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Description

The present invention relates to a method for manufacturing a lamella, termed fin in English, for a plate heat exchanger and to a method for manufacturing a plate heat exchanger. The invention further relates to a soldered plate heat exchanger having a lamella manufactured according to the method according to the invention.

Soldered plate heat exchangers of aluminium are used in numerous installations at the most varied of pressures and temperatures. They are used by way of example in the separation of air, the liquefaction of natural gas or in installations for the production of ethylene.

A soldered plate heat exchanger is shown by way of example and described on page 5 of “The standards of the brazed aluminium plate-fin heat exchanger manufactures association” ALPEMA, third edition 2010. An illustration taken from there is shown in Fig. 1 and will be described below.

The plate heat exchanger shown there comprises several separation plates 4 arranged spaced from one another in a stack and forming a plurality of passages 1 for the media which are to be brought into heat exchange with one another. The passages 1 are closed off from the outside by side bars 8 which are attached flush against the edge of the separation plates 4. Lamellae 3 having a wave-type structure, in English also called fins, are arranged inside the passages 1. The separation plates 4, the lamellae 3 and the side bars 8 are connected to one another by soldering and thus form a compact heat exchanger block 10. The entire heat exchanger block 10 is delimited on the outside by cover plates 5.

In order to supply and discharge the heat-exchanging media, semi-cylindrical shaped collectors 7 with nozzle pipes 6 are attached via inlet and outlet openings 9 of the passages 1 and serve to connect with supply and discharge pipelines. The collectors 7 are also called headers 7 in the following. The inlet and outlet openings 9 of the passages 1 are formed by so-called distributor lamellae or distributor fins 2 which ensure a uniform distribution of the media over the entire width of the individual passages 1. The media flow into the channels formed by the lamellae 3 and the separation plates 4 through the passages 1.

Plate heat exchangers of this kind are preferably made from aluminium. The lamellae 3, provided in part with solder, the separation plates 4, the distributor lamellae 2, cover plates 5 and side bars 8 are stacked one on the other in the form of a cuboid block and are then soldered in an oven into a heat exchanger block 10. The solder is generally applied on both sides of the separation plates and where applicable to the lamellae prior to soldering. After soldering in a soldering oven the collectors 7 with nozzles 6 are welded onto the heat exchanger bock 10.

The lamellae are generally made from thin flat sheet metal plates which are folded into wave-type structures by a press or other tools suitable for bending and reshaping. This is disclosed by way of example in DE 103 43 107 A1 in paragraph [0005] which thus forms the preamble for the method according to the invention. Fig. 2 shows an example for a lamella 3 which is formed by bend-forming. This has a plurality of wave crests 31 and wave flanks 32 which each follow one another in a first spatial direction (D1). The wave crests 31 of the corrugated structure are, as shown in Fig. 11, connected flat to each adjacent separation plate 4 by a soldered connection after soldering the heat exchanger block 10 in a soldering oven.

The lamellae 3 inside the passages fulfil three tasks:

On the one hand the heat exchange surface area is enlarged by the lamellae. In order to optimize the heat transfer, the alignment of the corrugated structure in adjacent passages is selected in dependence on the type of use so that the same, crossed, counter or counter-crossed flow is possible between the adjacent passages.

On the other hand, the lamellae produce with their wave crests via the soldered connections a materially bonded connection amongst the separation plates. The wave flanks of the lamellae take up the forces which act on the separation plates through the internal pressure.

Furthermore, the lamellae serve to divide the passages into small channels whereby a uniform distribution of a medium over the entire width of a passage is achieved and thus the heat exchange between the media flowing in the adjacent passages is improved.

As a result of the boundary conditions which are to be observed during the bend-forming process of the lamella 3, such internal radii R2 and external radii R1 of the metal-sheet edges 34 (Fig. 2) at the transition between the respective wave crest 31 and the wave flank 32 and the tolerances which arise during the bend-forming process, the lamella 3 frequently has deviations from a desired ideal shape with regard to an ideal force introduction. It has been seen that the mechanical strength of a plate heat exchanger is hereby restricted. The size of the external radii R1 is determined by the size of the internal radii R2 and the wall thickness S of the lamella.

In order to improve the mechanical strength of a plate heat exchanger having lamellae, the DE 103 43 107 A1 proposes making the lamellae from a thick plate which is either hot-extruded or is made with a cutting method in order to achieve a rectangular shape of the wave crests and the wave flanks. Further parameters are proposed for the ratio between the thickness of the corrugated structure itself and its separation, i.e. wave length and wave amplitude. The drawback with shaping by cutting is that when soldering the heat exchanger block in the soldering oven, the broken structure of the lamellae produced through the previous cutting work, takes up an increased amount of solder whereby the strength of the lamella material is disadvantageously reduced. A lamella made by heat extrusion can only have a narrowly restricted width - in the direction D2 shown in DE 103 43 107 A1 - with a few wave crests of about four to five. Furthermore, no perforated or sectioned geometries can be produced.

In the DE 10 2009 018 247 A1, in order to increase the strength of a plate heat exchanger it is proposed to provide a passage with a plurality of profiles arranged next to one another. By using profiles, the contact surface between the separation plate and the lamella is to be increased. Profiles furthermore have low manufacturing tolerances with regard to the desired angle degrees, so that a favourable force introduction is produced. The manufacturing costs of a plate heat exchanger with profiles as a heat conductive structure in the passages is however increased since the profiles have to be placed individually side by side on the separation plates prior to soldering.

The object of the present invention is to provide a method for manufacturing a lamella for a plate heat exchanger whereby a lamella is obtained which ensures a high strength in a soldered plate heat exchanger produced with the lamella and can thus be used for high pressure applications. The object is also to provide a soldered plate heat exchanger and a method for the manufacture thereof.

This is achieved with a method for manufacturing a lamella with the features according to claim 1, a soldered plate heat exchanger having the features according to claim 9, and a method for manufacturing a plate heat exchanger according to claim 8.

The present patent application provides a method for manufacturing a lamella for a plate heat exchanger which has the following steps:

a) providing a corrugated structure from a formed metal sheet, in particular a bend-formed metal sheet, having at least one wave crest with wave flanks, wherein the wave crest and the wave flanks are each connected by way of a metal-sheet edge, and wherein the metal-sheet edge has an internal radius and an external radius, and

according to the invention following the step (a), in particular adjoining step (a) by

b) compression-forming, preferably cold-extruding, the at least one wave crest having wave flanks of the corrugated structure from step a) in such a manner that the external radius of the metal-sheet edges between the wave crest and the respective wave flank is reduced.

Reducing the external radius of the metal-sheet edge has the effect that during the soldering process in the soldering oven between the respective separation plate and a wave crest an optimum soldering layer is formed. It is hereby achieved that the soldering layer between the separation plate and the wave crest of the lamella preferably covers up to more than 80%, more particularly preferred up to more than 90% of the cross-section of a wave flank projected perpendicular to the separation plate with uniform welding layer thickness. This ensures that the compression stresses acting during operation of the plate heat exchanger through the pressure of the media on the separation plates are introduced in optimum manner over the entire width of the wave flanks whereby the maximum mechanical load capacity of the wave flanks is exploited. Bursting pressures of above 600 bar can be hereby achieved.

The lamella made according to the invention has a high buckling resistance. Thin-walled lamellae with wall thicknesses of less than 0.3 mm can hereby be stacked up one on the other in greater numbers than before in the production process and thus the number of passages of a plate heat exchanger and the height thereof can thus be increased.

The external radius of the metal-sheet edge which after a reforming step according to step (a) lies mostly in a range from 0.2 mm to 1.6 mm, frequently in a range from 0.4 to 1.4 mm, is preferably reduced in step b) during compression-forming to an external radius in the range from preferably 0.05 mm to 1.5 mm, preferably 0.05 mm to 0.90 mm, further preferred to 0.05 mm to 0.30 mm, further particularly preferred from 0.05 mm to 0.18 mm, further particularly preferred 0.07 to 0.18 mm, further particularly preferred from 0.07 mm to 0.12 mm and in a further particularly preferred manner from 0.10 mm to 0.12 mm.

Compression-forming according to step b) is a method for reforming the already provided corrugated structure, wherein a plastic state of at least one part of the material is created, in particular in such a way that the material of the wave crests can be rearranged in the region of the metal-sheet edges. During compression-forming according to step (b) a plastic state is thus preferably reached which enables a shift in the grain boundary inside the material. The compressive strain during the compression-forming can be single or multi-axle. A compression-forming preferably takes place according to DIN 8583. It is particularly preferred if during compression-forming according to step b) a flat surface pressure is applied (preferably vertically) from outside onto at least one wave crest preferably by a planar ram, whilst the wave flanks adjoining the wave crest are further preferably fixed at the sides by a die and, further preferred, the second and third wave crest adjoining the wave flanks are supported by a die. The die can then be of a single or multi-part design. During extrusion which within the scope of the present invention is used in a particularly preferred manner as a compression-forming method, the material of the body is brought under a pressure to flow – i.e. plastically deform – which is preferably higher than the yield strength with 0.2% plastic deformation which is also given as $R_{p0.2}$ [N/mm^2] in material data sheets. This yield strength as $R_{p0.2}$[N/mm^2] can be in a tensile test according to ASTM B557M-15. A pressure of at least 80N/mm^2 is therefore preferably applied to the material. A ram then generally presses the body into, or where applicable through, a die.

A cold extrusion is preferably used wherein no heat is introduced externally into the material. I.e. in other words, the extrusion is carried out at ambient temperature, thus as a rule at temperatures below 50^{o}C, in particular below 40^{o}C. Cold-extruding enables a high shape accuracy. Both a forward extrusion and also a backward extrusion as well as a cross extrusion can be used. Also, any combinations of the said extrusion methods can be applied. During forward extrusion, the material flow is directed in the active direction of the ram, during backward extrusion however the material flow is directed counter to the active direction of the ram. During cross extrusion the material flow is directed transversely to the active direction of the ram.

During compression-forming according to step b) the at least one wave crest and the wave flanks are preferably brought into a rectangular arrangement, i.e. at an angle of 90^{o} to one another with a deviation of preferably less than 1^{o}, in particular preferably less than 0.5^{o}, or if a rectangular arrangement existed already prior to the compression- forming, the wave crest and wave flanks are held in their rectangular arrangement. It is hereby guaranteed that the compressive strains acting through the media pressure on the separation plates during operation of the plate heat exchanger are introduced without transverses stresses as tensile forces orthogonally into the wave flanks, whereby the maximum tensile strength of the wave flanks can be exploited. After the bend-forming of a planar metal sheet into the described corrugated structure which is preferably already provided in step a), the wave crest and wave flanks are however as a rule not arranged ideally at right angles to one another, but have deviations of some angular degrees - of up to 3^{o}.

During compression-forming according to step b) the corrugated structure is preferably reduced in its height. The height reduction preferably lies in the range from 0.4 mm to 1.2 mm, in particular preferably in the range from 0.8 mm to 1.0 mm.

The division preferably remains unchanged. Thus during the compression forming plasticized material or material rendered flowable is displaced from the wave flanks and the wave crest into a region of the metal-sheet edge between the wave crest and the wave flank, whereby the external radius of the metal-sheet edge is reduced.

The corrugated structure provided in step a) can be obtained by reforming a preferably planar sheet metal plate according to a reforming method known from the prior art. According to this, the method step a) comprises in addition to the provision of the corrugated structure also preferably the prior production of the corrugated structure by a reforming method. These are preferably reforming methods according to DIN 8582. The reforming of the sheet metal plate is preferably carried out by bend-forming. This can comprise bending with a rectilinear tool movement, rotational tool movement or a combination of the two movements. In all three said cases, the sheet metal is stressed to bending. Bend-forming preferably takes place according to DIN 8586.

The method of manufacture according to the invention for the lamella has the advantage that the wall thickness of the wave flanks is scarcely changed compared with the wall thickness of the planar sheet metal as the raw material. This is of great importance for the strength of the lamella in the soldered connection with the separation plates of a plate heat exchanger.

With the method according to the present invention a lamella is obtained in which the wall thickness of the flanks is changed only slightly compared with the wall thickness of the planar metal sheet, which forms the raw material. The percentage wall thickness reduction is calculated according to the following formula: ((S1-S2)/(S1)*100, in which S1 is the wall thickness of the planar sheet metal as the raw material and S2 is the wall thickness of the wave flank after the compression-forming according to step (b). The percentage wall thickness reduction is thus defined as the difference between the wall thickness S2 (shown in Fig. 9) of the wave flanks after compression-forming according to step b), and the wall thickness S1 of the planar sheet metal as the raw material (S1 in Fig. 8) divided by the wall thickness S1 of the planar sheet metal as the raw material multiplied by 100, in order to obtain the percentage proportions. This reduction in wall thickness amounts in the present invention to less than 10%, in particular to less than 5% and further in particular to less than 1%. This cannot be achieved with the conventional exclusive bend-forming method for a lamella. With the exclusive bend-forming method for a lamella the wall thickness reduction amounts as a rule to at least 20%.

With the method according to the present invention the wall thickness of the lamella in the region of the compression-formed metal-sheet edge, thus in the curved transition region from a wave crest to a wave flank, is advantageously increased in comparison to the wall thickness of the planar sheet metal as the raw material. The percentage wall thickness increase in the region of the compression-formed metal-sheet edge, is calculated according to the following formula: ((S3-S1)/S1)*100. Here S3 is the transverse wall thickness S3 (Fig. 9) in the region of the compression-formed bending edge and S2 (Fig. 8) is the wall thickness of the metal sheet which represents the raw material. This wall thickness increase is thus defined as the difference between S3 and S1 divided by S1 multiplied with 100, in order to obtain the percentage increase. The wall thickness increase amounts in the region of the compression-formed metal-sheet edge preferably to more than 1%, in particular more than 5% and further in particular preferably more than 10%. With the conventional bend-forming method for a lamella a wall thickness increase cannot be achieved in the region of the metal-sheet edge. With the exclusive bend-forming method according to the prior art a reduction in the wall thickness of the lamella occurs as a rule in the region of the bend-formed metal-sheet edge.

With the method according to the invention for manufacturing a lamella, in the case of the corrugated structure which is provided in step a), the wave crest and wave flank preferably follow one another alternately in a first spatial direction. The first spatial direction preferably coincides with the advancing direction of the sheet metal during forming of the sheet metal into the corrugated structure mentioned in step a). During compression-forming according to step b) the advance of the corrugated structure preferably also takes place in this first spatial direction. The advancing direction of the sheet metal during flat rolling to obtain a planar metal sheet prior to forming into the corrugated structure mentioned in step a) preferably coincides with the first spatial direction. This means in other words that the advancing direction of the sheet metal during flat rolling is in particular preferably the same as the advancing direction of the sheet metal during forming into the corrugated structure mentioned in step a) as well as the advancing direction of the corrugated structure during compression-forming according to step b).

The forming, preferably bend-forming, of a metal sheet mentioned in step a) into a corrugated structure and the compression-forming according to step b) preferably take place in one device or in two or more devices arranged in succession. It is hereby possible to process a metal sheet from a coil without breaking the material between the forming mentioned in step a) and the compression-forming described in step b). An intermediate storage of corrugated metal sheets is thereby unnecessary. It is however possible within the scope of the invention to subject an already prefabricated metal sheet with corrugated structure to a compression- forming process according to step b).

It is particularly preferred if the forming of a metal sheet into a corrugated structure according to step a) and the compression-forming according to step b) are carried out consecutively without any break in the material flow, preferably in the same device. Thus first the metal sheet is preferably formed with at least one wave crest – thus one wave crest or by way of example 2 or 3 wave crests – with respective wave flanks into the corrugated structure, preferably by bend-forming, and them preferably in the same advancing direction as during forming in step a), the at least one wave crest is compression-formed, preferably cold-extruded – with the wave flanks according to step b).

A method is particularly preferred in which at least a single, first wave crest with adjoining wave flanks is made by forming, preferably by bend-forming, and then this first wave crest with adjoining wave flanks is compression-formed, before a second wave crest with wave flanks is made, in particular by forming, preferably bend-forming, with subsequent compression forming. In other words, first a wave, comprising wave crest and adjoining wave flanks, is pre-formed by bend-forming and then immediately afterwards compression-formed, before the next wave is formed. The metal sheet can be advanced between the forming of the first wave according to step a) and the compression-forming of the first wave according to step b), or no material advance is provided, and this can then take place between the forming of the first wave and the second wave.

According to the present invention, a method is also provided for manufacturing a plate heat exchanger in which a plurality of separation plates and lamellae are disposed in an alternating manner on top of one another in a stack and are soldered to one another in a soldering oven so as to form a cuboid heat exchanger block. According to the invention at least one of the lamellae is made according to a method of manufacture described above. The separation plates are preferably provided with a solder layer which is preferably applied through lamination onto the separation plates.

The lamella manufactured according to the invention has a higher buckle resistance than lamellae which were folded solely according to the bend-forming method of the prior art. The separation plates and lamellae can hereby be layered up in a higher stack during production of the plate heat exchanger without the lamellae in the lower passages becoming buckled through the weight of the separation plates and lamellae positioned above same. For further advantages of the plate heat exchanger made with the method of manufacture reference is made to the above details.

With the method according to the invention a lamella can preferably be made from aluminium or an aluminium alloy for a plate heat exchanger, comprising a corrugated structure from a metal sheet:

- with wave crests arranged parallel to one another, wherein one wave crest is connected to a further wave crest via a wave flank;

- wherein the wave crest and wave flank follow one another in a first spatial direction;

- wherein the wave crest and wave flank are connected to one another by a metal-sheet edge;

- wherein each metal-sheet edge comprises an internal radius and an external radius; and

- wherein the wave crests have a flat outside surface.

The external radius of the metal-sheet edge preferably amounts to between 0.05 mm and 0.18 mm, preferably between 0.10 mm and 0.15 mm, and particularly preferred between 0.10 mm and 0.12 mm. It has been seen that during the soldering process in the soldering oven in the case of an external radius of the metal-sheet edge in the aforementioned regions between the adjacent separation plate and the wave crest of the lamella, a fillet weld of solder is formed in the region of the metal-sheet edge which enables optimum introduction force from the separation plate into the wave flank.

The determination of the external radii takes place within the scope of the present invention by casting a lamella portion having several wave crests and wave flanks in plastic and then separating it in a plane perpendicular to the wave crest and wave flanks and smooth polishing the surface. The external radius of the metal-sheet edge between the wave crest and wave flank is then determined by means of a 3-point measuring process. For this, three points on the smooth polished cross-section of the metal-sheet edge are placed on the external edge of the metal-sheet edge and their position are determined relative to one another by means of a measuring unit and microscope. The external radius is determined by computer from the detected two-dimensional coordinates of the three points.

The internal radius of the metal-sheet edge is preferably 0.2 mm to 0.4 mm and more particularly 0.3 mm.

Determining the internal radius of the metal-sheet edge is carried out in the same way as the method described above for determining the external radius of the metal-sheet edge. Differently from the method above, the measuring points are placed on the internal edge of the metal-sheet edge.

The wall thickness of the lamella, and thus the wall thickness of the wave crests and wave flanks, preferably amounts to 0.2 mm to 1.0 mm. The wave crests and wave flanks inside a lamella according to the invention preferably have the same wall thickness in the range defined above. In other words, this means that the wave crests and wave flanks of the lamella according to the invention preferably have straight wall portions with the same wall thickness wherein each one wave crest is connected to one wave flank by a curved sharp-edged metal-sheet edge.

The lamella is produced by forming a planar metal sheet, according to the method according to the invention by forming in two or more forming method steps, preferably according to one or more forming methods described in DIN 8582.

The preferably concluding forming method step is a compression-forming preferably according to DIN 8583, more particularly preferably a cold extrusion in which the external radii of the metal-sheet edges are brought into the desired region defined above.

The compression-forming preferably comprises neither a bending nor a drawing of the lamella material. With the lamella according to the invention the concluding compression-forming method step, in particular cold-extrusion step, can be recognized in that the structure particularly in the region of the metal-sheet edge has spherical grains in the transition from a wave crest to a wave flank. The structure preferably has up to more than 50%, in particular up to more than 80% and further in particular up to more than 95% structural grains which have a spherical form. The spherical-formed grain structure can be verified in a microscopic section.

In comparison with this, lamellae which were made solely by bend-forming or a machining production, have structures with elongated rice grain type structures. The reason for this is that flat-rolled sheet metals are used for bend-forming and for machining production which already have this structure with elongated rice grain type structures before bend-forming and machining production. These elongated grains can be stretched still further by bend-forming.

As a rule, the surface of the lamella, after the compression-forming step, has a mean roughness R_a of less than 0.4µm (micrometer), it mostly lies in the range from 0.2µm to 0.4µm. These surface roughness values are conditioned by the tool which is used for the compression-forming according to the invention. The surface roughness values of the surface of the tool acting on the lamella, by way of example of a ram, are transferred to the lamella during the compression-forming.

The mean roughness R_a indicates the mean distance of one measuring point - on the surface - to the centre line. The centre line intersects the actual profile within the reference stretch so that the sum of the profile deviations (in relation to the centre line) is minimal. The mean roughness R_a thus corresponds to the arithmetical mean of the deviation in distance from the centre line. The mean roughness of the lamella surface is reduced by means of the concluding compression-forming method step compared with the surface of a lamella which is made solely by bend-forming with or without drawing the material. The mean roughness R_a of the surface of lamellae formed by bend-forming is about 10µm.

The lamella is preferably formed by a bend-forming step followed by a compression-forming step. In the case of the bend-forming step, preferably according to DIN 8586, a – preferably planar – metal sheet is brought into a corrugated structure having at least one wave crest with wave flanks.

Bend-forming within the scope of the present invention can comprise a pure bend-forming by pivoting about a bending axis, and also pivoting about a bending axis with a draw-forming step in which the sheet metal is additionally drawn into a spatial direction. The compression-forming method step, preferably cold-extrusion method step, preferably then follows wherein the external radius of the metal-sheet edges formed during bend-forming is reduced between the wave crest and wave flank. The internal radius of the metal-sheet edges preferably does not change during the concluding compression-forming method step. The further preferred method of manufacture will be explained in more detail below.

With the lamella produced according to the invention the wave crest and wave flanks are preferably arranged orthogonal with one another, i.e. at an angle of 90^0 with a deviation of preferably less than 1^0, and more particularly of less than 0.5^0 to one another. It follows from this that the wave flanks of the lamella produced according to the invention are also preferably arranged parallel to one another. Furthermore the at least one wave crest has a planar, thus flat external surface in order to provide an optimum solder connecting surface for a separation plate in a plate heat exchanger. The lamella crests have in each case preferably a maximum deviation in their flatness of 0.02 mm from one metal-sheet edge to the adjacent metal-sheet edge.

The lamella is preferably perforated and/or cut (in English also termed “serrated”) as detailed and described in “The standards of the brazed aluminium plate-fin heat exchanger manufactures association” ALPEMA, Third edition 2010, pages 9 and 10. More advantageously the lamella consists of aluminium or an aluminium alloy and particularly preferred of an EN-AW 3003 alloy according to the European Standard. An aluminium alloy according to the present invention has accordingly aluminium as the main constituent part, preferably with a mass percentage proportion of aluminium to the overall alloy of at least 90% aluminium, preferably at least 95% aluminium, and preferably less than 99.9% aluminium, in particular of less than 99% aluminium. The mass proportion of aluminium in the aluminium alloy is preferably in the range from 96.8% to 99%. Further alloy constituents can be one or more selected from the group: manganese, iron, copper or silicon. The manganese content of the aluminium alloy in mass percent preferably lies in the range from 1.0% to 1.5% manganese. The iron content of the aluminium alloy in mass percent lies preferably at less than 0.7%. The mass percentage proportion of copper in the aluminium alloy is preferably less than 0.2%. The aluminium alloy preferably has a silicon content in mass percent of less than 0.5%, in particular of less than 0.1%.

The present invention also comprises a soldered plate heat exchanger having a plurality of separation plates which are arranged at a distance from one another in a stack and which form passages for at least two fluids entering into indirect heat exchange, wherein according to the invention at least one passage has a lamella described above or where applicable several lamellae described above. The passages are laterally defined by side bars generally arranged between the separation plates. The separation plates can generally be planar separation plates of sheet metal which are preferably formed like the lamella of aluminium or an aluminium alloy.

In the case of the plate heat exchanger the solder layer between the separation plate and wave crest of the lamella by way of a consistent solder layer thickness preferably covers up to more than 80%, preferably more than 90% and in particular more than 95% of the cross section of a wave flank projected perpendicularly onto the separation plate.

With the lamella produced according to the invention the above solder- covering geometries can be achieved and thus bursting pressures of the plate heat exchanger can be produced of more than 600 bar when using an EN-AW 3003 aluminium alloy for the lamella.

All the passages of the plate heat exchanger provided for the through flow of the media are preferably fitted with one or more of the lamellae described above. The plate heat exchanger then has in a preferred embodiment moreover the same component parts and the same construction as described at the beginning for Fig. 1.

The plate heat exchanger according to the invention can also be used for a core-in-shell or block-in-kettle – heat exchanger arrangement, as described and illustrated in "The standards of the brazed aluminium plate-fin heat exchanger manufactures association" ALPEMA, third edition, 2010 pages 66.

The component parts such as cover plate, separation plates and side bars of the plate heat exchanger are preferably formed from aluminium or aluminium alloy, as described in particular on pages 45 and 46 of "The standards of the brazed aluminium plate-fin heat exchanger manufactures association" ALPEMA, Third edition, 2010.

The separation plates which can also be termed separation sheets, preferably have a wall thickness in the range from 1.0 mm to 3.0 mm, more particularly from 1.2 mm to 2.5 mm and further in particular from 1.4 mm to 1.7 mm. The cover plates are generally designed with a greater wall thickness than the respective separation plates inside the heat exchanger block. The cover plates therefore preferably have a wall thickness in the range from 3 to 12 mm, in particular preferably from 5 to 8 mm.

The lamella according to the present invention can be used advantageously for plate heat exchangers in the various different process sections in air separation plants, petrochemical plants, hydrogen plants, synthesis gas plants or natural gas plants. The lamella can advantageously be used for applications in the temperature range from less than 80°C, preferably for cryogenic applications at temperatures in the range from 0∘C to -270°C.

The invention will now be explained in further detail below with reference to exemplary embodiments.

In the drawings:

Fig. 1 shows a plate heat exchanger from "The standards of the brazed aluminium plate-fin heat exchanger manufactures association" ALPEMA, Third Edition 2010, page 5;

Fig. 2 shows a bend-formed lamella 3 in a perspective view;

Fig. 3 shows the lamella of Fig. 2 after a compression-forming step according to the present invention;

Fig. 4 shows a bend-formed serrated lamella 3 in a perspective view;

Fig. 5 shows the lamella of Fig. 4 after a compression-forming step according to the present invention;

Fig. 6 shows a bend-formed perforated lamella 3 in a perspective view;

Fig. 7 shows a lamella according to Fig. 6 after a compression-forming step according to the present invention;

Fig. 8 shows a perspective view of a metal sheet with bend-formed and extruded sections according to a method according to the invention for manufacturing a lamella;

Fig. 9 shows a cross-section through a lamella 103 according to the invention with soldered separation plates 4;

Fig 10 shows the detailed section Y of Fig. 9;

Fig. 11 shows a cross-section through a bend-formed lamella 3 with soldered separation plates 4 according to the prior art;

Fig. 12 shows a diagrammatic view of the structure of a metal sheet 20 or a bend-formed lamella 3 according to step (a) of Fig. 8;

Fig 13 shows a diagrammatic view of the structure of a lamella 103 of Fig. 8 according to the invention after the compression- forming step (b).

The plate heat exchanger according to Fig. 1 was already explained in the introductory part of the present description. A preferred embodiment of a plate heat exchanger according to the invention has the same construction as shown in Fig. 1, but is equipped with at least one of the lamellae 103 described in general above or described below with reference to Figs. 3, 5, 7, 8, 9 and 10.

Fig. 2 shows a lamella 3 according to the prior art which is obtained by bend-forming a flat metal sheet with the wall thickness S1. The lamella 3 has a corrugated structure with lower and upper wave crests 31 which are connected to one another via wave flanks 32. The wave crests 31 and the wave flanks 32 are connected by rounded bending edges 34 wherein the bending edges 34 each comprise an external radius R1 and an internal radius R2. The external radius R1 of the bending edges 34 is determined by the internal radius R2 and the wall thickness S1. The wave crest 31 and the wave flank 32 follow one another in alternation in a first spatial direction D1. The height H1 of the lamella 3 extends into a second spatial direction D2 which is aligned perpendicular to the first spatial direction D1.

A plurality of channels 36 which are each formed by a wave crest 31 with adjoining wave flanks 32 and are delimited in a plate heat exchanger by separation plates 4 to which the lamella 3 is soldered extend in a third spatial direction D3 (Fig. 11). During operation of the plate heat exchanger a medium flows through the channels 36 in the spatial direction D3 (or in the counter direction thereto). The third spatial direction D3 is aligned both perpendicularly to the first spatial direction D1 and also perpendicularly to the second spatial direction D2.

The mark "P1" indicates the separation of the lamella 3. The separation P1 indicates the length of a structural section of the lamella 3 which is repeated in the first spatial direction D1. Here this is the distance from the wall centre of a wave flank 32 up to the wall centre of a following wave flank 32. The present lamella 3 has a relatively small separation P1 with a relatively large wall thickness S1 and thus a relatively large external radius R1. An only relatively small proportion of the external surface 35 of a wave crest 31 is hereby formed flat in each case.

Fig. 3 shows a lamella 103 according to an embodiment of the present invention. This would be formed by a manufacturing method which comprises a bend-forming step with a following compression-forming step. The manufacturing method will be explained in further detail below with reference to Fig. 8.

The lamella 103 according to Fig. 3 comprises a sharp-edged corrugated structure with wave crests 131 and wave flanks 132, which follow one another in alternation in the first spatial direction D1. The lower and upper wave crests 131 are flat and each run parallel to one another, i.e. with a maximum deviation of 1^{0}, preferably 0.5^{0}. The wave flanks 132 are each arranged at right angles to the wave crests 131. The wave flanks 132 which extend into the second spatial direction D2 therefore also run parallel to one another, i.e. with a maximum deviation of 1^{0}, preferably 0.5^{0}. The wave crests 131 are each connected to the wave flanks 132 via sharp-edged metal-sheet edges 134. The metal-sheet edges 134 each have an external radius R101 and an internal radius R102. The internal radii amount in the case of an aluminium alloy according to European Standard EN-AW-3003 to preferably 0.2 mm to 0.4 mm and the external radii amount according to the invention to 0.05 mm to 0.18 mm. The separation is indicated by P101 and as a rule amounts to 0.9 mm to 5.0 mm. The height H101 of the lamella 103 can amount to 4.0 mm to 12 mm. The wall thickness S101 can be in the range from 0.2 mm to 1.0 mm. The sharp-edged contour of the metal-sheet edges 134 with external radii R101 below 0.2 mm is achieved by a compression-forming step in which the bend-formed lamella 3 of Fig, 2 is compressed in particular in the direction of the second spatial direction D2 and is thus reduced in its height to a height 101. The reduction in height amounts as a rule to between 0.8 mm and 1.2 mm. The wave crests 131 hereby have over their entire width (width running in the first spatial direction D1), apart from the surface regions curved as a result of the external radii R101, flat external surfaces 135 for optimum connection by soldering with likewise flat separation plates 4 shown in Figs. 9 and 10.

Fig. 8 shows an embodiment of a method for manufacturing the lamella 103 shown in Fig. 3. The raw material for the production of the lamella 103 is a flat smooth sheet metal plate 20 by way of example of aluminium alloy according to the European Norm EN-AW-3003 with a material thickness or wall thickness S1. The metal sheet 20 is preferably unwound from a sheet metal coil (not shown). The flat metal sheet 20 is obtained by flat-rolling a cast bar. The structure of the metal sheet 20 therefore has elongated grains 21, as shown diagrammatically in Fig. 12.

In a first step (a) of the manufacturing method according to the invention the flat sheet metal plate 20, shown in the left part of the figure, is brought by bend-forming into a corrugated structure with one, two or more wave crests 31 each with adjoining wave flanks 32, as shown in Fig. 2 and described above. Of this, one or more tools preferably act in a rectilinear movement from below and/or above perpendicularly onto the metal sheet 20. A sliding drawing bending is preferred. The advancing direction D1, marked by arrows, of the metal sheet 20 during the sliding drawing bending process coincides with the spatial direction D1 drawn in Fig. 2. The bend-forming can also be carried out by a rotating movement of the tool or by a combination of the rectilinear and rotating tool movement. Bend-forming preferably takes place according to a method described in DIN 8586. The structure (Fig. 12) of the bend-formed lamella 3 has after the bend-forming according to step (a) elongated rice grain type structured grains 21 like the metal sheet 20 which forms the raw material. In the region of the rounded bent edges 34 of the lamella 3 the structured grains can also have curvatures, which is however not shown. If the bend-forming also includes a draw-forming proportion then the grains 21 can be further stretched compared to the structure present in the metal sheet 20, i.e. have a greater length, which is however likewise not shown. The advancing direction during flat-rolling of the metal sheet 20 coincides preferably with the spatial direction D1 and thus with the advancing direction D1 during bend-forming according to step (a).

The rounded corrugated structure 3 formed in the first step (a) and shown in the middle figure part of Fig. 8, is now further formed in a second step (b) of the manufacturing method according to the invention by compression-forming. For this, a flat surface pressure is applied perpendicularly from outside on the external surface 35 of one or more wave crests 31 of the corrugated structure, by way of example by means of a flat ram (indicated by the arrow 50). During the compression- forming the respective wave of the wave crest 31 and adjoining wave flanks 32 is fixed in a die (not shown).

The metal material is brought by the high compressive strain into a plastic state in which it starts to flow. The compression-forming takes place at ambient temperature, i.e. the metal is not heated from outside prior to the compression-forming or during the compression-forming. It is therefore termed cold-extrusion pressing. With this extrusion pressing, metal from the curved wave crest 31 and from the adjoining wave flanks 32 is moved by flowing into the region of the bending edge 34. The external radius of the edge 34 is hereby reduced from the original R1 to R101 and the lamella is compressed or reduced in height from H1 to H101. The structure of the compression-formed lamella 103 has spherical grains 121, as shown diagrammatically in Fig. 13. The lamella 102 thus made has a surface with a mean roughness Ra of less than 0.4 µm.

The external radius R101 (back to Fig. 8) after the compression-forming step amounts preferably to below 0.18 mm, more particularly below 0.15 mm. The advancing direction during compression-forming takes place as with the bend-forming in the spatial direction D1. The compression-forming of the corrugated structure takes place correspondingly mainly in the spatial direction D2.

The bend-forming step (a) and the compression-forming step (b) take place in the illustrated embodiment consecutively, preferably without any break in the flow of material in the same device.

The result of the manufacturing method according to the invention according to Fig. 8 is the lamella 103 already described above in Fig. 3.

The lamella 103 is used for manufacturing a plate heat exchanger as described above with reference to Fig. 1. Instead of the lamellae provided with the reference numerals 2 and 3 in Fig. 1, lamellae 103 according to Fig. 3 are used.

Separation plates 4 lined on both sides with solder are arranged alternately with lamellae 103 and bar strips 8 with outer cover plates 5 one above the other in a stack and soldered in a solder oven. Headers 7 with nozzles 6 are then welded onto the soldered heat exchanger block.

Fig. 9 shows a cross-section through a lamella 103 with adjoining soldered separation plates 4. Fig. 10 shows a detail Y of Fig. 9. It can be seen from both figures that between the wave crests 131 and the separation plates 4 there is in each case a solder layer 140 of constant thickness d which covers 100 % of the cross-section Q of the adjoining wave flank projected onto the separation plate 4. The forces acting by the internal pressure on the separation plates 4 can hereby be introduced perpendicularly through the solder layer 140 into the wave flanks 132 over their entire cross-section Q. A fillet weld 141 is formed with an external radius R101 in the region according to the invention of 0.05 mm to 0.18 mm outside of the projected wave flank cross-section Q whereby the aforementioned optimum solder layer covering geometry is achieved.

In Fig. 9, the wall thickness of the compression-formed lamella 103 in the region of the flank 132 is marked with the reference numeral S2. With the method according to the present invention the wall thickness S2 of the flanks 132 is reduced only slightly compared with the wall thickness S1 (Fig. 8) of the flat metal sheet 20 which represents the raw material. The percentage wall thickness reduction is calculated as follows: ((S1-S2)/S1)*100. This amounts to less than 10%, in particular preferably less than 5% and more particularly preferred less than 1%. This cannot be reached with the conventional bend-forming method for a lamella. With the exclusively bend-formed lamellae according to the prior art the percentage wall thickness reduction is generally at least 20%.

Furthermore, a transversal wall thickness in the region of the compression-formed metal-sheet edge 134 is marked by the reference numeral S3 in Fig. 9. With the method according to the present invention the transversal wall thickness S3 in the region of the metal-sheet edge 134 is increased compared with the wall thickness S1 (Fig. 8) of the flat sheet metal 20 which represents the raw material. The percentage wall thickness increase is calculated as follows: ((S3-S1)/S1)*100. This preferably amounts to more than 1%, in particular more than 5% and more preferably more than 10%. This cannot be reached with the conventional bend-forming method for a lamella. As a rule, a reduction occurs here in the wall thickness of the lamella in the region of an exclusively bend-formed metal-sheet edge.

Fig. 11 shows the soldering of an exclusively bend-formed lamella 3 according to Fig. 2 and thus according to the prior art. With this, the fillet weld 41 which is produced when soldering between the bending edge 34 having an external radius R1 and the separation plate 4, lies in the region of the projected wave flank cross-section Q. No solder layer of constant thickness is produced in the projected cross-section Q. The fillet weld 41 furthermore does not span the entire projected cross-section Q of the wave flank 32. Flat surface areas F of the wave flanks 32 are not connected to the separation plates 4 via a closed soldered layer. A solder connection of this kind has proved disadvantageous for the strength of the plate heat exchanger.

Fig. 4 shows a bend-formed serrated lamella 3 after step (a) (Fig. 8) of the method according to the invention and thus according to the prior art. This is produced by slide-draw-bending a flat sheet metal plate with superimposed simultaneously occurring cutting through individual rams which are off-set relative to one another. The off-set stagger is in the direction D1 and alternates over the entire sheet metal width in the direction D3. As a rule, the cut length L amounts to between 1.5 mm and 50 mm. In a following compression-forming step (b) according to the invention (according to Fig. 8), the result of which is shown in Fig. 5, the rounded corrugated structure of Fig. 4 is transformed into a sharp-edged corrugated structure of Fig. 5, in which the external radius of the bending edge is reduced from R1 to R101, preferably to 0.05 mm to 0.18 mm.

Fig. 6 shows a bend-formed perforated lamella 3 after step (a) (Fig. 8) of the method according to the invention and thus according to the prior art. The perforations (holes 50) generally have spacings between 2 mm and 30 mm and diameters in the range from 1 mm to 3 mm. In a following compression-forming step (b) (according to Fig. 8), the result of which is shown in Fig. 7, the rounded corrugated structure of Fig. 6 is transformed into a sharp-edged structure of Fig. 7, in which the external radius of the bending edge is reduced from R1 to R101 to 0.05 mm to 0.18 mm.

The lamella 103 according to Figs 3, 5 and 7 can be made with the method according to the invention in a width (in direction D3) of by way of example 450 mm and a length (in direction D1) of 1500 mm.

Reference numeral list

1	Passage
2	Distribution lamella
3	Bend-formed lamella (fin)
4	Separation plate
5	Cover plate
6	Nozzle pipe
7	Collector (header)
8	Edge strip (side bar)
9	Inlet or outlet opening
10	Heat exchanger block
D1	First spatial direction
D2	Second spatial direction
D3	Third spatial direction
20	Sheet metal plate
21	Structural grain
31	Wave crest
32	Wave flank
34	Bending edge
35	External surface of wave crest
36	Channel
41	Fillet weld
50	Ram
R1	External radius
R2	Internal radius
H1	Height
S1	Wall thickness of sheet metal plate 20
P1	Separation
F	Flat surface regions
103	Compression-formed lamella
121	Structural grain
131	Wave crest
132	Wave flank
134	Metal-sheet edge
135	External surface of wave crest
136	Channel
P101	Separation

R101 External radius
R102 Internal radius
H101 Height
140 Solder layer
141 Fillet weld
S101 Wall thickness of wave crest 131
S2 Wall thickness of wave flank 132
S3 Transversal wall thickness of metal-sheet edge 134
Q Projected cross-section
d Thickness of solder layer

Patentkrav

1. Fremgangsmåde til fremstilling af en lamel (103) til en pladevarmeveksler, hvilken fremgangsmåde har følgende trin: (a) tilvejebringelse af en bølgeformet struktur (3) af en omformet, især bøjningsomformet, plade med i det mindste et bølgetag (31) med bølgeribber (32), hvorved bølgetaget (31) og bølgeribberne (32) hver især er forbundet via en pladekant (34), og hvor pladekanten (34) har en indvendig radius (R2) og en udvendig radius (R1),
kendetegnet ved
(b) trykomformning, fortrinsvis kold flydepresning, af det i det mindste ene bølgetag (31) med den bølgeformede strukturs (3) bølgeribber (32) fra trin (a) sådan, at den udvendige radius (R1) af pladekanterne (34) mellem bølgetag (31) og den respektive bølgeribbe (32) reduceres (R101).

2. Fremgangsmåde ifølge krav 1, kendetegnet ved, at pladekanternes (34) udvendige radius (R1) i trin (b) reduceres til en udvendig radius (R101) i et område fra 0,05 mm til 1,5 mm, især fra 0,05 til 0,18 mm.

3. Fremgangsmåde ifølge krav 1 eller 2, kendetegnet ved, at ved trykomformningen reduceres den bølgeformede struktur (3) i sin højde (H), især med 0,4 mm til 1,2 mm.

4. Fremgangsmåde ifølge et af de foregående krav, kendetegnet ved, at det i det mindste ene bølgetag (31) og bølgeribberne (32) ved trykomformningen bringes i en retvinklet anbringelse i forhold til hinanden.

5. Fremgangsmåde ifølge et af de foregående krav, kendetegnet ved, at en plade (20) omformes, især ved bøjningsomformning, til den bølgeformede struktur (3) med i det mindste et bølgetag (31), især et, to eller tre bølgetage, og efterfølgende det i det mindste ene bølgetag (31) med tilstødende bølgeribber (32) trykomformes ifølge trin (b).

6. Fremgangsmåde ifølge et af de foregående krav, kendetegnet ved, at der ved trykomformningen ifølge trin b) påføres en fladepresning, især ved hjælp af et stempel (50) med plan flade, udefra på det i det mindste ene bølgetag (31), især mens de til bølgetaget (31) tilstødende bølgeribber (32) er fikseret sideværts, især ved hjælp af en matrice.

7. Fremgangsmåde ifølge et af kravene 5 eller 6, kendetegnet ved, at et første bølgetag (31) med tilstødende bølgeribber (32) dannes ved omformning, især bøjningsomformning, af pladen (20), og der efterfølgende trykomformes det første bølgetag (31) med bølgeribber (32), før der dannes et andet bølgetag (31) med bølgeribber (32).

8. Fremgangsmåde til fremstilling af en pladevarmeveksler, ved hvilken et multiplum af skilleplader (4) og lameller (3, 103) anbringes i en stabel skiftevist over hinanden og sammenloddes med hinanden i en loddeovn for at danne en kvaderformet varmevekslerblok, kendetegnet ved, at i det mindste en (103) af lamellerne (3, 103) er fremstillet ifølge en fremgangsmåde ifølge et af de foregående krav.

9. Loddet pladevarmeveksler med et multiplum af skilleplader (4), der er anbragt i en stabel og med afstand til hinanden, og som danner passager (1) for i det mindste to fluider, der træder i indirekte varmeveksling, kendetegnet ved, at i det mindste en passage (1) har en lamel (103) fremstillet ifølge en fremgangsmåde ifølge et af kravene 1 til 7.

10. Pladevarmeveksler ifølge krav 9, kendetegnet ved, at loddelaget (140) mellem skilleplade (4) og lamellens (103) bølgetag (131) i mere end 80 %, især i mere end 90 %, yderligere især i mere end 95 % dækker det vinkelret (140) på skillepladen (4) projicerede tværsnit (Q) af en bølgeribbe (132) med konstant loddelagstykkelse (d).

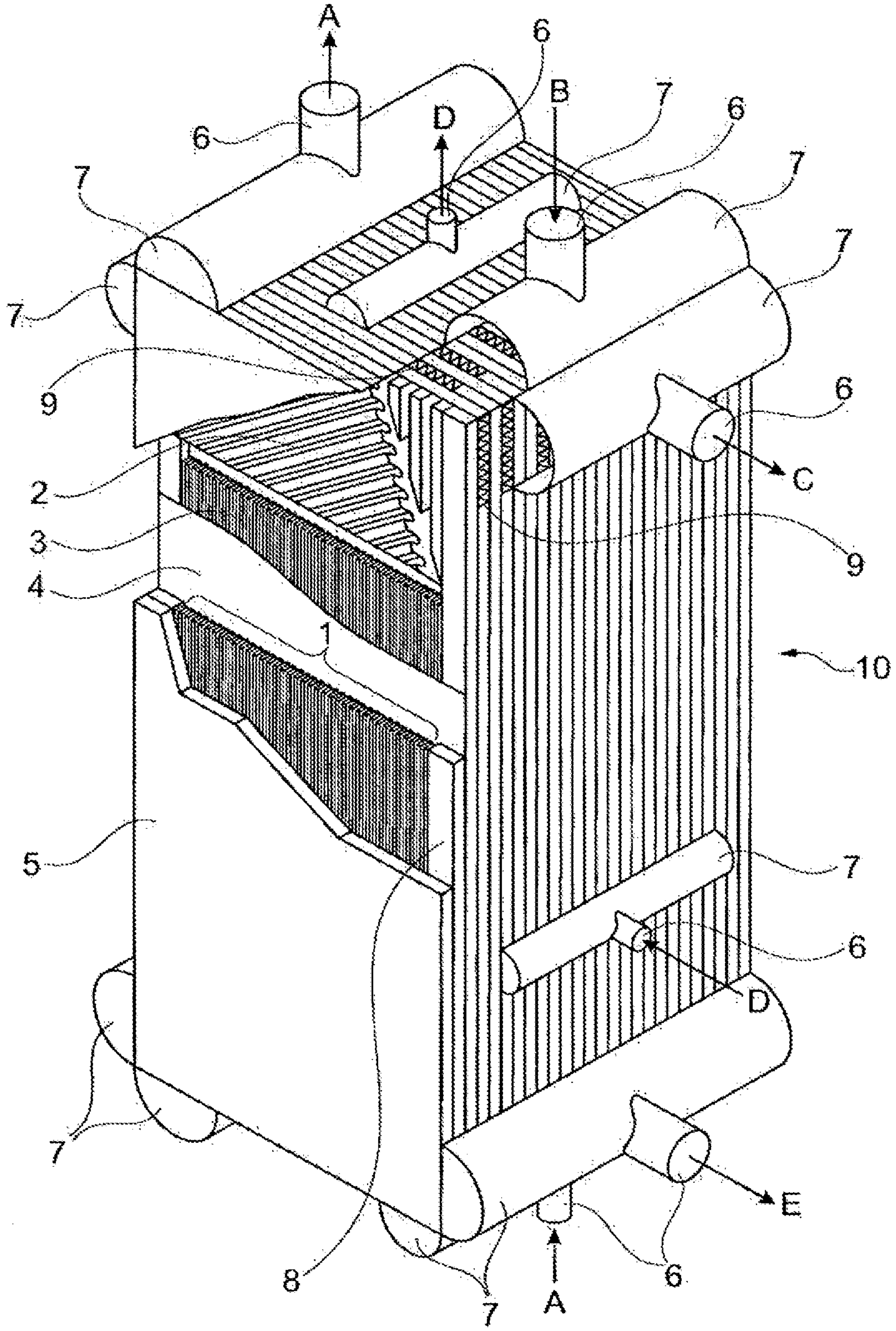
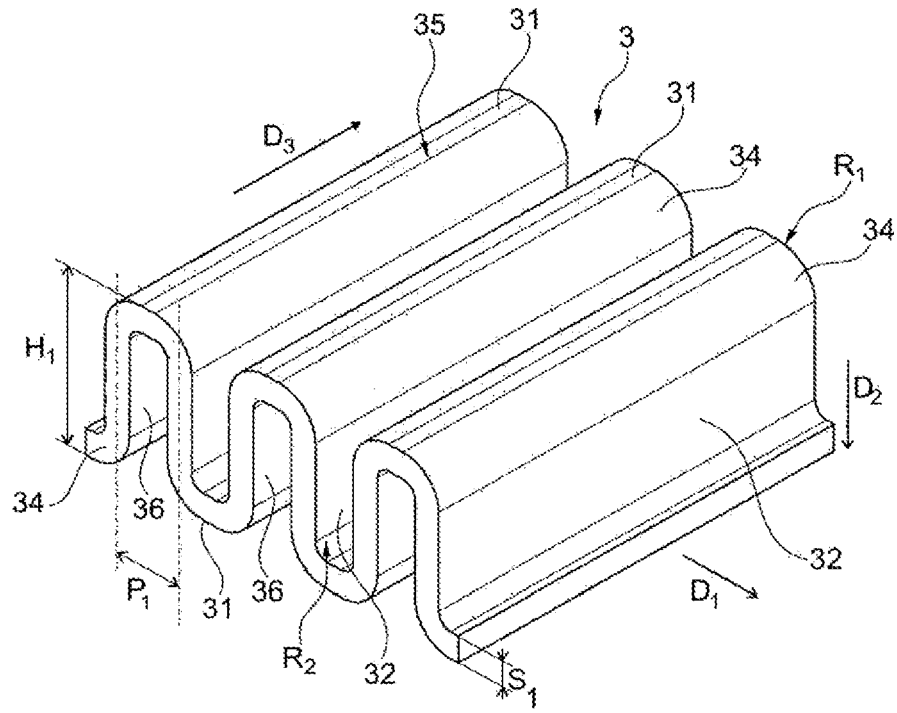


Fig. 1
Prior Art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3
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D_3
34
R_1
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H_1
D_2
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36
P_1
31
36
R_2
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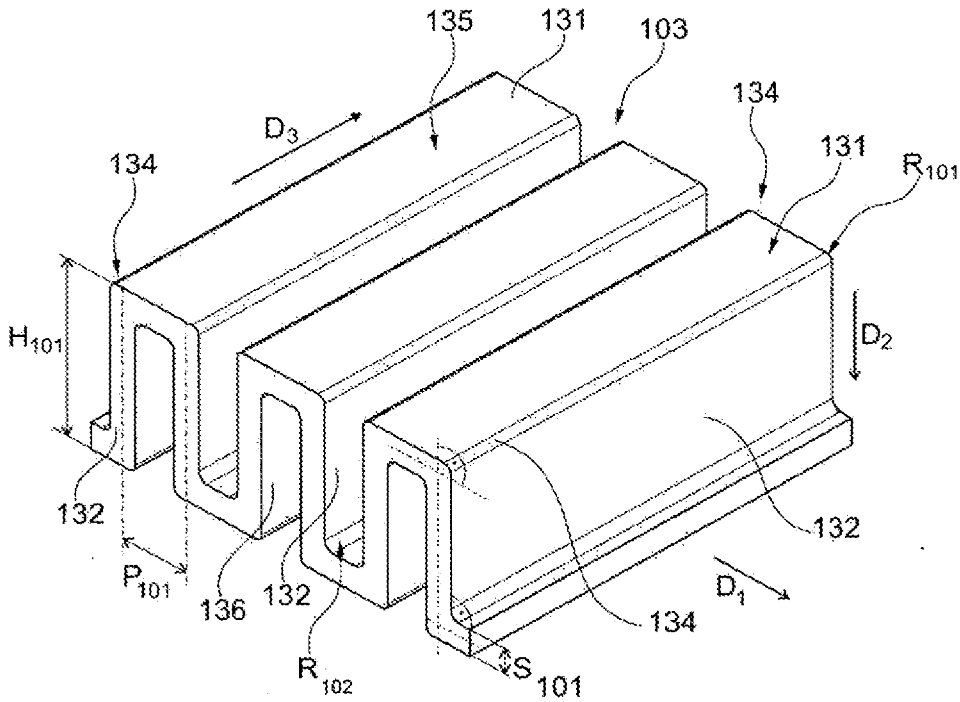
D_1
S_1

Fig. 2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103
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D_3
134
131
R_{101}
H_{101}
D_2
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P_{101}
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D_1
S_{101}

Fig. 3

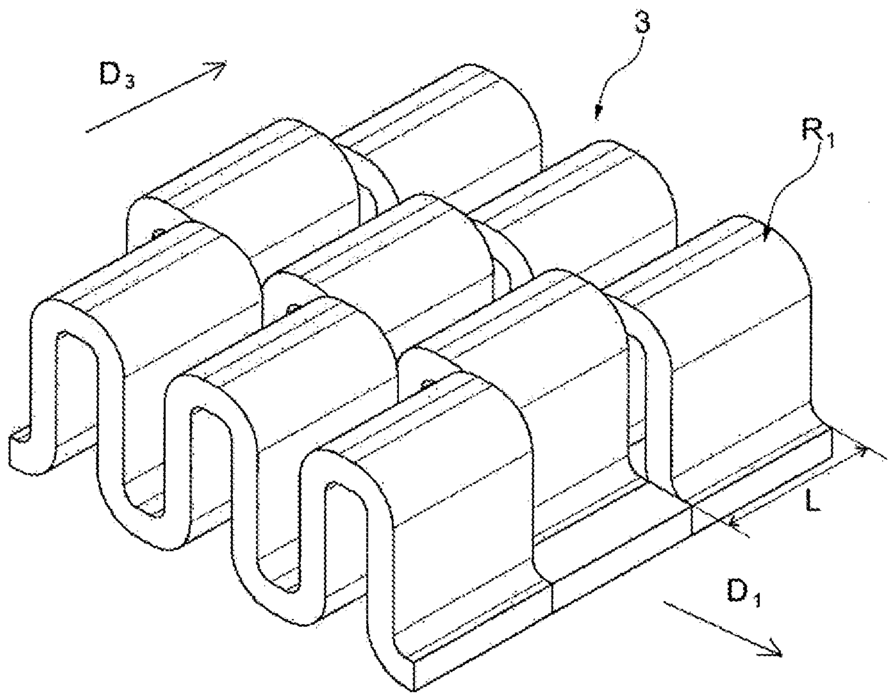

Fig. 4

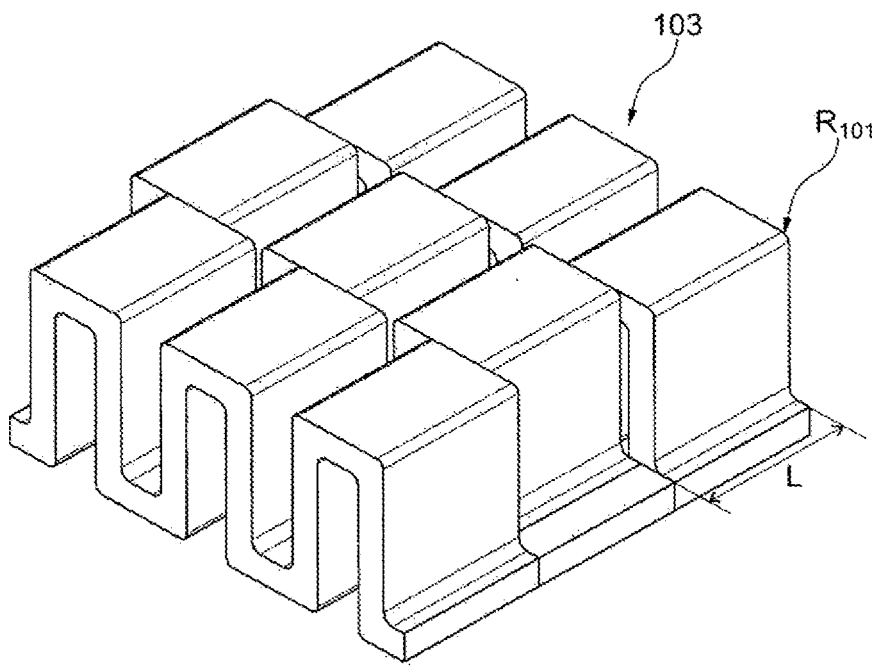

Fig. 5

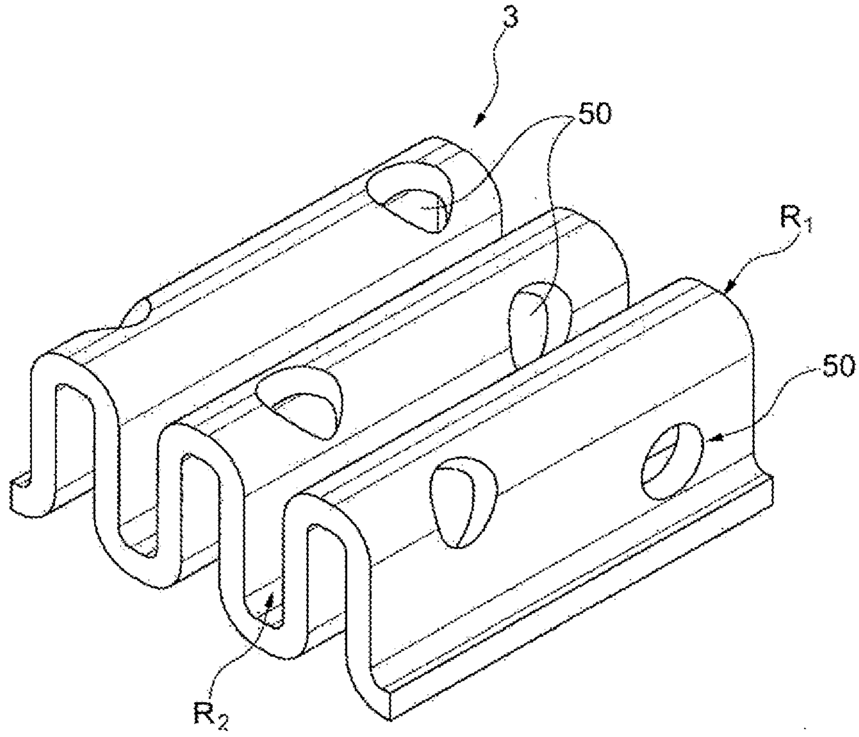

Fig. 6

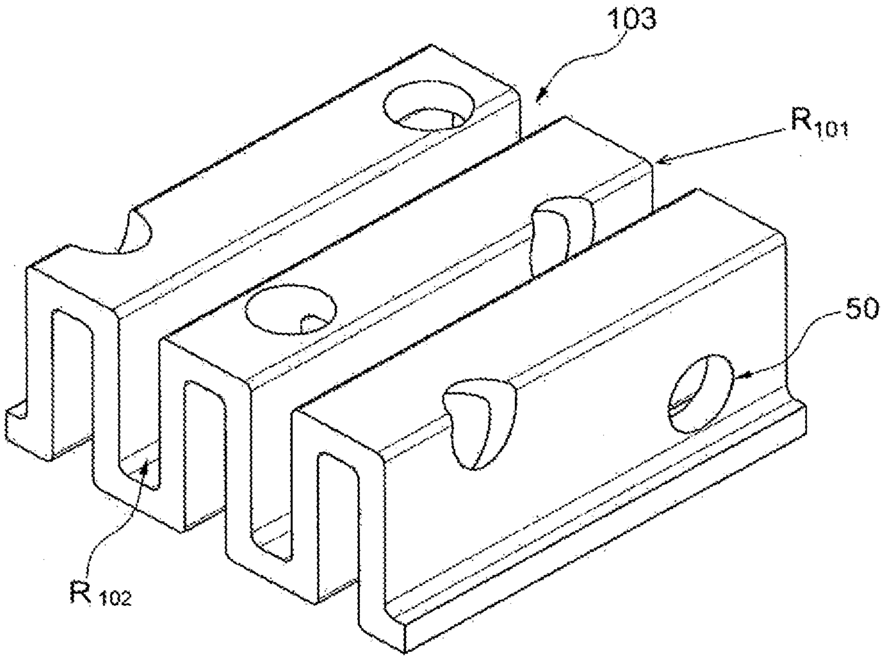

Fig. 7

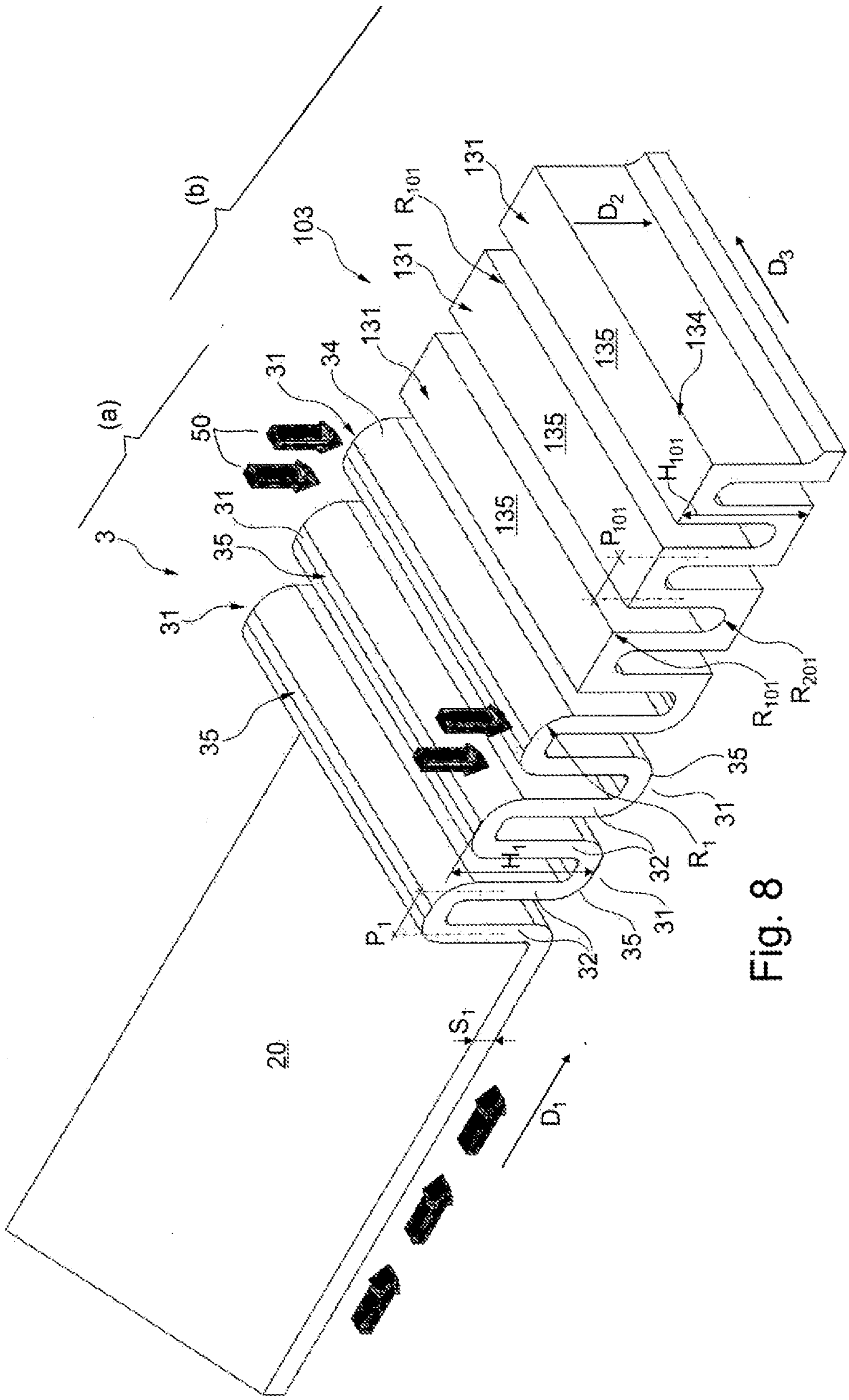
(a)
(b)
3
20
31
32
34
35
50
103
131
134
135
R_{101}
R_{201}
R_1
H_{101}
H_1
P_{101}
P_1
S_1
D_1
D_2
D_3

Fig. 8

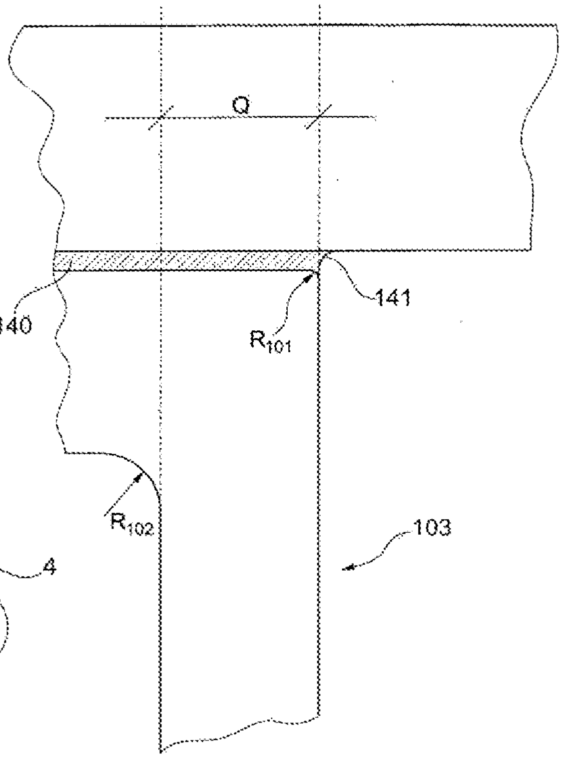
Q
Q
140
141
R101
R102
103

Fig. 10

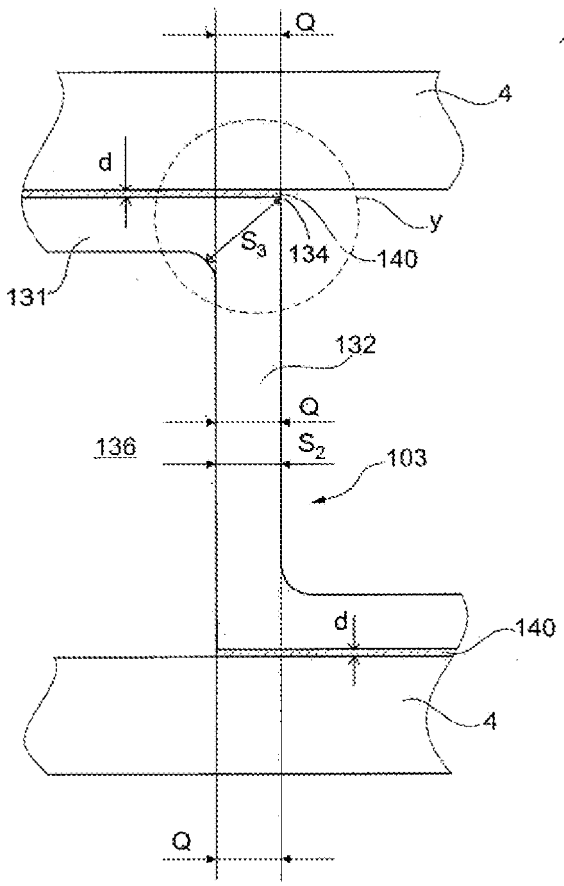
Q
4
d
y
S3
134
140
131
132
Q
136
S2
103
d
140
4
Q

Fig. 9

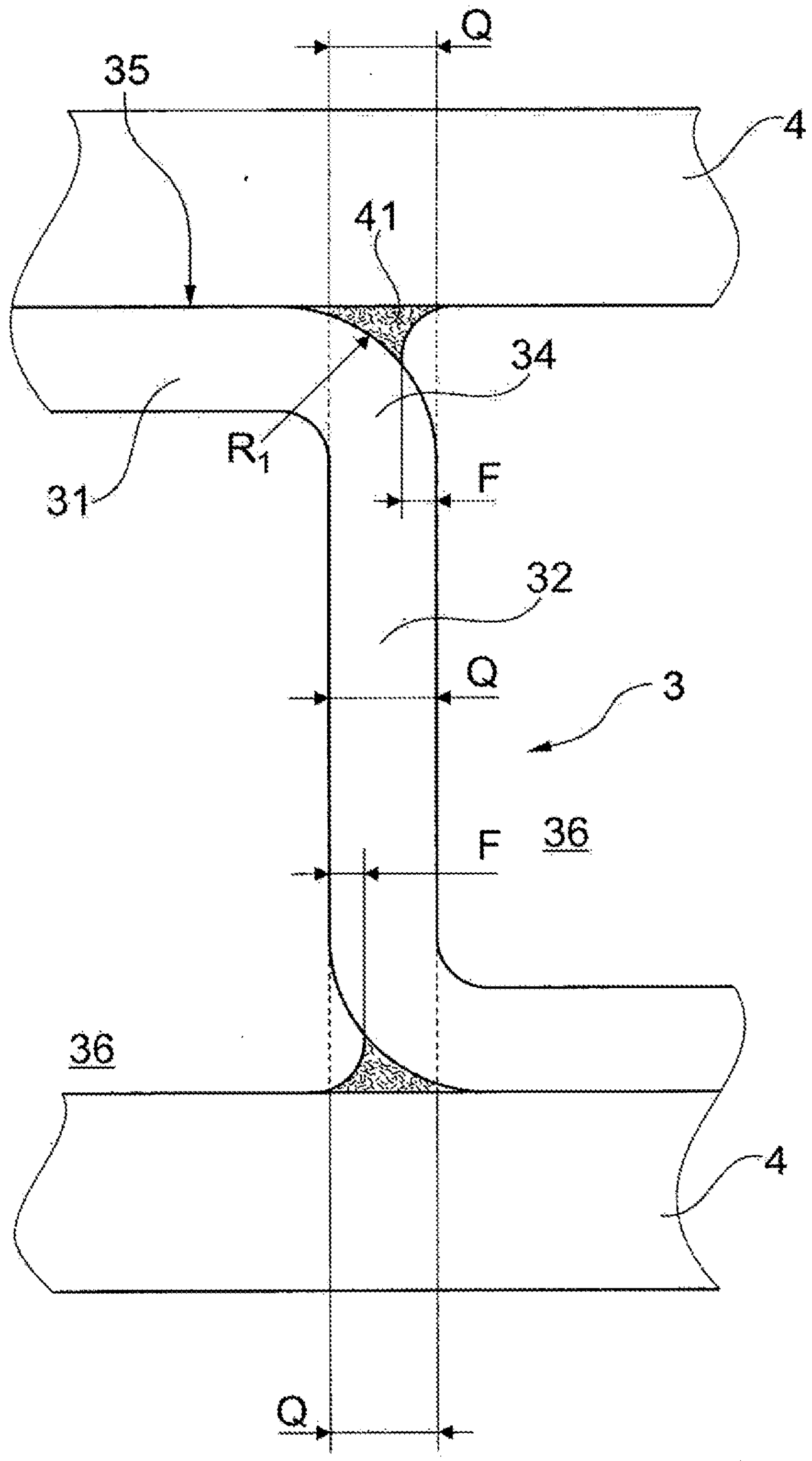

Fig. 11

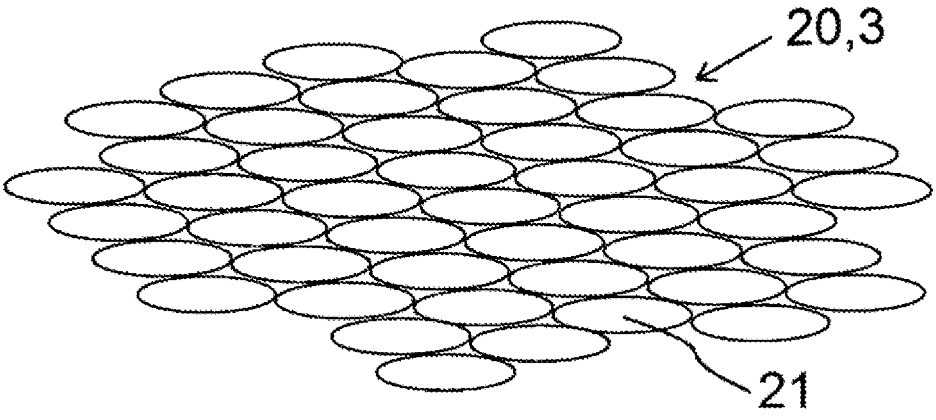

Fig.12

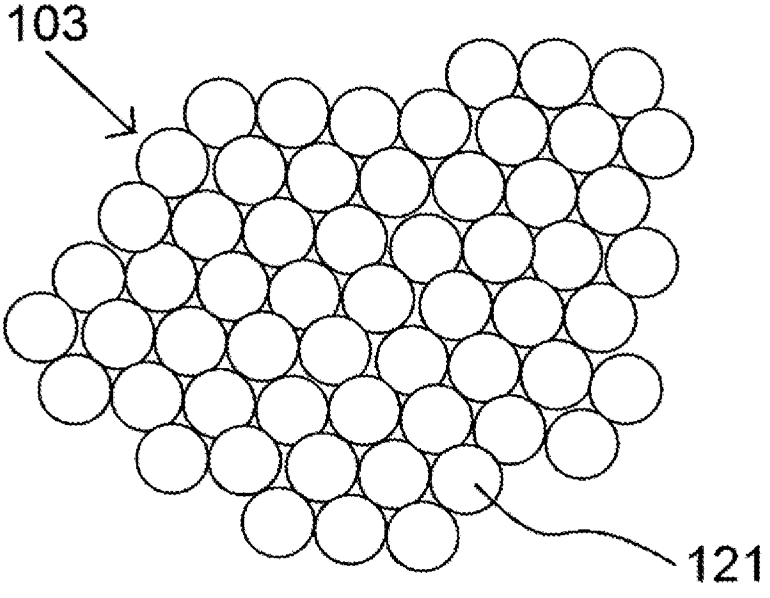

Fig.13