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(54) Superplastically forming components by gas inflating partially united plates.

(57) This invention relates to the forming of gas injection/exhaustion manifolds (37, 41) in a superplastic forming process. The manifolds (37, 41) themselves are formed by superplastic forming and allow gas under pressure to be directly applied to (or relieved from) each of the areas (8) which, by the application of the gas will inflate and form cells. The invention reduces the tendency of the formed cell walls to be undulate and distorted by imbalance of pressure between adjacent cells.

Fig. 1.

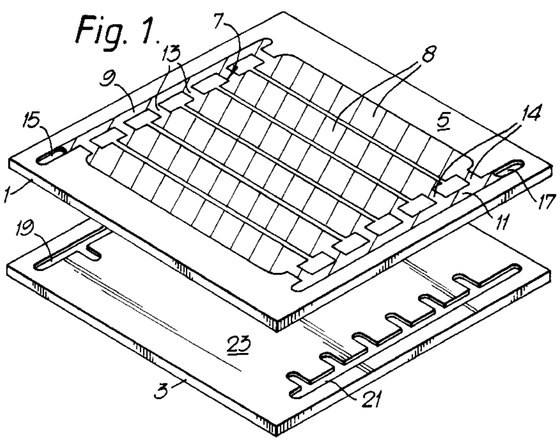
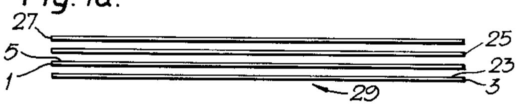


Fig. 1a.



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This invention relates to gas injection techniques for superplastically forming components, and particularly to the forming of components having cellular internal structures.

Metals having superplastic characteristics, such as titanium and many of its alloys, have a composition and microstructure such that, when heated to within an appropriate range of temperature and when deformed within an appropriate range of strain rate, they exhibit the flow characteristics of a viscous fluid. The condition in which these characteristics are attained is known as superplasticity and, in this condition, the metals may be deformed so that they undergo elongations of several hundred percent without fracture or significant necking. This is due to the fine, uniform grain structures of superplastically formable metals which, when in the condition of superplasticity, allow grain boundary sliding by diffusion mechanisms so that the individual metal crystals slide relative to one another.

Diffusion bonding is often combined with superplastic forming to enable the manufacture, from multiple sheets of metal, of components of complex structure. The diffusion bonding process concerns the metallurgical joining of surfaces by applying heat and pressure which results in the co-mingling of atoms at the joint interface, the interface as a result becoming metallurgically undetectable. In order to manufacture structures of a complex nature it is often a requirement that the metals are not bonded at all their contacting areas, and therefore bond inhibitors (commonly known as stop-off or stopping-off materials) are applied to selected areas by, for example, a silk screen printing process.

Titanium in sheet form is often used in these processes because in its received state it has the characteristics needed for superplastic forming. Furthermore it will absorb its own oxide layer at high temperature in an inert atmosphere to provide an oxide-free surface and it is particularly amenable to diffusion bonding under pressure. The optimum temperature for diffusion bonding and superplastic forming is approximately 930°C. Thus, superplastic forming and diffusion bonding of titanium components can be carried out at the same time.

The ability to combine superplastic forming and diffusion bonding has enabled our company to design and, using multiple sheets of metal, to manufacture components of complex structure that are essentially of one piece construction. One known such method of manufacture of components having a cellular internal structure is as follows. Two sheets of superplastically formable and diffusion bondable material which will form the internal structure of the finished component, hereafter referred to as the core sheets, are selectively interlaid with stop-off material. The stop-off material is applied to one face of one of the sheets in a series of substantially parallel elongate areas. Each area is separated from the others except for a relatively small region which runs between each area and its two adjacent areas. Two further sheets of superplastically deformable and diffusion bondable material are positioned one each side of the core sheets; these sheets will form the outer surface of the finished component, and are hereafter referred to as the skin sheets. Ceramic tubes are positioned between the sheets of the four sheet "pack" in rebates which are machined in the sheets to accommodate the tubes.

The pack is then placed in a form tool in a heated platen press that is heated to 930°C. An inert gas is injected into the space between each skin sheet and its adjacent core sheet. The pressure exerted by this gas causes the skin sheets to bow outwards and conform to the shape of the cavity of the form tool while at the same time causing the core sheets to be diffusion bonded in areas where stop-off material is not applied, and forming a gas-tight seal with the sheets around the tube.

When these steps have been completed, a gas is injected via one of the ceramic tubes into the areas between the core sheets where they are not diffusion bonded. The first stage in this gas injection process is known as hot breakthrough, and is carried out at relatively low pressure. The gas enters the first area (which will subsequently become one of the "cells" of the structure) and pushes the core sheets apart. As the sheets are pushed apart, a gas transfer hole is formed, due to the presence of the stop-off material, which connects the first area to the next adjacent area. The gas passes through each area sequentially in one direction, pushing the core sheets apart in each area by a relatively small amount, until a predetermined pressure is recorded at the gas outlet port.

The second stage in the gas injection process uses the gas transfer holes formed during the initial stage. In this second stage, the pressure exerted by the gas causes the core sheets to be further moved apart in each of the areas so that they eventually form substantially rectangular cells which occupy the space between the skin sheets. These cells are formed by the continued application of pressure from the gas - which causes parts of the surfaces of the core sheets to become parallel and adjacent to the skin sheets and to be diffusion bonded to them to form cell ceilings and floors, while at the same time causing other parts of the surfaces of the core sheets which, due to forming, extend between the ceilings and floors such that they are substantially vertical and adjacent to one another, to also be diffusion bonded to form cell walls. However, due to the inherent problems of balancing the gas pressure throughout the component when only using one gas inlet to feed all of the areas, the formed cell walls are often undulate, distorted and not precisely perpendicular to the ceiling and floors. These features are undesirable because the component will have maximum strength when the walls are straight and perpendicular.

An object of the present invention is to provide an improved gas injection technique for superplastic forming whereby the gas pressure which forms the cells of the finished component is evenly balanced so that the tendency for undulate and distorted cell walls to be produced is reduced.

According to one aspect of the present invention there is provided a method of manufacturing a component having a cellular structure from at least two sheets of material, at least one of which is superplastically formable, the method including the step of bonding two of said at least two sheets together in selected regions, thereby defining a plurality of non-bonded regions where the said two sheets are not bonded, including non-bonded cell regions which will form the cells of the manufactured component and characterised in that said plurality of non-bonded regions further include a non-bonded connecting region which will form a manifold in the manufactured component, said connecting region being connected to at least two of said cell regions; and further characterised in that fluid under pressure is applied to said connecting region thereby causing same to superplastically form said manifold such that said fluid is also applied to said at least two of said cell regions thereby causing same to superplastically form the cells.

Preferably the method may be further characterised in that said bonding is achieved by a diffusion bonding process.

Conveniently, the method may be further characterised in that said fluid is applied by way of a tube accommodated in a rebate in one of said two sheets.

Optionally, the method may be further characterised in that said bonding defines a further non-bonded connecting region which will form a further manifold in the manufactured component for exhausting said fluid.

According to another aspect of the invention there is provided a component manufactured by the above method.

For a better understanding of the invention, embodiments of it will now be described by way of example only and with particular reference to the accompanying drawings, in which:

Figure 1 is an isometric view showing a skin sheet and a core sheet of a component to be manufactured ;

Figure 1a shows a side elevation of a four sheet pack;

Figure 2 shows the hot breakthrough stage of superplastic formation of the pack shown in Figure 1a;

Figure 3 shows the superplastic formation of skin sheets of the pack shown in Figure 2;

Figure 4 shows the superplastic formation of the core sheets of the pack shown in Figures 2 and 3 whereby the internal cellular structure of the component is formed;

Figure 5 shows the diffusion bonding of the core sheets of the pack of Figure 4 to themselves and to the skin sheets;

Figure 6 shows an overhead view of a cross section of the formed component shown in Figure 5 along the line A-A ;

Figure 7 illustrates an alternative form of formed component to that shown in Figures 5 and 6; and,

Figure 8 shows a cross section through a superplastically formed component having an internal warren girder structure.

To aid understanding of the drawings, like elements which appear in more than one figure are designated by the same reference number.

Figure 1 shows a core sheet 1 and a skin sheet 3 of diffusion bondable and superplastically formable titanium alloy. A face 5 of the core sheet 1 is coated with a pattern of stop-off material 7 which prevents diffusion bonding in the areas where it is applied. The pattern of stop-off material 7 is such that it occupies a plurality of substantially parallel, rectangular elongate areas 8 on the face 5. Front and back elongate areas 9 and 11 run transversely to the longitudinal axes of areas 8, and are connected to the areas 8 by connecting regions 13 and 14 respectively. Rebates 15 and 17 are formed at one end of the front area 9 and the back area 11 respectively in the face 5 of the core sheet 1. The rebates 15 and 17 are formed by machining the face 5 in a manner well known to those skilled in the art. Rebates 19 and 21 are formed in a similar way in the face 23 of skin sheet 3. The shape of the rebate 19 corresponds to the pattern of front area 9 and connecting regions 13 of stop-off material on the core sheet 1. Similarly, the shape of rebate 21 corresponds to the pattern of back area 11 and connecting regions 14 of the stop-off material 7.

A further pair of core and skin sheets 25 and 27 respectively of titanium alloy are prepared with rebates in the same way as sheets 1 and 3. The four sheets 1, 3, 25 and 27 are then stacked one on top of the other to form a pack 29 as shown in Figure 1a. The sheets are orientated such that the faces 5 and 23 of sheets 1 and 3 respectively face upwards, and the corresponding faces which contain the rebates of sheets 25 and 27 respectively face downwards such that the rebates 15 and 17 in sheet 1 correspond in position to the rebates in sheets 25 and 27. During assembly of the pack 29 two ceramic tubes (not shown) are positioned between the core sheets 1 and 25 in the rebates 15 and 17 in core sheet 1 and in the corresponding rebates in sheet 25. These ceramic tubes enable connection to an external gas supply (not shown). Prior to assembling the skin sheets 3 and 27 of the pack, the core sheets 1 and 25 are diffusion bonded together in a diffusion bonding tool (not shown). Obviously, no diffusion bonding occurs in the areas where stop-off material has been applied.

Next the pack 29 is positioned in a first heated platen press 50 shown in Figure 2. The top and bottom tools 52 and 54 of the press 50 are spaced apart by approximately 4mm to facilitate the hot breakthrough stage of forming.

During this stage of forming an inert gas is applied via the ceramic tube in rebate 15 which feeds the areas where the stop-off pattern 7 has been applied between the core sheets 1 and 25. The gas is applied at relatively low pressure at the hot breakthrough stage of the forming process. As gas pressure is applied via the ceramic tube in rebate 15 the front stopped-off area 9 and connecting regions 13 are inflated to occupy the rebate 19 in skin sheet 3 and the corresponding rebate in sheet 27, thereby forming an inlet manifold 37 (see Figure 6). The gas then passes into elongate areas 8 which then form partly inflated cells. As the gas passes through the cells it inflates connecting regions 14 and back area 11 and causes them to occupy the rebate 21 in skin sheet 3 and the corresponding rebate in sheet 25, thereby forming an outlet manifold 41. The gas is exhausted via the ceramic tube positioned in rebate 17 in core sheet 1. The partial formation of the cells and rebates causes the skin sheets 3 and 27 to be pressed against the top and bottom tools 52 and 54 (see Figure 2).

The pack 29 is removed from the first press 50, cleared, and is then positioned between the two form tools 31 and 33 of a second heated platen press shown generally at 35 in Figures 3 and 4. This second heated platen press 35 has an internal shape which corresponds to the shape required for the finished component.

The second stage of forming then follows where a greater gas pressure is applied which causes the cells to take up a rectangular shape such that the pairs of opposing walls of the cells form the support walls and the interior surfaces (or ceilings and floors) of the finished component respectively (see Figure 4). To facilitate this, an inert gas is injected into the space between each skin sheet and its adjacent core sheet in a well known manner which causes the skin sheets 3 and 27 to superplastically form so that they conform to the inner shape of the form tools 31 and 33 respectively. Figure 3 shows the component in this stage of manufacture. The core sheets 1 and 25 are inflated to form the cells. The cells are then formed by the application of gas pressure to the ceramic tube in rebate 15.

The interior and exterior surfaces of the component and the adjacent walls of the cells are then diffusion bonded. This may be done in the heated platen press 35 by the continued application of gas pressure, or the pack 29 may be removed from the press 35 and subjected to hot isostatic pressing. Hot isostatic pressing is a technique well known in the field of powder metallurgy and involves the evacuation of the area between the exterior and interior surfaces of the component and the application of an isostatic pressure while maintaining the component at a required constant temperature. The arrows in Figure 5 show the force being exerted by the pressuring gas on the interior and exterior of the component in a hot isostatic press. An advantage of using a hot isostatic press for diffusion bonding is that it obviates the need for using highly stressed form tools. The bonding pressures act isostatically, and therefore do not require mechanical reaction.

When the diffusion bonding is completed by either of the above methods, the atoms of the interior and exterior surfaces of the component are interdiffused, thus forming a metallurgically bonded layer.

Figure 6 shows the manifolds 37 and 41 formed in the manner described above.

Figure 7 shows a similar view to Figure 6 of a formed component, but the component in Figure 7 has been formed in accordance with a second embodiment of the invention. In this second embodiment the stop-off pattern of the core sheets is altered to define lateral connecting regions between the elongate areas 8 of stop-off material. These connecting regions lead to the formation of gas communication channels 43 between each of the cells of the component as it is formed. The gas communications channels 43 obviate the requirement for the gas inlet and outlet manifolds 37 and 41 to directly communicate with each and every cell. Thus, in the second embodiment the gas inlet manifold 37 only feeds half of the total number of cells directly, while the gas outlet manifold 41 exhausts gas from the other half.

Obviously, it is not necessary to provide rebates 15, 17, 19 and 21 in sheets 1 and 3 with correspondingly located rebates in the sheets 25 and 27 if one set of rebates provides adequate volume for the ceramic tubes and the inlet and outlet manifolds 37 and 41.

In the embodiments described, the use of manifolds allows more than one cell to be injected with gas simultaneously. The gas pressure is therefore exerted in a more balanced way which reduces the tendency of the formed cell walls to be undulate and distorted, and the improved balance of pressure on either side of a cell wall may allow these walls to be more reliably formed to be perpendicular to the ceilings and floors of the component, thereby providing maximum strength. In the first embodiment the need for gas communication channels between the individual cells of the component is obviated, which further improves the strength of the finished component.

The invention is also applicable to the superplastic formation of components having "warren girder" and "X"-core cellular structures. The term warren girder refers to components having two sheets with a substantially planar portion between which strengthening walls extend. The strengthening walls are formed from a single core sheet and are therefore not perpendicular with respect to the ceilings and floors; a component having a warren girder internal structure is shown in Figure 8. One way to apply the invention to such a structure would be to apply a stop-off pattern 7 to each of the opposite faces of the core sheet. The stop-off pattern 7 would be offset from one another in the direction along the principle axes of the to be formed manifolds; the process being otherwise essentially the same as in the other embodiments described. "X" core structures could be manufactured in a similar way, being similar to warren girder structures but with two core sheets which are selectively bonded together so that, when formed, the strengthening walls of the component form an X shape.

Of course, the invention could be applied to just two sheets of superplastically formable material, with one side of the formed cells forming an exterior surface of the component.

Claims

1. A method of manufacturing a component having a cellular structure from at least two sheets of material, at least one of which is superplastically formable, the method including the step of bonding two of said at least two sheets together in selected regions, thereby defining a plurality of non-bonded regions where the said two sheets are not bonded, including non-bonded cell regions which will form the cells of the manufactured component and characterised in that said plurality of non-bonded regions (8) further include a non-bonded connecting region (9) which will form a manifold (37) in the manufactured component, said connecting region being connected to at least two of said cell regions (8); and further characterised in that fluid under pressure is applied to said connecting region (9) thereby causing same to superplastically form said manifold (37) such that said fluid is also applied to said at least two of said cell regions (8) thereby causing same to superplastically form the cells.

2. A method according to claim 1, characterised in that said bonding is achieved by a diffusion bonding process.

3. A method according to claim 1 or 2, characterised in that said fluid is applied by way of a tube accommodated in a rebate (15) in one (1) of said two sheets (1, 3).

4. A method according to claim 1, 2 or 3, characterised in that said bonding defines a further non bonded connecting region (11) which will form a further manifold (41) in the manufactured component for exhausting said fluid.

5. A component characterised in that it is manufactured by a method as claimed in any one of claims 1 to 4.

Fig. 1.

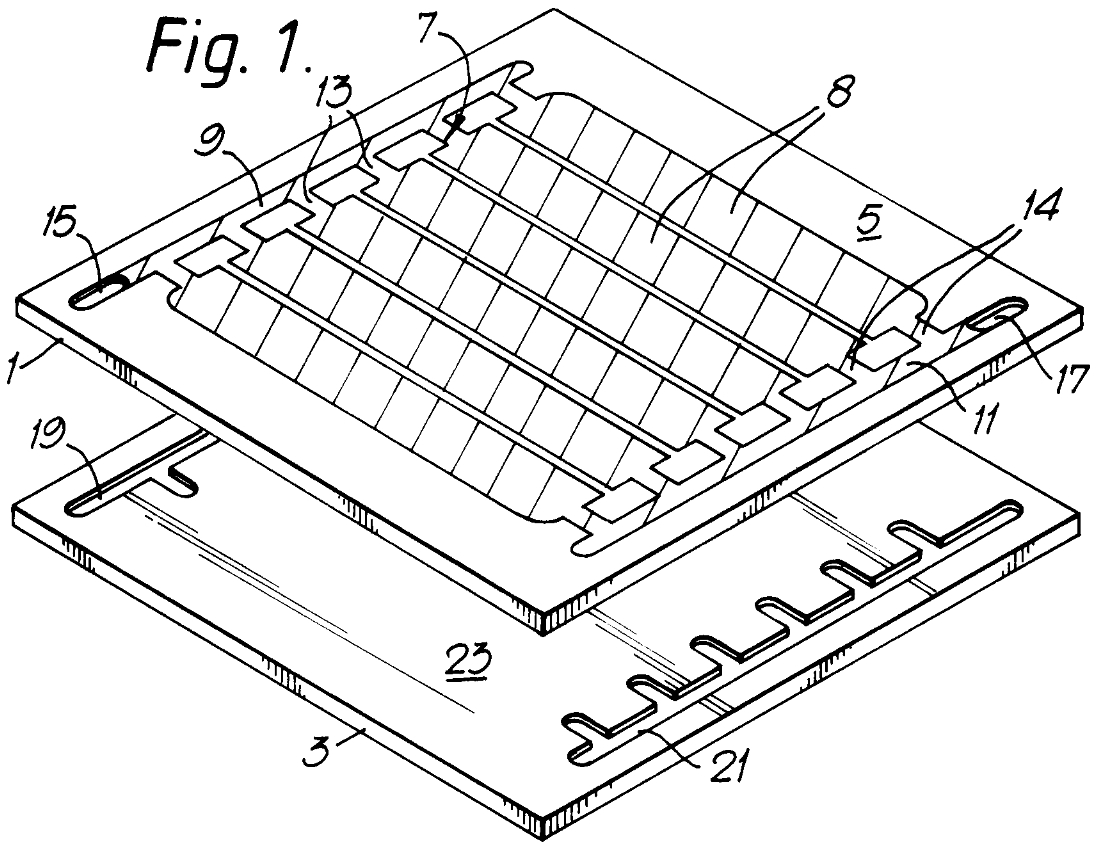


Fig. 1a.

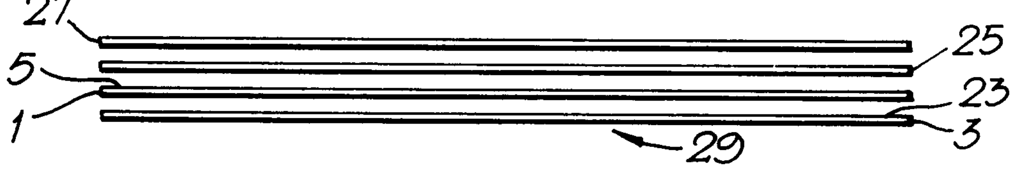


Fig. 2.

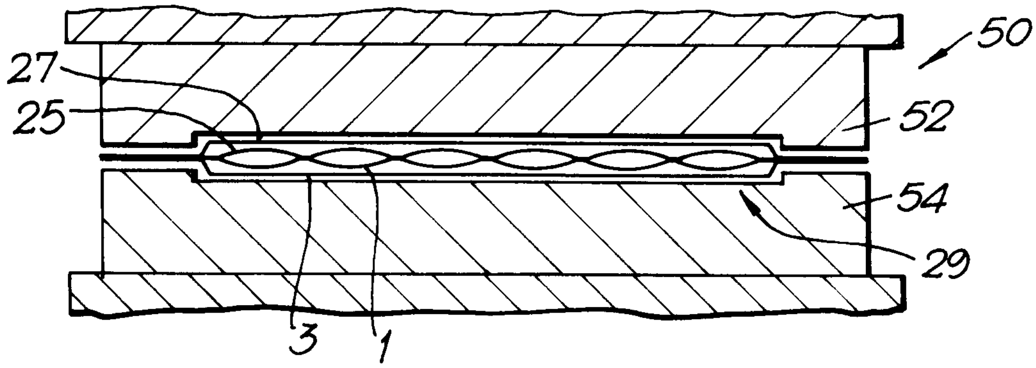


Fig.3.

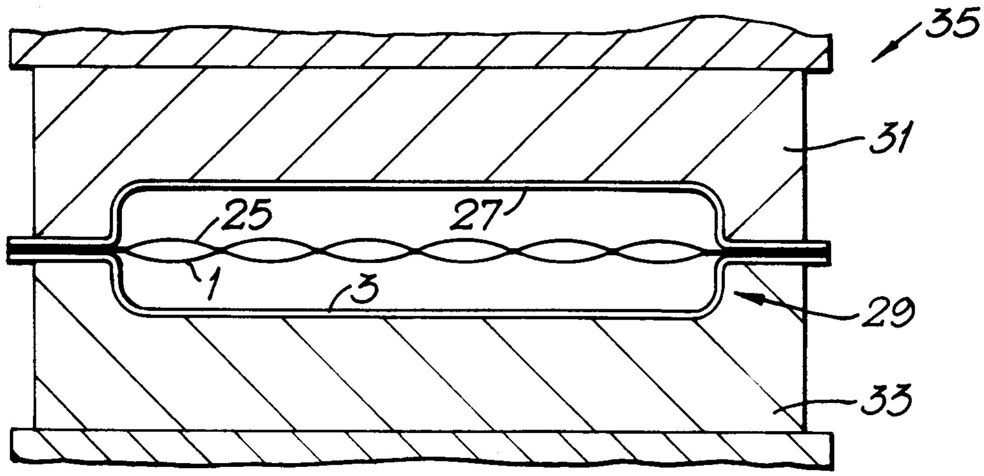


Fig.4.

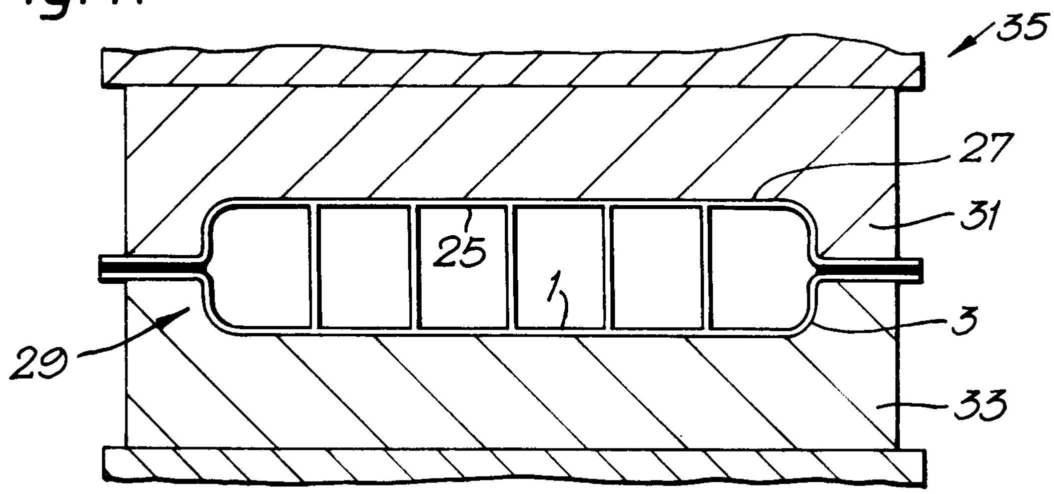


Fig.5.

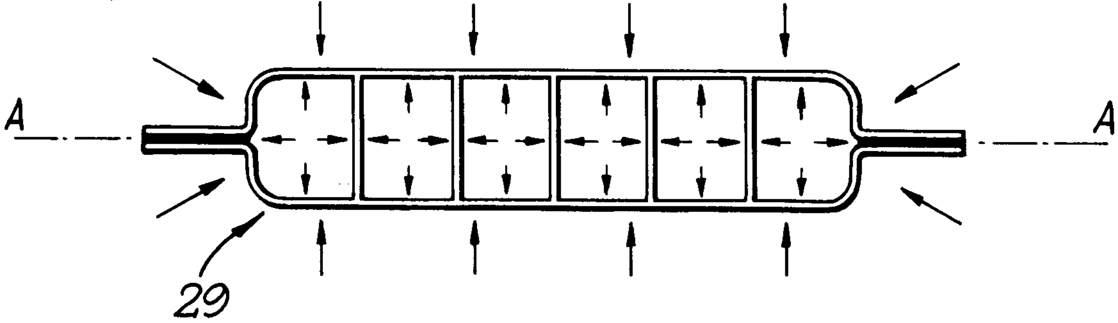


Fig.6.

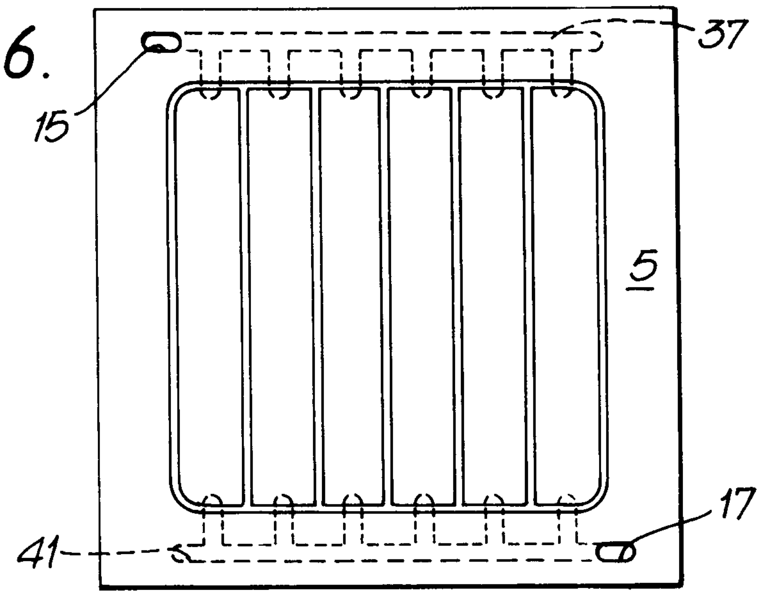


Fig.7.

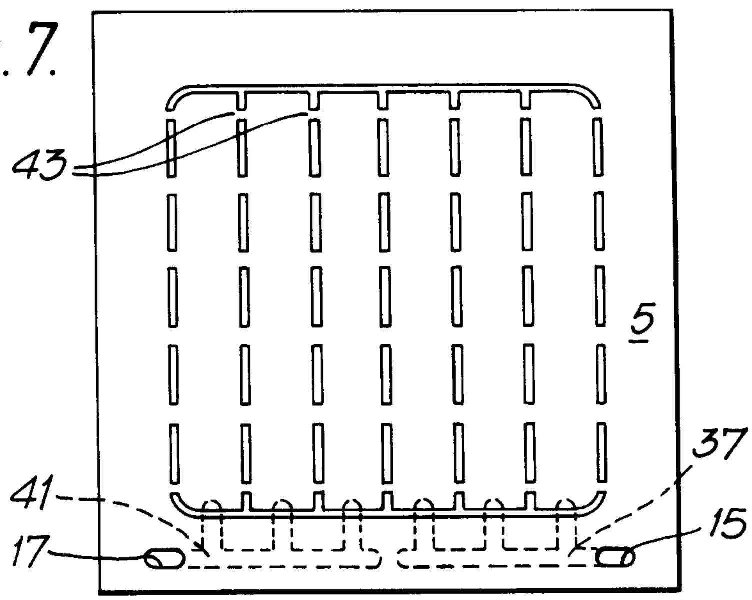
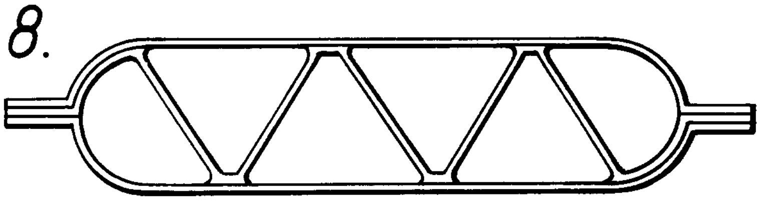


Fig.8.



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EUROPEAN SEARCH REPORT

Application Number
EP 93 30 2332

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
X Y	EP-A-0 414 435 (ROLLS-ROYCE PLC) * column 1, line 43 - column 2, line 15; claims; figures 6,11 *	1,2,4,5 3	B21D53/04 B21D26/02
Y	FR-A-1 516 513 (CABELKA) * page 2, right column, line 3-7; figures 3,5A *	3	
A	PATENT ABSTRACTS OF JAPAN vol. 8, no. 240 (M-336)(1677) 6 November 1984 & JP-A-59 119 184 (MATSUSHITA DENKO K.K.) 10 July 1984 * abstract *		
A	DE-A-3 132 751 (METALLGESELLSCHAFT)		
A	DE-A-3 443 797 (CEGEDUR)		
			TECHNICAL FIELDS SEARCHED (Int. Cl.5)
			B21D

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	29 JUNE 1993	PEETERS L.

CATEGORY OF CITED DOCUMENTS

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