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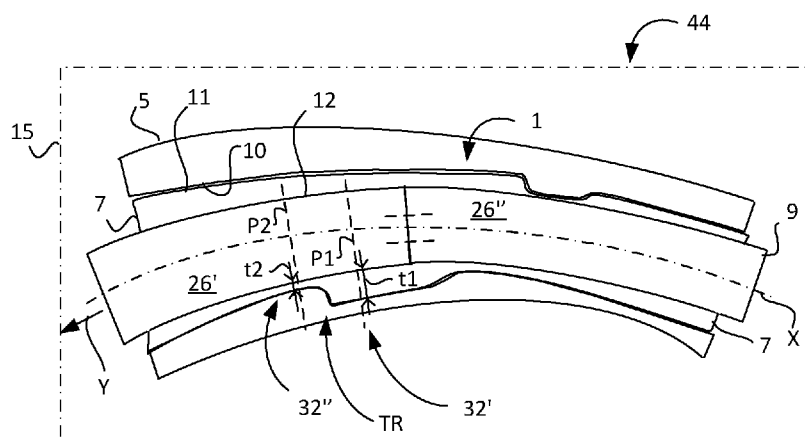


FIG. 8a

(57) Abstract: The present invention concerns a mould body assembly (1) and a method of forming a hollow feature (3) of an article (5), which hollow feature (3) is to be formed by the mould body assembly (1) extending along an imaginary axis (X). The mould body assembly (1) comprises a flexible caul member (7) and a rigid support member (9). The flexible caul member (7) is configured to be arranged onto the rigid support member (9) for bringing about a hollow feature forming surface (11) of the flexible caul member (7) configured to form the hollow feature (3). The flexible caul member (7) exhibits varying thickness for forming the hollow feature with trapping geometry.

A mould body assembly and a method of forming a hollow article

TECHNICAL FIELD

The present invention relates to a method of forming an article comprising a hollow feature, the hollow feature to be formed is formed by a mould body assembly extending along an imaginary axis.

The present invention also relates to the mould body assembly and a moulding tool comprising the mould body assembly.

The present invention also may relate to a production line for the manufacture of hollow structural or non-structural articles or any type of aerodynamically designed airfoil articles, wherein the production line comprises the inventive moulding tool.

The present invention may concern the industry manufacturing hollow articles, such as wings, stabilizers, control surfaces, doors, beams etc.

The present invention especially may concern the aircraft industry producing integrated matrix composite parts of multi-spar airfoil structures.

BACKGROUND

When manufacturing articles with hollow features, there is a challenge to remove an internal mould tool from the article, which tool is inherently trapped by the geometrical shape of the hollow feature.

Multi-piece rigid tooling utilizes separation of internal tool parts into several block sections providing that at least one tool part can be removed unobstructed, following that the remaining tool parts can be demounted and removed from the trapping geometry.

Multi-piece rigid tooling is prone to resin ingress between the rigid internal tool parts and requires extensive cleaning. Furthermore, complex geometries may require that the tool assembly must be composed of many tool parts for permitting removal of the tool assembly from the article. Such plurality of tool parts implies high production cost, due to high machining cost and manufacturing time for each composite part.

Flexible tooling utilizes formable and/or expandable material, which is positioned or applied internally in the article to be formed. The flexible tool, such as a bladder, comprises a cavity being pressurized during the cure cycle for providing distributed force over the internal

surface of the hollow feature. The flexible tooling requires several tool parts for achieving desired shape of the hollow feature. Difference in thermal conductivity between the pressurized cavity of the flexible tooling and an external tool may result in temperature gradients in the composite material during the cure cycle affecting the material quality negatively. Flexible tooling also typically may have relatively short life cycle in comparison with multi-piece rigid tooling.

SUMMARY OF THE INVENTION

There is an object to provide a cost-effective method of forming an article comprising a hollow feature.

There is an object to provide a method of forming an article comprising a hollow feature, which method increases the material quality of the finished article.

There is an object to provide a method of forming an article comprising a hollow feature, which method increases the life cycle of the mould body assembly.

There is an object to provide a method of forming an article comprising a hollow feature, which method implies that the hollow feature forming surface of the mould body assembly can be easily cleaned after removal from the cured article.

There is an object to provide a method of forming an article comprising a hollow feature, which method provides easy handling of tool parts.

There is an object to provide a method of forming an article comprising a hollow feature, which method is time saving when the mould body assembly is removed from the cured article.

There is an object to provide a design of a mould body assembly, which is easy and cost-effective to use, wherein the geometric tolerance of the hollow structure of the finished article is acceptable.

There is an object to reduce the number of tool parts in comparison with prior art.

There is an object to provide a mould body assembly having a rigid hollow feature forming surface.

There is an object to provide a moulding tool that can be used cost-effective in a production line configured to produce an article comprising a hollow feature.

There is an object to provide a moulding tool that can be used cost-effective in a production line configured to produce a composite matrix aircraft article comprising a hollow feature.

There is an object to provide a moulding tool that can be used cost-effective in a production line configured to produce integrated matrix composite parts of multi-spar airfoil structures.

- 5 This or at least one of said objects has been achieved by a method of forming a hollow feature of an article, which hollow feature is to be formed by a mould body assembly extending along an imaginary axis, the mould body assembly comprises a flexible caul member and a rigid support member, the flexible caul member is configured to be arranged onto the rigid support member for bringing about a hollow feature forming surface configured
10 to form said hollow feature, the flexible caul member exhibits varying thickness, the method comprises the steps of; providing the rigid support member; providing the flexible caul member; covering at least a portion of the rigid support member with the flexible caul member; applying a resin matrix material on the hollow feature forming surface and forming the resin matrix material; curing the resin matrix material; and removing the mould body
15 assembly from the article along the axial direction of the imaginary axis.

In such way there is achieved that an interior surface of the hollow feature will have trapping features by distinguishing different thicknesses of the flexible caul member.

- Alternatively, a flexible material (e.g. a stretchable material or shape-changing material) of
20 the flexible caul member is a material that enables change of the shape of the flexible caul member when the flexible caul member is removed from the hollow feature or enables change of the shape of the flexible caul member when the material is subjects to external stimuli before removal from the hollow feature.

- Alternatively, the flexible caul member may be arranged on a rigid support member having
25 an even envelope surface, which in turn promotes easy removal of the rigid support member from the flexible caul member before removing the flexible caul member from the hollow feature of the article.

Thereby is achieved easy handling of few tool parts by simpler design allowing facilitated disassembly and extraction of multiple core tool parts.

- 30 Alternatively, the method comprises the step of removing the mould body assembly from the article in a direction essentially pointing from a first position of the flexible caul member toward a second position of the flexible caul member and along the imaginary axis.

Alternatively, the first position intersects with a first imaginary cross-section plane of the flexible caul member and the second position intersects with a second imaginary cross-section plane of the flexible caul member.

5 Alternatively, the respective first and second imaginary cross-section plane is oriented normal to the imaginary axis.

Alternatively, a first wall portion of the flexible caul member in said first imaginary cross-section plane is thicker than a second wall portion of the flexible caul member in said second imaginary cross-section plane.

10 Alternatively, the first imaginary cross-section plane is positioned adjacent the second imaginary cross-section plane.

Alternatively, the first and second imaginary cross-section planes are positioned on both sides of a thickness transition region.

Alternatively, the thickness transition region comprises a stepped transition.

Alternatively, the thickness transition region comprises a tapered transition.

15 Alternatively, the thickness transition region comprises a gradual transition.

Alternatively, the step of removing the mould body assembly is followed by a step of cleaning the flexible caul member.

20 Alternatively, the step of providing the flexible caul member includes forming of a shape-memory polymer into a temporary shape comprising a forming surface corresponding with the hollow feature forming surface.

25 Alternatively, the step of providing the flexible caul member includes forming of a shape-memory polymer of the flexible caul member into a permanent shape permitting removal of the flexible caul member from the article.

Alternatively, the step of removing the flexible caul member from the article includes exterior stimuli to a shape-memory polymer of the flexible caul member reverting the material into a permanent shape permitting removal of the flexible caul member from the article.

30

Alternatively, the step of providing the flexible caul member may comprise injection/extrusion moulding configured for shape memory polymers having the ability to memorize a permanent

shape, from which it may be stretched to a temporary shape and subsequently relaxed to the original or memorized, stress-free shape for removal.

Alternatively, the shape-memory polymer is programmed with at least one temporary shape
5 and/or is configured to perform the subsequent shape-recovery by external stimuli.

Alternatively, the step of applying the resin material comprises application of a prepreg lay-up or a resin mould transfer procedure.

10 Alternatively, the procedure of resin mould transfer comprises a step of positioning the mould body assembly in an outer line forming tool member configured for resin transfer moulding and subsequently applying the resin material over the hollow feature forming surface.

Alternatively, the step of applying the resin material is followed by a step of curing the resin material in an autoclave.

15 Alternatively, the step of applying the resin material is followed by a step of curing the resin material in an autoclave or in an oven or in room temperature or by any other suitable curing procedure.

Alternatively, the procedure of applying prepreg lay-up comprises a step of positioning the prepreg lay-up onto the hollow feature forming surface of the mould body assembly

20 Alternatively, the step of positioning the prepreg lay-up onto the hollow feature forming surface is followed by a step of positioning a vacuum bag over the lay-up for vacuum bagging the lay-up.

Alternatively, the step of removing the mould body assembly is followed by a step of cleaning the mould body assembly, wherein only the hollow feature forming surface of the flexible caul member has to be cleaned as it also serves as a barrier between the resin material and the
25 rigid support member.

Alternatively, the step of cleaning the hollow feature forming surface of the flexible caul member is performed by means of water based cleaning agents.

Thereby is achieved environmental friendly cleaning can be provided at the same time as no corrosion
30 will affect the rigid support member of steel or other metal materials sensitive to corrosion.

Alternatively, the step of covering at least a portion of the rigid support member comprises fully covering an envelope surface of the rigid support member with the flexible caul member.

Alternatively, the step of applying the resin material comprises a procedure of resin mould transfer or applying prepreg lay-up on the hollow feature forming surface.

Alternatively, the step of forming the resin material comprises positioning the mould body assembly and the resin material in an outer line forming tool member.

- 5 Alternatively, the step of curing the resin material comprises the step of heating the resin material up to a curing temperature.

Alternatively, the step of curing the resin material comprises the step of positioning the mould body assembly and the bagged lay-up in an autoclave.

- 10 Alternatively, the step of removing the mould body assembly from the article comprises the step of firstly removing the rigid support member from the flexible caul member and thereafter removing the flexible caul member from the hollow feature of the article.

Alternatively, the step of removing the mould body assembly from the article comprises the step of removing the rigid support member together with the flexible caul member from the article

- 15 Alternatively, the step of removing the mould body assembly from the article comprises the step of firstly removing the flexible caul member and thereafter removing the rigid support member from the hollow feature of the article.

- 20 In such way is achieved that e.g. a specific hollow feature in the shape of a truncated cone having the widest end face enclosed by the mould body assembly at the same time as the flexible caul member is designed as thin as possible .

Alternatively, the step of providing the rigid support member comprises moulding, machining, grinding and/or other manufacturing processes.

Alternatively, the step of providing the flexible caul member comprises moulding and/or machining after the moulding.

- 25 Alternatively, the moulding comprises extrusion moulding or injection moulding.

Thereby it is achieved that the flexible caul member may have complex local variations deviating from the general shape, such as trapped geometrical features of the hollow feature.

Alternatively, the application of resin material on the hollow feature forming surface of the flexible caul member is performed by plastic injection moulding.

- 30 Alternatively, the application of resin material on the hollow feature forming surface of the flexible caul member is performed by plastic injection moulding of thermosetting polymers.

Alternatively, the mould body assembly is positioned in a female injection moulding tool prior the plastic injection moulding for producing the article.

Alternatively, the application of resin material on the hollow feature forming surface of the flexible caul member and/or the mould body assembly is performed by a lay-up comprising
5 partially cured thermoset resin matrix, such as resin pre-impregnated composite fibres or others.

Alternatively, the resin matrix comprises carbon fibres, nano filaments or other reinforcement material.

Alternatively, the curing of the resin material is performed in an oven or an autoclave.

10 This or at least one of said objects has been achieved by a mould body assembly configured to form a hollow feature of an article, the mould body assembly comprises a flexible caul member and a rigid support member, the flexible caul member is configured to be arranged onto the rigid support member for bringing about a hollow feature forming surface configured to form said hollow feature, wherein the flexible caul member exhibits varying thickness.

15 Thereby is achieved a cost-efficient mould body assembly having few tool parts.

Alternatively, the flexible caul member is configured to be arranged on the rigid support member in such way that the hollow feature forming surface will conform rigidity on the rigid support member.

Alternatively, the rigidity of the flexible caul member of the mould body assembly in
20 assembled condition, wherein the flexible caul member is positioned on the rigid support member, is achieved by enclosing the resin material to be formed on the flexible caul member with an outer line forming tool member and thereby fixating the flexible caul member.

Alternatively, the state of the flexible caul member of the mould body assembly in assembled
25 condition, wherein the flexible caul member is positioned on the rigid support member, may be called stretched state.

Alternatively, the flexible caul member is configured to be stretchable to such extent that it is possibly to remove it from the cured article, at the same time as it is configured in a stretched state to exhibit a rigid property.

30 Thereby is achieved that the geometric tolerance of the formed surface of the hollow feature of the finished article is acceptable.

Alternatively, the material of the flexible caul member comprises a flexible material.

Alternatively, the material of the flexible caul member comprises solid silicone rubber or other rubber-like material or other stretchable, resilient or flexible material.

5 In such way is achieved that the flexible caul member is configured to be removed from a hollow feature, wherein the material of the flexible caul member is configured to be sufficient soft to permit that the flexible caul member is possible to be stretched to such extent that it can be removed from the hollow feature of the article.

10 Thereby is achieved a simplified and cost-effective method of moulding an article having an internal geometrical surface providing complex local variation from the global shape or any hollow feature that otherwise would trap prior art hollow feature forming tools.

Alternatively, the material of the flexible caul member comprises a shape-changing material.

In such way there is achieved that an interior surface of the hollow feature having trapping features can be formed by providing different thicknesses of the flexible caul member.

15 Alternatively, the flexible caul member is configured to be arranged on the rigid support member having an even envelope surface, which in turn promotes easy removal of the rigid support member from the flexible caul member before removing the flexible caul member from the hollow feature of the article.

20 Alternatively, the flexible caul member may be configured to cover a joint between a first male tool part and a second male tool part, which are configured to be coupled to each other for forming the rigid support member.

In such way is prevented that resin flash occurs at the formed interior surface of the hollow feature in the position of the joint.

Alternatively, the material of the rigid support member may comprise steel or other suitable rigid material.

25 Alternatively, the flexible caul member is manufactured and configured with a hollow feature forming surface by casting, injection moulding, extrusion moulding and may be cured, vulcanized, catalysed or solidified in any suitable process.

30 Alternatively, the shape changing material of the flexible caul member comprises shape-memory polymer SMP or other active polymers having at least dual-shape property or other shape changing materials.

Alternatively, the material of the flexible caul member comprises hybrid metallic-plastic material.

5 Alternatively, the active polymers of the shape-memory polymer having at least dual-shape property being configured to change shape in a predefined way from a deformed shape to a permanent shape.

Alternatively, the programming of the shape-memory polymer and/or the shape-recovery may be repeated if necessary.

10

Alternatively, the structure of the shape memory polymer configured to provide a shape change of the flexible caul member from a temporary shape to a permanent shape is achieved by polymer morphology and upon external stimulus, such as heat, electrical current, electromagnetic fields, light, infrared light or other.

15 Alternatively, the shape-memory polymer is programmed with at least one temporary shape and/or is configured to perform the subsequent shape-recovery by said external stimuli or suitable heating set to be different from a curing heat that is used during the step of curing the resin material of the article to be produced.

20 Alternatively, the flexible caul member is produced by additive manufacturing (3D printing), injection moulding, thermoforming, extrusion moulding or other manufacture process.

Alternatively, the material of the flexible caul member may be a stimuli responsive polymer material, which is configured to soften upon external stimuli, such as heating the flexible caul member to a temperature different to the curing temperature of the resin material.

25 Alternatively, the mandrel is configured as a bar and/or configured with square tooling cross-section and/or rectangular cross-section.

Alternatively, the mould body assembly comprises, in average with global geometry, tapered and/or curved and/or straight shape.

Alternatively, the rigid support member comprises a tapered mandrel and/or a curved mandrel and/or straight mandrel or a combination thereof.

30 Alternatively, the rigid support member comprises at least a first mandrel part and a second mandrel part, which are configured to be coupled to each other and held to each other by means of a coupling member.

Alternatively, the coupling member comprises a guide pin of a first end face of the first mandrel part and a corresponding guide bore of a second end face of the second mandrel part.

5 Alternatively, the mould body assembly extending along an imaginary axis, which is curved or straight.

Alternatively, the flexible caul member comprises polymeric material and/or hybrid metallic-plastic material and/or active polymers having at least dual-shape property, e.g. shape-memory polymer.

10 Alternatively, the shape-memory polymer material of the shape-memory polymer having at least dual-shape property being configured to change shape in a predefined way from a temporary shape to a permanent shape.

Alternatively, the programming of the shape-memory polymer and/or the shape-recovery being repeated.

15 Alternatively, the hollow feature forming surface of the mould body assembly is configured to correspond with the inner surface geometry of the hollow feature of the article, when the flexible caul member is positioned onto and/or around the rigid support member.

Alternatively, the hollow feature forming surface of the flexible caul member corresponds with at least a portion of the interior surface geometry of the hollow feature and may correspond with the temporary shape or stretched state of the flexible caul member.

20 Alternatively, the hollow feature forming surface of the flexible caul member corresponds with at least a portion of the interior surface geometry of the hollow feature.

Alternatively, the flexible caul member is configured to be arranged onto the rigid support member, wherein a first hollow feature forming surface of the flexible caul member in combination with a second hollow feature forming surface of the rigid support member, not
25 covered by the flexible caul member, together with the first hollow feature forming surface constitute the hollow feature forming surface.

Alternatively, the outer line forming tool member comprises a vacuum bag.

This or at least one of said objects has been achieved by a moulding tool apparatus configured to form an article, the moulding tool comprises said mould body assembly and an
30 outer line forming tool member configured to form an outer surface of the article.

This or at least one of said objects has been achieved by a production line configured for manufacture of an article comprising a hollow feature, the production line comprises said moulding tool apparatus, wherein the production line is configured to manage the claimed method steps.

- 5 Alternatively, the method steps are performed manually and/or semi-automatic and/or automatic.

The article may be defined as a hollow article or hollow structural hollow article configured to be an integrated part of multi-spar airfoil structures, such as wings, stabilizers or control surfaces with slender beam sections.

- 10 Alternatively, the resin material may be in the form of prepreg tapes (micro and/or nano-fiber structure pre-impregnated with semi-cured resin) stacked on each other in lay-up to be cured.

The mould body assembly extends along the imaginary axis, which may be a longitudinal axis.

- 15 The axial direction of the imaginary axis is defined as a direction that extends coaxially or being parallel with the hollow feature.

The imaginary axis may be curved and/or straight.

Alternatively, the mould body assembly is removed from the article along a direction corresponding with the axial direction.

- 20 Alternatively, the flexible caul member fully covers the rigid support member, wherein the flexible caul member exhibits a first forming surface that constitutes the hollow feature forming surface.

- Alternatively, the flexible caul member partially covers the rigid support member, wherein the flexible caul member exhibits a first forming surface and the rigid support member exhibits a
25 second forming surface, wherein the first and second forming surfaces constitute the hollow feature forming surface.

- Alternatively, there is provided a method of forming an article comprising a hollow feature exhibiting at least a protrusion and/or step extending inwardly, the method comprises the steps of; providing a rigid mandrel comprising a rigid surface; providing a flexible caul
30 member; covering at least a portion of the rigid surface with the flexible caul member establishing a mould body assembly, wherein a protrusion forming surface of the flexible caul member is configured to form said protrusion; applying a resin material on the mould body

assembly for forming the article; curing the resin material; and removing the mould body from the article.

Alternatively, the flexible caul member exhibits a first end and a second end, and a central portion there between.

- 5 The first end may face in a first direction along the imaginary axis away from the central portion. The second end may face away from the central portion in a second direction, which is opposite the first direction.

Alternatively, the step of removing the mould body assembly from the cured article may be performed in the first direction.

- 10 Alternatively, the first direction is a direction that involves inherently trapped prior art tool due to a geometrical shape of the hollow feature of the article.

Alternatively, the first direction is a direction that involves removal of the flexible caul member from a trapping geometry of the hollow feature.

- 15 Alternatively, the step of removing the mould body assembly comprises a step of removing the flexible caul member from the cured article in the first direction providing that the first end of the flexible caul member firstly is brought out from the hollow feature, before the central portion and the second end of the flexible caul member are brought out from the hollow feature.

- 20 Alternatively, the step of removing the flexible shroud member from the cured article may be performed in the first direction after that the rigid support member has been removed at least partly or fully from the flexible shroud member.

Alternatively, the rigid support member is removed from the flexible shroud member in the first or second direction prior removal of the rigid support member from the cured article.

- 25 Alternatively, the imaginary axis (central line) extends along the rigid support member, which imaginary axis may be parallel or co-axial with the hollow feature of the article to be formed.

Alternatively, the flexible shroud member is arranged and mounted to the rigid support member by wrapping the flexible shroud member around the rigid support member and/or adhering the flexible shroud member to the rigid support member by means of e.g. adhesive or tape.

Alternatively, a protrusion and/or step of the surface of the hollow feature extends from the surface of the hollow feature of the article in a direction inwardly and/or in radial direction towards the imaginary axis.

5 In such way is achieved that an interior protrusion and/or step of an article will press away and deform a first portion of the hollow feature forming surface of the flexible caul member, which first portion is positioned between the first and second end of the flexible caul member.

Alternatively, a shape memory changing material of the flexible caul member is programmed to change shape from a permanent shape to a deformed shape or from a deformed shape to a permanent shape upon stimuli (e.g. application of heat stimuli) of the flexible caul member.

10 Alternatively, following the curing step and subsequent removal of the rigid support member from the flexible caul member, there is applied an external stimuli to the flexible caul member wherein the material of the flexible caul member is programmed to revert to its permanent shape, wherein the flexible caul member has such a cross-sectional dimension that it can be removed from the hollow feature of the article.

15 Alternatively, the cross-sectional dimension of the permanent shape of the flexible caul member is configured to have smaller (or same dimension) than the cross-sectional dimension of the hollow feature.

Alternatively, heat stimuli is applied to the flexible caul member after fulfilled curing of the resin, wherein the temperature of the heat stimuli is higher than the curing temperature.

20 In such way is achieved that the flexible caul member in said deformed shape freely will pass any interior protrusion and/or step of the article.

Alternatively, the first portion of the hollow feature forming surface being adjacent the protrusion forming surface.

25 Alternatively, the step of removing the mould body assembly is made in a first direction which is either linear or curvilinear or a combination thereof.

Alternatively, the first portion is defined as a section of the flexible caul member extending around the imaginary axis and extending from the general protrusion forming surface towards a first end of the article in the first direction.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will now be described by way of examples with references to the accompanying schematic drawings, of which:

Figs. 1a-1c illustrate a mould body assembly according to a first example;

- 5 Fig. 1d illustrates a cross-sectional view of an article formed by the mould body assembly in Figs. 1a-1c;

Figs. 2a-2b illustrate tool parts of a mould assembly according to a second example;

Figs. 3a-3b illustrate a mould assembly according to a third example;

Figs. 4a-4c illustrate a mould body assembly according to a fourth example;

- 10 Fig. 5a-5e illustrate a mould body assembly according to a fifth example;

Fig. 6a-6b illustrate a mould body assembly according to a sixth example;

Fig. 7 illustrates a mould body assembly according to a seventh example;

Figs. 8a-8b illustrate a mould body assembly according to an eight example;

- 15 Fig. 9 illustrates an exemplary production line configured for forming an article comprising a hollow feature;

Figs. 10-11 illustrate flowcharts showing exemplary methods of forming an article comprising a hollow feature; and

Fig. 12 illustrates a computer according to one aspect.

20 DETAILED DESCRIPTION

Hereinafter, exemplary embodiments of the present invention will be described with reference to the accompanying drawings, wherein for the sake of clarity and understanding of the invention some details of no importance may be deleted from the drawings.

- 25 Figs. 1a-1c illustrate a male mould assembly 1 according to a first example. The male mould assembly 1 extends along an imaginary axis X and is configured to form a hollow passage 3 of an article 5 to be formed. The male mould assembly 1 comprises a flexible shroud 7 comprising a flexible material (e.g. silicone rubber) and a rigid support core 9. The flexible shroud 7 is configured to be arranged onto the rigid support core 9 for bringing about a hollow passage forming surface 11 of the flexible shroud 7, which is configured to form an

interior surface 10 (see Fig. 1d) of the hollow passage 3 of the article 5. The flexible shroud 7 exhibits varying thickness t_1 and t_2 , wherein a first thickness t_1 is less than a second thickness t_2 . The flexible shroud 7 is configured to be arranged on the rigid support core 9 in such way that the hollow passage forming surface 11 will conform rigidity on the rigid support core 9.

In Fig. 1b is shown a dividable outer line forming female tool 15 enclosing the male mould assembly 1 and a resin material 13 to be formed.

The rigidity of the flexible shroud 7 in assembled condition onto the rigid support core 9, in which the flexible shroud 7 is wrapped around and positioned onto an envelope surface 12 of the rigid support core 9, may be achieved by enclosing the resin material 13 or blank to be formed on the flexible shroud 7 with the outer line forming female tool 15 and thereby fixating the flexible shroud 7 to be rigid as the stretched flexible material is prevented from changing shape by the surrounding outer line forming female tool 15.

In Fig. 1c is shown the male mould assembly 1 in Fig. 1a-1b according to a cross-sectional view. The hollow passage forming surface 11 exhibits a stepped elevation portion 14 configured to form a depression 17 of the in the interior surface 10 of the hollow passage 3 as shown in Fig. 1d.

Fig. 2a illustrates a flexible mantle 7 of a mould assembly according to a second example. The flexible mantle 7 is configured to be applied (stretched) over a rigid spindle 9 (shown in Fig. 2b), which may be made of steel or composite or any other suitable rigid material.

Figs. 3a-3b illustrate a mould assembly 1 according to a third example. The mould assembly 1 comprises a rigid support core 9 and a flexible shroud 7 comprising a shape-memory material.

The shape-memory material may comprise a shape-memory polymer, configured to be formed over the rigid support core 9. The shape-memory polymer of the flexible shroud 7 provides a temporary shape with a forming surface of the mould assembly 1 corresponding to the hollow passage forming surface.

The shape-memory polymer is programmed to change, upon removal of the rigid support core 9 from the flexible shroud 7, to a permanent shape permitting removal of the flexible shroud 7 from the article 5 as is shown in Fig. 3b.

The removal of the flexible shroud 7 from the article 5 may include exterior stimuli, such as heat, to the shape-memory polymer reverting the polymer material of the flexible shroud 7 into the permanent shape.

5 The production of the flexible shroud 7 may comprise injection/extrusion moulding of the shape-memory polymer, wherein the polymer material of the flexible shroud 7 is configured to exhibit the ability to memorize a permanent shape, from which it can be stretched to a temporary shape over the rigid support core 9.

10 An article 5 has been formed over the mould assembly 1 and has cured. The mould assembly 1 is removed from the article 5 along the axial direction of the imaginary axis X by means of firstly removing the rigid support core 9 as is shown in Fig. 3a.

Subsequently, upon exterior stimuli, the flexible shroud 7 changes to the permanent shape permitting removal of the flexible shroud 7 from the article 5 along the imaginary axis X by as
15 is shown in Fig. 3b.

Figs. 4a-4c illustrate a mould assembly 1 according to a fourth example. A flexible shroud 7 and a rigid support core 9 of the mould assembly 1 being configured to be removed simultaneously from the cured article 5 along the imaginary axis X.

20 As an example, shown in Fig. 4a, a resin material 13 configured as a prepreg lay-up 18 has been applied on a hollow passage forming surface 11 of the flexible shroud 7 and rigid support core 9. Subsequently, a vacuum bag 20 is wrapped over the prepreg lay-up 18 for vacuum bagging the prepreg lay-up 18.

After curing of the article 5 and after debagging the article 5, the flexible shroud 7 and the
25 rigid support core 9 are to be removed simultaneously from the hollow passage 3 of article 5 as shown in Fig. 4b.

The hollow passage forming surface 11 exhibits an elevated portion 14, which stretches and passes the global interior surface 10 of the hollow passage 3 of the article 5.

Subsequently, the flexible shroud 7 is removed from the rigid support core and cleaned for
30 reuse. The flexible shroud 7 is ready for reuse as shown in Fig. 4c.

Fig. 5a-5f illustrate a mould assembly 1 according to a fifth example. Fig. 5a shows a portion of a mould body assembly configured to form integrated matrix composite parts of a multi-spar airfoil structure, which may be an airfoil structure, for example a control surface such as

an aileron. The mould assembly 1 comprises a flexible shroud 7 partly covering a rigid support 9. A forming surface 11 of the flexible shroud 7 comprises elevated portions 14 configured to form trapping geometry or depressions of an interior surface of the airfoil structure.

5 Fig. 5b shows a cross-sectional view of the mould assembly 1 in Fig. 5a. The flexible shroud 7 has been mounted on the rigid support 9. Fig. 5c shows that the mould assembly 1 has been positioned in a dividable outer line forming tool 15 providing a RTM mould 16 configured for resin transfer moulding. A resin material 13 is injected into the RTM mould 16. The resin material is cured and the dividable outer line forming tool 15 is demounted after
10 curing of the resin material. In Fig. 5d is shown removal of the rigid support 9 from the flexible shroud 7, which remains in the hollow passage 3 of the article 5.

The flexible shroud 7 may comprises a shape-changing material or shape-memory material comprising e.g. a polymer having ability to return from a deformed state (when stretched over the rigid support 9 as shown in Fig. 5b) to an original shape induced by external stimulus,
15 such as specific and pre-determined temperature change.

In Fig. 5e is shown that the flexible shroud 7 has been subjected to external stimuli for restoring the flexible shroud 7 to its original shape, which is pre-determined with a geometry of such cross-sectional dimension that the flexible shroud 7 will be free from any trapping geometry when removed from the article 1.

20 Fig. 6a-6b illustrate a mould body assembly 1 according to a sixth example. The mould assembly 1 comprises a flexible shroud 7 of shape-changing material partly covering a rigid support 9. The flexible shroud 7 is adhered to the rigid support 9 by means of an adhesive.

Fig. 7 illustrates a mould assembly 1 according to a seventh example. The mould assembly 1 comprises a rigid frusto-conical shaped male tool 9, having a middle separable central section 21, and a flexible shroud 7. Fig 7 shows that, after finished curing of a resin material,
25 the flexible shroud 7 firstly is to be removed from the hollow cavity 3 of the article 5 and subsequently the rigid frusto-conical shaped male tool 9 is removed by separating the central section 21.

Figs. 8a-8b illustrate a male mould assembly 1 according to an eight example. The male
30 mould assembly 1 is configured to form an interior surface 10 of a hollow passage 3 (see Fig. 8b) of an article 5 to be formed. The male mould assembly 1 comprises a flexible caul 7 and a rigid support 9 consisting of a first tool part 26' and a second tool part 26'', which are configured to be releasable coupled to each other. The flexible caul 7 is configured to be

arranged onto the rigid support 9 for bringing about a rigid hollow passage forming surface 11 of the flexible caul 7 configured to form said hollow passage 3 of the article 5. The flexible caul 7 exhibits varying thickness.

The male mould assembly 1 is part of a moulding tool apparatus 44. The moulding tool apparatus 44 further comprises an outer line forming tool 15 configured to form an outer surface of the article 5.

In such way there is achieved that the interior surface 10 (having trapping features) is formed by providing different thicknesses of the flexible caul 7. The flexible caul 7 is arranged on a rigid support 9 having an even envelope surface 12, which in turn promotes easy removal of the rigid support 9 from the flexible caul 7 before removing the flexible caul 7 from the hollow passage 3 of the article 5.

The flexible material of the flexible caul 7 may comprise solid silicone rubber or other rubber-like material or other stretchable, resilient or flexible material.

The flexible material of the flexible caul 7 may comprise polymeric material and/or hybrid metallic-plastic material and/or active polymers having at least dual-shape property, e.g. shape-memory polymer or other shape-changing material.

Subsequently, after curing of the article 5, the male mould assembly 1 is removed from the article 1. This is performed by demounting the first tool part 26' from the second tool part 26'' and draw out the first tool part 26' along the axis X in direction Y and subsequently removing the flexible caul 7.

A first P1 and a second P2 imaginary cross-section plane being positioned on both sides of a thickness transition region TR.

A first wall portion 32' of the flexible caul 7 in the first imaginary cross-section plane P1 is thicker than a second wall portion 32'' of the flexible caul member 7 in the second imaginary cross-section plane P2.

The varying thickness being marked by t1 and t2, wherein a first thickness t1 is larger than a second thickness t2.

The outer line forming tool 15, such as a vacuum bag or membrane, encloses the male mould assembly 1 and the resin material. Alternatively, the outer line forming tool 15 may be a dividable female tool.

Fig. 8b shows the finished article 5 after removal of the male mould assembly from the hollow passage 3 comprising the interior surface 10.

Fig. 9 illustrates an exemplary production line 91 configured for forming an article comprising a hollow feature with trapping geometry by means of a mould body assembly of a moulding tool apparatus. The moulding tool apparatus further comprises an outer line forming tool configured to form an outer surface of the article.

5 A processor circuitry 900 is configured to control the adaption and assembly of the moulding tool apparatus and the moulding and manufacture of an article. The processor circuitry 900 is fed with data from a mould tooling model determined by a designer or by generative design program designing the mould body assembly from given parameters. The production line 91 comprises a first apparatus 93 configured to provide a rigid support member and a second
10 apparatus 95 configured to provide a flexible caul member having a hollow feature forming surface. The production line 91 further comprises a third apparatus 97 configured to mount the flexible caul member onto at least a portion of the rigid support member for providing the mould body assembly. A robot apparatus 99 is configured in a moulding station MS to manage the positioning the mould body assembly into the outer line forming tool and the
15 application of a resin material onto the hollow feature forming surface for forming the resin material. The production line 91 further may comprise a fourth apparatus 98 configured to manage a curing process for curing the resin material and a fifth apparatus 96 configured to remove the mould body assembly from the article. The flexible caul member is removed from the rigid support member and cleaned for reuse in the production line and is transported to
20 the moulding station MS.

Fig 10 illustrates a flow chart of a method of forming a hollow feature of an article according to an example. The method starts in a Step 1001. In Step 1002 there is provided a method of forming a hollow feature of an article. A mould body assembly comprises a flexible caul member and a rigid support member, wherein the flexible caul member is configured to be
25 arranged onto the rigid support member for bringing about a hollow feature forming surface of the flexible caul member configured to form said hollow feature, wherein the flexible caul member exhibits varying thickness. In Step 1003 the method is stopped.

The step 1002 may comprise the steps of; providing the rigid support member; providing the flexible caul member; covering at least a portion of the rigid support member with the flexible
30 caul member; applying a resin material on the hollow feature forming surface; forming the resin material; curing the resin material; and removing the mould body assembly from the article along the axial direction of the imaginary axis.

Fig 11 illustrates a flow chart of an exemplary method of forming a hollow feature of an article, which hollow feature is to be formed by a mould body assembly extending along an

imaginary axis, the mould body assembly comprises a flexible caul member and a rigid support member, the flexible caul member is configured to be arranged onto the rigid support member for bringing about a hollow feature forming surface of the flexible caul member configured to form said hollow feature, the flexible caul member exhibits varying thickness.

- 5 The method starts in a Step 1101. Step 1102 provides the rigid support member. Step 1103 provides the flexible caul member, wherein the flexible caul member may be formed of a shape-memory polymer or a stretchable material or other suitable material. Step 1104 provides covering of at least a portion of the rigid support member with the flexible caul member. Step 1105 provides application of a resin material in the form of a prepreg lay-up on
10 the hollow feature forming surface or by resin transfer moulding. Step 1106 provides forming of the resin material. Step 1107 provides curing of the resin material. Step 1108 provides removal of the mould body assembly from the article along the axial direction of the imaginary axis by firstly removing the flexible caul member from the hollow feature by application of external stimuli to the flexible caul member for shape-recovery. Step 1109
15 provides cleaning of the flexible caul member. In Step 1110 the method is stopped.

The flow charts in Fig. 10 and/or 11 may be applied to the production line described in Fig. 9.

- Fig. 12 illustrates a computer 1200 configured to control the method according to an example. The processor circuitry 900 of the production line described in Fig. 9 may comprise the computer 1200. The computer 1200 comprises a non-volatile memory NVM 1220, which
20 is a computer memory that can retain stored information even when the computer is not powered. The computer 1200 further comprises a processing unit 1210 and a read/write memory 1250. The NVM 1220 comprises a first memory unit 1230. A computer program (which can be of any type suitable for any operational database) is stored in the first memory unit 1230 for controlling the functionality of the computer 1200.

- 25 Furthermore, the computer 1200 comprises a bus controller (not shown), a serial communication port (not shown) providing a physical interface, through which information transfers separately in two directions. The computer 1200 also comprises any suitable type of I/O module (not shown) providing input/output signal transfer, an A/D converter (not shown) for converting continuously varying signals from detectors (not shown) of e.g. a
30 production line and other monitoring units (not shown) into binary code suitable for the computer 1200.

The computer 1200 also comprises an input/output unit (not shown) for adaption to time and date. The computer 1200 also comprises an event counter (not shown) for counting the number of event multiples that occur from independent events in the production line.

Furthermore, the computer 1200 includes interrupt units (not shown) associated with the computer for providing a multi-tasking performance and real time computing in e.g. the production line. The NVM 1220 also includes a second memory unit 1240 for external controlled operation.

- 5 A data medium storing program P comprising driver routines adapted for apparatus actuators (not shown) and provided for operating the computer 1200 for performing any exemplary method described herein. The data medium storing program P comprises routines for causing (in a production line configured to an automatic or semi-automatic manufacture) a plurality of apparatuses to produce the hollow article. The data medium storing program P
- 10 comprises a program code stored on a medium, which is readable on the computer 1200, for causing the computer 1200 to perform a method of forming a hollow feature of the article, which hollow feature is to be formed by a mould body assembly extending along an imaginary axis, the mould body assembly comprises a flexible caul member and a rigid support member, the flexible caul member is configured to be arranged onto the rigid support
- 15 member for bringing about a hollow feature forming surface of the flexible caul member configured to form said hollow feature, the flexible caul member exhibits varying thickness, wherein the method comprises; providing the rigid support member; providing the flexible caul member; covering at least a portion of the rigid support member with the flexible caul member; applying a resin material on the hollow feature forming surface; forming the resin
- 20 material; curing the resin material; and removing the mould body assembly from the article along the axial direction of the imaginary axis.

The data medium storing program P further may be stored in a separate memory 1260 and/or in a read/write memory 1250. The data medium storing program P is in this embodiment stored in executable or compressed data format.

- 25 It is to be understood that when the processing unit 1210 is described to execute a specific function that involves that the processing unit 1210 executes a certain part of the program stored in the separate memory 1260 or a certain part of the program stored in the read/write memory 1250.

- 30 The processing unit 1210 is associated with a data port 1299 for communication via a first data bus 1215. The non-volatile memory NVM 1220 is adapted for communication with the processing unit 1210 via a second data bus 1212. The separate memory 1260 is adapted for communication with the processing unit 1210 via a third data bus 1211. The read/write memory 1250 is adapted to communicate with the processing unit 1210 via a fourth data bus

1214. The data port 1299 may be connectable to data links of the production line 91 shown in Fig. 9.

When data is received by the data port 1299, the data will be stored temporary in the second memory unit 1240. After that the received data is temporary stored, the processing unit 1210 will be ready to execute the program code, in accordance with the above-mentioned procedure. Preferably, the signals (received by the data port 1299) comprise information about operational status of the production line 91 in Fig. 9, such as operational status regarding e.g. the positions of end effectors of a robot and actual mould body assembly status.

According to one aspect, signals received by the data port 1299 may contain information about actual positions and status of the mould body assembly and the flexible caul member by means of sensors.

The received signals at the data port 1299 can be used by the computer 1200 for controlling and monitoring a semi-automatic or automatic production line in a cost-effective way. The signals received by the data port 1299 can be used for automatically moving the mould body assembly between the apparatuses and used by the robot per se. The information may be measured by means of suitable sensors arranged at each apparatus of the production line 91. The information may also be manually fed to the processor circuitry 900 via a suitable communication device, such as a personal computer display.

Parts of the method can also be executed by the computer 1200 and the processor circuitry 900, which processor circuitry 900 runs the data medium storing program P being stored in the separate memory 1260 or the read/write memory 1250. When the computer 1200 runs the data medium storing program P, suitable method steps disclosed herein will be executed. A data medium storing program product comprising a program code stored on a medium is provided, which product is readable on a suitable computer, for performing the exemplary method steps herein, when the data medium storing program P is run on the computer 1200.

The present invention is of course not in any way restricted to the preferred examples described above, but many possibilities to modifications, or combinations of the described examples, thereof should be apparent to a person with ordinary skill in the art without departing from the basic idea of the invention as defined in the appended claims.

The flexible caul member shown the figures and examples may of course comprise a flexible material of any kind, such as rubber, silicone rubber, fibre reinforced silicone material, polyurethane rubber,

It may not be critical that the cross-sectional dimension of the end of the mould body assembly or flexible caul member configured to firstly be removed from the hollow feature of the article has to be smaller than the mid-section of the mould body assembly, but also an end with a cross-sectional dimension larger than that of the mid-section may be applicable.

5

The interior surface of the hollow feature may exhibit a geometry having complex local variations, deviating from the general shape of the hollow feature, such as trapped geometrical features of the hollow feature.

10 The word “caul” or “shroud” may be replaced by “covering”, “envelope”, “wrap”, “skin”, “jacket” or other.

The hollow feature forming surface of the flexible caul member may be configured to form a hollow passage through the article to be formed.

15

The hollow feature forming surface of the flexible caul member may be configured to form a cavity of the article to be formed.

20 The hollow feature of the article to be formed may comprise an interior surface which exhibits steps, protrusions, bumps etc. and which hollow feature of the article may be formed as a through hole or as a cavity or other type of hollow space comprising at least one single open end.

25 The shape-changing or shape-memory material of the flexible caul member may comprise a polymer that exhibits the ability to return from a deformed state to its original shape induced by an external stimulus, such as temperature change.

The material of the flexible caul member may be configured to be able to be stretched into any shape over the rigid support member.

30 By varying the mixture of molecular linkers among polymer strands, different versions of the shape-memory material may be designed for shape transformation at higher or lower temperatures, which may be different from the curing temperature.

The hollow feature may comprise a through hole, a cavity having a cavity bottom, a narrowed hole, etc.

The expression “resin matrix” may be changed to “resin”.

The article may be made of matrix composite with and/or without reinforcement members, such as micro fibres and/or nano fibres.

The article may be made of ABS, acetal, polypropylene or other material.

5 The mould body assembly may be assembled by stretching the flexible caul member over the rigid support member, wherein the flexible caul member material is configured to be able to be stretched over the rigid support member, at the same time as the flexible caul member material is configured to exhibit a rigidity sufficient to form the resin matrix material, when the flexible caul member is positioned over the rigid support member.

10 The imaginary axis may extend in a direction corresponding with the prolongation of the article or mould body assembly and/or oriented co-axial therewith.

The step of providing the rigid support member may be performed by casting and/or machining or other manufacture method, wherein the material of the rigid support member may be steel, composite etc.

15 The resin matrix material may be epoxy with or without, or partially without micro fibres, such as carbon fibres, glass fibres or other reinforcement material.

The resin matrix material may be epoxy provided with or without, or partially without nano-sized fibres, which may be carbon nano tubes, nano wires, graphene or other reinforcement material.

20 The step of removing the mould body assembly from the article along the axial direction of the imaginary axis may be performed by firstly removing the rigid support member from the mould body assembly.

The step of applying the resin matrix material on the hollow feature forming surface may be performed simultaneously as the applied resin matrix material is formed over the mould body assembly.

25 The step of applying the resin matrix material to a RTM mould (or other mould apparatus) comprising the mould body assembly may be performed prior the completed forming of the resin matrix material over the hollow feature forming surface of the mould body assembly.

CLAIMS

1. A method of forming a hollow feature (3) of an article (5), which hollow feature (3) is to be formed by a mould body assembly (1) extending along an imaginary axis (X), the mould body assembly (1) comprises a flexible caul member (7) and a rigid support member (9), the flexible caul member (7) is configured to be arranged onto the rigid support member (9) for bringing about a hollow feature forming surface (11) of the flexible caul member (7) configured to form said hollow feature (3), the flexible caul member (7) exhibits varying thickness, the **method comprises the steps of:**
- providing the rigid support member (9);
 - providing the flexible caul member (7);
 - covering at least a portion of the rigid support member (9) with the flexible caul member (7);
 - applying a resin matrix material (13) on the hollow feature forming surface (11) and forming the resin matrix material (13);
 - curing the resin matrix material (13); and
 - removing the mould body assembly (1) from the article (5) along the axial direction of the imaginary axis (X).
2. The method according to claim 1, **wherein** the step of removing the mould body assembly (1) is followed by a step of cleaning the flexible caul member (7).
3. The method according to claim 1 or 2, **wherein** the step of providing the flexible caul member (7) includes forming of a shape-memory polymer.
4. The method according to claim 3, **wherein** the step shape-memory polymer is programmed with at least one permanent shape and/or is configured to perform a subsequent shape-recovery by external stimuli.
5. The method according to any of claim 1 to 4, **wherein** the step of applying the resin material (13) comprises applying a prepreg lay-up (18) on the hollow feature forming surface (11).

6. A mould body assembly (1) configured to form a hollow feature (3) of an article (5), the mould body assembly (1) comprises a flexible caul member (7) and a rigid support member (9), the flexible caul member (7) is configured to be arranged onto the rigid support member (9) for bringing about a hollow feature forming surface (11) configured to form said hollow feature (3), **characterized in that** the flexible caul member (7) exhibits varying thickness.
7. The mould body assembly (1) according to claim 6, **wherein** the flexible caul member (7) is configured to be arranged on the rigid support member (9) in such way that the hollow feature forming surface (11) exhibits rigidity.
8. The mould body assembly (1) according to claim 6 or 7, **wherein** the material of the flexible caul member (7) comprises a flexible material.
9. The mould body assembly (1) according to any of claims 6 to 8, **wherein** the material of the flexible caul member (7) comprises a shape-changing material.
10. A moulding tool apparatus (44) configured to form an article (5), the moulding tool apparatus (44) comprises the mould body assembly (1) according to any of claims 6 to 9 and an outer line forming tool member (15) configured to form an outer surface of the article (5).
11. A production line (91) configured for manufacture of an article (1) comprising a hollow feature, the production line (91) comprises the moulding tool apparatus (44) according to claim 10, wherein the production line (91) is configured to manage the method steps according to any of the claims 1 to 5.
12. The production line (91) according to claim 11, wherein the production line (91) comprises a control unit (900) coupled to the moulding tool apparatus (44), the control unit (900) is configured to control the moulding tool apparatus (44) to perform the steps according to any of claims 1 to 5.
13. A data medium storing program (P) for causing in a production line (91) according to claim 12 an automatic or semi-automatic manufacture of an article (5) comprising a hollow feature (3), wherein said program (P) comprises a program code stored on a

medium, which is readable on a computer, for causing the control unit (900) to perform the method steps of:

-providing the rigid support member (9);

-providing the flexible caul member (7);

5 -covering at least a portion of the rigid support member (9) with the flexible caul member (7);

-applying a resin material (13) on the hollow feature forming surface (11);

-forming the resin material (13);

-curing the resin material (13); and

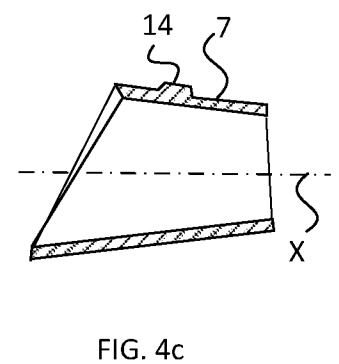
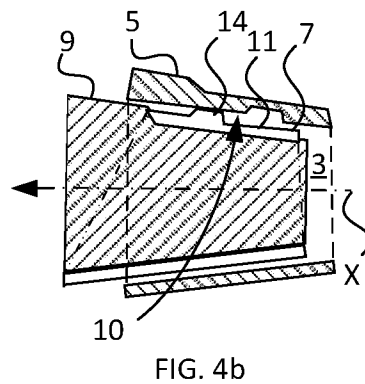
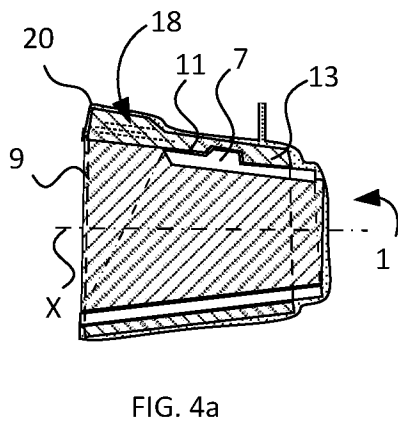
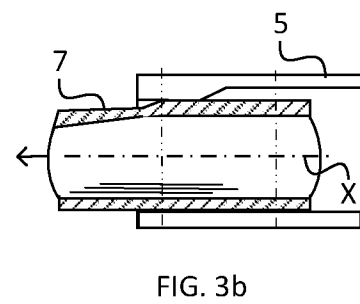
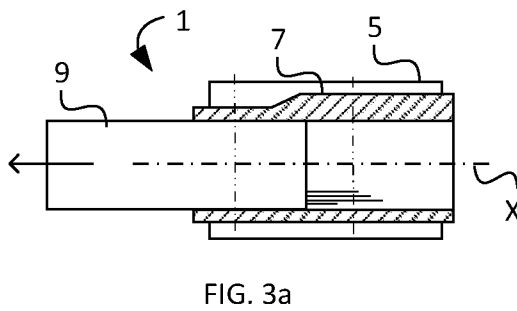
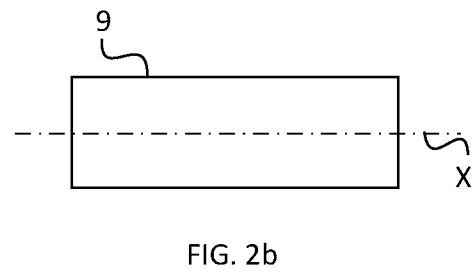
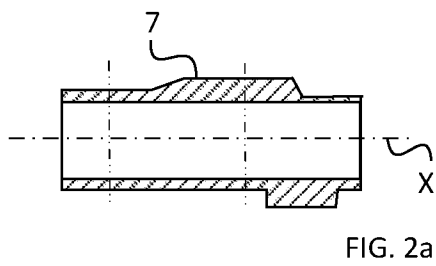
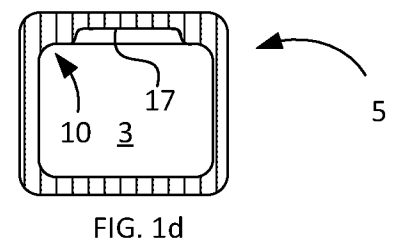
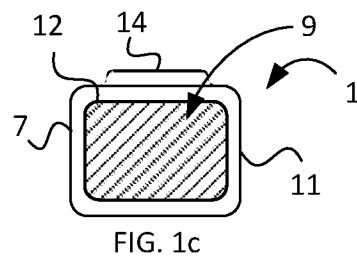
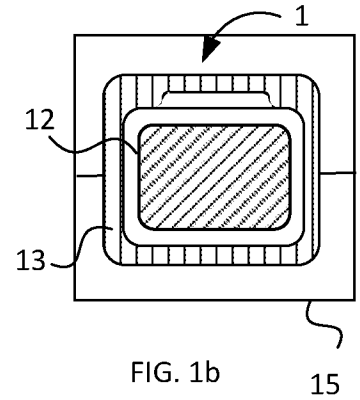
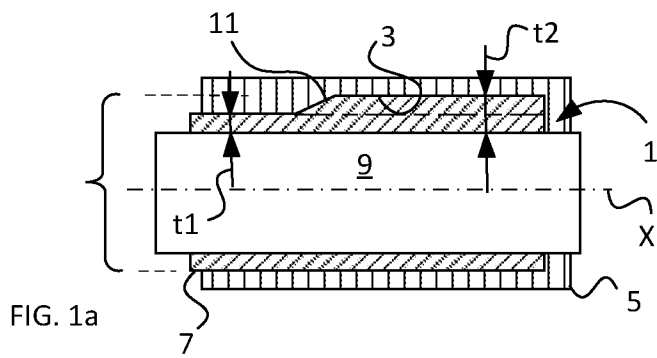
10 -removing the mould body assembly (1) from the article (5) along the axial direction of the imaginary axis (X).

14. A data medium storing program product comprising a program code stored on a

medium, which is readable on a computer (1200), for performing the method steps

15 according to any of claims 1 to 5, when a data medium storing program (P) according to claim 13 is run on the computer (1200).

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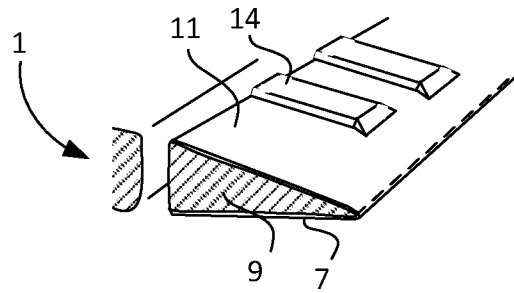


FIG. 5a

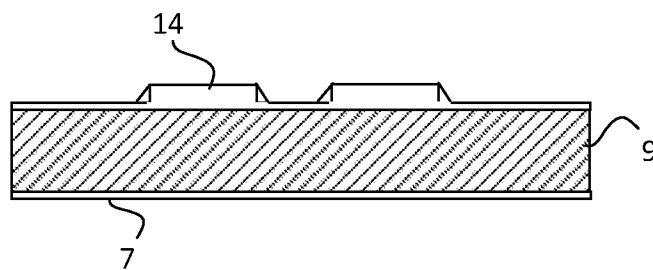


FIG. 5b

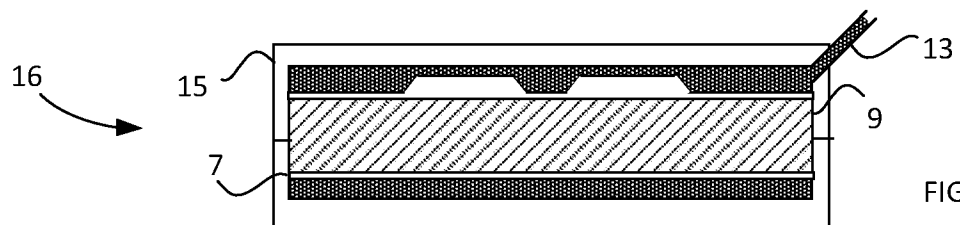


FIG. 5c

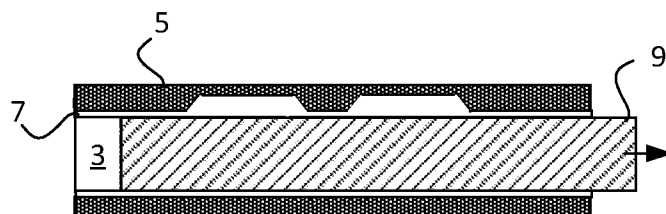


FIG. 5d

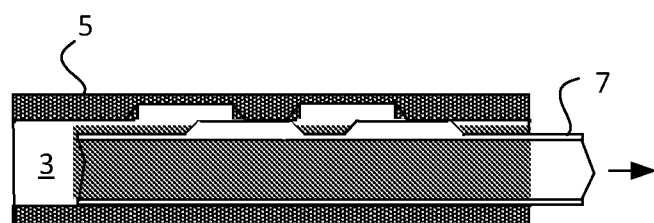


FIG. 5e

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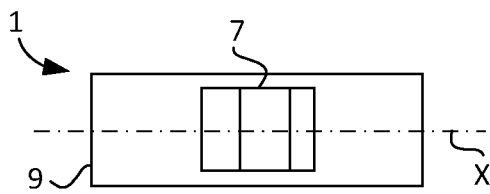


FIG. 6a

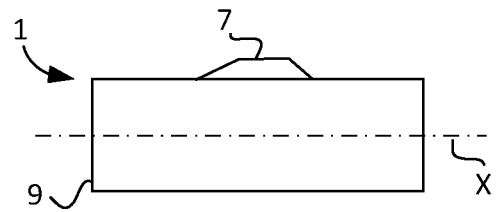


FIG. 6b

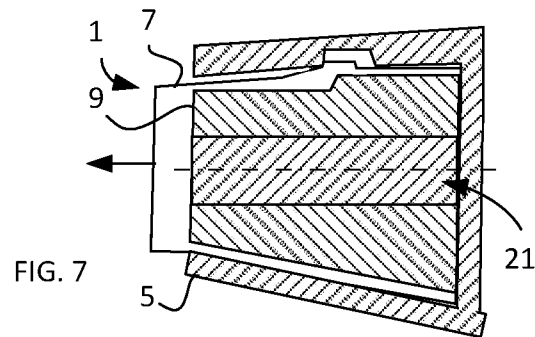


FIG. 7

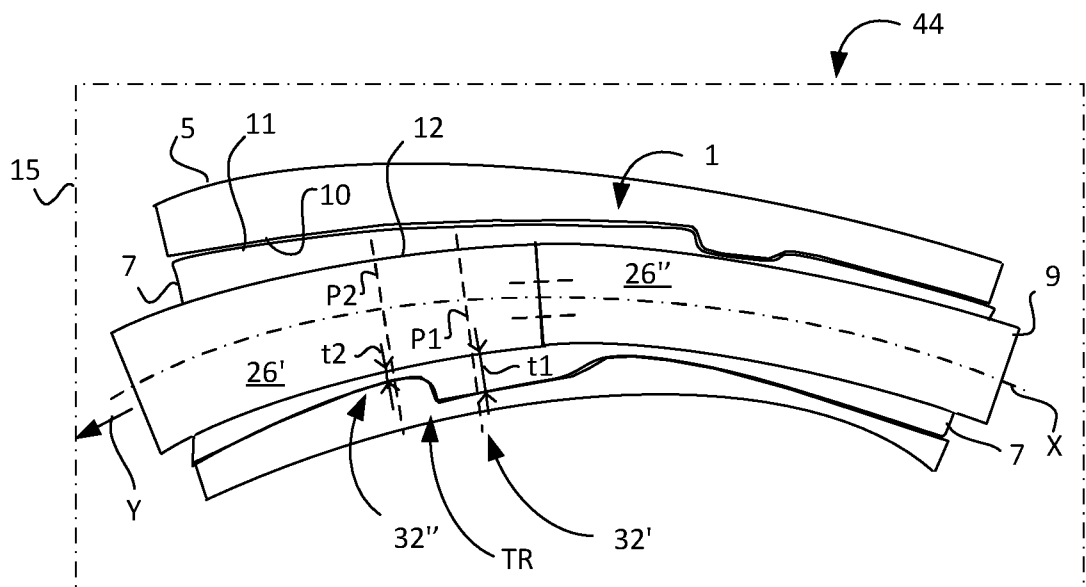


FIG. 8a

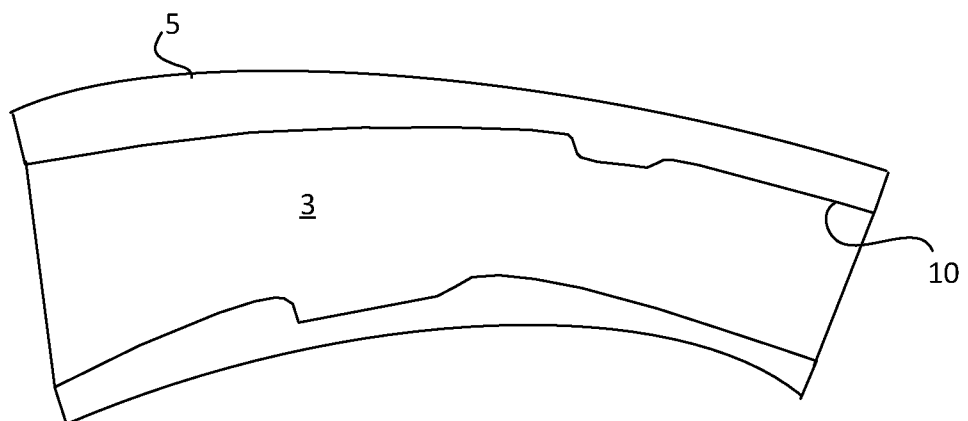


FIG. 8b

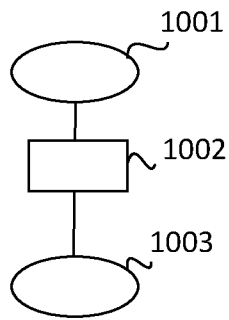


FIG. 10

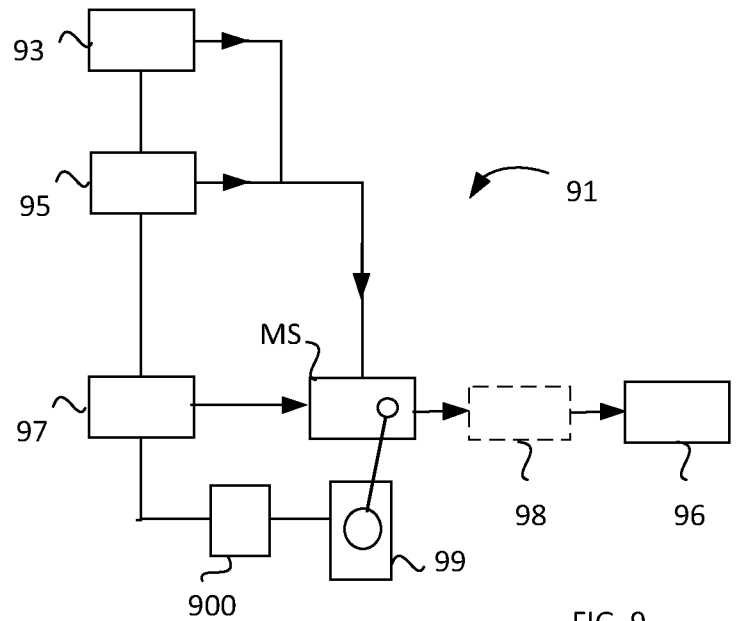


FIG. 9

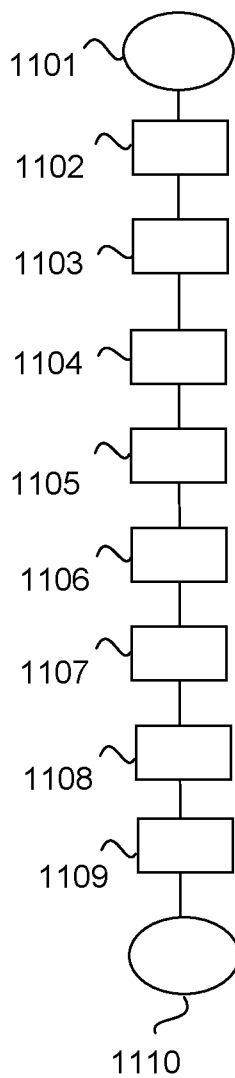


FIG. 11

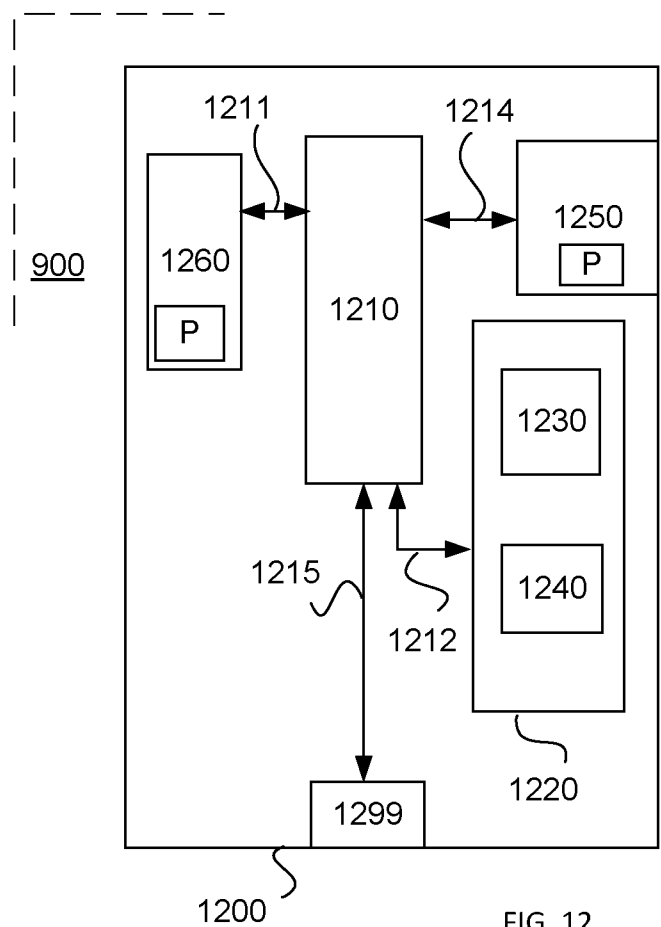


FIG. 12

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE2018/051325

A. CLASSIFICATION OF SUBJECT MATTER

IPC: see extra sheet

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC: B29C

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

SE, DK, FI, NO classes as above

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

EPO-Internal, PAJ, WPI data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 20090152775 A1 (GRANKALL TOMMY ET AL), 18 June 2009 (2009-06-18); paragraphs [0036]-[0047], [0059]; figures 1a-1i,7; claim 1 --	1-14
X	US 3962393 A (BLAD LEIV H), 8 June 1976 (1976-06-08); column 4, line 23 - line 26; column 5, line 48 - line 63; figures 1-4; claims 1-2 --	1-14
X	US 20050246824 A1 (BERGER JAN G ET AL), 10 November 2005 (2005-11-10); paragraphs [0038], [0114]; claim 1 --	1-14

☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:	"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
"A" document defining the general state of the art which is not considered to be of particular relevance	"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
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International Patent Classification (IPC)

B29C 33/50 (2006.01)

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