers, natural and/or synthetic, and can be manufactured by known techniques such as weaving, humid compression, thermal bonding, etc. Some examples of natural fibers include plant fibers such as wood fibers and cotton, and examples of synthetic fibers include polyester and polypropylene. When compared to synthetic fibers, natural fibers have certain advantages like the relatively low amount of energy required to transform them into the acoustic or thermal material, as well as a relatively low environmental impact.

An example of plant fiber used in thermal or acoustic insulation materials is milkweed fiber. Milkweed fibers are typically obtained by extracting milkweed floss from milkweed pods, and incorporated into the insulation material after several treatment steps and blending with other types of fibers. However, in milkweed-synthetic fiber blends known to date, the mechanical and/or insulation properties can still be improved.

In view of the above, many challenges still exist in the field of thermal and/or acoustic insulation.

SUMMARY

In some embodiments, there is provided a nonwoven material, comprising hollow
5 plant fibers having a mean length L_1 and a second fibrous material, the hollow
plant fibers and the second fibrous material being mixed substantially
homogeneously and thermally bonded together, the hollow plant fibers originating
from harvested hollow plant fibers having an initial mean length L_0 , wherein the
ratio $L_1:L_0$ is from 0.5 to 1.

10 In some embodiments, there is provided a nonwoven material, comprising hollow
plant fibers having a mean length L_1 and a second fibrous material, the hollow
plant fibers and the second fibrous material being mixed substantially
homogeneously, the first fibrous material and the second fibrous material being
chemically bonded together, the hollow plant fibers originating from harvested
15 hollow plant fibers having an initial mean length L_0 , wherein the ratio $L_1:L_0$ is from
0.5 to 1.

In some embodiments, the hollow plant fibers and the second fibrous material are
directionally oriented substantially parallel to one another.

In some embodiments, the hollow plant fibers and the second fibrous material are
20 randomly oriented with respect to one another.

In some embodiments, the hollow plant fibers comprise cellulosic hollow plant
fibers.

In some embodiments, the hollow plant fibers comprise milkweed fibers, ramie
fibers, urtica fibers, kapok fibers or a mixture thereof.

25 In some embodiments, the hollow plant fibers comprise milkweed fibers.

In some embodiments, the milkweed fibers comprise *Asclepias syriaca* (common milkweed), *Asclepias speciosa* (showy milkweed) or a mixture thereof.

In some embodiments, the ratio $L_2:L_0$ is from 0.5 to 2.

In some embodiments, the ratio $L_2:L_0$ is from 0.75 to 1.5.

- 5 In some embodiments, the second fibrous material comprises fibers of a cylindrical shape.

In some embodiments, the second fibrous material comprises synthetic fibers.

In some embodiments, the synthetic fibers comprise polyethylene and/or polypropylene.

- 10 In some embodiments, L_1 is between 20 mm and 60 mm.

In some embodiments, L_1 is between 20 mm and 40 mm.

In some embodiments, the hollow plant fibers have a diameter between 15 microns and 30 microns.

- 15 In some embodiments, the hollow plant fibers have an external wall thickness between 1 and 2 microns.

In some embodiments, the hollow plant fibers have a first density d_1 which is between 0.10 and 0.20 g/cm³.

In some embodiments, the hollow plant fibers have a first density d_1 which is between 0.10 and 0.40 g/cm³.

- 20 In some embodiment, the second fibrous material has a second density d_2 which is between 0.7 and 2.0 g/cm³.

In some embodiment, d_2 is between 0.7 and 1.5 g/cm³.

In some embodiment, d_2 is between 1.0 and 1.2 g/cm³.

In some embodiment, the nonwoven material includes:

70 vol% to 95 vol% of the hollow plant fibers; and

5 vol% to 30 vol% of the second fibrous material.

In some embodiment, the nonwoven material includes:

5 85 vol% to 95 vol% of the hollow plant fibers; and

5 vol% to 15 vol% of the second fibrous material.

In some embodiment, the nonwoven material includes:

87 vol% to 93 vol% of the hollow plant fibers; and

7 vol% to 13 vol% of the second fibrous material.

10 In some embodiments, the nonwoven material further includes a third fibrous material.

In some embodiments, the third fibrous material is selected from the group consisting of natural fibers, synthetic fibers, animal fibers, mineral fibers and blends thereof.

15 In some embodiments, the third fibrous material comprises a natural fiber selected from the group consisting of cotton, kapok, bamboo, linen, hemp, kenaf, jute, abaca, coir (coconut), ramie, sisal and blends thereof.

In some embodiments, the third fibrous material comprises an animal fiber selected from the group consisting of wool, alpaca, angora, cashmere, mohair,
20 vicuna, silk and blends thereof.

In some embodiments, the third fibrous material comprises a synthetic fiber selected from the group consisting of polyphenylene sulfide (PPS), polyester, acetate, triacetate, polyamide (nylon), poly (p-phenylene-2,6 benzobisoxazole) (PBO), liquid crystal polymer (aramid, fiber and Thermotropic as Vectran and

Ticona, polyhydroquinone- diimidazopyridine (PIPD), polyethylene (UHMWPE, HMPE, HPPE, HDPE, LDPE etc.), acetal, polyvinyl alcohol (PVA), polyvinylidene chloride (PVDC), polyvinyl chloride (PVC), modacrylic, acrylic, Polybenzimidazole (PBI) and blends thereof.

- 5 In some embodiments, the mineral fiber is selected from the group consisting of carbon fiber, glass fiber, metal fiber, basalt and blends thereof.

In some embodiments, the nonwoven material has a density between 3 and 120 kg/m³.

- 10 In some embodiments, the nonwoven material has a thickness between 0.5 cm and 15 cm.

In some embodiments, the nonwoven material has a thickness between 0.5 cm and 2.5 cm.

In some embodiments, the first fibrous material and the second fibrous material are thermally and chemically bonded together.

- 15 In some embodiments, there is provided the use of the nonwoven material described herein as a thermal insulator.

In some embodiments, there is provided the use of the nonwoven material described herein as an acoustic insulator.

- 20 In some embodiments, there is provided the use of the nonwoven material described herein as a sorbent material.

In some embodiments, a nonwoven web is provided, comprising the nonwoven material as described herein.

A process for manufacturing a nonwoven material is provided. In some embodiments, the process includes:

providing hollow plant fibers and a second fibrous material, the harvested hollow plant fibers having an initial mean length L_0 ;

mixing the hollow plant fibers and the second fibrous material to obtain a substantially homogeneous fiber mixture;

5 carding the fiber mixture to obtain a non-bonded web such that the hollow plant fibers of the non-bonded web have a mean length L_1 , wherein $L_1:L_0$ is from 0.5 to 1; and

10 bonding the non-bonded web, comprising heating the non-bonded web in order to thermally bond the hollow plant fibers and the second fibrous material, the heating being performed at a temperature between the fusion temperature of the second fibrous material and the degradation temperature of the hollow plant fibers, so as to obtain the nonwoven material as a thermally bonded web.

In some embodiments, the carding of the fiber mixture comprises:

15 feeding the fiber mixture to a taker-in cylinder provided with pins and having at least one of:

- a pin density between 1 and 80 pins/square inch;
- a pin height between 5 and 6.7 mm; and
- a pin angle between 100° and 115° ;

20 operating the taker-in cylinder to convey the fiber mixture to a carding cylinder; and

operating the carding cylinder to obtain the non-bonded web.

In some embodiments, the taker-in cylinder has:

- 25 - a pin density between 1 and 80 pins/square inch;
- a pin height between 5 and 6.7 mm; and

- a pin angle between 100° and 115°.

In some embodiments, the pin density is between 20 and 80 pins/square inch.

In some embodiments, the pin density is between 30 and 50 pins/square inch.

In some embodiments, the pin height is between 5.5 and 6.3 mm.

- 5 In some embodiments, the pin angle is between 102° and 107°.

In some embodiments, the taker-in cylinder has a substantially smooth or substantially pin-less surface.

In some embodiments, the taker-in cylinder has a rotation speed between 50 and 200 rpm.

- 10 In some embodiments, the taker-in cylinder has a rotation speed between 125 and 175 rpm.

In some embodiments, bonding the non-bonded web further comprises chemically bonding the non-bonded web in order to chemically bond the hollow plant fibers and the second fibrous material.

- 15 In some embodiments, the chemical bonding is performed concurrently to the thermal bonding.

In some embodiments, the chemical bonding is performed prior to the thermal bonding.

- 20 In some embodiments, the chemical bonding is performed after the thermal bonding.

In some embodiments, bonding the non-bonded web further comprises mechanically bonding the non-bonded web prior to the heating step.

In some embodiments, bonding the non-bonded web further comprises mechanically bonding the thermally bonded web after the heating step.

In some embodiments, the mechanical bonding comprises at least one of needling and jogging.

In some embodiments, the process further comprises opening the second fibrous material and the hollow plant fiber prior to the mixing step.

- 5 In some embodiments, the carding step is performed so as to directionally orient the hollow plant fibers and the second fibrous material substantially parallel to one another in the non-bonded web.

In some embodiments, the process further includes feeding the non-bonded web into a series of rotating cylinders in order to randomly orient the hollow plant
10 fibers and the second fibrous material with respect to one another.

In some embodiments, the process further includes winding the thermally bonded web.

In some embodiments, the heating temperature is selected to be between 5°C and 40°C higher than the fusion temperature of the second fibrous material.

- 15 In some embodiments, the heating temperature is selected to be between 5°C and 10°C higher than the fusion temperature of the second fibrous material.

In some embodiments, the second fibrous material has an initial length L_2 , and wherein the hollow plant fibers and the second fibrous material are selected such that the ratio $L_2:L_0$ is from 0.5 to 2.

- 20 In some embodiments, the ratio $L_2:L_0$ is from 0.75 to 1.5.

In some embodiments, the ratio $L_2:L_0$ is from 1 to 1.5.

In some embodiments, the hollow plant fibers comprise cellulosic hollow plant fibers.

- In some embodiments, the hollow plant fibers comprise milkweed fibers, ramie
25 fibers, urtica fibers, kapok fibers or a mixture thereof.

In some embodiments, the hollow plant fibers comprise milkweed fibers.

In some embodiments, the milkweed fibers comprise *Asclepias syriaca* (common milkweed), *Asclepias speciosa* (showy milkweed) or a mixture thereof.

5 In some embodiments, the second fibrous material comprises fibers of a cylindrical shape.

In some embodiments, the second fibrous material comprises synthetic fibers.

In some embodiments, the synthetic fibers comprise polyethylene and/or polypropylene.

10 In some embodiments, the hollow plant fibers have a diameter between 15 microns and 30 microns.

In some embodiments, the hollow plant fibers have an external wall thickness between 1 and 2 microns.

In some embodiments, the hollow plant fibers have a first density d_1 which is between 0.10 and 0.20 g/cm³.

15 In some embodiments, the hollow plant fibers have a first density d_1 which is between 0.10 and 0.40 g/cm³.

In some embodiments, the second fibrous material has a second density d_2 which is between 0.7 and 2.0 g/cm³.

In some embodiments, d_2 is between 0.7 and 1.5 g/cm³.

20 In some embodiments, d_2 is between 1.0 and 1.2 g/cm³.

In some embodiments, the process further comprises providing a third fibrous material, and wherein the mixing step comprises mixing the hollow plant fibers, the second fibrous material and the third fibrous material to obtain the substantially homogeneous fiber mixture.

In some embodiments, the third fibrous material is selected from the group consisting of natural fibers, synthetic fibers, animal fibers, mineral fibers and blends thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

5 Figure 1 is a x750 Scanning Electron Micrograph (SEM) showing milkweed fibers;

Figure 2 is a photograph of an embodiment of a nonwoven material according to an embodiment;

10 Figure 3 shows scanning electron micrographs (SEM) showing the structure of a nonwoven material according to an embodiment;

Figure 4 is a process flow diagram of a process for manufacturing a nonwoven material, according to an embodiment;

Figure 5A is a schematic representation of a carding step of the prior art;

15 Figure 5B is a schematic representation of a carding step, according to an embodiment; and

Figure 6 is a schematic representation of an optional web-processing after the carding step, according to an embodiment.

DETAILED DESCRIPTION

20 The nonwoven material described herein includes hollow plant fibers and a second material, the hollow plant fibers and the second material being mixed substantially homogeneously. The hollow plant fibers and the second material can be thermally bonded together, chemically bonded together and/or mechanically bonded together. In some embodiments the nonwoven material can include one or more additional materials.

Some embodiments of the nonwoven material can be used as a thermal insulation material and/or acoustic insulation material. The insulation material can be used in the construction industry or in other fields such as the transportation or clothing industries, among others. Alternatively, some embodiments of the nonwoven material can be suitable as an absorbent material. For instance, in some embodiments, the nonwoven material may be used as an absorbent material for absorbing oil/hydrocarbons, e.g. oil/hydrocarbons spilled on land or in a body of water. It is also understood that the nonwoven material can be used in various other applications. For example, the nonwoven material can be used in structural panels, thermoformable panels or as granules for energy-related applications. Other examples include the use of the nonwoven material as a filtration material, in composite materials, as mattress cover, as coating for furniture, or as a flotation material.

It is understood that the expressions "acoustic insulation" or "sound-insulation", as used herein, refer to the ability of a material to prevent, reduce, absorb, dampen, etc. the transmission of sound emanating from one side of the material to the other side of the material. Similarly, the expression "thermal insulation", as used herein, refers to the ability of a material to prevent, reduce, absorb, etc. the transmission of thermal energy from one side of the material to the other side of the material.

It is understood that the nonwoven material described herein is not limited to a particular shape or configuration, and can therefore take many forms depending on the application for which it is intended. For instance, one or several layers of the nonwoven material can be assembled to form a felt, which can be draped or applied to surfaces, thereby improving their thermal and/or acoustic insulation properties. The nonwoven material can be formed of a plurality of layers, each layer having a density ranging from about 10 to about 200 g/m². In such an application, the nonwoven material can be used in a partition wall in a space, or in a floor or ceiling assembly separating two spaces, to name but a couple of examples, thereby helping to provide these spaces with thermal and/or acoustical

insulation properties. In another example, the nonwoven material can be installed in a continuous fashion on the interior of exterior walls, thereby providing the space enclosed by these walls with thermal and/or acoustical insulation properties. In yet another example, the nonwoven material can be a flexible
5 board or panel made to any suitable shape and size, which can be used alone or applied to surfaces. In yet another example, a layer of the nonwoven material can be used in conjunction with other layers of materials (which can be layers of the nonwoven material or layers of other types of material). In yet another example, the nonwoven material is obtained as a nonwoven web. It is thus apparent that
10 the nonwoven material is not limited to a particular form, application, or installation, and can be manufactured or adapted for the purpose which it will serve.

It is understood that the hollow plant fibers are obtained from plants or vegetables. The plants or vegetables can include any plant or vegetable which is
15 known to possess hollow fibers. The terms "fiber" or "fibrous" refer to a filament or thread which can be manipulated, treated, blended, bonded together and/or with other fibers to form the nonwoven material. The term "hollow fiber" refers to a fiber which has a largely empty or void interior (such as at least 50% of the space being empty as seen on a cross-section of the hollow fiber) and which has
20 a low density when compared to non-hollow or "full fibers". In some embodiments, such hollow fibers advantageously improve thermal and/or sound insulation as a result of their empty interiors, and also as a result of their relatively low densities. In some scenarios, nonwoven materials comprising hollow plant fibers may demonstrate certain advantages over fibers made
25 exclusively from synthetic materials, in that hollow plant fibers may reduce the density of the insulation material and improve the insulation properties due to attenuation of mechanical vibrations, and they may have fewer environmental impacts while still offering similar or superior insulation properties.

In some scenarios, the hollow plant fibers can include cellulosic plant fibers. In
30 some scenarios, the hollow plant fibers can have a cylindrical shape. Non-limiting

examples of hollow plant fibers include milkweed fibers, ramie fibers, urtica fibers and kapok fibers. In some embodiments, the milkweed fibers include at least one of *Asclepias Syriaca* (common milkweed) and *Asclepias Speciosa* (showy milkweed). It is also understood that other species of the genus *Asclepias* can be suitable. In some embodiments, the milkweed fibers have a mean length L_1 in the nonwoven material, which is between about 10 and about 60 mm, between about 10 and about 40 mm, between about 20 and about 60 mm, or between about 20 and about 40 mm. In some embodiments, the milkweed fibers have a mean diameter ranging from about 15 to about 30 microns. In some embodiments, the milkweed fibers have a mean external wall thickness between 1 micron and 2 micron. In some embodiments, the hollow plant fibers have a density which is between 0.10 and 0.20 g/cm³ or between 0.10 and 0.35 g/cm³. The diameter and wall thickness can be seen, for example on the photograph shown on Figure 1. For example, the external wall thickness can be of about 1.3 microns.

In some embodiments, the mean length is such that the ratio $L_1:L_0$ is from 0.5 to 1, or from 0.75 to 1, wherein L_0 is the initial mean length of the hollow plant fibers. It is understood that the expression "initial mean length" refers to the mean length of the hollow plant fibers in their natural state, after being extracted from the plant/vegetable, but before receiving any treatment which would substantially reduce the mean length of the fibers. In other words, the "initial mean length L_0 " refers to the mean length of harvested hollow plant fibers before any blending, carding or bonding with the second material to form the nonwoven material.

For example, in the case of milkweed fibers, the initial mean length L_0 corresponds to the mean length of the fibers in milkweed floss extracted from milkweed pods, before treatments which may reduce the length of the fibers by mechanical and/or thermal damage. The harvested milkweed fibers can typically be obtained directly from cleaning milkweed floss extracted from milkweed pods, after having processed the milkweed floss to remove grains and other debris resulting from extraction. The milkweed fibers can then be blended with other fibers of the nonwoven material, carded, and then submitted to a bonding

process (such as thermal bonding). In some embodiments, the treatments used to obtain the nonwoven material described herein reduces the mean length of the milkweed fibers by at most half of the initial mean length of the milkweed fibers, or by at most 1/4 of the initial mean length of the milkweed fibers. It should
5 therefore be understood that in order to obtain a ratio $L_1:L_0$ which is from 0.5 to 1, or from 0.75 to 1, and depending on the type of hollow plant fibers used, certain parameters (e.g., blending, carding and/or bonding parameters) can be adjusted.

For example, in known materials and processes using milkweed fibers or other hollow plant fibers, a challenge which is typically faced is the degradation of the
10 fibers due to performing certain mechanical steps in conditions that can be considered too aggressive. It has been found that using typical carding parameters (i.e., a carding parameters as used, for example, to process traditional natural fibers such as cotton fibers) when processing hollow plant fibers such as milkweed fibers or kapok fibers, can degrade the hollow plant
15 fibers and reduce their mean length to less than half of their original mean length. In some cases, it has been found that using typical carding parameters can reduce the hollow plant fibers to a dust-like material, which is undesirable in most applications. However, it has been found that by using carding parameters that are considered less aggressive, the mean length of the carded milkweed fibers
20 can be kept at least at 0.5 times the initial mean length, which can enable it to retain its desired properties. A carding step of the prior art, suitable for processing traditional natural fibers such as cotton fibers is shown at Figure 5A and described below. A carding step featuring an example of certain mechanical steps that are suitable to process natural fibers is shown at Figure 5B. Both
25 processes are detailed below, for comparison purposes.

It should be understood that the term "carding", as used herein, refers to a mechanical process that disentangles, cleans and intermixes fibers to produce a continuous non-bonded web which is suitable for subsequent processing. The carding is typically achieved by passing the fibers between differentially moving
30 surfaces covered with card clothing. In some scenarios, the carding can break up

locks and unorganized clumps of fiber and can then align the individual fibers to be parallel with each other. In other scenarios, the carding can allow obtaining unitary layers having fibers which are randomly oriented with respect to each other.

- 5 As another example, too strong of a heat treatment or thermal bonding may damage or burn the milkweed fibers, thereby reducing the mean length of the milkweed fibers by too large of an amount. The thermal bonding step should therefore be carried out with care, by carefully selecting the heating temperature so as not to damage or burn the milkweed fibers.
- 10 In some embodiments, the hollow plant fibers and the second material are directionally oriented with respect to one another in the nonwoven material. It is understood that the term "directionally oriented" means that the hollow plant fibers and the fibers of the second material are not randomly dispersed with respect to one another, but are rather substantially oriented in the same direction
- 15 (i.e. substantially oriented parallel to one another, or directionally aligned). The hollow plant fibers and the second material can be directionally oriented mechanically, for example during carding.

In other embodiments, the hollow plant fibers and the second material are not directionally oriented. In other words, the hollow plant fibers and the second

20 material can be randomly oriented in the nonwoven material. In some embodiments, the random orientation of the hollow plant fibers and the second material can be provided by further processing the non-bonded web obtained by carding.

In some embodiments, the second material which is used in the nonwoven

25 material includes a polyolefin blend and/or a dry glue such as a polyurethane-based glue. In some embodiments, the second material is a fibrous material (hereinafter a second fibrous material). In some embodiments, the second fibrous material includes fibers having a cylindrical shape. It should be understood that the second fibrous material can have other shapes, which can be chosen

depending on the application sought for the nonwoven material. In some embodiments, the second fibrous material includes synthetic fibers, such as polyethylene and/or polypropylene. In some embodiments, the second fibrous material includes a polypropylene center wrapped or surrounded in a sheath of polyethylene. The second fibrous material can help to bond the hollow plant fibers together because the synthetic fibers can be melted under pressure and/or heat, so as to integrate the hollow plant fibers with each other. In other words, the second fibrous material can be thermally bonded with the hollow plant fibers. In some embodiments, the second fibrous material has a density between 0.70 and 1.50 g/cm³, or between 1.00 and 2.00 g/cm³. In some embodiments, the second fibrous material is a bio-based polymer fiber, such as a polylactic acid (PLA) or a polyhydroxyalkanoate (PHA). In some embodiments, the second fibrous material is a polyester, such as a biodegradable polyester (e.g. polybutyrate adipate terephthalate PBAT).

In some embodiments the second fibrous material is selected such that the mean length L_2 of the second fibrous material and the mean length L_1 of the hollow plant fibers are such that the ratio $L_2:L_0$ is from 0.5 to 2, from 0.75 to 1.5, or from 1 to 1.5. In some scenarios, the ratio $L_2:L_1$ is from 0.5 to 4, from 0.75 to 3, or from 1 to 3. In some scenarios, when the ratio $L_2:L_1$ or $L_2:L_0$ is selected as described herein, not only the mixing of the hollow plant fibers and the second fibrous material can be facilitated, but a blend with a substantially homogeneous distribution may also be obtained by mixing. Thanks to such a substantially homogeneous distribution, a suitable bonding of the hollow plant fibers with the second fibrous material can be obtained through the thermal and/or chemical bonding. In some scenarios, this can lead to improved mechanical properties of the nonwoven material, and/or improved thermal insulation properties.

It should be understood that the expression “substantially homogeneous” or “substantially homogeneously”, as used herein in reference to the hollow plant fiber and second fibrous material mixture, refers to a mixture where the components are uniformly distributed throughout the mixture. In other words, the

composition of a substantially homogeneous mixture is substantially the same throughout.

In some embodiments, the nonwoven material can include one or more additional material. The one or more additional material can include a third fibrous material

5 which can be a natural, animal, synthetic or mineral fibre. In some embodiments, the third fibrous material includes natural fibres, which can for example be selected from the group consisting of cotton, kapok, bamboo, linen, hemp, kenaf, jute, abaca, coir (coconut), ramie, sisal and blends thereof. In some
10 embodiments, the third fibrous material can include animal fibers, which can for example be selected from the group consisting of wool, alpaca, angora, cashmere, mohair, vicuna, silk and blends thereof. In some embodiments, the third fibrous material can include synthetic fibers, which can for example be selected from the group consisting of polyphenylene sulfide (PPS), polyester, acetate, triacetate, polyamide (nylon), poly (p-phenylene-2,6 benzobisoxazole)
15 (PBO), liquid crystal polymer (aramid, fiber and Thermotropic as Vectran and Ticona, polyhydroquinone- diimidazopyridine (PIPD), polyethylene (UHMWPE, HMPE, HPPE, HDPE, LDPE etc.), acetal, polyvinyl alcohol (PVA), polyvinylidene chloride (PVDC), polyvinyl chloride (PVC), modacrylic, acrylic, Polybenzimidazole (PBI) and blends thereof. In some embodiments, the third fibrous material can
20 include synthetic fibers, which can for example be selected from the group consisting of viscoseTM (cotton, bamboo etc.) and rayon (modalTM, lyocellTM). In some embodiments, the third fibrous material can include mineral fibers, which can for example be selected from the group consisting of carbon fiber, glass fiber, metal fiber, basalt and blends thereof.

25 In some embodiments, the nonwoven material includes:

60 vol% to 99 vol% of the hollow plant fibers such as milkweed fibers; and

1 vol% to 40 vol% of the second material such as a polyolefin blend (e.g. PP/PE) and/or a dry glue such as a polyurethane-based glue.

In some embodiments, the nonwoven material includes:

70 vol% to 99 vol% of the hollow plant fibers such as milkweed fibers; and

1 vol% to 30 vol% of the second material such as a polyolefin blend (e.g. PP/PE) and/or a dry glue such as a polyurethane-based glue.

5 In some embodiments, the nonwoven material includes:

70 vol% to 95 vol% of the hollow plant fibers such as milkweed fibers; and

5 vol% to 30 vol% of the second fibrous material such as a PP/PE blend.

In some embodiments, the nonwoven material includes:

85 vol% to 95 vol% of the hollow plant fibers such as milkweed fibers; and

10 5 vol% to 15 vol% of the second fibrous material such as a PP/PE blend.

In some embodiments, the nonwoven material includes:

87 vol% to 93 vol% of the hollow plant fibers such as milkweed fibers; and

7 vol% to 13 vol% of the second fibrous material such as a PP/PE blend.

In some embodiments, the nonwoven material includes:

15 60 vol% to 99 vol% of the hollow plant fibers such as milkweed fibers; and

0.5 vol% to 20 vol% of the second material such as a polyolefin blend (e.g. PP/PE) and/or a dry glue such as a polyurethane-based glue.

0.5 vol% to 20 vol% of the third material

In some embodiments, the nonwoven material includes:

20 70 vol% to 99 vol% of the hollow plant fibers such as milkweed fibers; and

0.5 vol% to 15 vol% of the second material such as a polyolefin blend (e.g. PP/PE) and/or a dry glue such as a polyurethane-based glue.

0.5 vol% to 15 vol% of the third material

In some embodiments, the nonwoven material includes:

- 5 70 vol% to 95 vol% of the hollow plant fibers such as milkweed fibers; and
- 2.5 vol% to 15 vol% of the second fibrous material such as a blend PP/PE.
- 2.5 vol% to 15 vol% of the third fibrous material

In some embodiments, the nonwoven material includes:

- 85 vol% to 95 vol% of the hollow plant fibers such as milkweed fibers; and
- 10 2.5 vol% to 7.5 vol% of the second fibrous material such as a blend PP/PE.
- 2.5 vol% to 7.5 vol% of the third fibrous material

In some embodiments, the nonwoven material includes:

- 87 vol% to 93 vol% of the hollow plant fibers such as milkweed fibers; and
- 15 3.5 vol% to 6.5 vol% of the second fibrous material such as a blend PP/PE.
- 3.5 vol% to 6.5 vol% of the third fibrous material

Referring to Figure 4, a process 10 for manufacturing the nonwoven material is provided. In some embodiments, a harvested hollow plant fiber, a second fibrous material and optionally a third fibrous material are provided. In some
20 embodiments, the hollow plant fibers and the second fibrous material can be selected such that the ratio $L_2:L_0$ is from 0.5 to 2, from 0.75 to 1.5, or from 1 to 1.5. In some embodiments, the process includes opening 12 the first, second and

optional third fibrous material, for example in a bale opener. In some embodiments, the process can further include blending 14 the hollow plant fibers with the second fibrous material and the optional third fibrous material to obtain a fiber blend 15. In some embodiments, the blending can include mixing the hollow plant fibers and the second fibrous material in a multi-mixer.

The process further includes carding 16 the fiber blend in order to obtain a non-bonded web 17. Optionally, the non-bonded web 17 can be further processed in a web-processing step 18 which will be described in further detail below. The web-processing step 18 can allow obtaining a processed non-bonded web 19 which can have modified or otherwise improved properties compared to the non-bonded web 17.

Now referring to Figure 5A, a typical carding step suitable for processing traditional natural fibers such as cotton fibers is shown. The fiber blend to be carded is transferred from a feed plate to the main carding cylinder via a feed roller and a taker-in cylinder (also called a licker-in cylinder). The taker-in cylinder is typically used to remove debris, seed bits, sand and other trash particles from the fiber blend (i.e., clean the fiber blend) prior to contacting the main carding cylinder. In order to be able to clean the fiber blend, the taker-in cylinder is typically operated at high speeds and several pins are typically provided on the surface of the cylinder. For example, typical taker-in parameters for processing a traditional natural fiber such as cotton include a pin density higher than about 110 pins/square inch, a pin height of at most 4.5 mm, pin angles between 80° and 90°, and a rotation speed between 450 and 1000 rpm. It has been found that using these parameters for carding hollow plant fibers tends to mechanically degrade the hollow plant fibers to an undesired extent.

Now referring to Figure 5B, a carding step according to an embodiment of the present description is shown. This carding step can be suitable for carding fiber blends including hollow plant fibers (i.e., the carding step can keep the ratio $L_1:L_0$ from 0.5 to 1, or from 0.75 to 1). It is understood that the embodiment shown is a

non-limiting example of such carding step, and that modifications may be made in accordance with the present description, in order to enable obtaining a nonwoven material in which the ratio $L_1:L_0$ is from 0.5 to 1, or from 0.75 to 1. In some embodiments, the fiber blend is provided on a feed plate 161 and conveyed towards a feed roller 162. The fiber blend is passed under the feed roller 162 and directed toward taker-in cylinder 163. The cylinder 163 can then convey the fiber blend towards the main carding cylinder 164 where the carding operation takes place. Compared to the carding step shown at Figure 5A, the taker-in cylinder 163 is configured to convey the fiber blend from the feed plate 161 to the main carding cylinder 164 in less aggressive conditions, so as to prevent the hollow plant fibers from degrading to an unacceptable degree (i.e., to prevent the hollow plant fibers from having their mean length L_1 lowered to less than half of their initial mean length L_0).

Taker-in parameters that can be suitable for processing hollow plant fibers include a lowered pin density, increased pin height and/or increased pin angle compared to typical taker-in parameters that are used for carding typical natural fiber such as cotton. In some embodiments, the pin density of the cylinder 163 is between 1 and 80 pins/square inch, or between 20 and 80 pins/square inch, or between 30 and 50 pins/square inch. In some embodiments, the pin height is between 5 and 6.7 mm, or between 5.5 and 6.3 mm. In some embodiments, the pin angle is between 100° and 115° , or between 102° and 107° . In some embodiments, the rotation speed of the cylinder 163 is between 50 and 200 rpm, or between 125 and 175 rpm. In some embodiments, the cylinder 163 has a substantially smooth surface (i.e., a surface which is pin-less or substantially pin-less). For example, the cylinder 163 can have a substantially smooth and substantially pin-less surface made of plastic such as a thermoplastic polymer. It is understood that the expression "substantially pin-less surface", as used herein, refers to a surface which has less than about 1 pin/square inch.

In some embodiments, the cylinder 163 can be obtained by modifying a typical taker-in cylinder, the modifying including at least one of lowering the pin density, increasing the pin length and increasing the pin angle.

5 In some embodiments, the cylinder 163 can be removed from the carding device, such that the fiber blend is fed directly from the feed plate to the main carding cylinder 164, for example via feed roller 162. It is understood that for such a configuration to be operational, the main carding cylinder 164 would have to be located closer to the feed plate, or that other guiding means would have to be used in order to guide the fiber blend from the feed plate 161 to the main carding
10 164.

It should also be understood that Figure 5B shows the main cylinder of the carding device, and that other secondary cylinders which are not shown in the Figures can be present, as known to a person skilled in the art. In some embodiments the speed of the secondary cylinders can be lowered to up to half
15 of their typical speeds, so as to further reduce the degradation of the hollow plant fibers. For example, the speed of the secondary cylinders can be set to 30 Hz or lower, as opposed to 60 Hz or higher in typical processes. The secondary cylinders can for examples be used for combing the fiber blend during the carding process.

20 In some embodiments, the hollow plant fibers can be conditioned prior to being blended with the other materials and prior to carding, in order to remove impurities and other debris that would typically be removed by a taker-in cylinder.

Now referring back to Figure 4, in some embodiments, the non-bonded web 17 or the processed non-bonded web 19 can be subjected to cross-lapping 20. The
25 cross-lapping step 20 can be performed using a crosslapper which can lay several layers of carded web to a desired width and surface weight. For example, the unitary layers obtained from the carding step 16 can be positioned on top of one another prior to eventually being bonded together in a bonding step 22. It should be understood that the bonding step includes thermal bonding or chemical

bonding, and can optionally further include mechanical bonding. It should be understood that the optional mechanical bonding can occur prior to and/or after the thermal or chemical bonding, as will be explained in further detail below. In some embodiments, the bonded nonwoven web 23 obtained after the bonding
5 step 22 can then be wound in winding step 24.

Now referring to Figure 6, the optional web-processing step 18 can include feeding the non-bonded web 17 into a plurality of cylinders, which can in some scenarios allow obtaining a web having improved mechanical properties such as increased mechanical resistance. In some embodiments, the first cylinder 31 can
10 be configured to receive a high quantity of material so as to increase to surface weight of the material. In some embodiments, the second cylinder 32 can be configured to confer random directionality to the fibers of the material (or un-parallelize the fibers), which can have the effect of increasing the mechanical properties. In some embodiments, the third cylinder can detach the web in order
15 to transfer it to the cross-lapping step 20 or bonding step 22. In the non-limiting example shown on Figure 6, the non-bonded web 17 is fed into a series of three (3) cylinders, and it is understood that the number of cylinders can vary. For example, the series of cylinders can include at least two cylinders for accumulating the non-bonded web and at least two cylinders for un-parallelizing
20 the fibers. Still referring to Figure 6, the cylinders 31, 32, 33 can be configured to rotate at varying speeds V_1 , V_2 , V_3 , and speed ratios. The cylinders 31, 32, 33 can be provided with a plurality of pins P1, P2, P3. The number of pins per square inch, angle of the pins with the surface of the cylinder and height of the pins can be adjusted based on the desired properties of the nonwoven material.
25 In some embodiments, the angles of the pins P1, P2, P3 can be between 50° and 120° , the height of the pins P1, P2, P3 can be between 2.5 and 4 mm, the density of the pins can be between 90 and 260 pins/square inch, and the linear number of pins can be between 5 and 11 pins/inch.

Other non-limiting examples of configurations include:

- angles of the pins P1, P2, P3 between 50° and 53° ; height of the pins P1, P2, P3 between 3 and 3.5 mm, density of the pins between 100 and 145 pins/square inch, and linear number of pins between 6 and 7.2 pins/inch;

5 - angles of the pins P1, P2, P3 between 53° and 55° ; height of the pins P1, P2, P3 between 2.5 and 3.05 mm, density of the pins between 141 and 258 pins/square inch, and linear number of pins between 7 and 10 pins/inch;

- angles of the pins P1, P2, P3 between 53° and 55° ; height of the pins P1, P2, P3 between 2.5 and 3.05 mm, density of the pins between 141 and 258 pins/square inch, and linear number of pins between 7 and 10 pins/inch; and

10 - angles of the pins P1, P2, P3 between 55° and 60° ; height of the pins P1, P2, P3 between 3.05 and 3.24 mm, density of the pins between 168 and 203 pins/square inch, and linear number of pins between 7.02 and 8.5 pins/inch; and

In some embodiments, the distance between the cylinders can be between 0.025 mm and 0.8 mm, or between 0.0254 mm and 0.762 mm. Non-limiting examples
15 include:

- the distance between the duffer (i.e., cylinder of the carding 16 shown on Figure 6) and the first cylinder 31 (i.e., accumulator cylinder) can be between 0.127 mm and 0.305 mm, the distance between the first cylinder 31 and the second cylinder 32 (i.e., scrambler cylinder) can be between 0,254 mm and 0,381 mm, and the
20 distance between the second cylinder 32 and the third cylinder 33 (i.e., the detaching cylinder) can be between 0.203 and 0.305 mm;

- the distance between the duffer (i.e., cylinder of the carding 16 shown on Figure 6) and the first cylinder 31 (i.e., accumulator cylinder) can be between 0.152 mm and 0.203 mm, the distance between the first cylinder 31 and the second cylinder
25 32 (i.e., scrambler cylinder) can be between 0,203 mm and 0,305 mm, and the distance between the second cylinder 32 and the third cylinder 33 (i.e., the detaching cylinder) can be between 0.203 and 0.254 mm;

- the distance between the duffer (i.e., cylinder of the carding 16 shown on Figure 6) and the first cylinder 31 (i.e., accumulator cylinder) can be between 0.051 mm and 0.102 mm, the distance between the first cylinder 31 and the second cylinder 32 (i.e., scrambler cylinder) can be between 0,127 mm and 0,178 mm, and the distance between the second cylinder 32 and the third cylinder 33 (i.e., the detaching cylinder) can be between 0.076 and 0.152 mm; and

- the distance between the duffer (i.e., cylinder of the carding 16 shown on Figure 6) and the first cylinder 31 (i.e., accumulator cylinder) can be between 0.189 mm and 0.254 mm, the distance between the first cylinder 31 and the second cylinder 32 (i.e., scrambler cylinder) can be between 0,305 mm and 0,406 mm, and the distance between the second cylinder 32 and the third cylinder 33 (i.e., the detaching cylinder) can be between 0.305 and 0.356 mm.

In some embodiments, the speed ratios $V0:V1$, $V1:V2$ and $V2:V3$ can vary between 0.8 and 1.3. Non-limiting examples include:

- The ratio $V0:V1$ between the speed of the duffer ($V0$) and the speed of the first cylinder ($V1$) can be between 1.05 and 1.1, the ratio $V1:V2$ between the speed of the first cylinder ($V1$) and the speed of the second cylinder ($V2$) can be between 1.05 and 1.07, and the ratio $V2:V3$ between the speed of the second cylinder ($V2$) and the third cylinder ($V3$) can be between 0.93 and 0.95;

- The ratio $V0:V1$ between the speed of the duffer ($V0$) and the speed of the first cylinder ($V1$) can be between 1.05 and 1.13, the ratio $V1:V2$ between the speed of the first cylinder ($V1$) and the speed of the second cylinder ($V2$) can be between 1.07 and 1.1, and the ratio $V2:V3$ between the speed of the second cylinder ($V2$) and the third cylinder ($V3$) can be between 0.87 and 0.90; and

- The ratio $V0:V1$ between the speed of the duffer ($V0$) and the speed of the first cylinder ($V1$) can be between 1.2 and 1.25, the ratio $V1:V2$ between the speed of the first cylinder ($V1$) and the speed of the second cylinder ($V2$) can be between

1.12 and 1.15, and the ratio $V2:V3$ between the speed of the second cylinder ($V2$) and the third cylinder ($V3$) can be between 0.9 and 0.93.

In some embodiments, several series of cylinders can be operated in parallel. In some embodiments, the cylinders can be perforated such that the web can be detached using a blast of air. In some embodiments, the series of cylinders can be replaced with a single cylinder provided with blades that can guide the material.

As mentioned above, the bonding step 22 can include thermal bonding or chemical bonding and can optionally further include mechanical bonding. Several embodiments of the bonding step 22 are described below. In some embodiments, the bonding step 22 includes heating the non-bonded web to obtain the nonwoven material. In some embodiments, the thermal bonding of the hollow plant fibers and the second fibrous material is performed in a closed system, such as an oven. This can allow distributing the heat substantially uniformly throughout the non-bonded web. The temperature at which the thermal bonding is performed depends on the hollow plant fiber and on the second fibrous material used. The thermal bonding temperature is selected to be at least the fusion temperature of the second fibrous material, while remaining lower than the degradation temperature of the hollow plant fiber. It is understood that the term "degradation temperature", as used herein, refers to the temperature at which the hollow plant fibers become unsuitable for use in the nonwoven material after being heated for the duration of the thermal bonding step, at most.

For instance, the temperature of the thermal bonding step can be selected to be higher than the fusion temperature of the second fibrous material, and lower than the caramelization temperature or Maillard degradation temperature of cellulosic fibers which can form at least part of the hollow plant fibers, so as to prevent coloration changes due to chemical degradation of the fibers. Furthermore, in some embodiments, the thermal bonding temperature can be selected to be several degrees higher than the fusion temperature of the second fibrous

material, such as between 5°C and 40°C or between 5 °C and 10°C higher, in order to account for the thermal barrier resulting from the empty space of the hollow plant fibers.

5 The heating time of the thermal bonding step can also be selected in order to obtain a suitable bonding between the second fibrous material and the hollow plant fibers, while remaining short enough not to rigidify the surface of the nonwoven material obtained.

10 In some embodiments the temperature of the thermal bonding is set between 100°C and 180°C. In the case of milkweed fibers and second fibrous material based on a polyolefin polymer or blend such as a Polyethylene/polypropylene blend, the heating temperature of the thermal bonding step can be selected to be between 125°C and 150°C, or between 130°C and 140°C , or about 135°C, provided that the heating temperature is higher than the melting temperature of the polyolefin polymer or blend. The heating time is selected so that it allows the
15 second fibrous material to melt and bond with the milkweed fibers, without substantial degradation of the milkweed fibers. The heating time can be between 2 and 20 minutes or between 2 and 10 minutes, 3 and 7 minutes, or between 4 and 6 minutes, or of about 5 minutes for a nonwoven material having a surface density between 50 and 1200 g/m² or between 50 and 200 g/m². It is understood
20 that the time of heating may vary depending on the surface density of the nonwoven material, the aim being that the second fibrous material can melt and bond with the plant fibers, without substantial degradation of the hollow plant fibers.

25 In some embodiments the first fibrous material and the second fibrous material can be chemically bonded. For example, the chemical bonding can include applying glue in order to bond the first fibrous material and the second fibrous material together. In some embodiments, applying the glue includes pulverizing, impregnating and/or coating the glue on the first fibrous material and/or the second fibrous material. In some scenarios, the glue can be applied to the first

fibrous material prior to contacting with the first material with the second fibrous material. In some scenarios, the glue can be applied to the second fibrous material prior to contacting the second fibrous material with the first fibrous material. In some scenarios, the glue can be applied to the first and second
5 fibrous materials before contacting them together.

In some embodiments, layers of non-bonded web can be mechanically bonded prior to being chemically and/or thermally bonded. In other embodiments, layers of non-bonded web can first be chemically and/or thermally bonded prior to being mechanically bonded. The layers can for example be mechanically bonded
10 together using needling and/or jogging. In some embodiments, the layers of material can include between 2 and 200 layers, or between 2 and 100 layers. In some embodiments, the third material can act as a binding fiber in order to hold the layers including the first and second fibrous material together. For example, the third material can be added via mechanical bonding so as to interpenetrate
15 several layers. In some embodiments, the interpenetrated third material can also be heated so as to be thermally bonded with the first and second fibrous material over some (or all) of the layers. In some embodiments, a non-bonded web including at least two layers of fibrous material can be subjected to needling in a needling unit. The needling unit can include a material supply and a needling
20 machine. The material supply can keep the layers together so that they can be needled. The needling machine can include a plurality of vertical needles with hooks that allow binding the unitary layers together. In some scenarios, during penetration of the needles into the material, the layers can cling to one another and are entrained in the vertical direction (i.e., a direction substantially orthogonal
25 to the feed direction). In some scenarios, this configuration can allow for improved mechanical properties such as improved mechanical resistance.

In some embodiments, the nonwoven material is obtained at densities between 3 kg/m³ and 10 kg/m³ after the thermal bonding step. In some embodiments, the nonwoven material can be further compressed, depending on the application. In
30 thermal insulation applications, the nonwoven material can have a density

between 3 kg/m^3 and 40 kg/m^3 . As a non-limiting exemplary value, a nonwoven material used for thermal insulation applications can have a thickness of about 2.5 cm with a surface density of about 150 g/m^2 , which translates into a density of about 6 kg/m^3 . In acoustic insulation applications, the nonwoven material can
5 have a density between 40 kg/m^3 and 120 kg/m^3 , or between 80 kg/m^3 and 120 kg/m^3 . As a non-limiting exemplary value, a nonwoven material used for acoustic insulation can have a thickness of about 0.5 cm with a surface density of about 500 g/m^2 , which translates into a density of about 100 kg/m^3 .

In some embodiments, there is provided a process for manufacturing a
10 nonwoven material comprising hollow plant fibers, the process including:

providing a harvested hollow plant fiber and a second fibrous material,
The hollow plant fibers and the second fibrous material being optionally
selected such that the ratio $L_2:L_0$ is from 0.5 to 2, from 0.75 to 1.5, or
from 1 to 1.5;

15 optionally opening the second fibrous material;

optionally pre-treating the hollow plant fibers in order to remove
harvested impurities;

mixing the hollow plant fibers and the second fibrous material to obtain a
fiber blend;

20 carding the fiber blend so as to obtain a non-bonded web in which the
hollow plant fibers has a fiber length L_1 such that the ratio $L_1:L_0$ is from
0.5 to 1;

optionally processing the non-bonded web, including feeding the non-
bonded web into a series of rotating cylinders;

25 optionally mechanically bonding the non-bonded web;

thermally bonding the non-bonded web, wherein the temperature is between the fusion temperature of the second fibrous material and the degradation temperature of the hollow plant fibers, or chemically bonding the non-bonded web;

- 5 optionally mechanically bonding the thermally bonded or the chemically bonded web; and

optionally winding the bonded web.

In some scenarios, the carding of the fiber blend allows obtaining a non-bonded web wherein the hollow plant fibers and the second fibrous material are oriented
10 substantially parallel to one another. In some embodiments, the processing of the non-bonded web through the series of rotating cylinders allows un-parallelizing the non-bonded web obtain from the carding step.

EXAMPLES

Example 1:

- 15 Experiments were conducted to prepare a nonwoven material based on a milkweed fiber and a PE/PP blend.

Harvested milkweed fibers of the species *Asclepias syriaca* (having a density of 0.15 g/cm³ and a mean length L_0 of 30mm), and polyolefin fibers (having a polypropylene center wrapped or surrounded in a sheath of polyethylene, having
20 a density of 1.15 g/cm³, a mean length of 50 mm, and a fusion temperature of 130°C) were provided.

The harvested milkweed fibers (90 vol.%) and the polyolefin fibers (10 vol.%) were mixed in a multi-mixer and carded. The blend obtained was thermally bonded in a closed oven at 135°C for 5 minutes.

- 25 The parameters of the taker-in were as follows:

- the angle of the pins was set to 105°;
- the pin density was 60 pins/square inch;
- the height of the pins was 5.3mm; and
- the speed of the taker-in cylinder was 200 rpm.

- 5 The material obtained had a density of about 4 kg/m³ and a mean length L_1 of 20mm, and was used as a thermal insulation material. For use in acoustic insulation applications, this material was be compressed to a higher density of about 100 kg/m³, and affixed to a panel.

10 A photograph of the material obtained is shown on Figure 2, and SEMs of the material obtained are shown on Figure 3.

Example 2:

Experiments were conducted to prepare a nonwoven material based on a milkweed fiber and a blend of PE/PP, cotton and polyester fiber.

15 Harvested milkweed fibers of the species *Asclepias syriaca* (having a density of 0.15 g/cm³ and a mean length L_0 of 30mm), PE/PP having a density of 1.15 g/cm³, a mean length of 50 mm, and a fusion temperature of 130°C, Cotton having a density of 1,5g/cm³ and polyester having a density of 1,35g/cm³ were provided.

20 The harvested milkweed fibers (43 vol.%), the PE/PP fibers (7 vol.%), cotton fibers (24 vol.%) and polyester fibers (26 vol.%) were mixed in a multi-mixer and carded. The blend obtained was thermally bonded in a continuous oven at 135°C for 3 minutes.

The parameters of the taker-in were as follows:

- the angle of the pins was set to 105°;

- the pin density was 40 pins/square inch;
- the height of the pins was 6mm; and
- the speed of the taker-in cylinder was 150 rpm. The material obtained had a density of about 12 kg/m^3 and a mean length L_1 of 20mm.

5 Example 3:

Experiments were conducted to prepare a nonwoven material based on a kapok fiber and a PE/PP blend.

Harvested milkweed fibers of the species *kapok fiber* (having a density of 0.35 g/cm^3), and polyolefin fibers (having a polypropylene center wrapped or
10 surrounded in a sheath of polyethylene, having a density of 1.15 g/cm^3 , a mean length of 50 mm, and a fusion temperature of 130°C) were provided.

The harvested kapok fibers (90 vol.%) and the polyolefin fibers (10 vol.%) were mixed in a multi-mixer and carded. The blend obtained was thermally bonded in a continuous oven at 135°C for 2 minutes.

15 The parameters of the taker-in were as follows:

- the angle of the pins was set to 105° ;
- the pin density was 40 pins/square inch;
- the height of the pins was 6mm; and
- the speed of the taker-in cylinder was 150 rpm. The material obtained had a
20 density of about 7 kg/m^3 , and was used as a oil sorbent pad. This material can be used to obtain sorbent pads of different surface area and weight, in order to absorb up to about 100 times its weight. For example, sorbent pads that can absorb up to 1L, 3L, 15L of oil, and more, can be obtained.

Exemple 4:

Experiments were conducted to prepare a nonwoven material based on a milkweed fiber and a blend of PE/PP.

Harvested milkweed fibers of the species *Asclepias syriaca* (having a density of 0.15 g/cm³ and a mean length L_0 of 30mm) and PE/PP having a density of 1.15 g/cm³, a mean length of 50 mm, and a fusion temperature of 130°C were provided.

The harvested milkweed fibers (90 vol.%), the PE/PP fibers (10 vol.%) were mixed in a multi-mixer and carded. After carding, the mean length L_1 was of 20mm. The non-bonded web obtained after carding was further processed in order to increase the surface weight to 30g/m² from 14 g/m², by feeding the non-bonded web to a series of three cylinders. The parameters of the cylinders were as follows:

- $V_0:V_1 = 1.1$;
- $V_1:V_2 = 1.07$;
- 15 - $V_2:V_3 = 0.93$;
- the distance between the carding cylinder and the first cylinder was 0.178 mm;
- the distance between the first cylinder and the second cylinder was 0.305 mm;
- the distance between the second cylinder and the third cylinder was 0.305 mm;
- the angle of the pins of the first cylinder was set to 50°;
- 20 - the angle of the pins of the second cylinder was set to 53°;
- the angle of the pins of the third cylinder was set to 120°;
- the pin density for the first cylinder was 143 pins/square inch;
- the pin density for the second cylinder was 140 pins/square inch;

- the pin density for the third cylinder was 130 pins/square inch;
- the linear number of pins was 7.05 pins/inch for the first cylinder;
- the linear number of pins was 6.99 pins/inch for the second cylinder; and
- the linear number of pins was 6 pins/inch for the third cylinder.

5 The parameters of the taker-in were as follows:

- the angle of the pins was set to 105°;
- the pin density was 40 pins/square inch;
- the height of the pins was 6mm; and
- the speed of the taker-in cylinder was 150 rpm.

10 This web processing configuration allowed increasing the density of the product by about 100%, compared to the material obtained after carding.

Example 5:

Experiments were conducted to prepare a nonwoven material based on a milkweed fiber and a blend of PE/PP and kapok fiber.

15 Harvested milkweed fibers of the species *Asclepias syriaca* (having a density of 0.15 g/cm³ and a mean length L_0 of 35mm), PE/PP having a density of 1.15 g/cm³, a mean length of 50 mm, and a fusion temperature of 130°C, and Kapok fibers having a density of 0,35g/cm³ were provided.

The harvested milkweed fibers (76 vol.%), the PE/PP fibers (6 vol.%) and kapok
20 fibers (18 vol.%) were mixed in a multi-mixer and carded. The blend obtained was thermally bonded in a continuous oven at 135°C for 5 minutes.

The parameters of the taker-in were as follows:

- the angle of the pins was set to 105°;
- the pin density was 40 pins/square inch;
- the height of the pins was 6mm; and
- the speed of the taker-in cylinder was 150 rpm. The material obtained had a density of about 4 kg/m³ and a mean length L₁ of 20mm and was used as a spill sorbent. For use in spill sorption applications, this material was enclosed in a PP envelope to create a pillow sorbent.

Example 6:

Experiments were conducted to prepare a nonwoven material based on a milkweed fiber and a PE/PP blend.

Harvested milkweed fibers of the species *Asclepias syriaca* (having a density of 0.25g/cm³ and a mean length L₀ of 40mm), and polyolefin fibers (having a polypropylene center wrapped or surrounded in a sheath of polyethylene, having a density of 1.15 g/cm³, a mean length of 51 mm, and a fusion temperature of 128°C were provided.

The harvested milkweed fibers (86 vol.%) and the polyolefin fibers (14 vol.%) were mixed in a multi-mixer and carded. The blend obtained was thermally bonded in a continuous oven at 135°C for 5 minutes.

The parameters of the taker-in were as follows:

- the angle of the pins was set to 105°;
- the pin density was 40 pins/square inch;
- the height of the pins was 6mm; and
- the speed of the taker-in cylinder was 150 rpm. The material obtained had a density of about 6 kg/m³, and was used as a thermal insulation material. After

transformation the milkweed fibers in the nonwoven material had a mean length L_1 of 25mm.

Example 7:

Experiments were conducted to prepare a nonwoven material based on a
5 milkweed fiber and a blend of HDPE/PP.

Harvested milkweed fibers of the species *Asclepias syriaca* (having a density of 0.25g/cm³ and a mean length L_0 of 40mm), and PE/PP having a density of 0.95 g/cm³, a mean length of 38.1 mm, and a fusion temperature of 128°C were provided.

10 The harvested milkweed fibers (86 vol.%) and the polyolefin fibers (14 vol.%) were mixed and carded by hand. Several layers were stacked and bonded to one another by spraying an adhesive composed of a synthetic elastomer having a solid content between 22% by weight (3M Foam Fast 74 Spray Adhesive). The blend obtained was thermally bonded with an iron at 200°C for 1 minutes.

15 The mean length L_1 was equal to 30mm.

Comparative Example:

Experiments were conducted to prepare a nonwoven material based on a milkweed fiber and a PE/PP blend.

20 Harvested milkweed fibers of the species *Asclepias syriaca* (having a density of 0.25g/cm³ and a mean length L_0 of 40mm), and polyolefin fibers (having a polypropylene center wrapped or surrounded in a sheath of high density polyethylene, having a density of 0.95 g/cm³, a mean length of 38.1 mm, and a fusion temperature of 128°C were provided.

The harvested milkweed fibers (90 vol.%) and the polyolefin fibers (10 vol.%)
25 were mixed in a multi-mixer and carded.

The parameters of the taker-in were as follows:

- the angle of the pins was set to 90°;
 - the pin density was 113 pins/square inch;
 - the height of the pins was 4.5mm; and
- 5 - the speed of the taker-in cylinder was 450 rpm.

The output blend obtained did not possess suitable mechanical properties, as the carded milkweed fibers had a mean length $L_1 = 0.13$ mm, such that $L_1:L_0 = 0.325$ (i.e., lower than 0.5). It is believed that this increased mechanical degradation of the milkweed fibers was due to the parameters of the taker-in cylinder.

CLAIMS

1. A nonwoven material, comprising hollow plant fibers having a mean length L_1 and a second fibrous material, the hollow plant fibers and the second fibrous material being mixed substantially homogeneously and thermally bonded together, the hollow plant fibers originating from harvested hollow plant fibers having an initial mean length L_0 , wherein the ratio $L_1:L_0$ is from 0.5 to 1.
2. The nonwoven material of claim 1, wherein the hollow plant fibers and the second fibrous material are directionally oriented substantially parallel to one another.
3. The nonwoven material of claim 1, wherein the hollow plant fibers and the second fibrous material are randomly oriented with respect to one another.
4. The nonwoven material of any one of claims 1 to 3, wherein the hollow plant fibers comprise cellulosic hollow plant fibers.
5. The nonwoven material of any one of claims 1 to 4, wherein the hollow plant fibers comprise milkweed fibers, ramie fibers, urtica fibers, kapok fibers or a mixture thereof.
6. The nonwoven material of any one of claims 1 to 5, wherein the hollow plant fibers comprise milkweed fibers.
7. The nonwoven material of claim 5 or 6, wherein the milkweed fibers comprise *Asclepias syriaca* (common milkweed), *Asclepias speciosa* (showy milkweed) or a mixture thereof.
8. The nonwoven material of any one of claims 1 to 7, wherein the ratio $L_2:L_0$ is from 0.5 to 2.
9. The nonwoven material of any one of claims 1 to 8, wherein the ratio $L_2:L_0$ is from 0.75 to 1.5.

10. The nonwoven material of any one of claims 1 to 9, wherein the second fibrous material comprises fibers of a cylindrical shape.

11. The nonwoven material of any one of claims 1 to 10, wherein the second fibrous material comprises synthetic fibers.

5 12. The nonwoven material of claim 11, wherein the synthetic fibers comprise polyethylene and/or polypropylene.

13. The nonwoven material of any one of claims 1 to 12, wherein L_1 is between 20 mm and 60 mm.

10 14. The nonwoven material of any one of claims 1 to 12, wherein L_1 is between 20 mm and 40 mm.

15. The nonwoven material of any one of claims 1 to 14, wherein the hollow plant fibers have a diameter between 15 microns and 30 microns.

16. The nonwoven material of any one of claims 1 to 15, wherein the hollow plant fibers have an external wall thickness between 1 and 2 microns.

15 17. The nonwoven material of any one of claims 1 to 16, wherein the hollow plant fibers have a first density d_1 which is between 0.10 and 0.20 g/cm³.

18. The nonwoven material of any one of claims 1 to 16, wherein the hollow plant fibers have a first density d_1 which is between 0.10 and 0.40 g/cm³.

20 19. The nonwoven material of any one of claims 1 to 18, wherein the second fibrous material has a second density d_2 which is between 0.7 and 2.0 g/cm³.

20. The nonwoven material of claim 19, wherein d_2 is between 0.7 and 1.5 g/cm³.

21. The nonwoven material of claim 19, wherein d_2 is between 1.0 and 1.2 g/cm³.

22. The nonwoven material of any one of claims 19 to 21, which comprises:

70 vol% to 95 vol% of the hollow plant fibers; and

5 vol% to 30 vol% of the second fibrous material.

23. The nonwoven material of any one of claims 19 to 21, which comprises:

85 vol% to 95 vol% of the hollow plant fibers; and

5 vol% to 15 vol% of the second fibrous material.

5 24. The nonwoven material of any one of claims 19 to 21, which comprises:

87 vol% to 93 vol% of the hollow plant fibers; and

7 vol% to 13 vol% of the second fibrous material.

25. The nonwoven material of any one of claims 1 to 24, further comprising a third fibrous material.

10 26. The nonwoven material of claim 25, wherein the third fibrous material is selected from the group consisting of natural fibers, synthetic fibers, animal fibers, mineral fibers and blends thereof.

27. The nonwoven material of claim 26, wherein the third fibrous material comprises a natural fiber selected from the group consisting of cotton, kapok,
15 bamboo, linen, hemp, kenaf, jute, abaca, coir (coconut), ramie, sisal and blends thereof.

28. The nonwoven material of claim 26 or 27, wherein the third fibrous material comprises an animal fiber selected from the group consisting of wool, alpaca, angora, cashmere, mohair, vicuna, silk and blends thereof.

20 29. The nonwoven material of any one of claims 26 to 28, wherein the third fibrous material comprises a synthetic fiber selected from the group consisting of polyphenylene sulfide (PPS), polyester, acetate, triacetate, polyamide (nylon), poly (p-phenylene-2,6 benzobisoxazole) (PBO), liquid crystal polymer (aramid, fiber and Thermotropic as Vectran and Ticona, polyhydroquinone-
25 diimidazopyridine (PIPD), polyethylene (UHMWPE, HMPE, HPPE, HDPE, LDPE

etc.), acetal, polyvinyl alcohol (PVA), polyvinylidene chloride (PVDC), polyvinyl chloride (PVC), modacrylic, acrylic, Polybenzimidazole (PBI) and blends thereof.

30. The nonwoven material of any one of claims 26 to 29, wherein the mineral fiber is selected from the group consisting of carbon fiber, glass fiber, metal fiber,
5 basalt and blends thereof.

31. The nonwoven material of any one of claims 1 to 30, having a density between 3 and 120 kg/m³.

32. The nonwoven material of any one of claims 1 to 31, having a thickness between 0.5 cm and 15 cm.

10 33. The nonwoven material of any one of claims 1 to 31, having a thickness between 0.5 cm and 2.5 cm.

34. A nonwoven material, comprising hollow plant fibers having a mean length L_1 and a second fibrous material, the hollow plant fibers and the second fibrous material being mixed substantially homogeneously, the first fibrous material and
15 the second fibrous material being chemically bonded together, the hollow plant fibers originating from harvested hollow plant fibers having an initial mean length L_0 , wherein the ratio $L_1:L_0$ is from 0.5 to 1.

35. The nonwoven material of claim 34, wherein the hollow plant fibers and the second fibrous material are directionally oriented substantially parallel to one
20 another.

36. The nonwoven material of claim 34, wherein the hollow plant fibers and the second fibrous material are randomly oriented with respect to one another.

37. The nonwoven material of any one of claims 34 to 36, wherein the hollow plant fibers comprise cellulosic hollow plant fibers.

38. The nonwoven material of any one of claims 34 to 36, wherein the hollow plant fibers comprise milkweed fibers, ramie fibers, urtica fibers, kapok fibers or a mixture thereof.

5 39. The nonwoven material of any one of claims 34 to 38, wherein the hollow plant fibers comprise milkweed fibers.

40. The nonwoven material of claim 38 or 39, wherein the milkweed fibers comprise *Asclepias syriaca* (common milkweed), *Asclepias speciosa* (showy milkweed) or a mixture thereof.

10 41. The nonwoven material of any one of claims 34 to 40, wherein the ratio $L_2:L_0$ is from 0.5 to 2.

42. The nonwoven material of any one of claims 34 to 41, wherein the ratio $L_2:L_0$ is from 0.75 to 1.5.

43. The nonwoven material of any one of claims 34 to 42, wherein the second fibrous material comprises fibers of a cylindrical shape.

15 44. The nonwoven material of any one of claims 34 to 43, wherein the second fibrous material comprises synthetic fibers.

45. The nonwoven material of claim 44, wherein the synthetic fibers comprise polyethylene and/or polypropylene.

20 46. The nonwoven material of any one of claims 34 to 45, wherein L_1 is between 20 mm and 60 mm.

47. The nonwoven material of any one of claims 34 to 45, wherein L_1 is between 20 mm and 40 mm.

48. The nonwoven material of any one of claims 34 to 47, wherein the hollow plant fibers have a diameter between 15 microns and 30 microns.

49. The nonwoven material of any one of claims 34 to 48, wherein the hollow plant fibers have an external wall thickness between 1 and 2 microns.

50. The nonwoven material of any one of claims 1 to 49, wherein the hollow plant fibers have a first density d_1 which is between 0.10 and 0.20 g/cm³.

5 51. The nonwoven material of any one of claims 1 to 49, wherein the hollow plant fibers have a first density d_1 which is between 0.10 and 0.40 g/cm³.

52. The nonwoven material of any one of claims 1 to 51, wherein the second fibrous material has a second density d_2 which is between 0.7 and 2.0 g/cm³.

53. The nonwoven material of claim 52, wherein d_2 is between 0.7 and 1.5 g/cm³.

10 54. The nonwoven material of claim 52, wherein d_2 is between 1.0 and 1.2 g/cm³.

55. The nonwoven material of any one of claims 52 to 54, which comprises:

70 vol% to 95 vol% of the hollow plant fibers; and

5 vol% to 30 vol% of the second fibrous material.

56. The nonwoven material of any one of claims 52 to 54, which comprises:

15 85 vol% to 95 vol% of the hollow plant fibers; and

5 vol% to 15 vol% of the second fibrous material.

57. The nonwoven material of any one of claims 52 to 54, which comprises:

87 vol% to 93 vol% of the hollow plant fibers; and

7 vol% to 13 vol% of the second fibrous material.

20 58. The nonwoven material of any one of claims 34 to 57, further comprising a third fibrous material.

59. The nonwoven material of claim 58, wherein the third fibrous material is selected from the group consisting of natural fibers, synthetic fibers, animal fibers, mineral fibers and blends thereof.

60. The nonwoven material of claim 59, wherein the third fibrous material
5 comprises a natural fiber selected from the group consisting of cotton, kapok, bamboo, linen, hemp, kenaf, jute, abaca, coir (coconut), ramie, sisal and blends thereof.

61. The nonwoven material of claim 59 or 60, wherein the third fibrous material
10 comprises an animal fiber selected from the group consisting of wool, alpaca, angora, cashmere, mohair, vicuna, silk and blends thereof.

62. The nonwoven material of any one of claims 59 to 61, wherein the third
fibrous material comprises a synthetic fiber selected from the group consisting of
polyphenylene sulfide (PPS), polyester, acetate, triacetate, polyamide (nylon),
poly (p-phenylene-2,6 benzobisoxazole) (PBO), liquid crystal polymer (aramid,
15 fiber and Thermotropic as Vectran and Ticona, polyhydroquinone-
diimidazopyridine (PIPD), polyethylene (UHMWPE, HMPE, HPPE, HDPE, LDPE
etc.), acetal, polyvinyl alcohol (PVA), polyvinylidene chloride (PVDC), polyvinyl
chloride (PVC), modacrylic, acrylic, Polybenzimidazole (PBI) and blends thereof.

63. The nonwoven material of any one of claims 59 to 62, wherein the mineral
20 fiber is selected from the group consisting of carbon fiber, glass fiber, metal fiber, basalt and blends thereof.

64. The nonwoven material of any one of claims 34 to 63, having a density
between 3 and 120 kg/m³.

65. The nonwoven material of any one of claims 34 to 64, having a thickness
25 between 0.5 cm and 15 cm.

66. The nonwoven material of any one of claims 34 to 65, having a thickness
between 0.5 cm and 2.5 cm.

67. The nonwoven material of any one of claims 1 to 66, wherein the first fibrous material and the second fibrous material are thermally and chemically bonded together.

5 68. The nonwoven material of any one of claims 1 to 67, for use as a thermal insulator.

69. The nonwoven material of any one of claims 1 to 67, for use as an acoustic insulator.

70. The nonwoven material of any one of claims 1 to 67, for use as a sorbent material.

10 71. A nonwoven web, comprising the nonwoven material of any one of claims 1 to 67.

72. A process for manufacturing a nonwoven material, comprising:

providing hollow plant fibers and a second fibrous material, the harvested hollow plant fibers having an initial mean length L_0 ;

15 mixing the hollow plant fibers and the second fibrous material to obtain a substantially homogeneous fiber mixture;

carding the fiber mixture to obtain a non-bonded web such that the hollow plant fibers of the non-bonded web have a mean length L_1 , wherein $L_1:L_0$ is from 0.5 to 1; and

20 bonding the non-bonded web, comprising heating the non-bonded web in order to thermally bond the hollow plant fibers and the second fibrous material, the heating being performed at a temperature between the fusion temperature of the second fibrous material and the degradation temperature of the hollow plant fibers, so as to obtain the nonwoven
25 material as a thermally bonded web.

73. The process of claim 72, wherein the carding of the fiber mixture comprises:

feeding the fiber mixture to a taker-in cylinder provided with pins and having at least one of:

- a pin density between 1 and 80 pins/square inch;
- a pin height between 5 and 6.7 mm; and
- a pin angle between 100° and 115°;

operating the taker-in cylinder to convey the fiber mixture to a carding cylinder; and

operating the carding cylinder to obtain the non-bonded web.

74. The process of claim 73, wherein the taker-in cylinder has:

- a pin density between 1 and 80 pins/square inch;
- a pin height between 5 and 6.7 mm; and
- a pin angle between 100° and 115°.

75. The process of claim 73 or 74, wherein the pin density is between 20 and 80 pins/square inch.

76. The process of claim 75, wherein the pin density is between 30 and 50 pins/square inch.

77. The process of any one of claims 73 to 76, wherein the pin height is between 5.5 and 6.3 mm.

78. The process of any one of claims 73 to 77, wherein the pin angle is between 102° and 107°.

79. The process of claim 73, wherein the taker-in cylinder has a substantially smooth or substantially pin-less surface.

80. The process of any one of claims 73 to 79, wherein the taker-in cylinder has a rotation speed between 50 and 200 rpm.

81. The process of any one of claims 73 to 79, wherein the taker-in cylinder has a rotation speed between 125 and 175 rpm.

5 82. The process of any one of claims 72 to 81, wherein bonding the non-bonded web further comprises chemically bonding the non-bonded web in order to chemically bond the hollow plant fibers and the second fibrous material.

83. The process of claim 82, wherein the chemical bonding is performed concurrently to the thermal bonding.

10 84. The process of claim 82, wherein the chemical bonding is performed prior to the thermal bonding.

85. The process of claim 82, wherein the chemical bonding is performed after the thermal bonding.

15 86. The process of any one of claims 72 to 85, wherein bonding the non-bonded web further comprises mechanically bonding the non-bonded web prior to the heating step.

87. The process of any one of claims 72 to 86, wherein bonding the non-bonded web further comprising mechanically bonding the thermally bonded web after the heating step.

20 88. The process of claim 86 or 87, wherein the mechanical bonding comprises at least one of needling and jogging.

89. The process of any one of claims 72 to 88, further comprising opening the second fibrous material and the hollow plant fiber prior to the mixing step.

90. The process of any one of claims 72 to 89, wherein the carding step is performed so as to directionally orient the hollow plant fibers and the second fibrous material substantially parallel to one another in the non-bonded web.

5 91. The process of any one of claims 72 to 90, further comprising feeding the non-bonded web into a series of rotating cylinders in order to randomly orient the hollow plant fibers and the second fibrous material with respect to one another.

92. The process of any one of claims 72 to 91, further comprising winding the thermally bonded web.

10 93. The process of any one of claims 72 to 92, wherein the heating temperature is selected to be between 5°C and 40°C higher than the fusion temperature of the second fibrous material.

94. The process of any one of claims 72 to 92, wherein the temperature is selected to be between 5°C and 10°C higher than the fusion temperature of the second fibrous material.

15 95. The process of any one of claims 72 to 94, wherein the second fibrous material has an initial length L_2 , and wherein the hollow plant fibers and the second fibrous material are selected such that the ratio $L_2:L_0$ is from 0.5 to 2.

96. The process of claim 95, wherein the ratio $L_2:L_0$ is from 0.75 to 1.5.

97. The process of claim 95, wherein the ratio $L_2:L_0$ is from 1 to 1.5.

20 98. The process of any one of claims 72 to 97, wherein the hollow plant fibers comprise cellulosic hollow plant fibers.

99. The process of any one of claims 72 to 98, wherein the hollow plant fibers comprise milkweed fibers, ramie fibers, urtica fibers, kapok fibers or a mixture thereof.

100. The process of any one of claims 72 to 99, wherein the hollow plant fibers comprise milkweed fibers.

101. The process of claim 99 or 100, wherein the milkweed fibers comprise *Asclepias syriaca* (common milkweed), *Asclepias speciosa* (showy milkweed) or
5 a mixture thereof.

102. The process of any one of claims 72 to 101, wherein the second fibrous material comprises fibers of a cylindrical shape.

103. The process of any one of claims 72 to 102, wherein the second fibrous material comprises synthetic fibers.

10 104. The process of claim 103, wherein the synthetic fibers comprise polyethylene and/or polypropylene.

105. The process of any one of claims 72 to 104, wherein the hollow plant fibers have a diameter between 15 microns and 30 microns.

106. The process of any one of claims 72 to 105, wherein the hollow plant fibers
15 have an external wall thickness between 1 and 2 microns.

107. The process of any one of claims 72 to 106, wherein the hollow plant fibers have a first density d_1 which is between 0.10 and 0.20 g/cm³.

108. The process of any one of claims 72 to 106, wherein the hollow plant fibers have a first density d_1 which is between 0.10 and 0.40 g/cm³.

20 109. The process of any one of claims 72 to 108, wherein the second fibrous material has a second density d_2 which is between 0.7 and 2.0 g/cm³.

110. The process of claim 109, wherein d_2 is between 0.7 and 1.5 g/cm³.

111. The process of claim 109, wherein d_2 is between 1.0 and 1.2 g/cm³.

112. The process of any one of claim 72 to 111, further comprising providing a third fibrous material, and wherein the mixing step comprises mixing the hollow plant fibers, the second fibrous material and the third fibrous material to obtain the substantially homogeneous fiber mixture.

- 5 113. The process of claim 112, wherein the third fibrous material is selected from the group consisting of natural fibers, synthetic fibers, animal fibers, mineral fibers and blends thereof.

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FIG. 1

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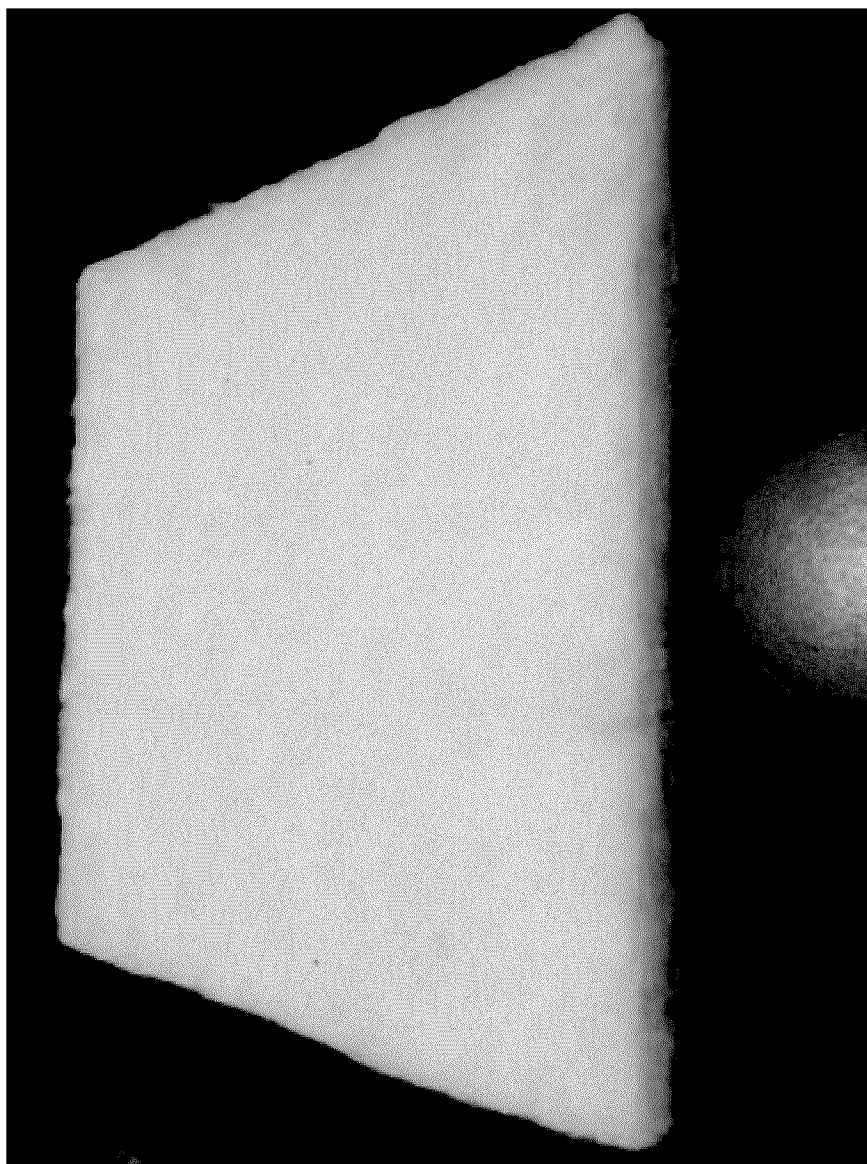


FIG. 2

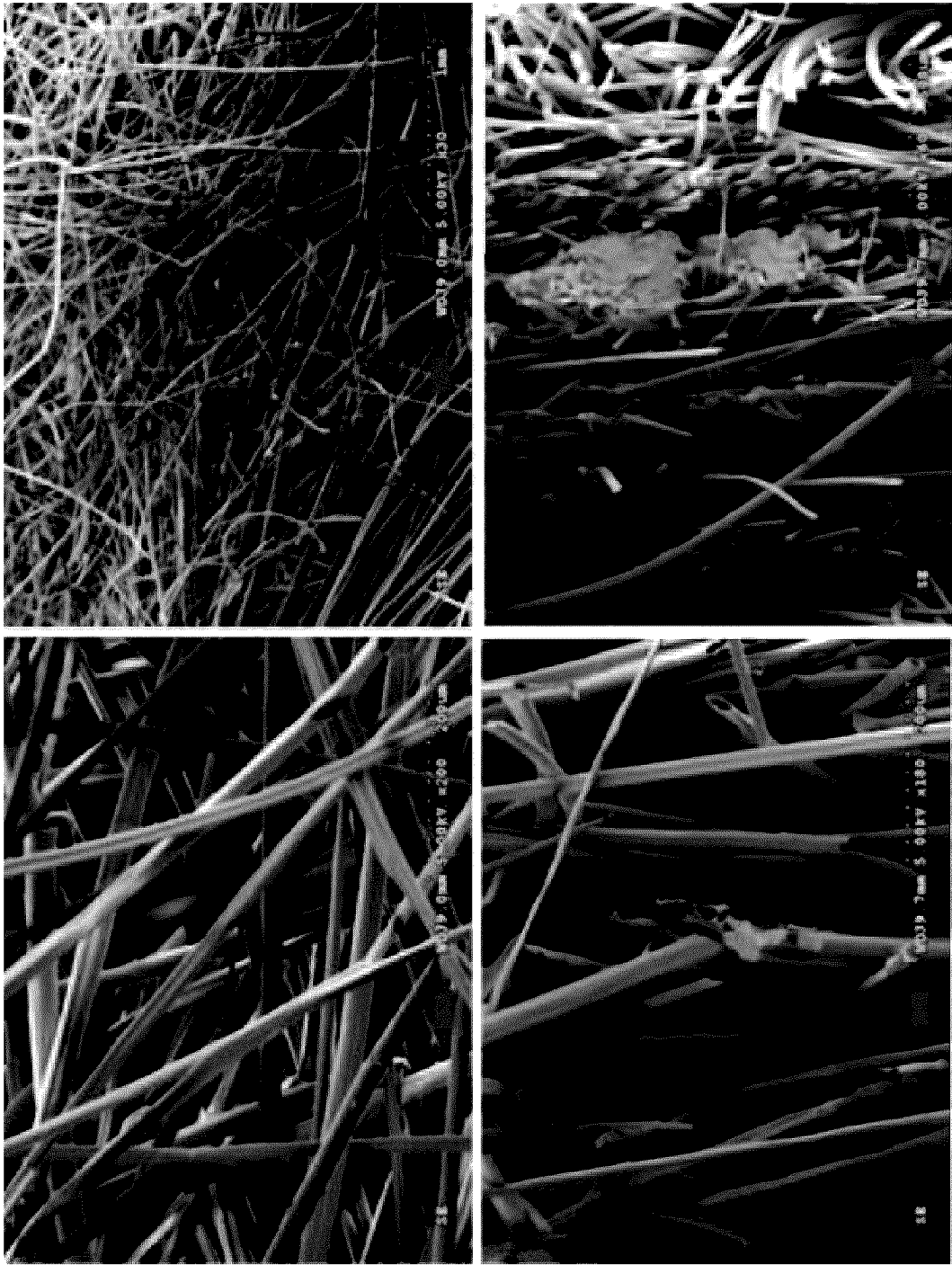


FIG. 3

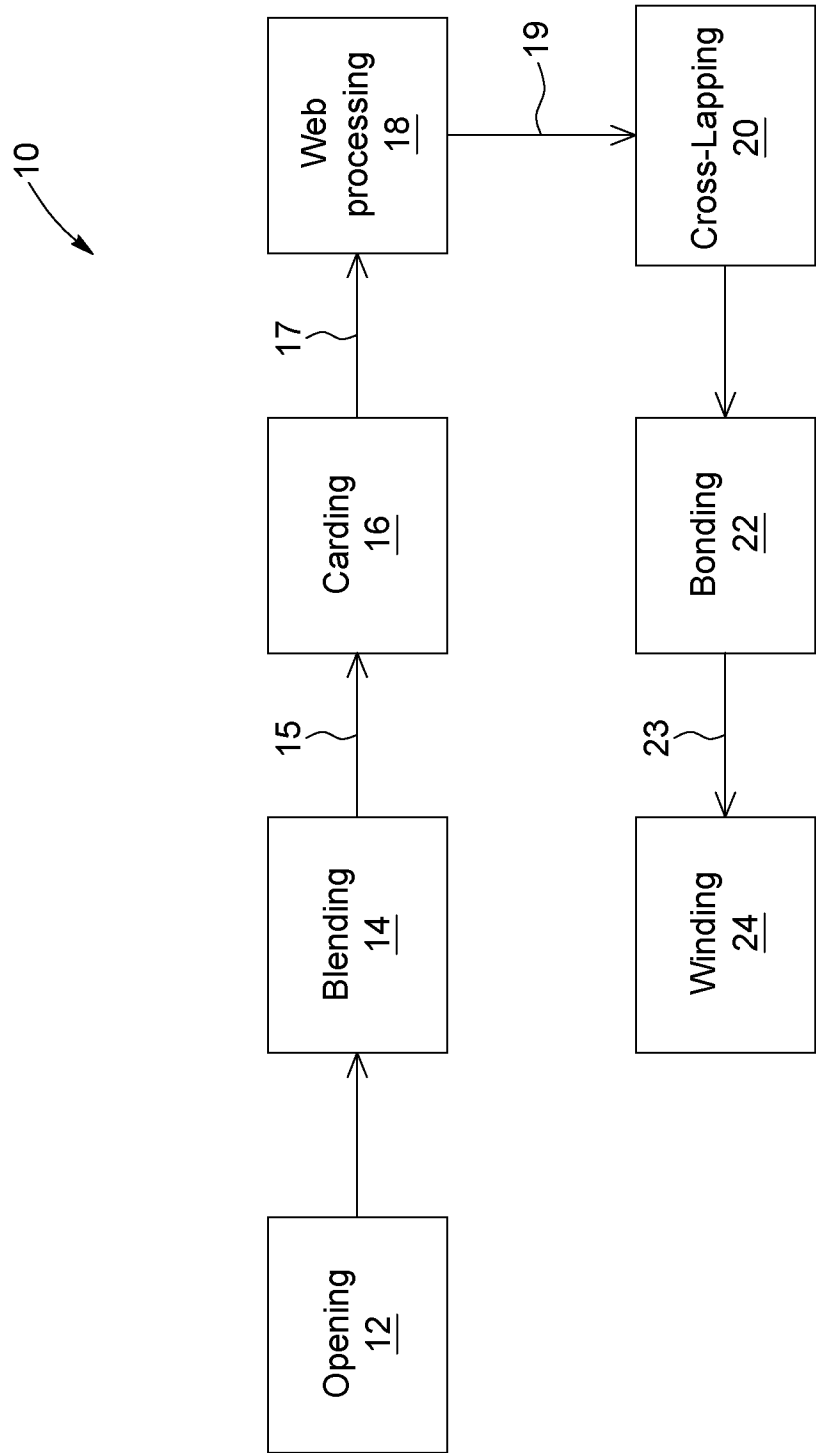


FIG. 4

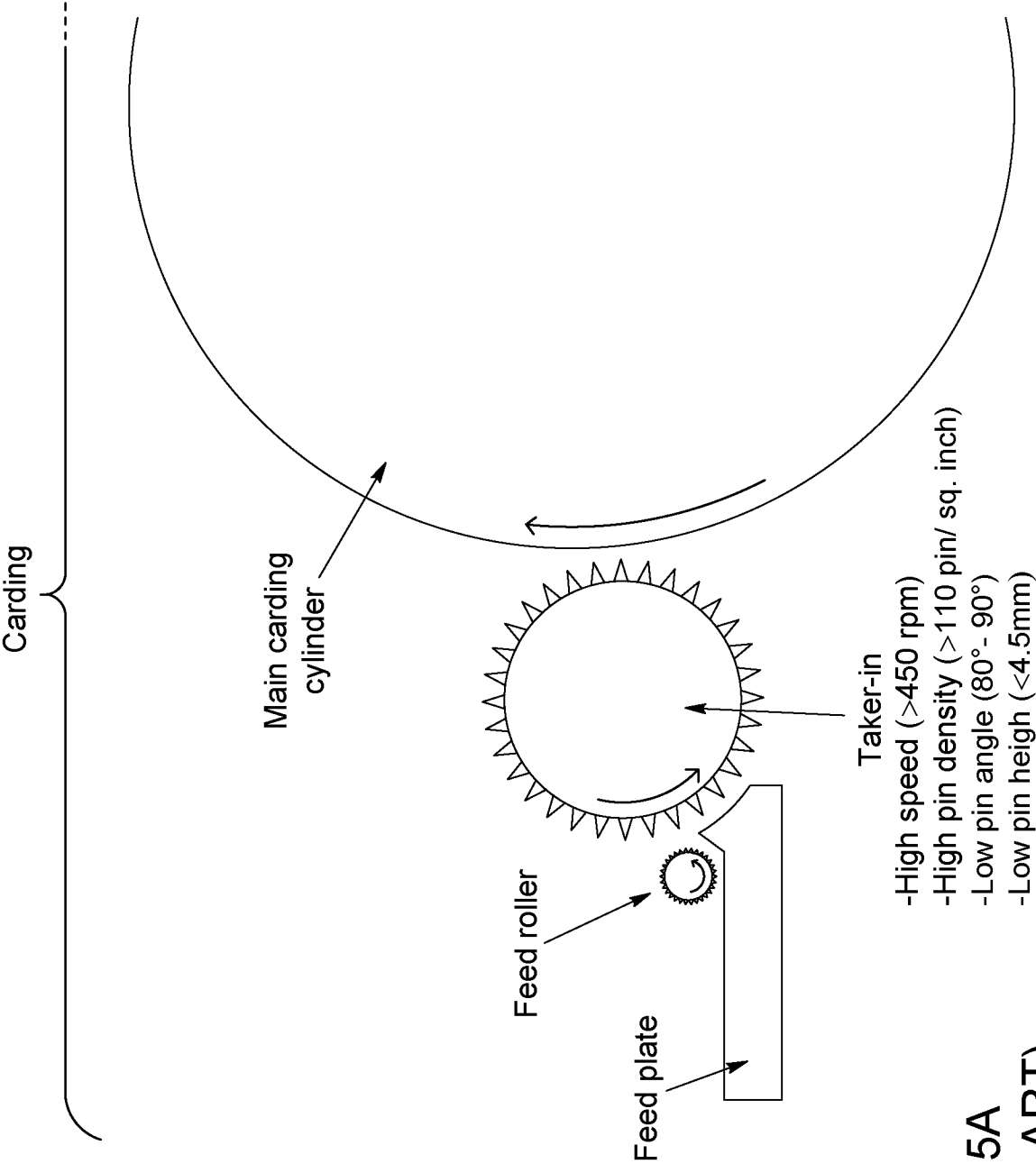


FIG. 5A
(PRIOR ART)

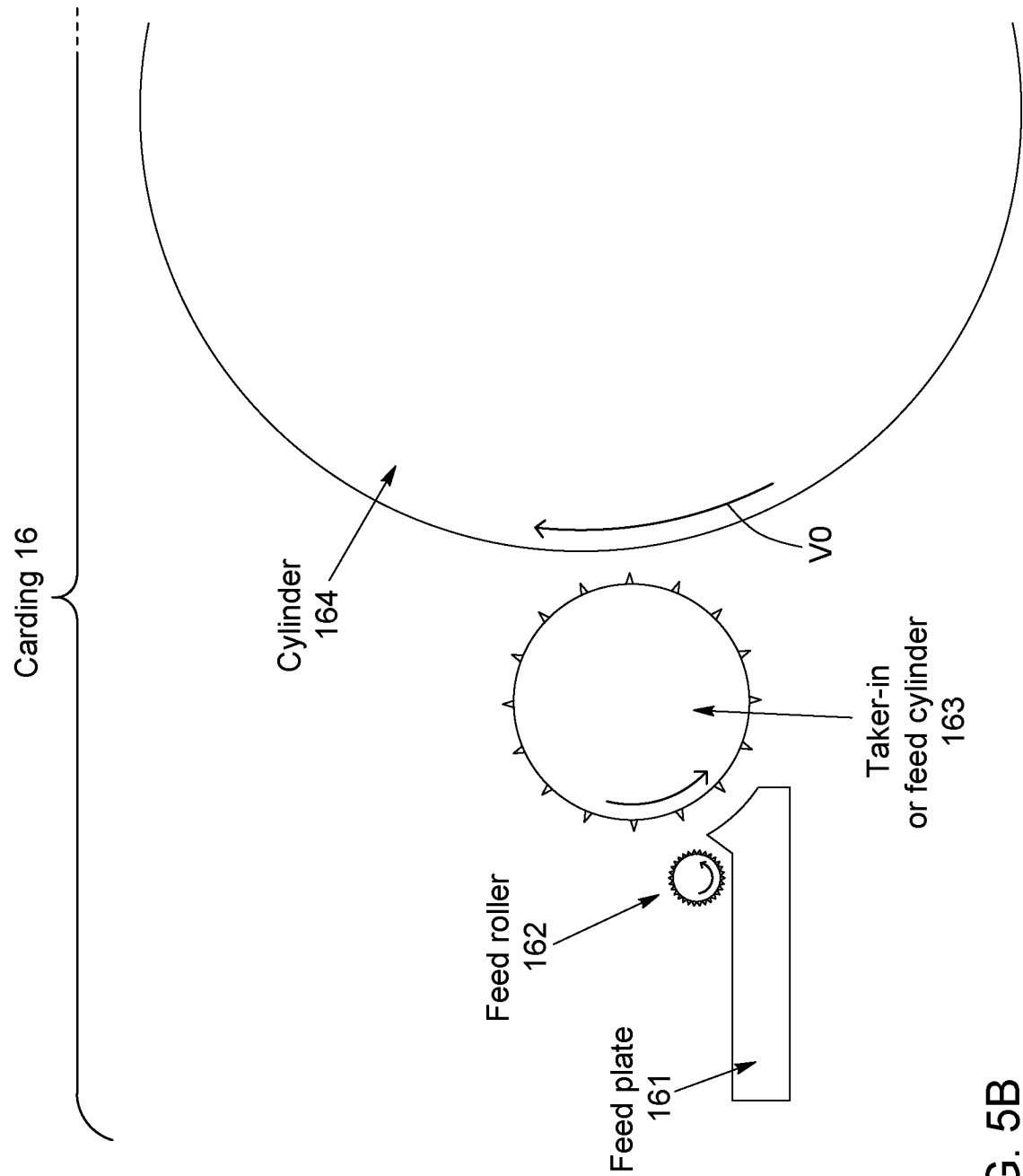
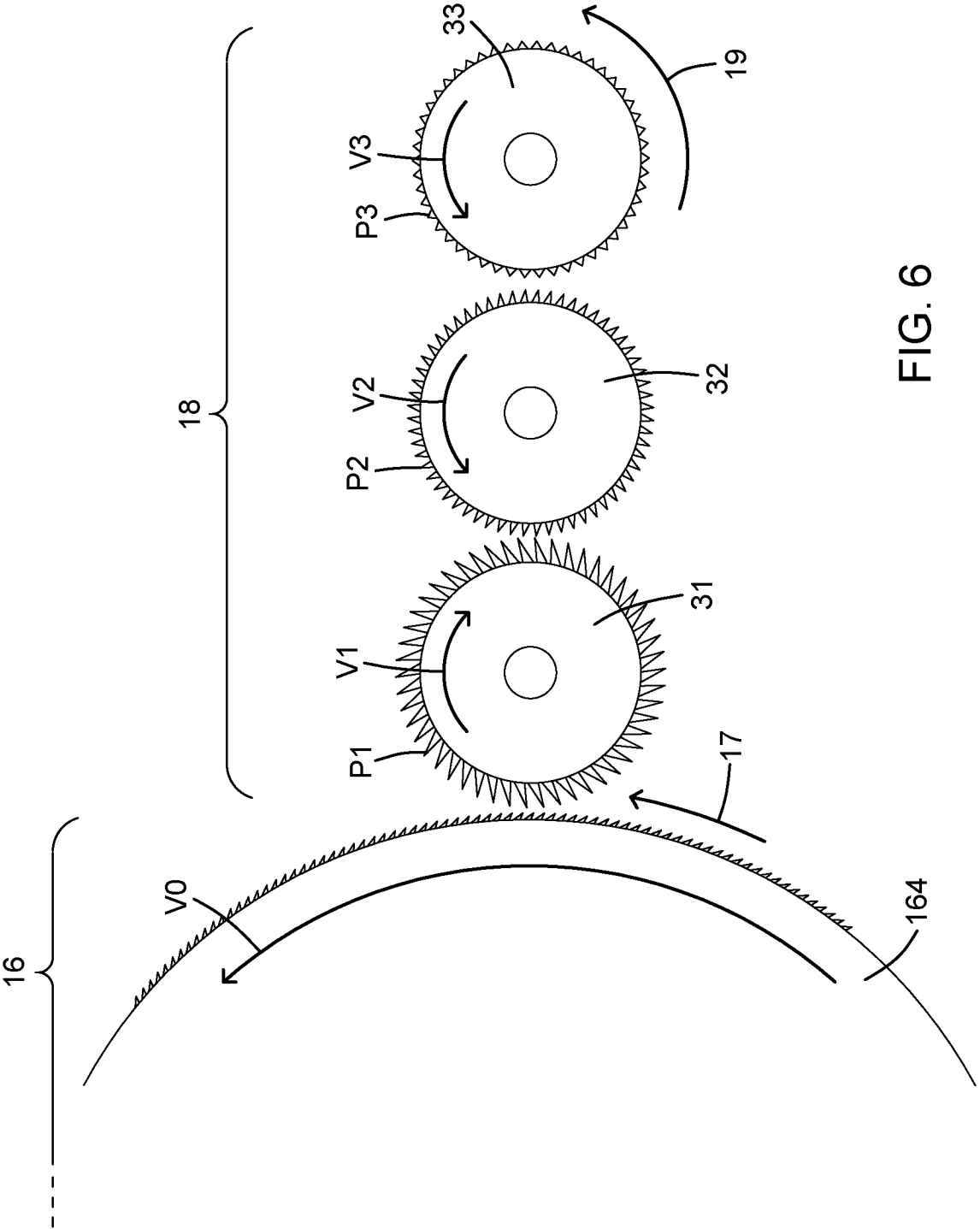


FIG. 5B



INTERNATIONAL SEARCH REPORT

International application No.

PCT/CA2016/051286

A. CLASSIFICATION OF SUBJECT MATTER

IPC: **D04H 1/488** (2012.01) , **D04H 1/58** (2012.01) , **D04H 1/70** (2012.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC: **D04H** (2012.01)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)

Questel-Orbit with key words, such as: plant, fiber, hollow, milkweed, length, bond+, diameter, density, etc.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2014201558 A1 (SIMARD, D. et al.) 24 December 2014 (24-12-2014) *whole document*	1,3-27,29-34,36-60,62-85, 95-111
Y		2, 35, 90
X	WO 2015023558 A1 (BAER, S. C. et al.) 19 February 2015 (19-02-2015) *whole document*	1,3-5,10-12,25-29,36-38,43-45, 58-62,67-89,91-94,98,99, 102-104,112,113
Y	US 2407548 A (GOLDMAN, J.) 10 September 1946 (10-09-1946) *whole document*	2, 35, 90

Further documents are listed in the continuation of Box C.

See patent family annex.

* "A" "E" "L" "O" "P"	Special categories of cited documents: document defining the general state of the art which is not considered to be of particular relevance earlier application or patent but published on or after the international filing date document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) document referring to an oral disclosure, use, exhibition or other means document published prior to the international filing date but later than the priority date claimed	"T" "X" "Y" "&"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art document member of the same patent family
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Date of the actual completion of the international search
03 January 2017 (03-01-2017)Date of mailing of the international search report
10 January 2017 (10-01-2017)Name and mailing address of the ISA/CA
Canadian Intellectual Property Office
Place du Portage I, C114 - 1st Floor, Box PCT
50 Victoria Street
Gatineau, Quebec K1A 0C9
Facsimile No.: 819-953-2476

Authorized officer

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/CA2016/051286

Patent Document Cited in Search Report	Publication Date	Patent Family Member(s)	Publication Date
WO2014201558A1	24 December 2014 (24-12-2014)	None	
WO2015023558A1	19 February 2015 (19-02-2015)	WO2015023558A1 CA2921537A1 CN105579634A EP3033449A1 IL244114D0 TW201522735A US2016201239A1	19 February 2015 (19-02-2015) 19 February 2015 (19-02-2015) 11 May 2016 (11-05-2016) 22 June 2016 (22-06-2016) 21 April 2016 (21-04-2016) 16 June 2015 (16-06-2015) 14 July 2016 (14-07-2016)
US2407548A	10 September 1946 (10-09-1946)	US2407548A GB642890A	10 September 1946 (10-09-1946) 13 September 1950 (13-09-1950)