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(54) Title: A METHOD OF MAKING A WIND TURBINE BLADE

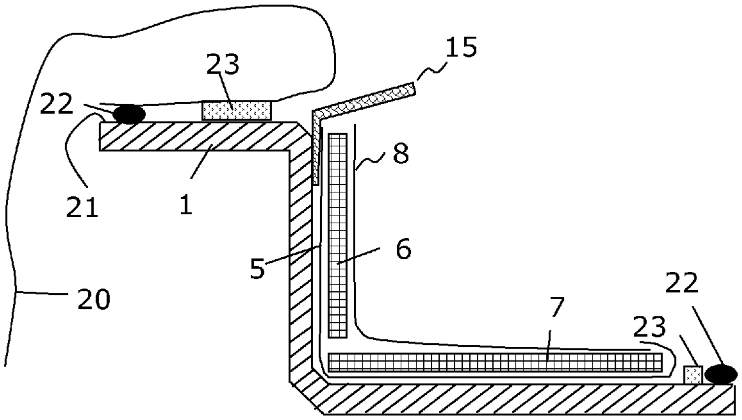

Fig. 4

(57) Abstract: The invention provides a method of making a tubular element for a wind turbine blade where at least two sections of the blade are assembled to form the tubular element, e.g. a spar or a blade shell. According to the invention, the sections are prepared individually and assembled by co-curing of uncured resin of one of the sections. Accordingly, the process of applying glue and the glue itself is avoided, and the bonding quality can potentially be increased.

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A METHOD OF MAKING A WIND TURBINE BLADE

Technical field

The present invention relates to a method of making a wind turbine blade, to a method of making a spar for a wind turbine blade, and to the blade or spar itself.

Background of the invention

Traditionally a blade for a wind turbine comprises a shell forming a shell cavity and a spar arranged in the cavity. The spar often extends substantially throughout the shell cavity in order to increase the strength of the wind turbine blade. Typically the spar is tubular and forms a spar cavity.

To increase the strength to weight ratio of the blade, the spar and sometimes the shell include various combinations of different composite materials typically including epoxy and carbon fibres.

Traditionally, the shell is moulded in two half sections in two individual female moulds. After removal of the sections from the moulds, the sections are assembled by use of an adhesive. The spar is traditionally made by winding a suitable fibre laminate around a mandrel or a similar male mould while simultaneously adding polyester, epoxy etc.

When winding or by other means applying a material onto a mandrel or a core, the inner geometry of the final tubular element is defined by the geometry of the mandrel or core, thus allowing for a well-defined inner geometry. On the contrary, the outer geometry of the final tubular element is less well-defined as the effect of even small variations on the mandrel or core and/or small variation on the innermost layers of the winded material is increased with the number of windings.

Alternatively, a spar is sometimes made from two separately moulded elements which subsequently are joined adhesively in order to define a tubular element. In order to achieve a tubular element of the right size, a height adjustment element can be applied to assure that the final spar fits in the cavity between the two shell parts defining the wind turbine blade.

<u>Summary of the invention</u>

It is an object of embodiments of the present invention to provide an improved method of manufacturing a spar for a wind turbine blade and to provide an improved spar.

Thus, in a first aspect, the invention provides a method of making a tubular element for a wind turbine blade where at least two sections of the blade are assembled to form the tubular element, the method comprising preparing the two sections individually by arranging fibres and uncured resin to form uncured fibre laminates in two separate moulds, arranging the two moulds relative to each other so that an uncured fibre laminate of one of the sections overlaps a fibre laminate of the other section, and assembling the sections by co-curing the uncured laminate, the method comprising the steps of:

- adhering to the uncured fibre laminate in each mould, a corresponding upstand comprising at least partly cured fibre laminate which stands free above a surface of the corresponding uncured fibre laminate;

- closing the moulds by arranging the two separate moulds in positions relative to each other so that a layer of the partly cured fibre laminate of one of the moulds overlap a layer of the uncured fibre laminate of the other mould; and

assembling the sections by co-curing the uncured laminate while the sections are in the moulds.

By co-curing the uncured laminate is meant that the resin of the uncured fibre laminate bonds to the fibre laminate in the other mould so that the laminates in the two moulds becomes solidly fixed by the resin when it cures.

The sections are assembled by co-curing the uncured resin of the uncured fibre laminate which not only spares the use of additional adhesive but also ensures a more continuous bonding with reduced risk of de-lamination along a bonding line. Accordingly, the invention may facilitate not only a simpler manufacturing but also an improved quality of the wind turbine blade.

Since the sections are assembled by joining overlapping layers while they are in the moulds, reorientation of the sections after removal from the moulds is avoided and process time is therefore spared.

Since each mould comprises the combination between an uncured fibre laminate and an at least partly cured fibre laminate, the uncured fibre laminate may facilitate the co-curing, and the upstand may ensure sufficient rigidity of the overlapping layers and thereby ensure sufficient control over the correct position of the overlapping layers for correct assembling of the sections.

In this connection, a “tubular element” means a hollow element with an elongated shape. The shape may be non-uniform. The outer geometry may be of a substantially rectangular shape, a partly circular shape, an oval shape or any other shape. The inner geometry may be different from the outer shape, thus defining a tubular element in the form of an elongated ring of an arbitrary shape. The tubular element may e.g. constitute the shell itself, or it may constitute the spar.

In a cross section, the tubular element may have any suitable shape which may provide a desired characteristic with respect to aerodynamic properties, strength, space etc.

If the tubular element constitutes a spar, it may have a substantially rectangular cross sectional shape, e.g. with rounded corners. The area of the cross section may decrease from a root end where the wind turbine blade joins with a hub to the tip where the wind turbine blade terminates. The width of the spar may increase locally to increase strength and stiffness of the spar locally. In a preferred embodiment, the spar may thus be approximately conical, i.e. may have a base which is substantially circular transforming into an approximately rectangular shape with rounded corners and with sides which taper towards each other. The spar may have a length of approximately 45 metres, a maximum width of approximately 1.0 meter, and a maximum height of approximately 0.8 metres. Compared hereto the minimal width of the spar may be approximately 100 millimetres. It should be understood that this is only one example of a spar. Other spars being both smaller and larger may also be used depending of the wind turbine blade to be manufactured.

In accordance with the invention, the two sections are made individually. Herein this means that the elements are made in separate moulds, and this again means that the moulds can move relative each other prior to the closing of the moulds. Even though the moulds are separate moulds, they could be joined by hinges or similar means which allow manipulation of one mould relative to the other mould. In a similar manner, the two sections could be joined in a manner which allows movement of one section relative to the other section. As an example, the uncured fibre laminate in both moulds may be constituted by a single sheet of laminate which extends from one of the moulds into the other mould.

The sections could be made simultaneously which herein means that both sections comprise an uncured fibre laminate at the same time so that the moulds can be closed and the sections be consolidated into one coherent element.

In this connection, fibre laminate denotes any kind of commercially available fibre reinforced material such as glass or carbon fibre reinforced resins e.g. of polyester or epoxy. The fibre laminate could be a prepreg laminate which comprises fibres which have been pre-impregnated with a resin prior to the arrangement of the prepreg in the mould.

The fibre laminate may comprise, or be constituted completely by unidirectional fibres and a resin matrix. A filler may also be added. The fibres may e.g. be carbon, glass, wood or natural fibres. As an example, the resin may be a thermoset resin, such as Epoxy, or it may be a thermoplastic resin, such as PET (Polyethylene Terephtalate). An example of a suitable filler comprises Nano particles. The fibre laminate may also comprise, or be constituted completely by biaxially oriented fibres and a resin matrix. The fibre may e.g. be of glass or wood. And as an example, the resin may be a thermoset resin, such as Epoxy, or it may be a thermoplastic resin, such as PET.

The wording "*uncured fibre laminate*" means that the resin of the laminate is uncured, and the wording "*uncured*" means that the uncured fibre laminate is still soft and allows reshaping, and has a tacky surface which may optionally facilitate adhesion of the at least partly cured upstand to the uncured fibre laminate. The uncured fibre laminate can be further consolidated e.g. by heating or by use of UV-radiation etc.

The wording "*at least partly cured fibre laminate*" means a laminate which is sufficiently consolidated to maintain the upright shape extending outwardly from a surface of the uncured fibre laminate. In one embodiment, the at least partly cured fibre laminate is completely cured and allows no further consolidation, and in another embodiment, the at least partly cured fibre laminate can be further consolidated after the moulds are closed.

The uncured fibre laminate may be arranged in the moulds in accordance with traditional techniques for moulding composite laminates such as glass or carbon fibre reinforced resins e.g. of polyester or epoxy. The upstand could be adhering to the uncured fibre laminate by use of the uncured resin of the uncured fibre laminate.

The wording "*closing of the moulds*" describes that the moulds are moved to the position relative to each other at which the elements therein form the claimed overlap. The moulds may, but do not have to, form a closed space between the moulds.

The materials selected for the uncured fibre laminate may be the same materials selected for the at least partly cured fibre laminate, or the materials may be different. As an example, the uncured fibre laminate may comprise biaxially oriented fibres while the at least partly cured fibre laminate may comprise unidirectional fibres.

In this way, the upstand may have characteristics being different from those of the remaining part of the sections e.g. with respect to strength, weight, flexibility etc.

The sections may be provided as sandwich constructions having a core comprising e.g. a thermoplastic or thermoset foam or balsa. Other core materials may also be used. The sections may comprise an inner and an outer layer on each side of the core, which layers as an example may primarily comprise biaxially fibres and a resin matrix. The fibres may e.g. be glass fibres and the resin may e.g. be a thermoset resin, such as Epoxy, or it may be a thermoplastic resin, such as PET.

The upstand and the uncured fibre laminate in each mould may be covered completely by a vacuum film before the moulds are closed. In this case, the vacuum film will become in-between the layer of the partly cured fibre laminate of one of the moulds and the layer of the uncured fibre laminate of the other mould, when the mould are closed. In this case, the vacuum film therefore become bonded between the overlapping layers and therefore subsequently forms part of the tubular element.

In an alternative method of manufacturing the tubular element, at least two layers of a vacuum film are arranged on the fibre laminate in one of the moulds before closing of the moulds. When the moulds are closed, the two layers of vacuum film may each cover the fibre laminates in one of the moulds. Before consolidation, a space between the vacuum films and the moulds can therefore be evacuated to promote good strength of the consolidated section. In this connection, evacuate means that the pressure in the space is lowered compared to an ambient pressure.

The vacuum film could be of the kind known already for providing reduced air pressure in a mould for moulding fibre laminates.

If the two layers of vacuum film are joined to form a tubular element or to form a bag, it may be possible not only to evacuate the spaces between the moulds and the laminates but also to increase pressure between the two vacuum film layers.

To avoid that the layers of the vacuum film are captured between edges of the mould when the moulds are closed, it may be an advantage to fix each layer to the moulds.

Since the interior of the mould is typically covered with the fibre laminates which are moulded in the mould, one option is typically to fix the vacuum film layers to the moulds by use of bonding tabs which extend from the interior of the mould to an external surface on which the tabs are attached. In particular, it may be an advantage to arrange such bonding tabs across the edges of the fibre laminates in the moulds so that the tabs come in-between the overlaps between the upstand and the uncured fibre laminates in the moulds and thereby become bonded to fibre laminates and become part of the tubular element after consolidation of the sections.

To reduce the influence of the bonding tabs on the strength and general characteristic of the tubular element, the bonding tabs could be made from a fibre laminate – e.g. an at least partly cured fibre laminate e.g. corresponding to that of the upstand.

In particular, the method could be used for making spars for a wind turbine blade. In this case, the uncured fibre laminate of each section can be formed with a web portion and a cap portion extending towards free ends in transverse directions from a corner area. The corner area could preferably form a rounded corner, and the transverse directions could be between 80 and 100 degrees to each other. In this case, the corresponding upstand may in particular be arranged in the mould so that it extends along the free end of the web portion. In one embodiment, the upstand is provided and arranged so that it extends along the free end of the web portion and so that it stands upward from the web portion at an angle of ±20 degrees to the cap portion, e.g. so that it is parallel to the cap portion.

The upstand could be a cured element with a V-shape with between 80 and 110 degrees between the two legs forming the V-shape. One of the legs could be bonded to the uncured fibre laminate, e.g. by use of the uncured resin contained in this laminate, and the other leg could stand upward from the uncured fibre laminate. For this purpose, it may be an advantage to arrange the upstand firstly in the mould, and the uncured fibre laminate secondly in the mould so that one of the legs of the upstand becomes located between an inner surface of the mould and the uncured fibre laminate.

In a second aspect, the invention provides a wind turbine blade comprising a tubular element made as described above and as claimed herein. The tubular element could be the spar, it could be the blade shell forming the outer geometry of the blade or it could be any other component on a wind turbine blade.

DESCRIPTION OF EMBODIMENTS OF THE INVENTION

Embodiments of the invention will be described with reference to the accompanying drawings in which:

Fig. 1 illustrates a cross sectional view of a mould;

Fig. 2 illustrates the mould in Fig. 1 with fibre laminate therein;

Fig. 3 illustrates a cross section of the section without the mould;

Fig. 4 illustrates a cross section of the mould with fibre laminate and an upstand;

Fig. 5 illustrates an upstand;

Fig. 6, illustrates a cross section of the mould in Fig. 4, being closed with another mould; and

Figs. 7 and 8 illustrate in cross sectional views, an alternative way of covering the fibre laminates.

Fig. 1 illustrates in a cross sectional view a mould 1 for moulding separate sections of the tubular element. The mould 1 has an inner surface 2 against which the sections can be moulded and an outer surface 3, herein defined as that part of the mould which is not covered by a section which is moulded in the mould.

Fig. 2 illustrates the mould 1 in which a section is prepared. The sections are prepared by arranging fibres and uncured resin against the inner surface 2 whereby uncured fibre laminates are laid up.

Each section comprises a stiffening element 4 made from a cured laminate which is arranged against the inner surface 2 of the mould, an outer layer 5 of uncured fibre laminate, a core 6, e.g. of a foam material, a flange section 7, e.g. constituted by a pre-consolidated slap which is typically uni-directional fibres in a pre-consolidated resin, and an inner layer 8 of uncured fibre laminate.

The outer layer 5 is illustrated with an end portion which is curled around so that the flange section 7 becomes completely encapsulated. In alternative embodiments, the end of the flange section is exposed, and in other alternative embodiments, the flange section 7 and optionally also the core 6 is substituted with more layers of uncured fibre laminate.

In the illustration in Fig. 2, the layers are shown separate from each other, this is for visualisation only. In practise, the layers are typically adhesively bonded to each other to form a laminated structure. In Fig. 3, a cross-section of the section is illustrated as a solid element without the mould. In this view, the sections form the shape of a V. This shape is particularly suitable if the tubular element is a spar for a wind turbine blade.

In the V-shape we have used the notation "web portion" for the upward leg 10, and "cap portion" for the outward leg 11. The web portion 10 and the cap portion 11 extend towards free ends 12, 13 in transverse directions, i.e. substantially perpendicular to each other from a corner area 14.

The tubular element according to the invention is made of at least two elements made in individual moulds. The moulds and the sections could be identical or they could have different shapes. However, in the following, the same reference numbers apply for both moulds and for the items making up the sections in the moulds.

Fig. 4 illustrates the mould 1 in which an upstand 15 is adhered to the uncured fibre laminate. In the embodiment shown in Fig. 4, the upstand 15 replaces the stiffening element 4 shown in Fig. 2. The stiffening element 4 may, however, also be used in combination with the upstand 15.

Fig. 5 illustrates in a cross sectional view, the upstand alone 15. The upstand is made from fibres in an at least partly cured resin or in a completely cured resin. The upstand 15 is V-shaped in the cross sectional view, and one of the legs 16 of the V-shape is arranged parallel with the web portion 10 of the uncured fibre laminate. The other leg 17 of the V-shape extends upright from the surface of the uncured fibre laminate, approximately at an angle of a bit more than 90 degrees, e.g. between 90 and 100 degrees to the surface of the uncured fibre laminate, i.e. the angle A indicated in Fig. 5 may e.g. be between 90 and 100 degrees or even 110 degrees.

Figs. 2 and 4 illustrate a vacuum film 20 which covers the fibre laminates in the moulds. The vacuum film is attached at an edge 21 of the moulds by use of an adhesive 22. At the edge 21, the moulds further comprises a bleeder fabric 23 which forms a vacuum channel through which air pressure in the space between the mould and the vacuum film 20 can be reduced relative to pressure in the ambient space. As illustrated in Figs. 2 and 4, the vacuum film 20 is attached to the moulds and arranged to cover the fibre laminates therein before the moulds are closed.

Fig. 6 illustrates a cross section of the mould in Fig. 4 after the vacuum film 20 has been arranged to cover the fibre laminate in the mould and after another mould has been arranged in a position herein referred to as "closed", i.e. the moulds are in positions relative to each other so that a layer 24 of the partly cured fibre laminate of one of the moulds overlap a layer 25 of the uncured fibre laminate of the other mould, and in this position, the laminates can be co-cured while the sections are in the moulds. Fig. 6 illustrates the two sections with a distance to each other, this is for illustration only, and in practise the moulds and sections are pressed towards each other. This is also indicated by the angle of the layer 24 which corresponds to the leg 17 on the upstand 15. This leg is now pressed down to become perpendicular with the cap portion of the opposite section.

An adhesive 26 is in this embodiment arranged between the two sections. The adhesive 26 thereby joints the sections, and the vacuum film 20 becomes part of the finished tubular element. For this purpose the vacuum film 20 may be made from PET, PES, PEEK, nylon, silicone, or from compositions comprising one or more of the mentioned materials. The adhesive 26 could be hardened, e.g. thermally during curing of other part of the tubular element.

Figs. 7 and 8 illustrate in cross sectional views, an alternative way of covering the fibre laminates. According to this method, a bag 27 is arranged in one of the moulds 28. The bag 27 is fixed to the mould 28 by use of two bonding tabs 29, 30. The bonding tabs 29, 30 are made from an at least partly cured fibre laminate. In one end, the bonding tabs 29, 30 are attached to the bag 27, and in an opposite end, the bonding tabs 29, 30 are attached to an outer surface 31 of the mould 28. When the mould 28 is turned around and arranged on the other mould 32, the bonding tabs 29, 30 become in-between the joint line where the two moulds assemble and become in-between those layers of the fibre laminate 33, 34 in the moulds which are joined. Accordingly, the bonding tabs 29, 30 form part of the finished tubular element.

CLAIMS

1. A method of making a tubular element for a wind turbine blade where at least two sections of the blade are assembled to form the tubular element, the method comprising preparing the two sections individually by arranging fibres and uncured resin to form uncured fibre laminates in two separate moulds, arranging the two moulds relative to each other so that an uncured fibre laminate of one of the sections overlaps a fibre laminate of the other section, and assembling the sections by co-curing the uncured laminate, the method comprising the steps of:

- adhering to the uncured fibre laminate in each mould, a corresponding upstand comprising at least partly cured fibre laminate which stands free above a surface of the corresponding uncured fibre laminate;

- closing the moulds by arranging the two separate moulds in positions relative to each other so that a layer of the partly cured fibre laminate of one of the moulds overlap a layer of the uncured fibre laminate of the other mould; and

- assembling the sections by co-curing the uncured laminate while the sections are in the moulds.

2. A method according to claim 1, wherein the at least partly cured fibre laminate and the uncured fibre laminate in each mould are covered by a vacuum film which is joined to the overlapping layers during assembling of the sections.

3. A method according to claim 1, wherein two layers of a vacuum film are arranged on the fibre laminate in one of the moulds before closing of the moulds.

4. A method according to claim 3, wherein the two layers form a bag.

5. A method according to claims 3 or 4, wherein the two layers are fixed to the mould by use of at least one bonding tab made from an at least partly cured fibre laminate.

6. A method according to any of claims 3-5, wherein the spaces between one of the moulds and one of the layers and between the other mould and the other layer are evacuated and the fibre laminates are co-cured in the moulds.

7. A method according to any of the preceding claims, the uncured fibre laminate of each section being formed with a web portion and a cap portion extending towards free ends in transverse directions from a corner area where the cap and web portions are joined, wherein the corresponding upstand extends along the free end of the web portion.

8. A method according to any of the preceding claims, where the upstand is adhesively bonded to the uncured fibre laminate by use of uncured resin in the uncured laminate.

9. A method according to claim 8, wherein the uncured resin in the uncured laminate is consolidated while the sections are in the moulds.

10. A wind turbine blade comprising a tubular element made according to a method claimed in any of claims 1-9.

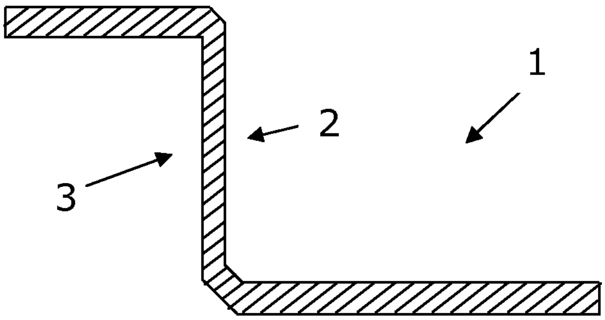

Fig. 1

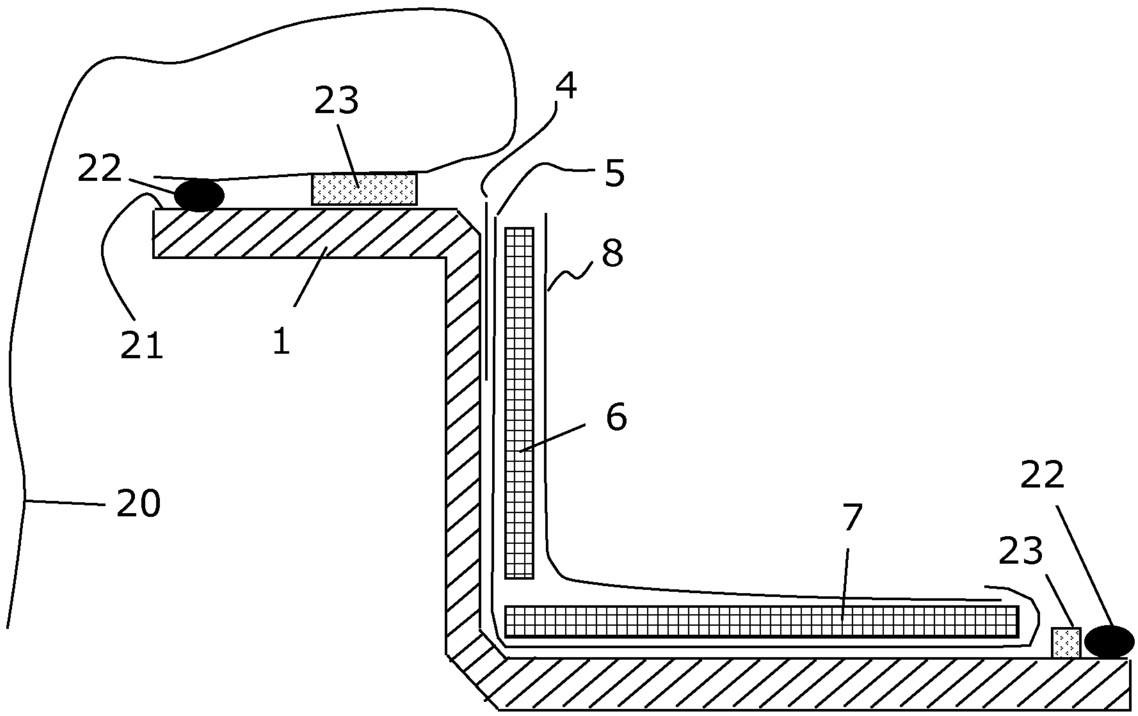

Fig. 2

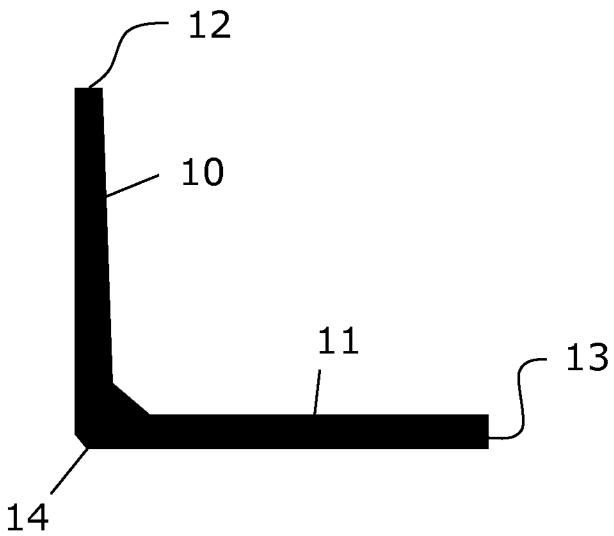

Fig. 3

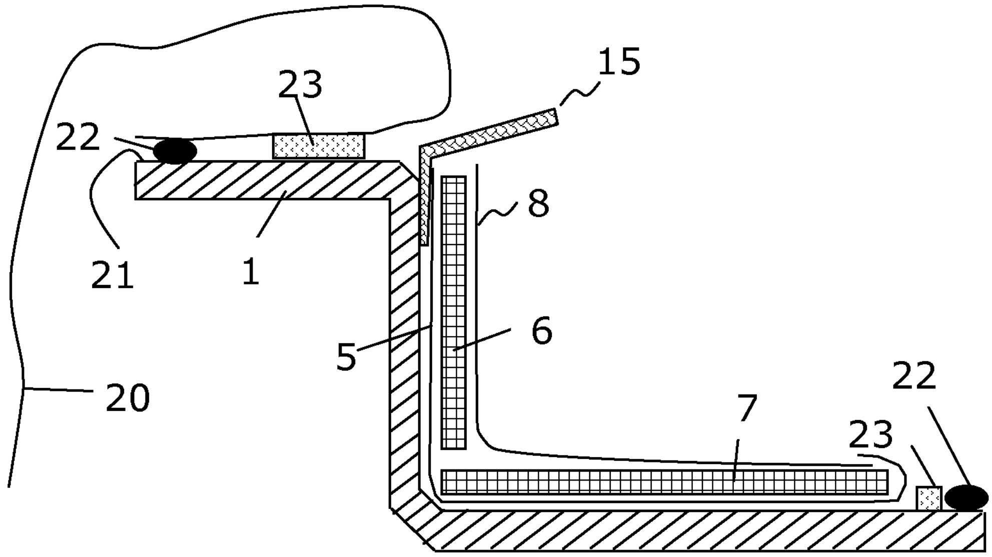

Fig. 4

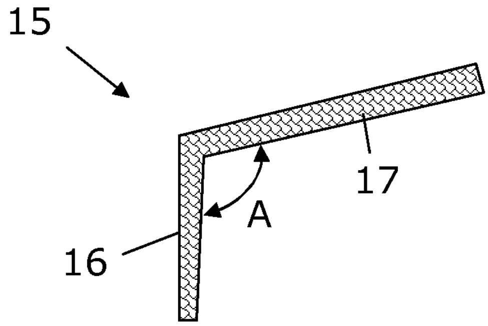

Fig. 5

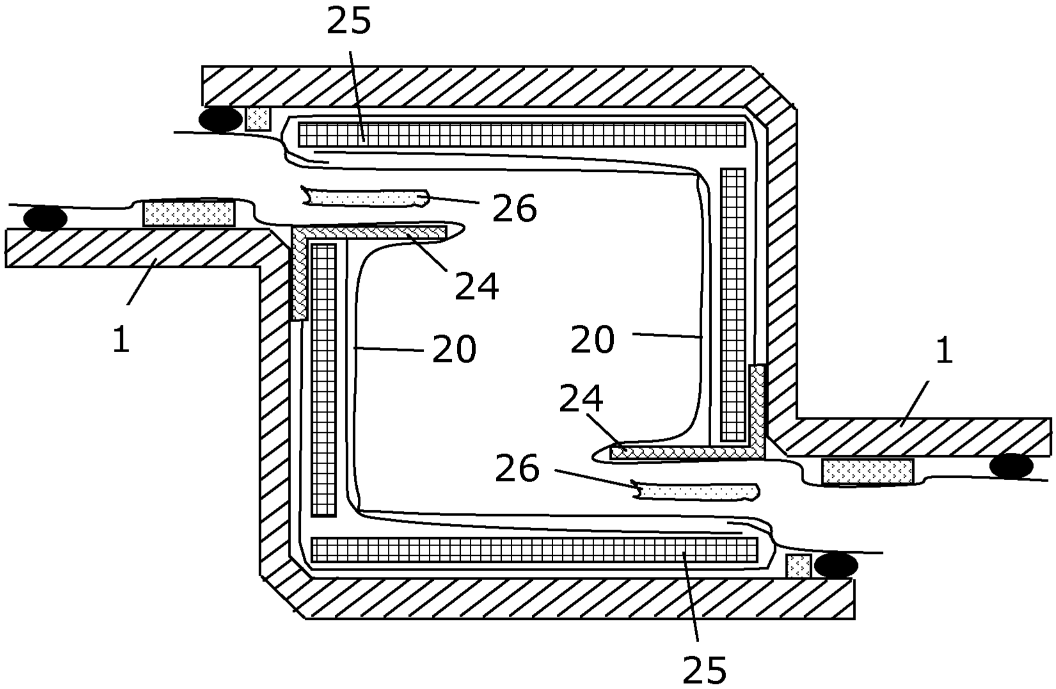

Fig. 6

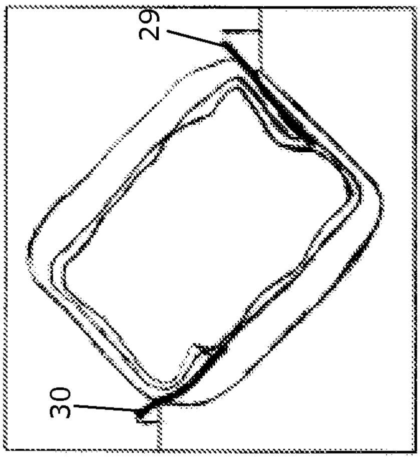

Fig. 8

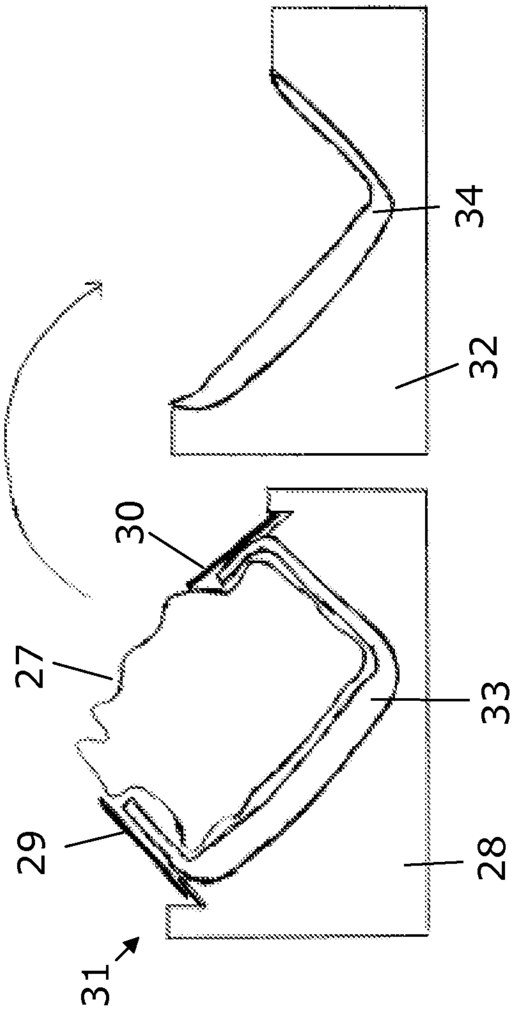

Fig. 7

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2009/062656

A. CLASSIFICATION OF SUBJECT MATTER
INV. B29C65/00 B29C65/48 B29C70/30
ADD. F03D1/06

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)
F03D B29C B63B E04H B29D

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 practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4 698 011 A (LAMALLE JEAN [FR] ET AL) 6 October 1987 (1987-10-06) column 6, line 61 - line 67; figure 13	1-10
A	FR 2 429 661 A (ADRIEN CLAUDE [FR]) 25 January 1980 (1980-01-25) page 5, line 13 - page 7, line 17; figures 4,8-10	1-10
X	WO 2008/071195 A (UNIV DENMARK TECH DTU [DK]; FIND MOELHOLT [DK] UNIV DANMARKS TEKNISKE) 19 June 2008 (2008-06-19)	10
A	page 17, line 9 - line 13; figures 7c,7d	1-9

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

[X] See patent family annex.

* Special categories of cited documents :

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Date of the actual completion of the international search	Date of mailing of the international search report
5 January 2010	14/01/2010

Name and mailing address of the ISA/	Authorized officer
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INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2009/062656

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4 494 910 A (HAHN MICHAEL [DE] ET AL) 22 January 1985 (1985-01-22) column 3, line 27 - column 4, line 34; figures 1-4	1-10
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