(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
25 May 2023 (25.05.2023)

(10) International Publication Number
WO 2023/088951 A1

(51) International Patent Classification:
B29B 17/00 (2006.01)

(21) International Application Number:
PCT/EP2022/082110

(22) International Filing Date:
16 November 2022 (16.11.2022)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
2100173-0 16 November 2021 (16.11.2021) SE
2200045-9 03 May 2022 (03.05.2022) SE

(71) Applicant: **WINGBEAM AS** [NO/NO]; Vauerveien 370, 1684 Vesterøy (NO).

(72) Inventors: **HANSEN, Pål Francis**; Vauerveien 370, 1684 Vesterøy (NO). **DIETRICHSON, Stein**; St Croixgate 10 D, 1604 Fredrikstad (NO).

(74) Agent: **BERGENSTRÅHLE & PARTNERS AB**; P.O. Box 17704, 118 93 Stockholm (SE).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CV, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IQ, IR, IS, IT, JM, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, CV, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, ME, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report (Art. 21(3))*

(54) Title: METHOD FOR PRODUCING A STRUCTURAL ELEMENT BASED ON USED WIND TURBINE BLADES AND STRUCTURAL ELEMENT MADE OF USED WIND TURBINE BLADES

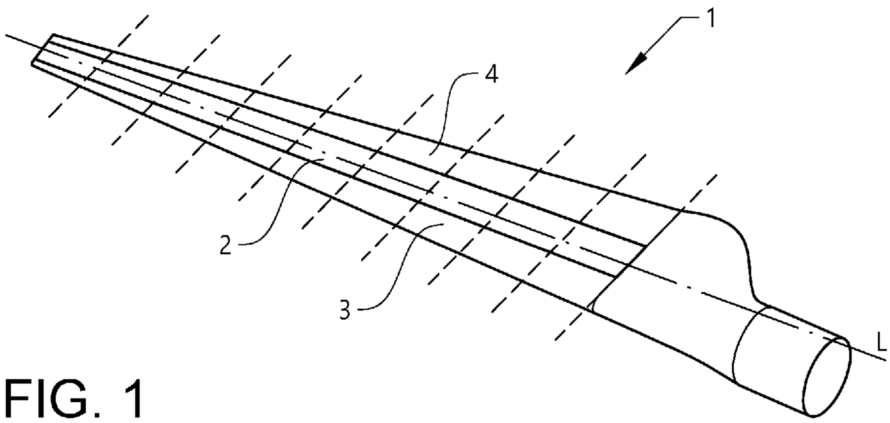

FIG. 1

(57) Abstract: A method for producing a structural element (10) based on used wind turbine blades (1), the method comprising the steps: cutting (S100) at least one composite section (11) from a used wind turbine blade (1); placing (S102) the at least one cut composite section (11) in a mould which defines the dimensions of the structural element (10); adding (S104) a binding agent (12) to the mould; and allowing (S106) the binding agent (12) to solidify to obtain the structural element (10). At least one dimension of the cut composite section (11) substantially corresponds to at least one dimension of the structural element (10). A corresponding structural element (10) is also provided.

WO 2023/088951 A1

DESCRIPTION

Title of Invention:

METHOD FOR PRODUCING A STRUCTURAL ELEMENT BASED ON USED WIND TURBINE BLADES AND STRUCTURAL ELEMENT MADE OF USED WIND TURBINE BLADES

Technical Field

[0001] The present disclosure relates generally to recycling of composites, specifically used wind turbine blades and sections thereof. More specifically, the present disclosure relates to a method for producing a structural element based on used wind turbine blades, such as railway sleepers or load-carrying beams, and to such structural elements.

Background Art

[0002] A limited number of disclosures and scientific articles describe the recycling of wind turbine blades. The issue is relatively new as the expansion of wind power in the past 20 years only now generates a predictable and sizeable flow of used wind turbine blades of known composition and known properties. Blades have a lifetime of about 15 years. In Scandinavia and Germany alone, a total of >40 000 installed turbines generate a flow of about 40 000 tons of used blades annually (at 5 ton/blade).

[0003] Typically, wind turbine blades are cut and ground to powder form. To the extent possible, fractions such as glass fibre, wood, plastics etc are separated according to methods known in the art of recycling. Some powder streams are used as fillers for railway sleepers, see e.g. an initiative by Eneco in The Netherlands: https://news.eneco.com/old-wind-turbines-become-railway-sleepers/.

[0004] J.P. Jensen et al. (2018), “Wind turbine recycling: Experiences, challenges and possibilities in a circular economy”. *Renewable and Sustainable Energy Reviews*, *97*, pages 165-176 explores available treatment technologies for glass fibre reinforced plastics (GFRP) in used wind turbine blades and secondary applications in new products.

[0005] In general, separating and recirculating raw materials directly to identical or similar applications is considered most appropriate in circular economy thinking. Use of materials in new applications is considered “downcycling”. The present disclosure is an example that downcycling can be highly appropriate, better for the environment and cheaper for all stakeholders such as wind turbine blades suppliers, recycling companies, customers for long-lived articles of use such as railway sleepers or construction elements, and society.

[0006] Geiger et al., (2020), “Composite wind turbine blade recycling – value creation through Industry 4.0 to enable circularity in repurposing of composites”. *IOP Conference Series: Materials Science and Engineering*, *942*, 012016; describes cases where whole sections of used wind turbine blades are used as roofs or architectural components for bridges and the like. These examples are very convincing; however, they are difficult to scale, i.e. difficult to apply in a mass production of articles for industries under cost pressure.

[0007] Korniejenko et al., (2021), “Tackling the circular economy challenges – composites recycling: used tyres, wind turbine blades and solar panels”, *J. Compos. Sci.*, *5*, 243, describe the various options for recycling of blades such as material recovery, chemical recovery, incineration.

[0008] Yazdanbakhsh et al., (2018), “Concrete with discrete slender elements from mechanically recycled wind turbine blades”, *Resources, Conservation & Recycling*, *128*, 11–21; describes processing wind turbine blade shells made of glass fibre reinforced polymer (GFRP) composite materials into slender elements referred to as “Needles” and mixing the Needles into concrete to increase toughness.

[0009] Industrial companies are active in the field of recycling wind turbine blades. Typically, they cut blades and grind the materials to powder or fibre form. An example is the German company Roth, see: https://www.roth-international.de/en/recycling-recovery/recycling-of-rotor-blades.

[0010] There is a demand in the railway industry for functional, cheap and sustainable railway sleepers. Functional demands relate to hardness, stability in use, mechanical properties, ease of application etc. The industry has to be cost-competitive, therefore prices are a prime selection criterion. Public purchasing has to take environmental arguments seriously in consideration, therefore concrete sleepers with their inherently high carbon footprint will be de-selected by public (and private!) purchasing provided that equally performing alternatives are available.

[0011] Railway sleepers, one of the target application of the present disclosure, are characterised by these general facts: Typical dimensions: L×W×H (cm) 260×26×16 (heavy haul track sleeper), typical weight wood (creosote impregnated): 80-115 kg, in the case of steel reinforced concrete: 360 kg. Typical distance between sleepers is 0,70 m.

[0012] Market demand:
Norway: 4.200 km railways giving about 6 mill. Sleepers,
EU: 208.000 km railways giving about 297 mill. Sleepers,
World: 1.307.000 km railways giving about 1.867 mill. sleepers.
Market demand for sleepers is in a similar order of magnitude as the potential supply of components from used wind turbine blades which makes the present disclosure highly attractive on the marketplace.

[0013] A railway sleeper is but one example of a useful application of used composites from the wind industry. In the building industry, beams and load-carrying components are required, typically in the form of steel, wood. The invention allows to replace steel and wood, and as composites can be cut-out to meet specific requirements, the invention meets an existing market demand.

[0014] General characteristics of wind turbine blades are as follows: Typical blades of 37 m length weight 5.000 kg per blade, of 47 m length: 12.500 kg per blade, >47 m length > 15.000 kg per blade.

[0015] Typical composite materials are:
- 40 % Thermoset resin systems and gelcoats (epoxy, vinylester, polyester),
- 35 % Glass fibre reinforcement (multiaxial, uni-directional and woven mats, optimized for overall max stiffness and strength control,
- 25 % Sandwich core materials for increased stiffness and weight reduction (PVC, BALSA, PET).

Summary of Invention

[0016] Given the prior art, the objective of the present disclosure is to provide novel structural elements, especially but not limited to railway sleepers, based on used wind turbine blade parts and binding agents, with excellent or very acceptable properties regarding strength, processability, ability to manufacture cheaply, and other properties, all allowing to use waste such as used wind turbine blades in a better and more sustainable manner.

[0017] This object is achieved in a first aspect of the present disclosure, in which there is provided a method for producing a structural element based on used wind turbine blades, the method comprising the steps:

cutting at least one composite section from a used wind turbine blade;

placing the at least one cut composite section in a mould which defines the dimensions of the structural element;

adding a binding agent to the mould; and

allowing the binding agent to solidify to obtain the structural element,

wherein at least one dimension of the cut composite section substantially corresponds to at least one dimension of the structural element.

[0018] By cutting out a composite section from a used wind turbine blade with at least one dimension substantially corresponding to at least one dimension of the structural element, the present disclosure enables maintaining the material properties of the composite section and impart these material properties to the final structural element. Examples of material properties imparted to the structural element include fibre content, fibre orientation/direction, fibre type, lay-up type, durability, elasticity, flexibility, hardness, stiffness, toughness, etc. Thus, a structural element with substantially the same or corresponding material properties as the used wind turbine blade may be obtained.

[0019] An additional advantage is that the method requires significantly less energy compared to the known recycling methods in which the used material is milled to powder or small elements and used as reinforcement or filler in production of new raw materials. This leads to lower production costs as well as reducing environmental impact.

[0020] In one embodiment, the at least one composite section is cut from the spar component of the used wind turbine blade. By cutting the composite section from the spar, which is the load bearing component of the wind turbine blade, it is possible to manufacture structural elements with a high strength and stiffness owing to the material properties of the cut composite sections.

[0021] In one embodiment, the length of the at least one cut composite section substantially corresponds to the length of the structural element. By cutting sections of the used wind turbine blade of suitable length, less additional material is required for producing the structural element, which leads to reduced costs. Also, the material properties of the composite section are imparted to substantially the whole length of the structural element. In this context, the term substantially corresponding should be interpreted as meaning within a tolerance range of 10 %. Preferably, the additional material used for the structural element encapsulates the cut composite section, especially the ends thereof.

[0022] In one embodiment, the mould is made of shredded and/or ground composite material from used wind turbine blades and at least one thermoplastic polymer. In this way, more composite material from the used wind turbine blade may be recycled and incorporated in the structural element, leading to a further reduction in cost and environmental impact

[0023] In one embodiment, the mould comprises an open or closed vessel or a prefabricated matrix. The method enables using different methods of casting and forming the structural element.

[0024] In one embodiment, the method further comprises shredding and/or grinding composite material from used wind turbine blades; and mixing up to 50% by weight of the shredded/ground composite material and at least one thermoplastic polymer in a compounding device to form the binding agent. In this way, the cost of the binding agent may be reduced by recycling composite materials from the used wind turbine blade.

[0025] In one embodiment, the method further comprises shredding and/or grinding composite material from used wind turbine blades; mixing the shredded/ground composite material and at least one thermoplastic polymer in a compounding device; extruding a longitudinal bar of the mixture from the compounding device; and adding at least one extruded block to the mould. In this way, more composite material from the used wind turbine blade may be recycled and incorporated in the structural element, leading to a further reduction in cost and environmental impact. Preferably, the at least one extruded block has a length which substantially corresponds to the length of the structural element.

[0026] In one embodiment, the method further comprises prestressing the at least one cut composite section and/or the at least one extruded block prior to adding the binding agent. In this way, it is possible to produce structural elements with predetermined shapes and/or load/stress adapted to the intended use thereof.

[0027] In one embodiment, the thermoplastic polymer is selected from one or more of polyethylene, polypropylene, polyolefin, polyesters, polyurethanes, elastomers such as SBS, SEBS, PVB, either as recycled material or virgin polymer or a mixture thereof.

[0028] In a second aspect of the present disclosure, there is provided a structural element made from used wind turbine blades, the structural element comprising: at least one composite section cut from a used wind turbine blade; and a solidified binding agent bonding the at least one cut composite section, wherein at least one dimension of the cut composite section substantially corresponds to at least one dimension of the structural element.

[0029] In one embodiment, the at least one composite section is cut from the spar component of the used wind turbine blade.

[0030] In one embodiment, the length of the at least one cut composite section substantially corresponds to the length of the structural element.

[0031] In one embodiment, the structural element further comprises at least one extruded longitudinal block made of shredded and/or ground composite material from used wind turbine blades and at least one thermoplastic polymer.

[0032] In one embodiment, the structural element further comprises a prefabricated matrix defining a plurality of longitudinal recesses, each recess being arranged to receive a cut composite section to form the structural element. By means of the prefabricated matrix, a simple and robust solution for producing the structural element in a desired geometry is achieved.

[0033] In one embodiment, each recess comprises one or more raised ridges extending the length of the recess on an interior surface thereof. The ridges act as spacer elements ensuring optimal positioning of the cut composite section in the recess to facilitate an even distribution of the binding agent in the gap between the cut composite section and the interior surface of the recess.

[0034] In one embodiment, the prefabricated matrix is made of shredded and/or ground composite material from used wind turbine blades and at least one thermoplastic polymer.

[0035] In one embodiment, the structural element is a railway sleeper, a beam or a pillar. Other possible structural elements encompassed by the present disclosure include rods, posts, struts and ties.

Brief Description of Drawings

[0036] The present disclosure is now described, by way of example, with reference to the accompanying drawings, in which:

Fig. 1 shows a perspective view of an exemplary wind turbine blade.

Fig. 2 shows a cross-sectional view of an exemplary wind turbine blade.

Fig. 3 is a schematic view of a structural element according to one embodiment of the present disclosure, in the form of a railway sleeper.

Figs. 4–7 show exemplary cross-sectional views of the railway sleeper in Fig. 3.

Figs. 8a and 8b show perspective views of an exemplary cut composite section from a used wind turbine blade and an extruded block comprising shredded/ground composite material from a used wind turbine blade, respectively.

Fig. 9 is a schematic drawing of the production process for structural elements according to one embodiment of the present disclosure.

Figs. 10a and 10b show an exemplary structural element according to one embodiment of the present disclosure in the form of an I-beam in an exploded and an assembled view, respectively.

Figs. 11a and 11b shows an exemplary structural element according to one embodiment of the present disclosure in the form of a pillar in an exploded and an assembled view, respectively.

Fig. 12 shows a close-up view of a detail of the structural element in Figs. 10a and 10b.

Description of Embodiments

[0037] In the following, a detailed description of a method for producing a structural element based on used wind turbine blades, and a structural element made from used wind turbine blades according to the present disclosure is presented. In the drawing figures, like reference numerals designate identical or corresponding elements throughout the several figures. It will be appreciated that these figures are for illustration only and are not in any way restricting the scope of the invention.

[0038] Composites: shall be understood as materials comprising inorganic and organic materials including glass fibre or carbon fibre and wood, and binding agent materials, including thermosets such as epoxy or polyurethane or thermoplastics, see below. In particular, wind turbine blades or sections thereof are composites according to the invention, and sections cut-to-size for use in the present disclosure may comprise carbon or glass fibres, wooden support or beam structures, epoxy or polyurethane coatings and binding agents and hard foam sections.

[0039] Thermoplastics: shall be considered as the group of polymers which melt at a temperature in the range 60 – 200 °C, specifically comprising polyolefins, including polyethylene (PE), polypropylene (PP), polyesters including polyethylene terephthalate (PET) and polylactic acid (PLA), polystyrene, polyvinylchloride (PVC), thermoplastic elastomers such as SBS, SIS, SEBS and other plastics and mixtures or compounds of said plastic types, also collectively called “polymer” or “thermoplastics” below, which can be processed in compounding devices such as twin-screw compounding machines or in extruders.

[0040] Compounding device(s): shall denote any intensive mixer, such as kneaders, batch mixers, continuous mixers, extruders capable of mixing materials, such as planetary extruders and twin-screw compounders which are able to mix polymer blends under pressure. Venting and removal of gases such as water vapour in a controlled manner, e.g. by pressure relief valves or extruder sections which allow controlled gas removal, are advantageous in the present disclosure as some raw materials for the articles-of-use described later may be humid.

[0041] Referring now to Figs. 1 and 2, there is shown perspective and cross-sectional views, respectively, of a wind turbine blade 1. As seen in Fig. 2, the wind turbine blade 1 has an airfoil shape with a leading edge 3 and a trailing edge 4. The main load bearing structure of the wind turbine blade 1 is the spar component 2, which is either integrated in the shell as a spar cap 5 or a separate spar structure comprising shear webs 6. The spar component 2 is usually made of thick glass fibre-reinforced materials (GFRM) or carbon fibre-reinforced materials (CFRM) with a high modulus of elasticity for structural solidity. To this end, the spar component 2 is a composite laminate built up in a plurality of layers with a thickness of several centimetres. The composite laminate material is typically GFRM and/or CFRM comprising fibres oriented parallel to the longitudinal extension L of the wind turbine blade 1 (known as the 0 direction), in a direction ±45° to the longitudinal extension L (double bias), and/or in a direction perpendicular to the longitudinal extension L. Usually, at least 70 % of the fibres are oriented in the 0 direction.

[0042] Fig. 1 illustrates which areas (spar component 2) of the wind turbine blade 1 are suitable for cutting into composite sections 11 of desired geometry to be used in structural elements, and which areas are (leading edge 3 and trailing edge 4 constituting the remaining shell components) suitable for shredding/grinding to powder or fibres and mixing with additional materials (e.g. thermoplastics) to form the matrix material and/or binding agent 12 of the structural element 10, or act as a filler/reinforcement. For easy logistics, the wind turbine blade 1 is cut in the transverse direction in suitable lengths as indicated by the hatched lines. It has been found that cut composite sections from a used wind turbine blade 1 made of GFRM shows an elastic modulus of higher than 60 GPa in the 0 direction, and up to 300 GPa in used wind turbine blade 1 made of CFRM.

[0043] According to the present disclosure, the composite section 11 cut from a used wind turbine blade has at least one dimension substantially corresponding to at least one dimension of the structural element. In one embodiment, the length of the cut composite section 11 substantially corresponds to the length of the structural element 10. In this context, the term ‘substantially correspond’ should be interpreted as representing a tolerance range, e.g. about 10%, of the dimension in question. This enables maintaining the material properties of the composite section 11 and imparting these material properties to the final structural element 10. Examples of material properties imparted to the structural element include fibre content, fibre orientation/direction, fibre type, lay-up type, durability, elasticity, flexibility, hardness, stiffness, toughness, etc. Thus, a structural element 10 with substantially the same or corresponding material properties as the used wind turbine blade 1 may be obtained.

[0044] Referring to Fig. 3, there is shown in a perspective view a structural element 10 according to the present disclosure, made of cut composite sections 11 from a used wind turbine blade 1 and other materials. The structural element 10 may be a railway sleeper having typical dimensions of about 3 m in length, about 16 cm in height and about 25 cm in width. Other types and dimensions of structural elements are also foreseen by the present disclosure, such as beams and pillars for building construction.

[0045] With reference to Figs. 4–7, a number of exemplary cross-sectional views of the structural element 10 in Fig. 3 according to different embodiments of the present disclosure are shown. Each of the embodiments comprise the same or similar components, wherein the number and/or placement within the structural element 10 can be varied. 11 indicates a composite section of multi-axial glass and/or carbon fibre reinforced thermoset or thermoplastic laminate from a used wind turbine blade 1, precisely cut to desired geometry and surface treated for best bonding in the beam matrix system. Fibre content is minimum 40% by weight of the laminate. A surface liner may be applied to the cut composite section 11 which introduces optimal bonding between laminate surface and a beam matrix system. 13 indicates an extruded block or bar made from minimum 50% shredded/ground composite laminates from used wind turbine blade 1 or other components with minimum 40% glass fibre content by weight, and mixed with maximum 50% thermoplastic (recycled and/or virgin materials) and other additives for improved flow and bonding so that a solid block consolidation is achieved. A surface liner with high content of thermoplastic may be used for optimal bonding to a beam matrix system. 12 indicates a binding agent, e.g. a thermoplastic or thermoset or other possible beam matrix systems which by injection moulding processing makes the components of the structural element 10 completely fixed and bonded together, and as well giving the structural element 10 precise geometry and approved environmental resistance requirements.

[0046] Referring now to Fig. 4, there is shown a cross-sectional view of an exemplary structural element 10. In this embodiment, the cross-section is a sandwich system comprising two horizontally oriented, cut composite sections 11 sandwiching a single horizontally oriented block 13 comprising shredded/ground composite material from a used wind turbine blade 1, taken from the leading edge 3 and/or trailing edge 4.

[0047] Referring now to Fig. 5, there is shown a cross-sectional view of another exemplary structural element 10. In this embodiment, the single block 13 comprising shredded/ground composite material from Fig. 4 has been replaced by alternating cut composite sections 11 and blocks 13 comprising shredded composite material which are arranged with their long sides in a vertical orientation, substantially perpendicular to the long sides of the two horizontally oriented cut composite sections 11.

[0048] Referring now to Fig. 6, there is shown a cross-sectional view of another exemplary structural element 10. In this embodiment, the cross-section is a sandwich system comprising six horizontally oriented, cut composite sections 11 sandwiching a single block 13 comprising shredded/ground composite material with three cut composite sections 11 arranged on top of each other on either side.

[0049] Referring now to Fig. 7, there is shown a cross-sectional view of another exemplary structural element 10. In this embodiment, the cross-section is a sandwich system comprising eight horizontally oriented, cut composite sections 11 sandwiching a single block 13 comprising shredded/ground composite material with four cut composite sections 11 arranged side by side on either side.

[0050] Referring now to Figs. 8a and 8b, there is shown perspective views of an exemplary strong laminate composite section 11 cut from a used wind turbine blade 1 and an extruded block 13 comprising shredded/ground composite material from a used wind turbine blade 1, respectively. The geometry and profile of the composite section 11 and extruded block 13 may vary according to the desired configuration and shape, as well as the intended use, of the finished structural element 10. The block 13 may be a reinforced thermoplastic profile with a minimum of 25 % by weight of short fibres.

[0051] Referring now to Fig. 9, there is shown a flow chart illustrating a production method in accordance with the present disclosure. In step S100, at least one composite section 11 is cut from a used wind turbine blade 1, preferably from the spar component 2 as shown in Figs. 1 and 2. In step S102, the cut composite section 11 is placed into a mould. In step S104, a binding agent 12 is added to the mould. The binding agent 12 may comprise a mixture of thermoplastics, preferably containing other solids, to form a suitable beam matrix system 12 as explained above. In step S106, the binding agent 12 is allowed to solidify, e.g. by cooling the mould. Injection of materials, such as the binding agent 12, into the mould may proceed at atmospheric or elevated pressure, and may be batch-wise or (semi-)continuous. Note that Fig. 9 is just one potential embodiment in accordance with the present disclosure. Various modifications of injection moulding, inlet moulding, 2-

component moulding and even semi-continuous or continuous processes similar to pultrusion are conceivable and encompassed by the present disclosure.

[0052] The method according to the present disclosure may further comprise a step S103 in which raw materials such as shredded/ground composite material 7 from the used wind turbine blade 1 and a thermoplastic polymer 8 are fed into a compounding device (e.g. an extruder or mixing device) which may receive further feedstocks 9, such as granulated solid waste, through a side feeder. The shredded/ground composite material 7 and the thermoplastic polymer 8 are mixed to form the binding agent 12, which is subsequently added to the mould in step S104. The binding agent 12 thus formed may contain up to 50% by weight of the shredded/ground composite material 7.

[0053] Referring now to Figs. 10a and 10b, there is shown an example of an I-beam 20 made of cut composite sections 11 which are placed into a prefabricated matrix 14 which acts as a mould. To this end, the matrix 14 comprises a plurality of recesses or cavities 15 arranged to receive the cut composite sections 11. The matrix 14 may be obtained by mixing shredded/ground composite material 7 from the used wind turbine blade 1 and a thermoplastic polymer 8 in suitable amounts, and extruding a longitudinal profile. Subsequently, the cut composite sections 11 may be bonded to the matrix 14 by a injecting a binding agent and connected using further composite parts 16 to form the I-beam 20 as shown in Fig. 10b.

[0054] Referring now to Figs. 11a and 11b, there is shown an example of a pillar 30 made of cut composite sections 11 which are placed into a prefabricated matrix 14 which acts as a mould. To this end, the matrix 14 comprises a plurality of recesses or cavities 15 arranged to receive the cut composite sections 11. The matrix 14 may consist of fibre-reinforced thermoplastic polymer (ideally recycled) and obtained in a similar manner to the matrix described in connection with Figs. 10a and 10b above. Subsequently, the cut composite sections 11 may be bonded to the matrix 14 by a binding agent (e.g. glue) to form the pillar 30 as shown in Fig. 11b. The composite parts, and the final pillar 30 may be covered by an extra protective layer 17, such as a film or as extruded polymer.

[0055] Referring now to Fig. 12, there is shown a close-up view of a recess 15 in the prefabricated matrix 14 of Figs. 10a–b and 11a–b in cross-section. One or more raised ridges 18 are provided on the interior surface of the recess 15 and extend along the length of the matrix 14. The ridges 18 act as spacer elements to ensure that the cut composite section 11 is positioned at a distance from the interior surface of the recess 15, thus forming a gap therebetween. This gap facilitates injection and even distribution of the binding agent 12 between the cut composite section 11 and the interior surface of the recess 15.

Example 1:

[0056] Example 1 relates to a railway sleeper consisting of 40% by weight of a cut composite section 11 from a used wind turbine blade 1, the remainder being thermoplastic polymer comprising 40% by weight solid waste, mainly consisting of granulate and fibres from shredded/ground wind turbine blades 1. The cut composite section 11 is selected from certain areas, i.e. the spar component 2 of the wind turbine blade 1 as explained above, see Figs. 1 and 2. Essentially, flat geometries are preferred for standardized processes and certification. If several sections are used, these may be glued together, e.g. using a polyurethane based glue which exhibits good adhesion to composite materials. The gluing may be performed in an open mould at atmospheric pressure.

Example 2:

[0057] Example 2 relates to construction of buildings, such as commercial greenhouses. Load-carrying pillars, 4–10 m in height, and horizontal beams e.g. to carry the roof, 5–22 m in length, are made by combining cut composite sections 11 from used wind turbine blades 1 and matrices 14 e.g. made by extrusion. Figs. 10a–b and 11a–b show possible configurations.

[0058] In one embodiment, thermoplastics are mixed with solid powders and fibres prepared from wind turbine blades 1 in a kneading or mixing device such as an extruder, in particular a planetary roll extruder, and injected into a mould already containing at least one composite element, i.e. a cut-out turbine blade section or a plurality of such sections.

[0059] In one embodiment, one or more of polyethylene, polypropylene, polyolefins, polyester is used as thermoplastic binding agent.

[0060] In one embodiment, elastic materials such as styrene-butadiene block copolymers or polyvinyl butyrate (PVB) is added, among others to improve binding of solid materials.

[0061] In one embodiment, structural elements of thermoplastic binding agent mixed with solid powders or fibres are prepared independently and used in the same manner as cut-out sections from turbine blades. Optionally, the plurality of cut-out sections and binding agent/solid beams or sections are glued together prior to filling the mould with additional binding agent material.

[0062] In one embodiment, glues and adhesives based on polyurethane, epoxy or acryl, i.e. thermosetting or permanently cross-linking adhesives are used as binding agent materials. Some of these adhesives, notably polyurethane, can expand during hardening, sometimes generating a structural foam. When composite sections 11 are filled in a prefabricated matrix 14 (see below), they may not fill the whole cavity, and it may be difficult to cut composite sections 11 which exactly fit a cavity such as shown in figures, see e.g. Figs. 10a–b and 11a–b. An expanding adhesive will fill out the whole cavity and provide excellent adhesion between matrix 14 and the cut composite sections 11.

[0063] In one embodiment, bio-based fibres such as wood fibres or olive residues are used as fillers. In one embodiment, minerals are used as additional fillers. In one embodiment, flame-retarding materials are used as additional fillers.

[0064] In one embodiment, the mould is formed such that sensors, mechanical fastening elements, cable ducts and the like can easily be connected to the final products, e.g. by leaving holes or cavities in the otherwise bar-like geometry.

[0065] In one embodiment, the finished structural element 10 is encapsulated in a protective outer layer 17 which may be thermoplastic or a thermoset.

[0066] In one embodiment, hollow sections are left in the final product for easier cooling of the final product, or as functional cavity, e.g. serving as cable duct. In one embodiment, the structural element 10 is further subjected to a finishing step selected from one or more of mechanical treatment, fastening of further elements such as eyelets, hooks, brackets and/or drilling holes. Thus, the structural element 10 may be adapted to the intended use.

[0067] In one embodiment, the at least one cut composite section 11, and the at least one extruded block 13 (if present) is prestressed prior to adding the binding agent 12. In this way, it is possible to produce structural elements 10 with predetermined shapes and/or load/stress adapted to the intended use thereof. Similar to glued laminated timber (glulam), prestressing the cut composite section 11 may be used to obtain bent or arched structural elements 10 as desired.

[0068] In one embodiment, see in particular Figs. 10a–b and 11a–b, a matrix 14 is produced, e.g. based on fibres and other residues from the inner parts of wind turbine blades 1 and e.g. a thermoplastic binding agent. By extrusion of these materials, prefabricated matrices 14 in many geometries can be provided. Recesses or cavities 15 in this prefabricated matrix 14 can be filled with cut composite sections 11 from the used wind turbine blade 1 such as rods, plates or other geometries. These sections can be glued to the matrix 14 using adhesives such as described above. Different sections can be glued together, using even more wind turbine sections. Beams and pillars can be produced in this manner. In particular thermosetting adhesives which expand slightly upon hardening are useful, as the recesses or cavities 15 will be completely filled, resulting in strength of the finished article. The prefabricated matrix 14 may contain a thermoplastic binding agent such as low density polyethylene (LDPE) and elastic materials such as ethylene-vinyl acetate (EVA) which accommodate deformation of the finished article in use.

MATERIALS FOR ONE SLEEPER (260 cm×26 cm×16 cm)	**WEIGHT (kg) (estimated)**	**% OF TOTAL**
A. Flanges/high modulus wind turbine laminates	53	30
B. Core/milled wind turbine blade 1 laminates	65	37
SUM (MATERIALS FROM WIND TURBINE BLADE 1)	**117**	**67**
B. Core/virgin and recycled TP and other additives	36	20
C. Encapsulation and bonding matrix	24	13

BEAM TOTAL	**177**	**100**

Table 1

[0069] The density of a sleeper will be the weighted average of the components, it will thus be in the range of 0,8-1,2 g/cm^3, to be compared with 1,4 for wood/creosote and >2 for concrete, at comparable strength and reduced brittleness (versus concrete).

[0070] In one embodiment, the finished article such as shown in fig 9 and 10, is used as load-carrying beam for construction of private or commercial buildings. Load-carrying beams need to be able to carry heavy loads, and the downward deflection of a beam must typically be lower than 0,5% of its length, i.e. a beam of 10 m length may not deform downwards more than 50 mm. This is achievable using wind power sections according to the present disclosure.

[0071] In one embodiment, beams designed according to one of the attached figures can be used as vertical pillars or as horizontally (plus or minus inclination for roof construction, e.g. 4 to 30%) placed beams. In this case, the same connection devices for connecting beams and pillars as known in the prior art may be used.

[0072] In one embodiment, the structural elements according to the invention can be used for construction purposes in wet environments where there would be a risk for corrosion of metal or degradation of wood. As an example, the walls of swimming pools, district or solar heating tanks or fish pools can be constructed using structural elements of the present disclosure, together with suitable fastening elements, insulation materials, liners to prevent water leakage etc. In this sense, the structural elements of the present disclosure can replace significant amounts of concrete.

[0073] In one embodiment, wood-plastic-composites (WPC) are improved in the following manner: WPC are used as flooring material e.g. for terraces. Often, WPC flooring material is provided as long extrudates, and they can be produced with cavities. Composite sections 11 from used wind turbines can be inserted into these cavities, and the remaining volume can be filled with binding agent such as polyurethane or hot-melting glues based e.g. on thermoplastic elastomers. The resulting flooring slabs are significantly more stable than the ones with cavities. This technique is cheaper, easier and CO_2 saving compared to the alternative where shredded wind turbine blade 1 powder is used to fill the cavities or the WPC as such.

[0074] The CO_2 footprint is drastically reduced by utilizing both larger cut-out sections as well as grinded powder and fibres based on used wind turbine blades 1.

[0075] Mechanical stability is, in general, increasing with maximising the content of sections and power/fibre residues. Some preferred final products, as apparent from above table, will be characterized by the following weight ratios of components whereby these ratios depend on the intended use:
% weight cut-out sections in sleeper: range 10 -50%, possibly more;
% weight solid powder/fibre in sleeper: 10 - 60%; and
% weight thermoplastic polymer in sleeper: 10- 50%

[0076] Preferred embodiments of a method for producing a structural element 10 based on used wind turbine blades 1 have been disclosed above. However, the person skilled in the art realises that this can be varied within the scope of the appended claims without departing from the inventive idea.

[0077] All the described alternative embodiments above or parts of an embodiment can be freely combined or employed separately from each other without departing from the inventive idea as long as the combination is not contradictory.

CLAIMS

1. A method for producing a structural element (10) based on used wind turbine blades (1), the method comprising the steps:

cutting (S100) at least one composite section (11) from a used wind turbine blade (1);

placing (S102) the at least one cut composite section (11) in a mould which defines the dimensions of the structural element (10);

adding (S104) a binding agent (12) to the mould; and

allowing (S106) the binding agent (12) to solidify to obtain the structural element (10),

wherein at least one dimension of the cut composite section (11) substantially corresponds to at least one dimension of the structural element (10).

2. The method according to claim 1, wherein the at least one composite section (11) is cut from the spar component (2) of the used wind turbine blade (1).

3. The method according to claim 1 or 2, wherein the length of the at least one cut composite section (11) substantially corresponds to the length of the structural element (10).

4. The method according to any one of the preceding claims, wherein the mould is made of shredded and/or ground composite material (7) from used wind turbine blades (1) and at least one thermoplastic polymer (8).

5. The method according to any one of the preceding claims, wherein the mould comprises an open or closed vessel or a prefabricated matrix (14).

6. The method according to any one of the preceding claims, further comprising:

shredding and/or grinding composite material (7) from used wind turbine blades (1); and

mixing (S103) up to 50% by weight of the shredded/ground composite material (7) and at least one thermoplastic polymer (8) in a compounding device to form the binding agent (12).

7. The method according to any one of the preceding claims, further comprising:

shredding and/or grinding composite material (7) from used wind turbine blades (1);

mixing the shredded/ground composite material (7) and at least one thermoplastic polymer (8) in a compounding device;

extruding a longitudinal block (13) of the mixture from the compounding device; and

adding at least one extruded block (13) to the mould.

8. The method according to any one of the preceding claims, further comprising:

prestressing the at least one cut composite section (11) and/or the at least one extruded block (13) prior to adding the binding agent (12).

9. The method according to any one of the preceding claims, wherein the thermoplastic polymer (8) is selected from one or more of polyethylene, polypropylene, polyolefin, polyesters, polyurethanes, elastomers such as SBS, SEBS, PVB, either as recycled material or virgin polymer or a mixture thereof.

10. A structural element (10) made from used wind turbine blades (1), the structural element (10) comprising:

at least one composite section (11) cut from a used wind turbine blade (1); and

a solidified binding agent (12) bonding the at least one cut composite section (11) to form the structural element (10),

wherein at least one dimension of the cut composite section (11) substantially corresponds to at least one dimension of the structural element (10).

11. The structural element (10) according to claim 10, wherein the at least one composite section (11) is cut from the spar component (2) of the used wind turbine blade (1).

12. The structural element (10) according to claim 10 or 11, wherein the length of the at least one cut composite section (11) substantially corresponds to the length of the structural element (10).

13. The structural element (10) according to any one of claims 10–12, further comprising at least one extruded longitudinal block (13) made of shredded and/or ground

composite material (7) from used wind turbine blades (1) and at least one thermoplastic polymer (8).

14. The structural element (10) according to any one of claims 10–13, further comprising a prefabricated matrix (14) defining a plurality of longitudinal recesses (15), each recess (15) being arranged to receive a cut composite section (11) to form the structural element (10).

15. The structural element (10) according to claim 14, wherein each recess (15) comprises one or more raised ridges (18) extending the length of the recess (15) on an interior surface thereof.

16. The structural element (10) according to claim 14 or 15, wherein the prefabricated matrix (14) is made of shredded and/or ground composite material (7) from used wind turbine blades (1) and at least one thermoplastic polymer (8).

17. The structural element (10) according to any one of claims 10–16, wherein the structural element (10) is a railway sleeper, a beam (20) or a pillar (30).

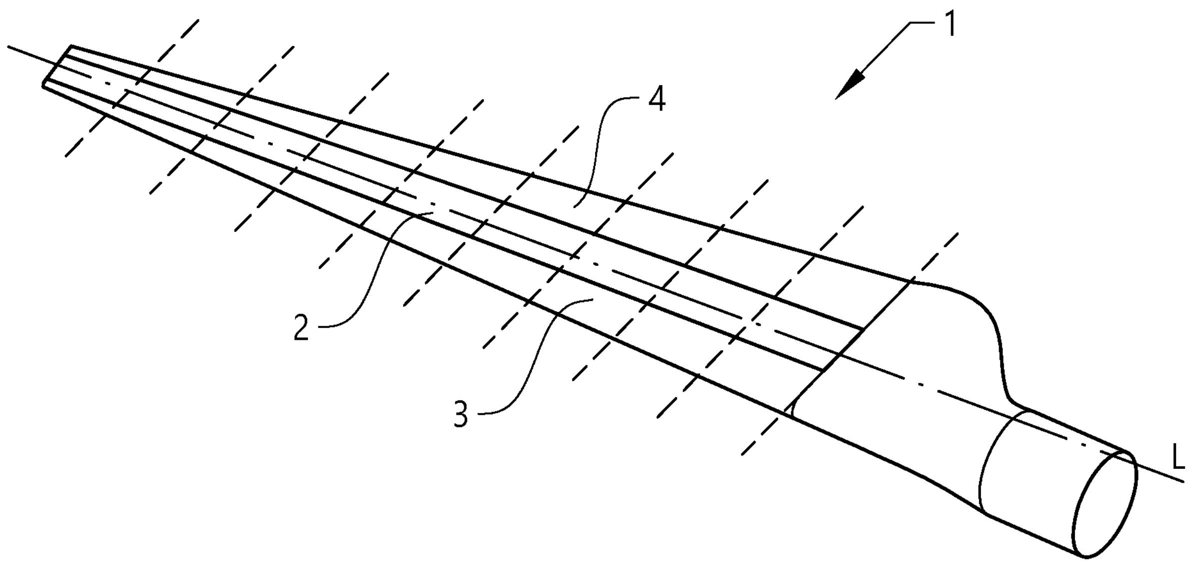

FIG. 1

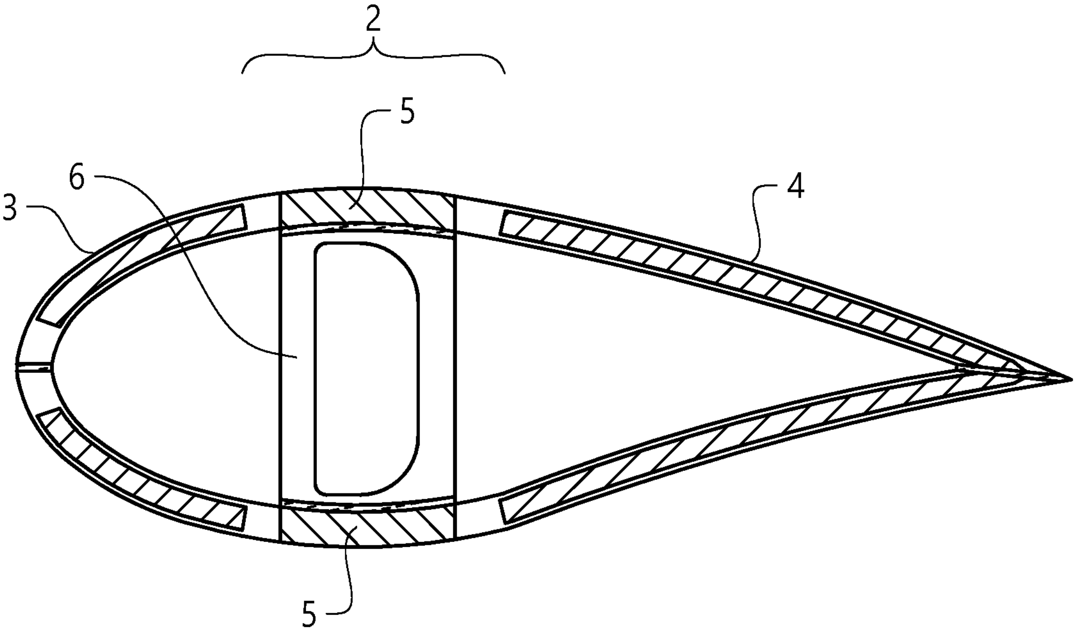

FIG. 2

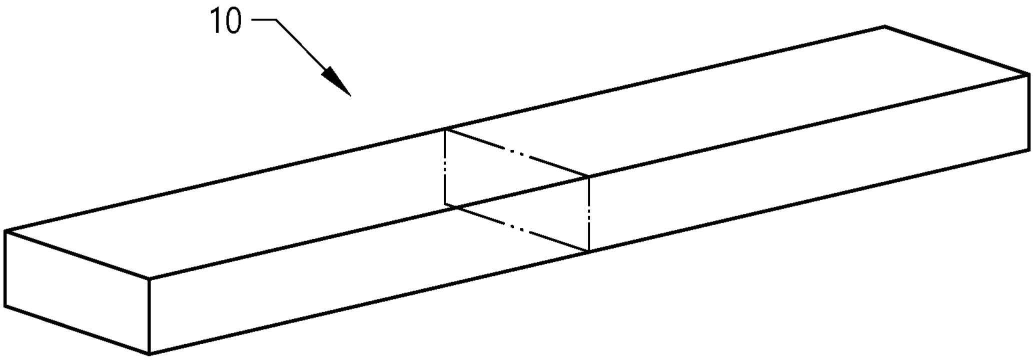

FIG. 3

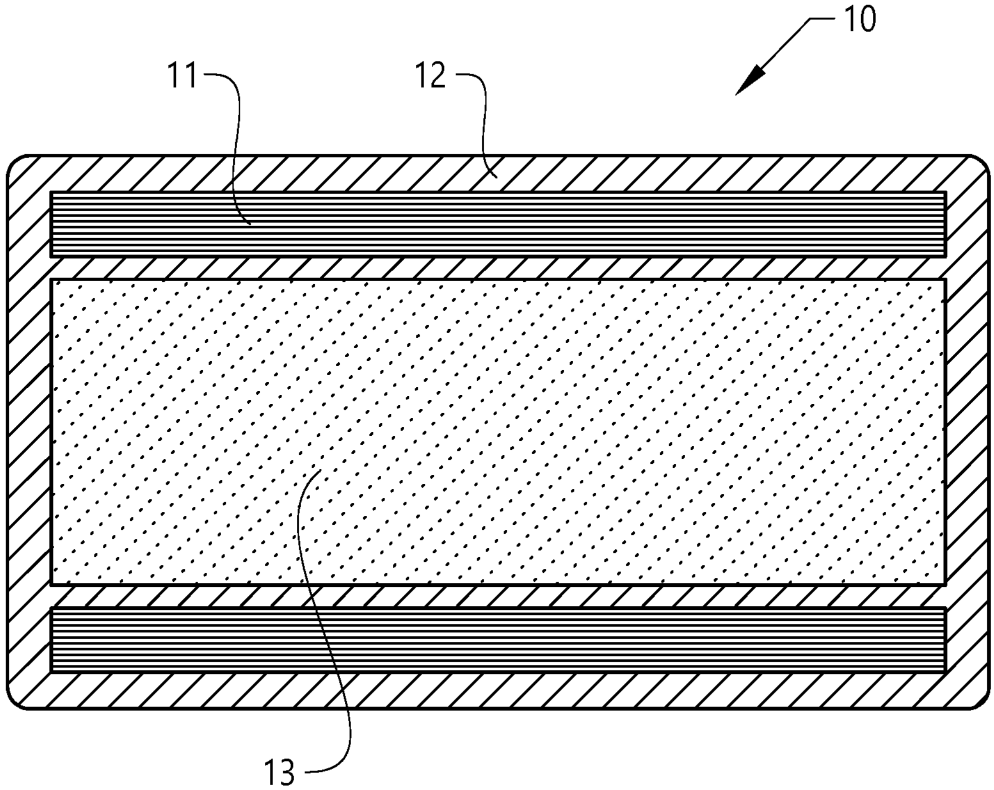

FIG. 4

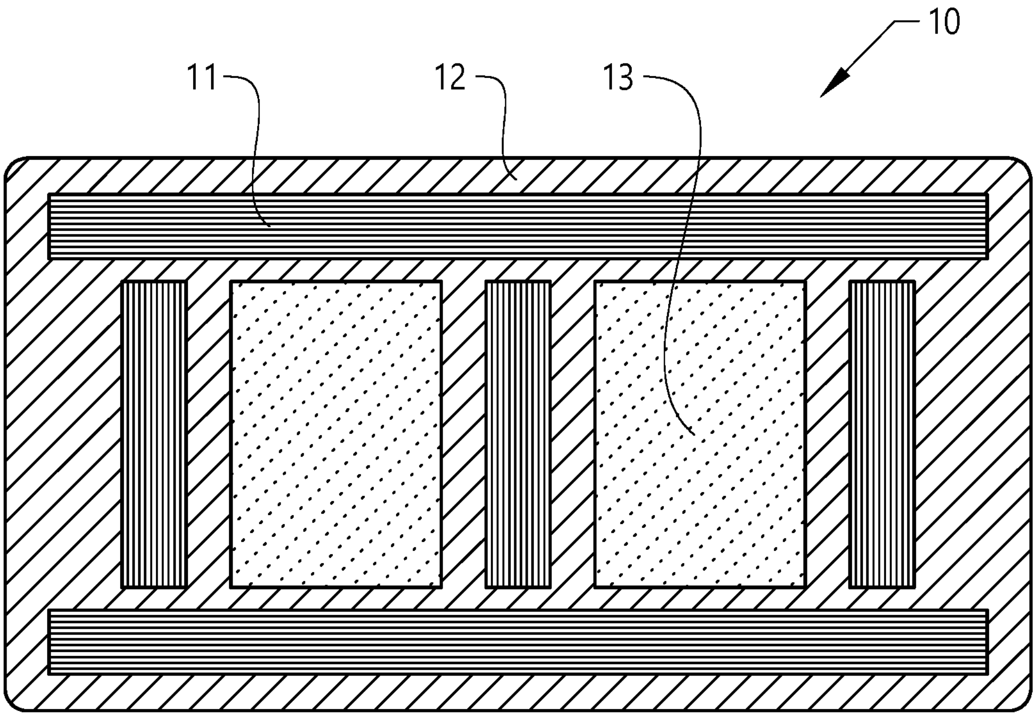

FIG. 5

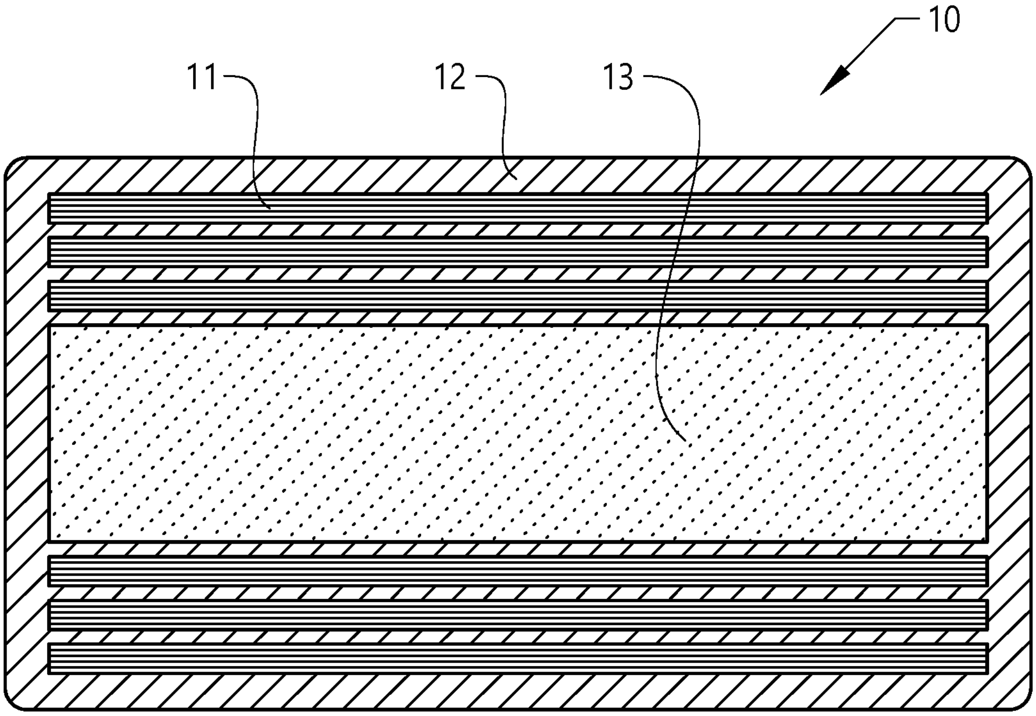

FIG. 6

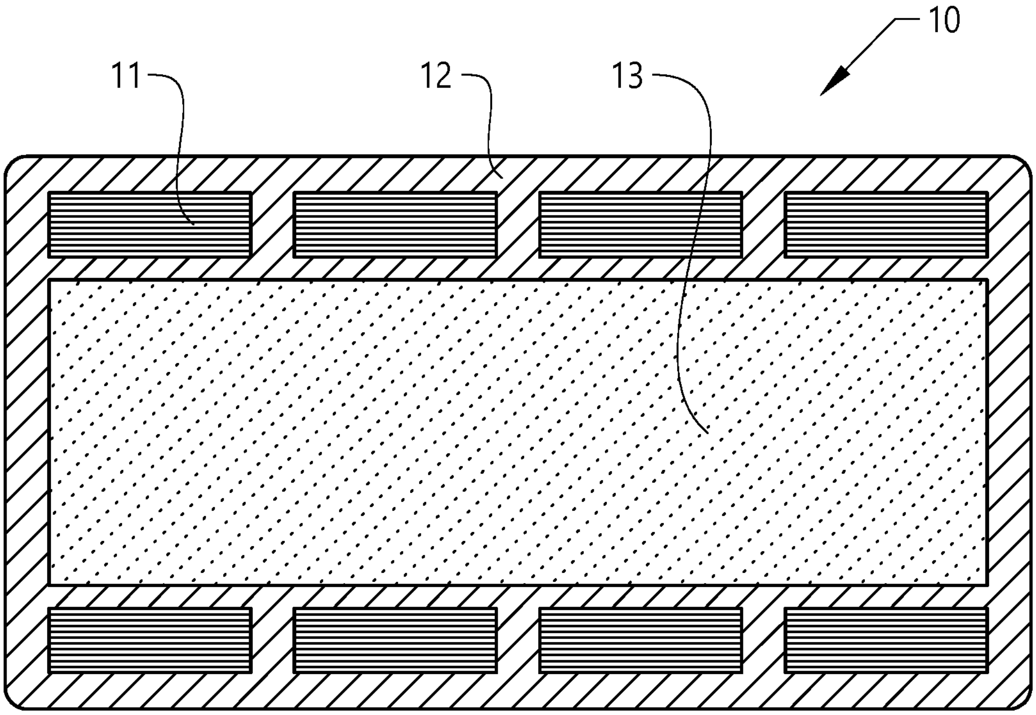

FIG. 7

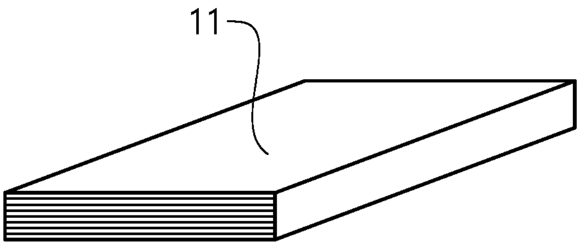

FIG. 8a

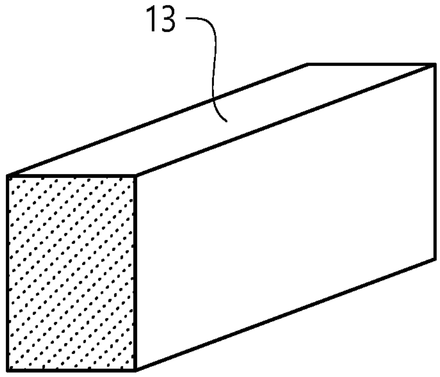

FIG. 8b

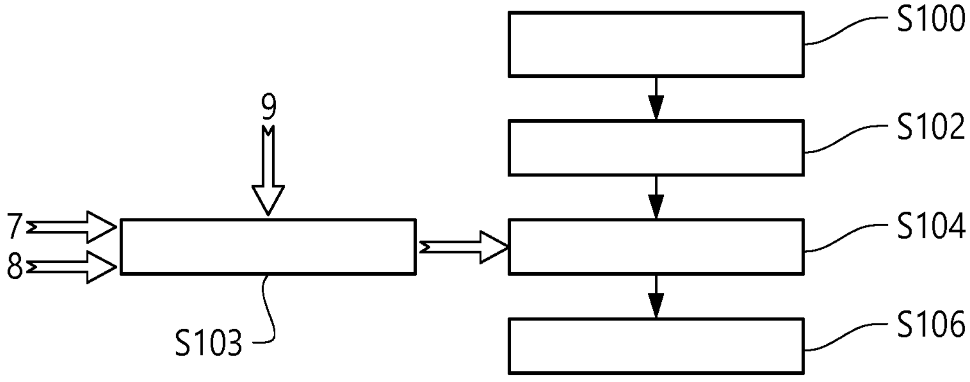

FIG. 9

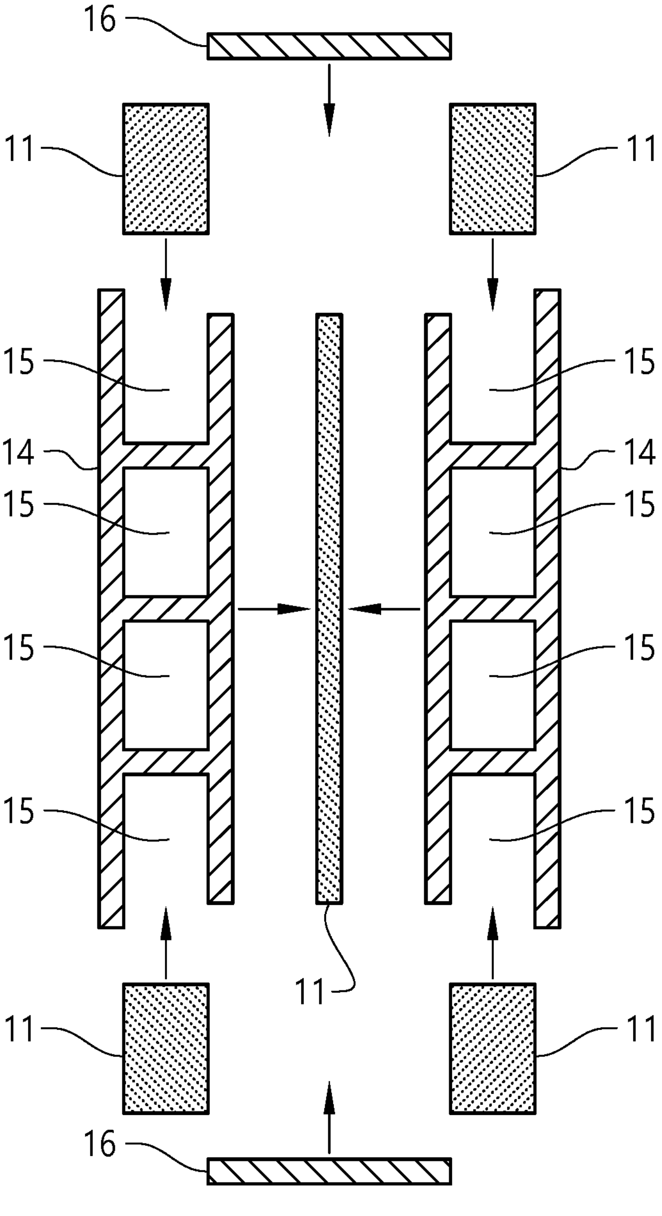

FIG. 10a

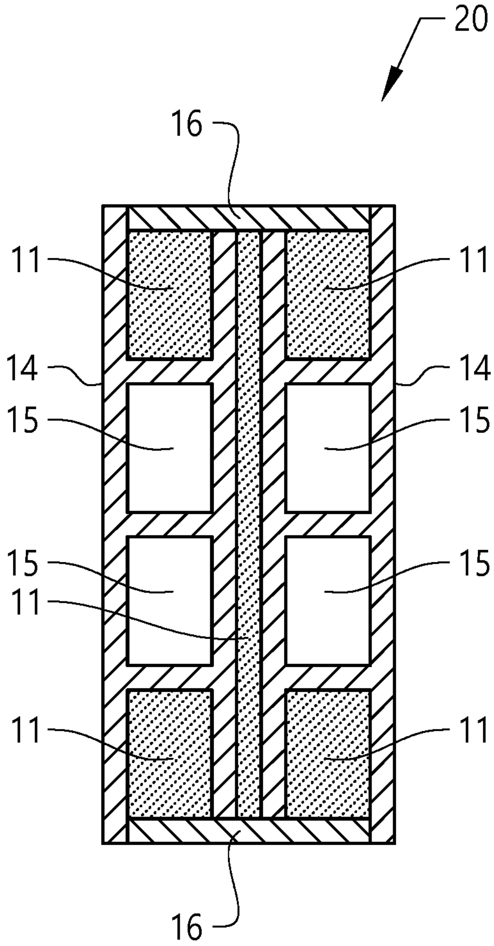

FIG. 10b

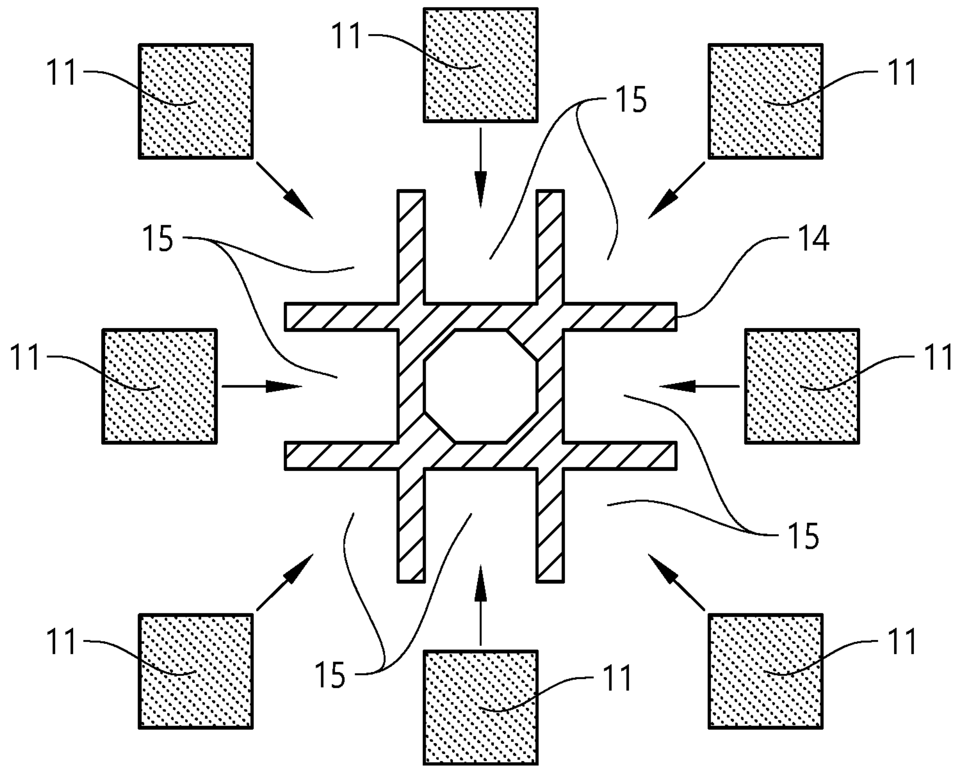

FIG. 11a

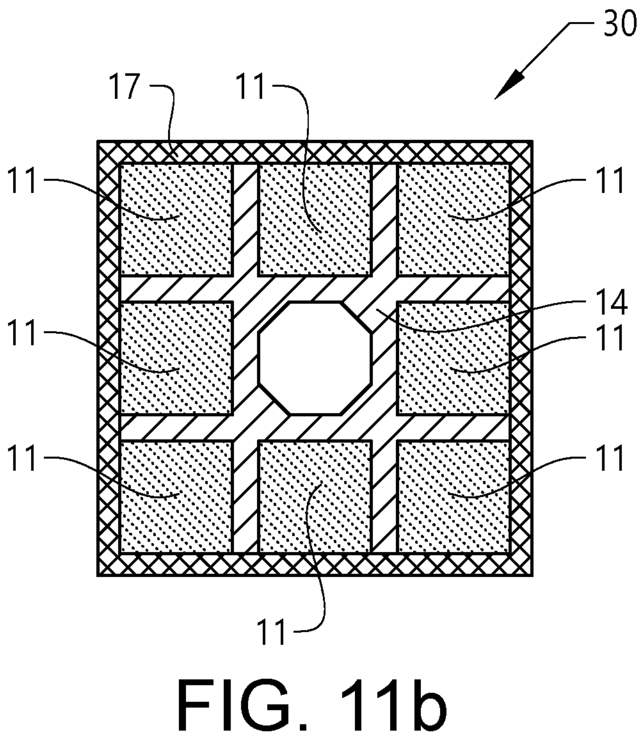

FIG. 11b

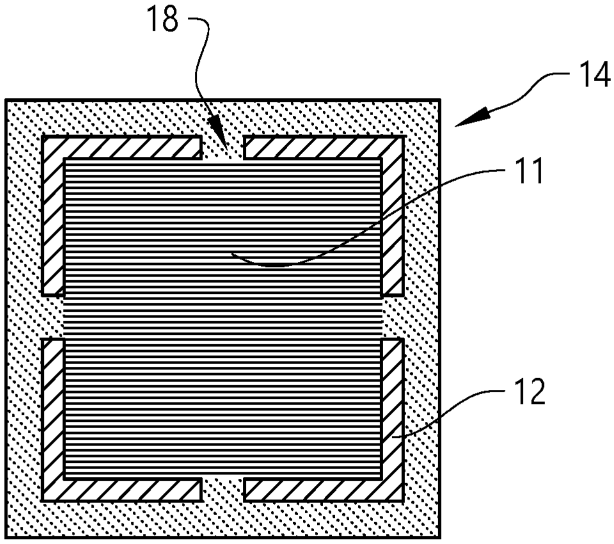

FIG. 12

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2022/082110

A. CLASSIFICATION OF SUBJECT MATTER
INV. B29B17/00
ADD.

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)
B29B B29L

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 3 526 000 A1 (UNIV WASHINGTON STATE [US]; GFSI GROUP LLC [US]) 21 August 2019 (2019-08-21) the whole document -----	1-17
X	JENSEN J P ET AL: "Wind turbine blade recycling: Experiences, challenges and possibilities in a circular economy", RENEWABLE AND SUSTAINABLE ENERGY REVIEWS, ELSEVIERS SCIENCE, NEW YORK, NY, US, vol. 97, 30 August 2018 (2018-08-30), pages 165-176, XP085497586, ISSN: 1364-0321, DOI: 10.1016/J.RSER.2018.08.041 cited in the application section 3.1.2.2 -----	10-12

-/--

[x] Further documents are listed in the continuation of Box C.

[x] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" 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)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" 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

"X" 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

"Y" 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

Date of the actual completion of the international search	Date of mailing of the international search report
6 February 2023	13/02/2023

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Rüdiger, Patrick

1

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	DE 10 2019 007654 A1 (STOER ROLAND [DE]; ZHANG CUIMEI [CN]) 29 April 2021 (2021-04-29) the whole document -----	1-17
X	JOUSTRA JELLE ET AL: "Structural reuse of high end composite products: A design case study on wind turbine blades", RESOURCES, CONSERVATION AND RECYCLING, vol. 167, 1 April 2021 (2021-04-01), page 105393, XP055977100, AMSTERDAM, NL ISSN: 0921-3449, DOI: 10.1016/j.resconrec.2020.105393 Retrieved from the Internet: URL:https://www.sciencedirect.com/science/article/pii/S0921344920307114/pdfft?md5=7a1ea1615f9c98b364fd329877abc5c3&pid=1-s2.0-S0921344920307114-main.pdf> sections 3. and 4. -----	10-12

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2022/082110

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 3526000 A1	21-08-2019	CA 3040064 A1	26-04-2018
		CN 110087845 A	02-08-2019
		CN 114789518 A	26-07-2022
		EP 3526000 A1	21-08-2019
		WO 2018075126 A1	26-04-2018
DE 102019007654 A1	29-04-2021	CN 112706315 A	27-04-2021
		DE 102019007654 A1	29-04-2021