Method and device for manufacturing a product of a composite material of reinforcing elements.

The invention relates to a method for manufacturing a product of a composite material of reinforcing elements. The method comprises the steps of positioning a flexible material structure comprising elongated reinforcing elements onto a mould according to a particular routing that is defined by a sequence of positions on the mould; fixating at least part of the material structure before removing the mould from the thus formed product. In the method a computer program determines the optimal routing by assigning, for a first position on the mould, a penalty to possible second positions and calculating the sequence of positions with the lowest total penalty. The invention also relates to a device for carrying out the method, and to an apparatus comprising a processor and a memory coupled to the processor, the memory containing programming code executed by the processor adapted to carry out the method steps.
Method and device for manufacturing a product of a composite material of reinforcing elements

The invention relates to a method for manufacturing a product of a composite material of reinforcing elements. The invention further relates to a device for carrying out the method, and to a nodal frame of interconnected structural members, such as for a car, a boat and the like, obtainable by the method of the invention.

Products made of a composite material, i.e. a material comprising reinforcing elements embedded in a polymer matrix, combine high strength and low weight. Although several methods exist for manufacturing such composite products, known methods such as for instance prepreg lay-up, filament winding, pultrusion, resin transfer moulding, compression moulding and the like, offer room for improvement. The filament winding method for instance comprises the steps of impregnating elongated reinforcing elements with the polymer matrix, positioning the reinforcing elements onto a mould along specific paths to create a desired configuration for the reinforcing elements, and hardening the polymer matrix at elevated temperature and pressure. Although the known method yields suitable finished products, the filament winding method has its limitations. It is for instance difficult to control the configuration of the reinforcing elements onto the mould, and some configurations may not be attainable at all. As a result, the finished product may show a less than optimal performance with respect to weight and strength.

Also, the manufacture of many products of composite material requires assembling previously made parts. This is in particular the case for products comprising a nodal frame of interconnected structural members, such as for use in a car. Assembling parts is time consuming and moreover may lead to less than optimal properties, due to stiffness and strength penalties at positions where two or more parts join. It would therefore be highly desirable to be able to manufacture a nodal frame of interconnected structural members, such as for use in a car, without having to assemble different parts and within an economically feasible period of time.

One object of the present invention is to provide such a method for manufacturing a product of composite material, in particular a nodal frame of structural members. It is a
further object to provide a device for manufacturing a product of composite material, in particular a nodal frame of structural members.

The invention thereto provides a method for manufacturing a product of a composite material of reinforcing elements, the method comprising the steps of:

- providing a flexible material structure comprising elongated reinforcing elements;
- providing a mould that defines the shape of the product;
- positioning the material structure onto the mould according to a particular routing that is defined by a sequence of positions on the mould;
- fixating at least part of the material structure in order to stabilize the product; and
- removing at least a part of the mould from the thus formed product;

whereby a computer program determines the optimal routing for positioning the material structure by

- assigning, for a first position on the mould, a penalty to possible second positions;
- calculating the sequence of positions with the lowest total penalty, and
- positioning the material structure according to the optimal routing.

The invented method enables to produce a composite material product with improved mechanical properties in a reduced time period, as compared to state of the art methods, such as the method that involves assembling of pultruded structural members.

In a preferred embodiment of the method according to the invention, the product is a nodal frame of interconnected structural members, such as for use in a car, the mould is adapted to support the flexible material structure at least over those parts of the mould that correspond to the position of the structural members, the routing of the material structure comprises the structural members, and the possible positions involve the nodes of the frame.

Another preferred embodiment of the method according to the invention is characterized in that the penalty for the possible second positions is updated each time the material structure has been positioned to a new first position.
In yet another preferred embodiment of the method according to the invention, the penalty assigned to possible second positions is a function of the geometrical distance from the possible second positions to the first position over the mould surface. Such distance may be measured along the geodesic path that runs from the first position to the possible second positions, but may also run along a non-geodesic path, depending on the desired reinforcement direction in the product for instance. A preferred function comprises the geometrical distance multiplied by some penalty value.

In another embodiment, the method according to the invention is characterized in that the penalty assigned to possible second positions is equal to the geometrical distance from the possible second positions to the first position over the mould surface. The geometrical distances may be measured on the mould beforehand but typically are known from geometrical models, such as CAD-models and finite element models of the product to be manufactured. Such models, in particular finite element models, are for instance used when designing the product in accordance with the typical loads the product needs to withstand during its lifetime.

Another embodiment of the method according to the invention involves a method wherein the possible second positions comprise those positions that are to be connected to the first position by a structural member. These positions are typically known from the initial design of a nodal framework of structural members. In this embodiment, the penalty assigned to possible second positions are set to a high value (for instance infinity) for those second positions that need not to be connected to a first position.

The method according to the invention allows to position the flexible material structure according to an optimal routing or path, where such routing is defined by a sequence of positions on the mould. The invention is not limited to any specific optimum criterion. In fact the optimal routing may be determined in function of several desirable parameters. It has advantages however to characterize the method according to the invention in that the penalty assigned to the possible second positions is a function of decision variables that represent production time, production cost, material cost and/or product weight. Such embodiment allows to find the routing that leads to a minimum production time and/or the lowest use of material and/or the lowest weight.
In the minimization algorithm, a so-called objective function is typically minimized. A preferred objective function comprises the sum of the relative distances for an entire routing path with a total of N nodes or instances:

\[
\min \left[ \sum_{m=1}^{n=N} \Delta D_m (\alpha_1, \alpha_2, \ldots, \alpha_n) \right]
\]

In the present embodiment, the distance increment per node or instance \(\Delta D_m\) depends on the decision variables \(\alpha_m\) which preferably represent production time, production cost, material cost and/or product weight.

In the method according to the invention the objective function is preferably subjected to three sets of constraints. The first constraint is formulated as follows:

\[
\left[ \sum_{m=1}^{n=N} \Delta D_m (\delta_1, \delta_2, \ldots, \delta_n) \right] \leq f_n (\delta_n)
\]

in which the state variables \(\delta_n\) and their respective constraint functions \(f_n (\delta_n)\) may be related to the product center of gravity, and/or the product thickness build-up of nodes in the nodal frame.

The second constraint is preferably formulated as follows:

\[
\left[ \sum_{m=1}^{n=N} \Delta D_m (\gamma_1, \gamma_2, \ldots, \gamma_n) \right] = f_n (\gamma_n)
\]

in which the state variables \(\gamma_n\) and their respective constraint functions \(f_n (\gamma_n)\) may be related to the product symmetry, and/or the desired thickness of discrete member paths and the fibre volume fraction, and/or the order in which discrete member paths are crossed.

The third constraint that is to be satisfied by the objective function is preferably formulated as follows:
\[ \Delta D_n(\Theta_1, \Theta_2, \ldots, \Theta_n) \leq f_n(\Theta_n) \]

in which the state variables \( \Theta_n \) and their respective constraint functions \( f_n(\Theta_n) \) may be related to the maximum angle of a path or routing change between nodes or instances, and/or limitations of the fibre placement apparatus with respect to for instance the size of the product.

A particularly preferred method according to the invention is characterized in that the material structure has variable mechanical properties along its length. Using this preferred method may allow for improving the strength to weight ratio of the frame, if the variable mechanical properties along the length of the material structure are such that they correspond to the preferred mechanical properties of the instances.

The invention also relates to an apparatus for positioning a material structure comprising elongated reinforcing elements onto a mould according to a particular routing that is defined by a sequence of positions on the mould, the apparatus comprising:

- a processor; and
- a memory coupled to the processor, the memory containing programming code executed by the processor adapted to:
  - a) assign, for a first position on the mould, a penalty to possible second positions;
  - b) calculate the sequence of positions with the lowest total penalty, and
  - c) position the material structure according to this optimal routing.

The advantages of the apparatus according to the invention have already been elucidated above and will not be repeated here.

In a preferred embodiment, the programming code of the apparatus according to the invention is adapted to carry out steps a) to c) each time the material structure has been positioned to a new first position.
The method and device according to the invention are particularly suitable for the manufacture of a nodal frame of interconnected structural members, such as for use in a car.

In another aspect of the invention, a device for manufacturing a product of a composite material of reinforcing elements is provided, the device comprising:

- a mould that defines the shape of the product;
- positioning means adapted to position a material comprising elongated reinforcing elements onto the mould according to a particular routing that is defined by a sequence of positions on the mould;
- fixating means adapted to fixate at least part of the material structure in order to stabilize the product; and
- an apparatus according to claim 10 or 11.

Although the material comprising reinforcing elements may be positioned onto the mould by any positioning means, a device, wherein the positioning means comprise a robot unit, a multiple-robot cell or a filament winding apparatus is particularly preferred.

In yet another aspect of the invention, the device comprises a mould provided with recesses or grooves that correspond to the position of the structural members. The positioning means are in this embodiment adapted to position the material comprising elongated reinforcing elements onto the mould along the recesses or grooves, which define the positions on the mould that should be provided with material. The sequence or routing is however determined by the method as elucidated above.

A composite product derives its stiffness and strength mainly from the reinforcing elements, such as reinforcing fibres for instance. It is therefore important to be able to achieve a desired configuration of the reinforcing elements in the finished product, by which is preferably meant that the reinforcing elements are positioned such that they take the majority of the loads imposed on the product in actual use. The desired configuration of the reinforcing elements may be obtained by means known in the art, such as by finite element calculations.
The reinforcing elements may comprise tapes or fibres of any material, including carbon or graphite and glass fibres. Other fibres to be suitably applied in the method according to the invention are drawn thermoplastic polymer fibres, comprising poly(p-phenylene-2, 6-benzobisoxazole) fibres (PBO, Zylon®), aramid fibres, and poly(2,6-diimidazo-(4,5b-4’,5’e)pyridinylene-1,4(2,5-dihydroxy)phenylene) fibres (M5® fibres), or combinations thereof. The reinforcing elements may also comprise reinforcing elements embedded in an uncured or partially cured matrix material. According to the method of the invention, these so-called prepreg tapes are positioned onto the mould and fixated by heating for instance. The matrix material in the preregs may serve as fixation means. It is also possible to locally heat (and therefore cure) the prepreg tapes to obtain the fixations at the heated locations.

Any matrix material known in the art may be used in the method of the invention. Examples of suitable matrix materials for the reinforcing elements include thermoplastic polymers such as polyamides, polyimides, polyethersulphones, polyetheretherketone, polyurethanes, polyethylene, polypropylene, polyphenylene sulphides (PPS), polyamide-imides, acrylonitrile butadiene styrene (ABS), styrene/maleic anhydride (SMA), polycarbonate, polyphenylene oxide blend (PPO), thermoplastic polyesters such as polyethylene terephthalate, polybutylene terephthalate, as well as mixtures and copolymers of one or more of the above polymers. Suitable matrix materials also comprise thermosetting polymers such as epoxies, unsaturated polyester resins, melamine/formaldehyde resins, phenol/formaldehyde resins, polyurethanes, and the like.

The invention will now be described in more detail, by way of example, with reference to the accompanying figures, in which: figure 1 schematically represents a flow chart of an embodiment of the method for manufacturing a product according to the invention; figure 2 schematically represent a nodal frame of structural members, that may be manufactured by a method according to the invention; and figures 3A to 3G schematically represent several parts of a routing for manufacturing the nodal frame of figure 2.
The method according to the invention uses a computer based algorithm, designed to find an optimal or near-optimal path or routing to place a material structure, such as a continuous string of reinforcing fibres, on a substantially single path, in or around a mould, which may be symmetrical or asymmetrical. The path may be geodesic or non-geodesic. With substantially single path is meant that the elongated material structure is placed onto the mould in a substantially continuous operation. This also covers a situation where a single material structure is positioned onto the mould with the aid of for instance two robot units operating simultaneously on two separate paths, that may ultimately meet.

The method seeks the (near-)optimal sequence in which to place the material structure as discrete members onto the mould. The discrete members are viewed as instances in the optimization algorithm. The nodes in the material structure positioning (and in particular the fibre placement) problem are the geometric locations where structural members of a frame change direction, cross or join each other. The nodes in the actual fibre placement problem usually have no relation to the nodes or instances in the virtual problem, as will become apparent hereinafter.

The distance between the instances, i.e. the distance between the discrete members, may not be absolute and may not bear a direct relation to the geometrical distance between the instances. According to the invented method, the relative distances between the instances are adapted according to a set of parameters related for instance to the design and/or production process. Unfavorable routing choices are identified beforehand and are given a relative distance penalty over favourable ones, after which a routing algorithm finds the sequence with the lowest total penalty.

This approach allows to search for a (near-)optimal routing sequence in a dynamic way, as the relative distance penalties are preferably re-assessed after each considered routing step. In the method of the invention, a separate algorithm operates in parallel to the actual routing algorithm, to interpret the previously made routing choice(s). It then adapts the relative distance between each affected instance accordingly, by adding or removing distance penalties. The adaptations are governed by a set of separately defined knowledge rules, in which the operator of the algorithm can tailor or add specific constraints, suited to the problem at hand.
With reference to figure 1, an embodiment of the method for manufacturing a
composite material product comprises a pre-processing stage that involves a routine 1
for analysis of a product geometry in terms of strength and stiffness requirements,
whereby general design knowledge rules 2, known per se, and a product geometry 3 are
used. For a structural frame for instance, the pre-processing stage results in an overall
frame geometry, i.e. known positions and orientations of the structural members. Also,
the thickness as well as the required material properties are known at this stage for each
member.

On the basis of this knowledge, an initial dynamic Relative Distance Matrix (dRDM) is
compiled by subroutine 20. The initial dRDM is a matrix, the elements of which
represent the relative distances between members, to which penalties have been
assigned (see further below). The initial dRDM is then used as a starting point for the
routing algorithm 4. The routing algorithm involves the selection of a next instance (a
second position following a first position) on the basis of lowest relative distance
penalty. The current sequence of positions is then assessed at subroutine 5.

It is then assessed at subroutine 6 whether the sequence is complete (whether all frame
members have been travelled). If this is positive, the routing sequence is analysed in
terms of the required parameters, such as total production time, total material cost,
mechanical properties and the like at subroutine 7, and an analysis report 9 is issued as
part of a post-processing stage. A subroutine 8 then assesses whether the quality is
acceptable (whether the actual routing is close enough to the required parameter values).

If the quality is acceptable the routine is terminated at 10. If the quality is not
acceptable, the routing algorithm is reiterated, with a different initial dRDM.

If the assessment by subroutine 6 reveals that the sequence of positions is not complete,
a subroutine 11 examines whether a continuation of the routing is possible, for instance
whether there are second positions available following the present first position. If the
examination reveals that it is not possible to continue, subroutine 12 assesses whether
backtracking is a possibility, i.e. returning from the present position to a former
position. If this is not possible, the search for a second position is terminated at 13 and
the routing sequence analysed by subroutine 7. If the examination of subroutine 11, or
the examination of subroutine 12, reveals that it is possible to continue, the dRDM and/or the routing parameters are updated at subroutine 14. This step involves a recalculation of the dRDM whereby penalties (and therefore relative distances between instances) are updated. The updated dRDM 15 is then loaded into routing subroutine 4 and another iteration is initiated.

To illustrate the method of the invention in more detail, reference is made to figure 2 and figures 3A - 3G, in which a simplified structural frame 30 is presented. The structural frame 30 involves a 5-sided pyramid. The method according to the invention provides an optimized routing sequence in which to position a continuous string of fibres to construct this pyramidal frame, whereby one or more parameters need to be minimized.

In the embodiment shown, the routing algorithm minimizes the angle between two successive member paths. For the sake of clarity, no additional constraints for constructing the truss frame are imposed in terms of whether, or which, members are allowed to be visited twice. However, additional constraints may be implemented by activating the knowledge based design rules. The routing algorithm adjusts the search parameters accordingly, in order to find a (near-)optimal routing path for the continuous fibre placement. All routing parameters are preferably user-adjustable, including quantification of production constraints and penalties.

For clarity reasons also, only part of the information flow which runs during the routing routine is discussed below. Many more variables are generated, updated and carried over when the routing algorithm is running, but they are considered less relevant to explain the algorithms working principles.

When the frame member coordinates are imported from a data file (subroutine 1, see figure 1), the members are assigned a unique number for use within the routing algorithm. The members in the present example have been assigned a unique number from 31 to 38. The members are then assigned coordinates and with the member coordinates as input, a dRDM is constructed with a row and a column for each member. The dRDM is to be read as follows: a member’s unique number corresponds to a column; in this column the different rows indicate the connections to the other
members. For instance, in the following example member 32 connections are listed in the second column, while members 38 connections are listed in the eighth column:

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This dRDM contains the following information with respect to the connections of member 32:

- Member 32 has a possible and favorable connection (in this example: a shallow or right angle) to members 31 and 33, i.e. member 32 has a relatively low relative distance of 10 to members 31 and 33; rows 1 and 3 in the dRDM;
- Member 32 has a possible, but unfavorable, connection (in this example: a sharp angle) to members 37 and 38, i.e. member 32 has a relatively high relative distance of 20 to members 37 and 38; rows 7 and 8 in the dRDM;
- Member 32 has no physical connection to the other members. Therefore the relative distance to the other members should be very high, as to avoid selecting these connections in the routing algorithm, i.e. member 32 has a relative distance of infinity (Inf) to all other members in all other rows.

By assigning high relative distances between members, connections are unfavoured, low relative distances favor connections.

Starting the routing algorithm at member 31 (i.e. searching for the next instance in column 1 of the dRDM), the routing sequence and the dRDM are depicted for each step in the embodiment shown:

1. The starting member is member 31, which has a connection to members 32, 34, 35 and 37. The cheapest available instance is selected as the next step in the routing sequence, i.e. member 32:
The selected current sequence is 31 (see figure 3A)

2. Member 32 is the current member, which has a connection to members 31, 33, 37 and 38. However, members 31 and 37 are not considered for the next step in the routing sequence, as they are both connected to the (actual) node which is also connected to the previous instance (member 31). The algorithm thus automatically prevents backtracking over the same member, which is not allowed in this context, as a path for continuous fibre placement is sought.

Since member 31 has been used in the sequence now, the routing algorithm wants to prevent using it again if there are other feasible connections available which have not been used yet. Therefore, the relative distance between member 31 and its feasible connections have been given a penalty of 20, as is evident from the dRDM below:

The current sequence is 31-32 (see figure 3A)
3. For the next instance, the current member’s connection column is highlighted by bold faced letter and the selected next instance’s row is indicated with an arrow next to it:

\[
\begin{array}{cccccc}
5 & \mathbf{Inf} & 30 & \mathbf{Inf} & 30 & 40 & \mathbf{Inf} & 40 & \mathbf{Inf} \\
30 & \mathbf{Inf} & 30 & \mathbf{Inf} & \mathbf{Inf} & \mathbf{Inf} & \mathbf{Inf} & 40 & 40 \\
\mathbf{Inf} & 30 & \mathbf{Inf} & 30 & \mathbf{Inf} & \mathbf{Inf} & \mathbf{Inf} & 40 & \mathbf{Inf} \\
10 & \mathbf{Inf} & 10 & \mathbf{Inf} & 20 & 20 & \mathbf{Inf} & \mathbf{Inf} & \mathbf{Inf} \\
20 & \mathbf{Inf} & 20 & \mathbf{Inf} & 20 & 20 & \mathbf{Inf} & \mathbf{Inf} & \mathbf{Inf} \\
10 & \mathbf{Inf} & 20 & \mathbf{Inf} & 20 & 20 & \mathbf{Inf} & \mathbf{Inf} & \mathbf{Inf} \\
20 & 20 & \mathbf{Inf} & \mathbf{Inf} & \mathbf{Inf} & \mathbf{Inf} & \mathbf{Inf} & \mathbf{Inf} & \mathbf{Inf} \\
\end{array}
\]

The current sequence is 31-32-33 (see figure 3A) and no backtracking is allowed over the same member.

4. For the next instance, the current member’s connection column is highlighted by bold face and the selected next instance’s row is indicated with an arrow next to it:

\[
\begin{array}{cccccc}
20 & \mathbf{Inf} & 30 & \mathbf{Inf} & 30 & 40 & \mathbf{Inf} & 40 & \mathbf{Inf} \\
30 & \mathbf{Inf} & 30 & \mathbf{Inf} & \mathbf{Inf} & \mathbf{Inf} & \mathbf{Inf} & 40 & 40 \\
\mathbf{Inf} & 30 & \mathbf{Inf} & 30 & \mathbf{Inf} & \mathbf{Inf} & \mathbf{Inf} & 40 & \mathbf{Inf} \\
30 & \mathbf{Inf} & 30 & \mathbf{Inf} & \mathbf{Inf} & \mathbf{Inf} & \mathbf{Inf} & 40 & \mathbf{Inf} \\
20 & \mathbf{Inf} & \mathbf{Inf} & \mathbf{Inf} & \mathbf{Inf} & 20 & \mathbf{Inf} & \mathbf{Inf} & \mathbf{Inf} \\
25 & \mathbf{Inf} & \mathbf{Inf} & 20 & \mathbf{Inf} & \mathbf{Inf} & \mathbf{Inf} & \mathbf{Inf} & \mathbf{Inf} \\
20 & 20 & \mathbf{Inf} & \mathbf{Inf} & \mathbf{Inf} & \mathbf{Inf} & \mathbf{Inf} & \mathbf{Inf} & \mathbf{Inf} \\
\mathbf{Inf} & 20 & 20 & \mathbf{Inf} & \mathbf{Inf} & \mathbf{Inf} & \mathbf{Inf} & \mathbf{Inf} & \mathbf{Inf} \\
\end{array}
\]

The current sequence is 31-32-33-34 (see figure 3B)

5. For the next instance, the current member’s connection column is highlighted by bold face and the selected next instance’s row is once again indicated with an arrow next to it:

\[
\begin{array}{cccccc}
35 & \mathbf{Inf} & 30 & \mathbf{Inf} & 30 & 40 & \mathbf{Inf} & 40 & \mathbf{Inf} \\
30 & \mathbf{Inf} & 30 & \mathbf{Inf} & \mathbf{Inf} & \mathbf{Inf} & \mathbf{Inf} & 40 & 40 \\
\mathbf{Inf} & 30 & \mathbf{Inf} & 30 & \mathbf{Inf} & \mathbf{Inf} & \mathbf{Inf} & 40 & \mathbf{Inf} \\
\end{array}
\]
30  Inf  30  Inf  40  40  Inf  Inf
40  Inf  Inf  40  Inf  40  40  40
Inf  Inf  20  20  20  Inf  20  20  20
20  20  Inf  Inf  20  20  Inf  20  20
5  Inf  20  20  Inf  20  20  20  Inf

The current sequence is 31-32-33-34-35 (see figure 3C)

6.  In the same manner, the next instance yields:

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20  The current sequence is 31-32-33-34-35-36 (see figure 3D)

7.  In the same manner, the next instance yields:

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The current sequence is 31-32-33-34-35-36-33 (see figure 3E)

8.  For the next instance, running the routing routine yields:

<p>| | | | | | | | |</p>
<table>
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<tr>
<th></th>
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</table>
The current sequence: 31-32-33-34-35-36-33-38 (see figure 3F)

9. Finally, the next instance yields:

The complete sequence finally is: 31-32-33-34-35-33-36-38-37 (see figure 3G)

The routing algorithm continues searching for the next available, cheapest instance, until all instances have been visited at least once. This condition can be extended, as indicated above, by adding constraints. For instance, when a symmetrical positioning routing is desired, the algorithm will continue to extend the sequence until all instances are visited at least once and the routing sequence is symmetrical.

In the example given, the only activated constraint was that the routing sequence should visit each instance at least once. All instances, members, have, and member 33 has been visited twice. For this geometry and set of applied constraints, this was necessary to complete the routing sequence.
Conclusies

1. Werkwijze voor het vervaardigen van een product uit een composiet materiaal uit versterkende elementen, omvattend de stappen van:

   - het verschaffen van een flexibele materiaal structuur omvattende langwerpige versterkende elementen;
   - het verschaffen van een de vorm van het product definiërende mal;
   - het op de mal positioneren van de materiaal structuur volgens een specifieke route die is gedefinieerd door een volgorde van posities op de mal;
   - het fixeren van ten minste een deel van de materiaal structuur voor het stabiliseren van het product; en
   - het verwijderen van ten minste een deel van de mal van het aldus gevormde product;

   waarin een computerprogramma de (sub)optimale route voor het positioneren van de materiaal structuur bepaalt door:

   - het voor een eerste positie op de mal toewijzen van een waarde aan mogelijke tweede posities;
   - het berekenen van de volgorde van posities met de laagste totale waarde; en
   - het volgens de optimale route positioneren van de materiaal structuur.

2. Werkwijze volgens conclusie 1, waarbij het product een raamwerk uit onderling verbonden constructiedelen is, zoals voor gebruik in een auto, waarbij de mal is aangepast voor het op ten minste de met de positie van de constructiedelen overeenstemmende delen van het raamwerk ondersteunen van de flexibele langwerpige materiaal structuur, waarbij de route van de materiaal structuur de constructiedelen omvat en de mogelijke posities de knooppunten van het raamwerk behelzen.

3. Werkwijze volgens conclusie 1 of 2, waarbij de waarde aan de mogelijke tweede posities is hernieuwd elke keer dat de materiaal structuur naar een nieuwe eerste positie is gepositioneerd.

4. Werkwijze volgens een der voorgaande conclusies, met het kenmerk dat de aan de mogelijke tweede posities toegewezen waarde een functie is van de geometrische
afstand van de mogelijke tweede posities naar de eerste positie over het oppervlak van de mal.

5.   Werkwijze volgens conclusie 4, met het kenmerk dat de aan de mogelijke tweede posities toegewezen waarde gelijk is aan de geometrische afstand van de mogelijke tweede posities naar de eerste positie over het oppervlak van de mal.

6.   Werkwijze volgens een der conclusies 2 - 5, met het kenmerk dat de mogelijke tweede posities de posities omvatten die door een constructiedeel dienen te worden verbonden met de eerste positie.

7.   Werkwijze volgens een der conclusies 2 - 6, met het kenmerk dat voor tweede posities die meerdere keren dienen te worden verbonden met de eerste positie, de aan deze tweede posities toegewezen waarde laag is gesteld, zodat de materiaal structuur de overgang van de eerste naar de tweede positie en vice-versa meerdere keren zal maken.

8.   Werkwijze volgens een der voorgaande conclusies, met het kenmerk dat de aan de tweede posities toegewezen waarde een functie van beslissingsvariabelen is, die productietijd, productiekosten, materiaalkosten en/of productgewicht representeren.

9.   Werkwijze volgens een der voorgaande conclusies, met het kenmerk dat de materiaal structuur variabele mechanische eigenschappen over zijn lengte heeft.

10.  Inrichting voor het positioneren van een materiaal structuur omvattende langwerpige versterkende elementen op een mal volgens een specifieke route die is gedefinieerd door een volgorde van posities op de mal, de inrichting omvattende:
     - een processor; en
     - een met de processor verbonden geheugen, waarbij het geheugen een door de processor uitgevoerde programmeercodering omvat, aangepast voor:
     a)   het voor een eerste positie op de mal toewijzen van een waarde aan mogelijke tweede posities;
     b)   het berekenen van de volgorde van posities met de laagste totale waarde; en
     c)   het volgens deze optimale route positioneren van de materiaal structuur.
11. Inrichting volgens conclusie 10, waarbij de programmeercodering is aangepast voor het uitvoeren van de stappen a) - c) elke keer dat de materiaal structuur naar een nieuwe eerste positie is gepochioneerd.

12. Raamwerk uit onderling verbonden constructiedelen, zoals voor gebruik in een auto, verkrijgbaar volgens de werkwijze volgens een der voorgaande conclusies 1 – 9.

13. Inrichting voor het vervaardigen van een product uit een composiet materiaal uit versterkende elementen, de inrichting omvattende:
   - een de vorm van het product definiërende mal;
   - positioneermiddelen aangepast voor het op de mal positioneren van een materiaal omvattende langwerpige versterkende elementen volgens een specifieke route die is gedefinieerd door een volgorde van posities op de mal;
   - fixeermiddelen aangepast voor het fixeren van ten minste een deel van de materiaal structuur voor het stabiliseren van het product; en
   - een inrichting volgens conclusie 10 of 11.


15. Inrichting volgens conclusie 13 of 14, waarbij de mal met de positie van de constructiedelen overeenstemmende uitsparingen of groeven omvat.
SAMENWERKINGSVERDRAG (PCT)

RAPPORT BETREFFENDE NIEUWHEIDSONDERZOEK VAN INTERNATIONAAL TYPE

<table>
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<tr>
<th>IDENTIFICATIE VAN DE NATIONALE AANVRAGE</th>
<th>KENMERK VAN DE AANVRAGER OF VAN DE GEMACHTIGDE</th>
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Aanvrager (Naam)

DELFt UNIVERSITY OF TECHNOLOGY

Datum van het verzoek voor een onderzoek van internationaal type | Door de Instantie voor Internationaal Onderzoek aan het verzoek voor een onderzoek van internationaal type toegekend nr.

| 16-03-2010 | SN 53831 |

I. CLASSIFICATIE VAN HET ONDERWERP (bij toepassing van verschillende classificaties, alle classificatiesymbolen opgeven)

Volgens de internationale classificatie (IPC)

| B29C70/38 | B62D23/00 | B62D29/04 |

II. ONDERZOCHTE GEBIEDEN VAN DE TECHNIEK

Onderzochte minimumdocumentatie

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Onderzochte andere documentatie dan de minimum documentatie, voor zover dergelijke documenten in de onderzochte gebieden zijn opgenomen

III. GEEN ONDERZOEK MOGELIJK VOOR BEPAALDE CONCLUSIES (opmerkingen op aanvullingsblad)

IV. GEBREK AAN EENHEID VAN UITVINDING (opmerkingen op aanvullingsblad)

Form PCT/ISA 201 A (11/2000)
ONDERZOEKSRAPPORT BETREFFENDE HET
RESULTAAT VAN HET ONDERZOEK NAAR DE STAND
VAN DE TECHNIEK VAN HET INTERNATIONALE TYPE

A. CLASSIFICATIE VAN HET ONDERWERP

INV. B29C70/38  B62D23/00  B62D29/04
ADD.

Volgens de Internationale Classificatie van octrooien (IPC) of zowel volgens de nationale classificatie als volgens de IPC.

B. ONDERZOEKDE GEBIEDEN VAN DE TECHNIEK

Onderzochte minimum documentatie (classificatie gevolgd door classificatiesymbolen)

B29C B62D

Onderzochte andere documentatie dan de minimum documentatie, voor dergelijke documenten, voor zover dergelijke documenten in de onderzochte gebieden zijn opgenomen

Tijdens het onderzoek geraadpleegde elektronische gegevensbestanden (naam van de gegevensbestanden en, waar uitvoerbaar, gebruikte trefoorden)

EPO–Internal

C. VAN BELANG GECITEERDE DOCUMENTEN

<table>
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<tr>
<th>Categorie</th>
<th>Geciteerde documenten, eventueel met aanduiding van speciaal van belang zijnde passages</th>
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<tr>
<td>X</td>
<td>EP 1 495 856 A1 (CORETEX STRUCTURES LTD [GB]) 12 januari 2005 (2005-01-12) * alineaas [0001], [0007], [0008], [0011], [0014], [0016], [0018], [0019], [0021], [0022], [0023], [0030], [0031], [0032], [0035]; figuren 1,2,8-10 *</td>
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<td>E</td>
<td>WO 2009/149778 A1 (DAIMLER CHRYSLER AG [DE]; ILZHOEFER KARL-HEINZ [DE]; SALKIC ASMIR [DE]) 17 december 2009 (2009-12-17) * bladzijden 1-3,4-7 *</td>
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</table>

☐ Verdere documenten worden vermeld in het vervolg van vak C. ☑ Leden van dezelfde octrooifamilie zijn vermeld in een bijlage

* Speciale categorieën van aangehaalde documenten

"A" niet tot de categorie X of Y behorende literatuur die de stand van de techniek beschrijft

"D" in de octrooiaanvraag vermeld

"E" eerdere octrooiaanvraag, gepubliceerd op of na de indieningsdatum, waarin dezelfde uitvinding wordt beschreven

"L" om andere redenen vermelde literatuur

"O" niet-schriftelijke stand van de techniek

"P" tussen de voorrangssdatum en de indieningsdatum gepubliceerde literatuur

"T" na de indieningsdatum of de voorrangssdatum gepubliceerde literatuur die niet bezwaarlijk is voor de octrooiaanvraag, maar wordt vermeld ter verheldering van de theorie of het principe dat ten grondslag ligt aan de uitvinding

"X" de conclusie wordt als nieuw of niet inventief beschouwd ten opzichte van deze literatuur

"Y" de conclusie wordt als niet inventief beschouwd ten opzichte van de combinatie van deze literatuur met andere geceilte literatuur van dezelfde categorie, waarbij de combinatie voor de vakman voor de hand liggend wordt geacht

Datum waarop het onderzoek naar de stand van de techniek van internationaal type werd voltooid

20 juli 2010

Naam en adres van de instantie

European Patent Office, P.B. 5816 Patentlaan 2
NL – 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Verzendsdatum van het rapport van het onderzoek naar de stand van de techniek van internationaal type

De bevoegde ambtenaar

Jouannon, Fabien

Formulier PCT/ISA/201 (tweede blad) (Januari 2004)
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<td>A1 17-12-2009</td>
<td>DE 102008027429 A1</td>
<td>17-12-2009</td>
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This opinion contains indications relating to the following items:

- Box No. I  Basis of the opinion
- Box No. II  Priority
- Box No. III  Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
- Box No. IV  Lack of unity of invention
- Box No. V  Reasoned statement with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
- Box No. VI  Certain documents cited
- Box No. VII  Certain defects in the application
- Box No. VIII  Certain observations on the application

Examiner
Jouannon, Fabien

Form NL237A (Dekblad) (July 2006)
Box No. I  Basis of this opinion

1. This opinion has been established on the basis of the latest set of claims filed before the start of the search.

2. With regard to any nucleotide and/or amino acid sequence disclosed in the application and necessary to the claimed invention, this opinion has been established on the basis of:
   a. type of material:
      □ a sequence listing
      □ table(s) related to the sequence listing
   b. format of material:
      □ on paper
      □ in electronic form
   c. time of filing/furnishing:
      □ contained in the application as filed.
      □ filed together with the application in electronic form.
      □ furnished subsequently for the purposes of search.

3. □ In addition, in the case that more than one version or copy of a sequence listing and/or table relating thereto has been filed or furnished, the required statements that the information in the subsequent or additional copies is identical to that in the application as filed or does not go beyond the application as filed, as appropriate, were furnished.

4. Additional comments:

Box II  Priority

This opinion has been established as if the claimed priority date were valid, unless indicated otherwise on the separate sheet

NL237B (July 2006)
**Box No. V**  Reasoned statement with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

<table>
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<th>Novelty</th>
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<th>No: Claims 12</th>
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<tr>
<td>Inventive step</td>
<td>Yes: Claims</td>
<td>No: Claims 1-15</td>
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<td>Industrial applicability</td>
<td>Yes: Claims 1-15</td>
<td>No: Claims</td>
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</table>

2. Citations and explanations

*see separate sheet*

---

**Box No. VI**  Certain documents cited

- Certain published documents
  *see the Search Report*
- Non-written disclosures

**Box No. VII**  Certain defects in the application

*see separate sheet*

**Box No. VIII**  Certain observations on the application

*see separate sheet*
Re Item V

Reasoned statement with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

D1  EP 1 495 856 A1 (CORETEX STRUCTURES LTD [GB]) 12 januari 2005 (2005-01-12)

1 The present application does not meet the criteria of patentability, because the subject-matter of claim 12 is not new.

A product claim (claim 12) defined by the process is allowable only if the product, per se, satisfy to the requirements of patentability. This is not the case in the present application as document D1 discloses a nodal frame of interconnected members (figure 1).

2 The present application does not meet the criteria of patentability, because the subject-matter of claims 1 and 10 does not involve an inventive step.

2.1 Document D1 is regarded as being the prior art closest to the subject-matter of claim 1, and discloses a method for manufacturing a product of a composite material of reinforcing elements (paragraph 0001), the method comprising the steps of
- providing a flexible material structure comprising elongated reinforcing elements (paragraph 0014);
- providing a mould that defines the shape of the product (paragraphs 0022 and 0023 and figure 2);
- positioning the material structure onto the mould according to a particular routing that is defined by a sequence of positions on the mould (paragraphs 0030 and 0031);
- fixating at least part of the material structure in order to stabilize the product (paragraph 0023); and
- removing at least a part of the mould from the thus formed product (paragraph 0023);
whereby a computer program determines the routing for positioning the material structure (paragraphs 0008, 0030 and 0031).

The subject-matter of claim 1 therefore differs from this known method in that a specific algorithm is used in order to define the routing and is therefore new.

The present independent method claim 1 is based on a computer implemented method. As this computer implemented method provides a technical effect, namely the positioning of the material structure, it is not excluded from patentability.
As previously mentioned, the positioning of material using a computer is already known from document D1.

Therefore, in assessing whether there is an inventive step resulting from the differencing feature which is in this case a pure algorithm, it has to be established if an objective technical problem has been overcome by this said feature.

However, it appears that no objective technical problem could be found, resulting in that the claimed subject-matter does not satisfy the requirement for an inventive step because there is no technical contribution to the art.

2.2 The same reasoning applies, mutatis mutandis, to the subject-matter of the corresponding independent claim 10, which therefore is also considered not inventive.

3 Dependent claims 2 to 9, 11 and 13 to 15 do not contain any features which, in combination with the features of any claim to which they refer, meet the requirements of inventive step, see document and references applying to this document cited in the search report.

Re Item VI

Certain documents cited

<table>
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<tr>
<th>Application No Patent No</th>
<th>Publication date (day/month/year)</th>
<th>Filing date (day/month/year)</th>
<th>Priority date (valid claim) (day/month/year)</th>
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Re Item VII

Certain defects in the application

The relevant background art disclosed in document D1 is not mentioned in the description, nor is this document identified therein.

Re Item VIII

Certain observations on the application

1 The term "function" used in claims 4 and 8 is vague and unclear and leaves the reader in doubt as to the meaning of the technical feature to which it refers, thereby rendering the definition of the subject-matter of said claims unclear.
Claim 9 does not meet the requirement of clarity because the matter for which protection is sought is not clearly defined. The claim attempts to define the subject-matter in terms of the result to be achieved, which merely amounts to a statement of the underlying problem, without providing the technical features necessary for achieving this result.