Oct. 18, 1960 R. W. ALLRED ET AL 2,956,651

HONEYCOMB PANEL

Filed May 2, 1957 3 Sheets-Sheet 1

FIG. 1

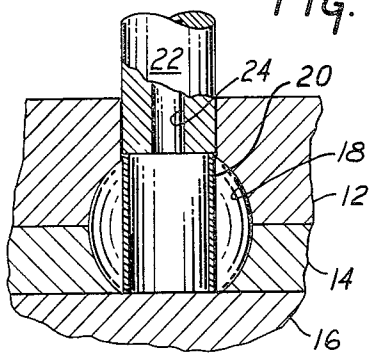
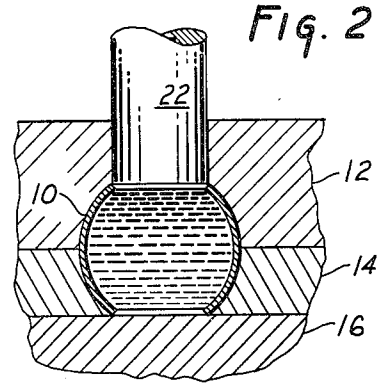


FIG. 2



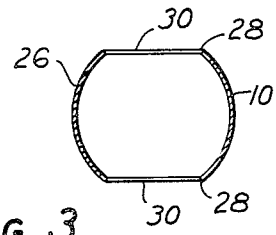


FIG. 3

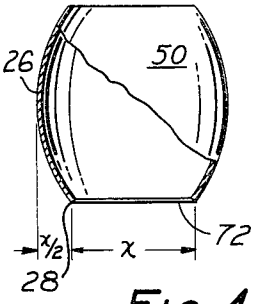


FIG. 4

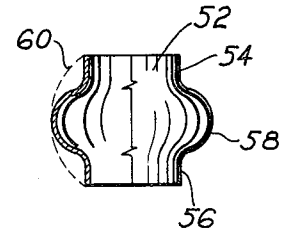


FIG. 5

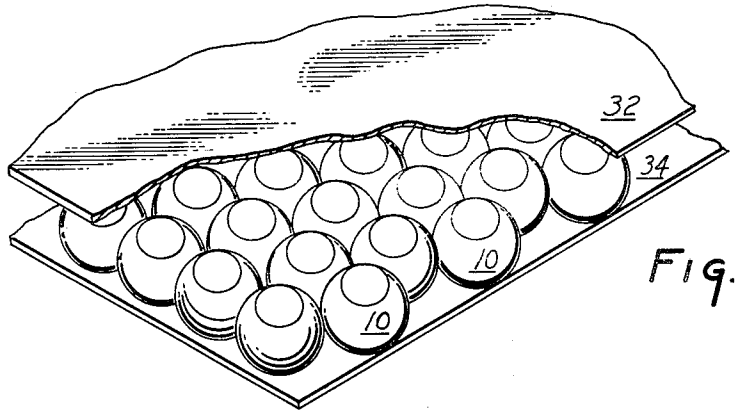


FIG. 6

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HONEYCOMB PANEL

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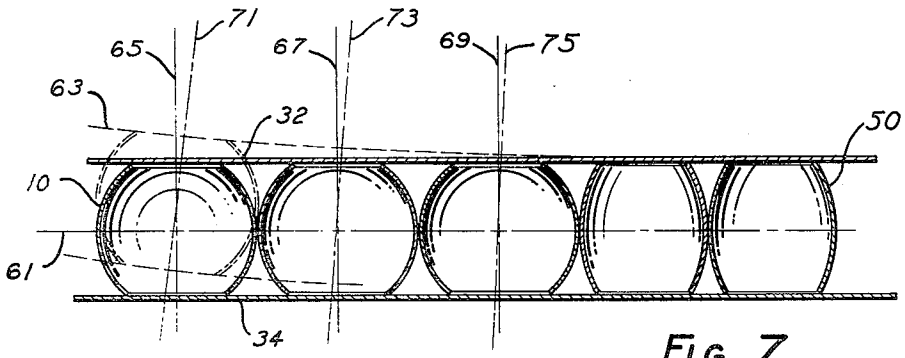


Fig. 7

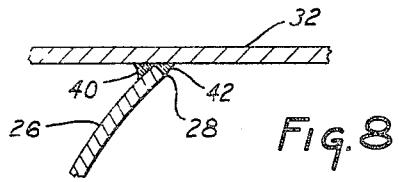


Fig. 8

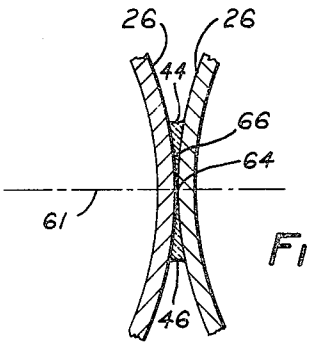


Fig. 9

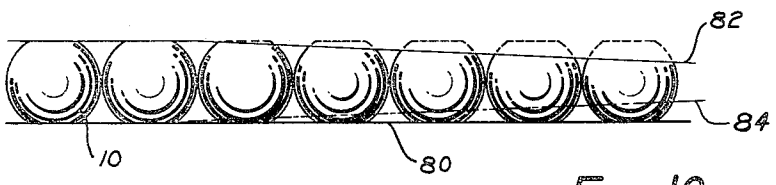


Fig. 10

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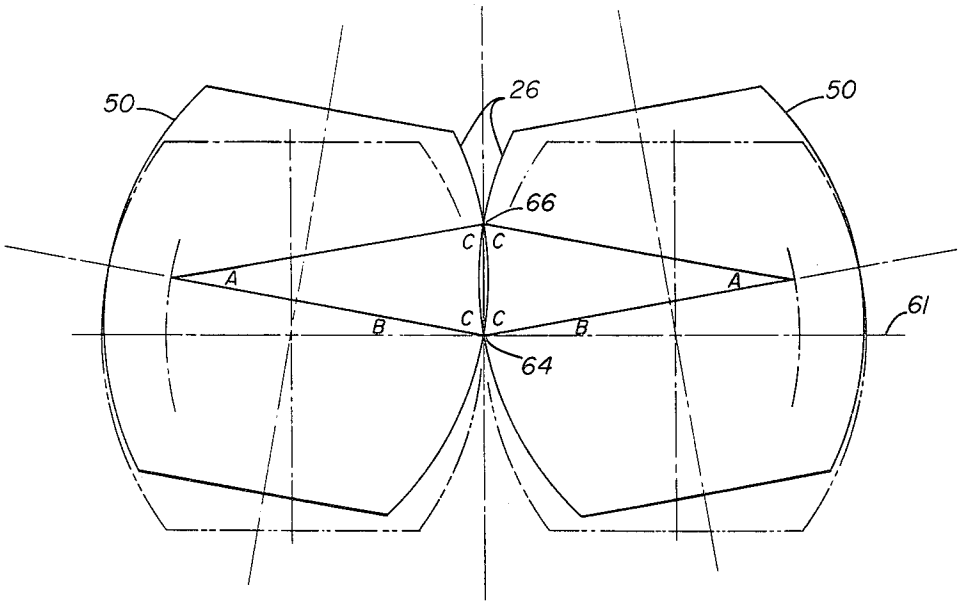


FIG. 11

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2,956,651

HONEYCOMB PANEL

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Filed May 2, 1957, Ser. No. 656,664

7 Claims. (Cl. 189—34)

Our invention relates to metal honeycomb panels. The core of our panel is formed from barrel or spherical sided cells, brazed together at their abutting sides and brazed at the edges of their open ends to face sheets.

Honeycomb panels have been used in recent years in the aircraft industry because of their advantages in achieving low weight and temperature resistance and in having good strength and vibration characteristics for certain purposes. These have found application chiefly in thin sections such as at the wing trailing edges. The term "honeycomb" is meant to include multi-cell hexagonal configurations and other open-ended, multi-cell constructions. The prior hexagonal honeycomb has been found useable in flat panels, although considerable improvement is needed, but it has not been readily adaptable to either single or double curvatures because of extreme anti-clastic bending characteristics. It is an object of our invention to provide a honeycomb type panel which may be formed with single or double curvatures. More specifically it is an objective to provide a panel having cells permitting some pivoting thereof about the neutral axis of the panel.

Further objectives of our invention include: to provide a formable honeycomb panel having a good temperature resistance and strength-weight ratio and to achieve minimum cost and a low rejection rate of imperfect parts, in-so-far as these are obtainable while meeting the objective of formability.

Our invention will be best understood, together with additional objectives and advantages thereof, from a reading of the following description, read with reference to the drawings in which:

Figures 1 and 2 are fragmentary views, partly in section, showing the forming of a specific embodiment of our new honeycomb cells;

Figure 3 is a cross-sectional view of a cell having sides of spherical curvature;

Figure 4 is a view similar to Figure 3 only on an enlarged scale and showing a barrel-shaped cell;

Figure 5 is a view similar to Figure 3 only showing a cell in which the curvature is restricted to the medial portion;

Figure 6 is a fragmentary perspective view of a honeycomb assembly;

Figure 7 is a sectional view of a panel;

Figures 8 and 9 are enlarged fragmentary cross sectional views of areas of brazing of the panels;

Figure 10 is a view illustrating the forming of a tapered panel; and

Figure 11 is a view showing the geometrical and trigonometrical relationships of abutting cells in curved panels.

The honeycomb cells **10** could be produced in a number of ways and Figures 1 and 2 show one method in which the cells are formed from sections of tubing. A die having three sections **12, 14, 16** is shown forming a cavity **18** of the desired contour of the cell. A length of tubing **20** is positioned therein and a plunger **22** descends against and seals the tube upper edge. The forming operation may be principally from hydraulic fluid introduced through plunger passageway **24**. The plunger **22** may also apply a forming force against the part upper edge. At the completion of the forming operation, the tube has been formed into the cell **10** shown in Figure 2.

The walls, as **26**, may be spherical and modified from a true sphere only by having the two end segments missing. If the process shown in Figures 1 and 2 is used to form cells **10**, the edges **28** at end openings **30** will expose sharp corners, although the corners may be somewhat blunted by the abutting die and plunger surfaces. Edges **28** may be brazed equally well to the face sheets **32, 34** if they are sharp or blunted corners or are instead parallel to the inner faces of the sheets. The height of the cells will depend on the thickness of the panel to be constructed and may range from a fraction of an inch to in excess of an inch. The cell wall thickness might go as low as .010 inch.

The following will give an example of some details in fabricating a panel. However, those skilled in the art will understand the various applicable processes without this disclosure. To form a panel the cells and face sheets are subjected to prebraze cleaning which may include vapor degreasing, liquid blasting and a butanone wash. A suitable flux is applied to the parts, such as a silver brazing flux of which Handy and Harmon "Handy Flux," MIL–F–4483 is an example. A group of cells **10** are placed on a first panel **34** and abutted and then a top sheet **32** is placed over the assembly. As the assembly is laid up, foil or shim brazing sheets are interposed between the sheets and the cells. The face sheets of the example are AISI type 321 stainless steel annealed, having a nominal gage of .020, and the cells have a nominal wall thickness of .025 and are formed from AISI type 303(*s*) stainless steel tubing. A suitable brazing alloy for these materials is Handy and Harmon "Easy-Flo" Regular, per QQ–S–561*b*, class 4, .005 inch thickness. The cells in the most dense arrangement will have each cell abutted by six surrounding cells as shown in Figure 6. If a square row and file arrangement is substituted, each cell will be abutted by four other cells. Other alloys and materials, sheet and cell thicknesses, compatible sheet, paste or liquid brazing material and flux can be substituted as will be understood by those skilled in the art. Brazing is preferred, but it may become desirable in certain applications to substitute a form of welding or adhesive bonding. Substantial wall thicknesses would be needed for welding and the strength of present adhesives would limit formability.

The assembly is clamped in the position shown in Figure 6 and then placed in an air-atmosphere furnace. Suitable brazing temperatures for the example given would be 1400 degrees F. for 26 to 28 minutes after furnace recovery. Post-brazing cleaning for flux removal

follows, i.e., soaking in hot water and liquid blasting, but this cleans the flux only in accessible areas.

Under heating, the brazing material of the foil goes to a liquid state and flows down into the various areas of abutment of the parts. Figures 8 and 9 show respectively the upper edge brazing and the cell wall abutment brazing. Brazed fillets, as **40**, **42**, **44**, **46**, are formed and will normally have concave faces. These fillets are exaggerated in Figures 8 and 9 and may be between .003 and .007 inch. Best results will be obtained if the fixture used to clamp the assembly during heating allows for expansion during heating. For example, a clamping fixture having a graphite backing about the part permits limited expansion.

Figures 4 and 5 show two other forms of cells. Cell **50** of Figure 4 is of less curvature than the spherical cell **10** and may be characterized as barrel-shaped. The curvature of the sides may be a true arc of a circle. Cell **52** of Figure 5 shows another construction in which the cell walls are straight in the end portions **54**, **56** and the walls are bulged medially at **58**. The dotted lines **60** in Figure 5 compare the bulged construction with a barrel or spherical shape. Particularly for more abrupt bending of a panel, the Figure 5 construction is advantageous in permitting more pivoting before the brazed joint is broken. The cells are normally in abutment and as the panel is curved the cells must flex by rocking on the panel neutral axis **61**. Considering the point **64** in Figure 9, as the cells are pivoted, rocked or rolled, adjacent points such as **66** move toward abutment and place the brazed material under tension and compression. In the bulged construction of Figure 5, this action will occur more gradually than with the regular arc shown by dotted line **60**. The adoption of the Figure 5 construction may thus depend on the degree of curvature to which the panel is subjected.

To explain the action that occurs upon bending in more detail, when the panel is formed into a curvature the inner concave sheet **32** is compressed (shortened) and the outer convex sheet **34** is tensed (lengthened). The neutral axis **61** retains the same length according to the bending theory for balanced panels. Points **64** of adjacent panels remain in abutment in theory or else neutral axis **61** would lengthen. The major axes of the cells are reoriented during bending to positions aligned with radials of the arc of bending, i.e., in the example given below of a panel rolled to a 29.65" radius, the axes **65**, **67** **69** of the cells assume new positions **71**, **73**, **75** directed through the center of the circle having the 29.65" radius. Whereas the axes **65**, **67**, **69** of the cells before bending were parallel to each other, the axes **71**, **73**, **75** of adjacent cells after bending will form an angle with each other. This angle may be computed approximately by determining the number of cells around the circumference of a circle having the radius of curvature. For example, if the radius of curvature is approximately 30 inches (29.65"), the circumference of the circle of that radius ($\pi 2r$) is approximately 188½". Assuming the cells to have a 0.50" minor axis (maximum diameter in plan view), approximately 377 abutted cells would equal the circumference. Therefore, the angle between the axes of adjacent cells would be approximately 1° under these assumed conditions. This 1° angle may be said to be accomplished during curvature by rocking each adjacent cell about point **64** through an angle of approximately ½°. As will be evident from an examination of Figure 9, this rocking action brings the walls of the cells into abutment at a second point **66** spaced some distance from point **64**. If the panel does not deviate from bending theory, points **64** and **66** both will be in abutment after the panel has been curved, and the portions of the cells between the points will be distorted by flattening so that the cells will be in abutment throughout the area from point **64** to point **66**. It should be noted, however, that the panel may not conform exactly to bending theory and any one of a number of factors may act to avoid the distortion of the cells, i.e., depending on the tolerances of the parts, some cells may be separated a few thousandths of an inch at **64** instead of being in abutment, some giving of the brazed weld at **40**, **42** (Figure 8) may influence the action, etc. This analysis demonstrates a point of the present invention that the cells have a minimum resistance to curvature of the panel. For example, the distortion of the cells to accommodate bending (providing the panel conforms exactly to bending theory for balanced panels) occurs principally (*a*) in distortion of the cells between points **64** and **66**, (*b*) in distortion or stressing of the brazing welds between **44** and **46**, and (*c*) in any accommodation of the ends of the cells or of brazing welds **40**, **42** to contraction of inner face sheet **32** and to the expansion of outer face sheet **34**. This may be contrasted to prior hexagonal honeycomb which, to an extent, is like an I-beam, e.g., the hexagonal honeycomb has, in effect, a web extending from face sheet to face sheet in a plane at right angles to the axis of the arc of curvature, and the inner part of the web must contract and the outer part of the web must expand. In other words, the hexagonal honeycomb would, in effect, have a web instead of a void in the space between adjacent cell walls **26** in Figure 9.

To further examine the difference between the Figure 4 and Figure 5 constructions, let it be assumed that the radius of curvature of the barrel-shaped walls in Figure 4 is 0.017, that the radius of curvature of the bulged walls **58** in Figure 5 is 0.125, and that the minor axes of the cells are each 0.50 (these proportions are approximately those shown in Figures 4 and 5). Further assuming the conditions set forth above that the panel is curved on an approximately 30" radius whereby each cell is rocked about ½°, the distances between points **64** (neutral axis abutment) and **66** (point where cells abut due to rocking action) may be computed by observing the trigonometrical relationships. The distance **64** to **66** is a chord between the points **64**, **66** on the arc defined by the cell walls. The center angle "A" subtended by the chord is double the angle "B" each cell is rocked. This may be proven as follows: angle "B" plus the chordal angle "C" is equal to 90° (the angle defined by **66**, **64**, **61** in Figure 9 is 90°) or $2\angle B+2\angle C=180°$ and $\angle A+2\angle C=180°$ (the sum of the angles of a triangle is 180°). $\therefore \angle A=2\angle B$. The distance **64** to **66** thus is the chordal length for for a 1° angle. Consulting trigonometrical tables, the chordal length is 0.01745 times the radius. The distance **64** to **66** for the Figure 5 bulged walls is $0.01745\times 0.125=0.00218$" and the distance **64** to **66** for the Figure 4 barrel-shaped walls is $0.01745\times 0.417=0.00727$". It will be observed, thus, that the distance **64** to **66** is directly proportionate to the radius of curvature of the cell walls. The flattening of the cell between points **64** and **66** in the above example of 0.50" diameter barrel-shaped cells having walls formed with 0.417" arc radius is about .00002" (chordal height), according to trigonometric tables for a 1° arc.

Figure 7 shows the action of the cells as the panel is formed into a curvature represented by line **63**. Figure 7 is not intended by purpose (and is not on a scale) to show any distortion of the cells due to bending of the panel although it will be apparent to those skilled in the art that, by theory, a small amount of distortion may occur in the cells, i.e., .00002" in the above example. The amount of such distortion may be reduced by any giving of brazed fillets **40**, **42**. Any distortion in the cells is substantially discrete and does not build up across the face of the panel. The normal cell axes are shown by lines **65**, **67**, **69** and the displacement is shown respectively by axes **71**, **73**, **75**. The curvature may be produced by adaptation of present forming techniques, i.e., roll forming or hydro-press forming, with results comparable to those achieved in other honeycomb processing.

For example, a specimen was rolled to a 29.65 inch radius using 12 inch diameter rolls and .25 inch aluminum alloy starter plates. Another specimen was formed in a hydro-press on a 57 inch radius Kirksite male form block. The panel was interposed between two sheets of .188 aluminum alloy and 250 tons pressure was used. This is precision work and the techniques must be adapted for this type of forming and for the various types of parts to be formed.

The strength of the panel will be partially a function of the distance between directly supported areas of sheets **32, 34**. For example, in Figure 4 the panel over end opening **72**, across the diameter *x*, will not be directly supported. In the preferred construction, the distance between adjacent edge corners **28** will be no greater than the diameter *x*. This means that the distance between the planes of edge **28** and the middle of side wall **26** will be no greater than $x/2$.

Normally, each panel will have the same type of cells throughout so that the density, strength and vibration characteristics will be uniform. However, Figure 7 shows a panel in which the density is varied by the use of an area of cells **10** and an area of cells **50**. More dense portions may be used in the area of fasteners or the like.

Figure 10 shows the forming of a tapered panel. This may be accomplished by first bonding a series of cells **10** to a sheet on a line **80** and then milling the cells on the tapered line **82**. If a double taper is desired, then the cells next can be bonded to a sheet on line **82**, the sheet **80** removed and the cells milled on line **84**. The tapers are exaggerated in Figure 10 for the purpose of illustration and normally a slighter taper would be desired.

Having thus described our invention, we do not wish to be understood as limiting ourselves to the precise details of construction shown, but instead wish to cover those modifications thereof which will occur to those skilled in the art from our disclosure and which fairly fall within the scope of our invention, as described in the following claims.

We claim:

1. A honeycomb type panel, comprising: a pair of superposed face sheets; a multiplicity of cells between said face sheets having their ends squared forming annular edges and said annular edges abutting said sheets forming a honeycomb panel; said cells having their outer side surfaces, between said ends, bulged in at least their medial portions, forming convex, arcuate, annular medial portions to abut adjacent cells; said cells having said medial portions abutted and securing means securing together said medial portions at the points of abutment, the inner surfaces of said face sheets being secured to said annular edges of said cells; said panel having a curvature and the axes of said cells in the area of the curvature being directed substantially as radials of the curvature, the panel being fabricated flat with said sheets in parallel position and said securing means being rigid whereby said securing means is stressed as said cells are rocked on said bulged medial portions from an original position with their axes parallel to the position as radials.

2. A honeycomb type panel, comprising: a pair of superposed, parallel metal face sheets, a series of rows of hollow metal cells between said face sheets having their ends open forming annular edges and said annular edges abutting said sheets forming a honeycomb panel and the outer surface of said cells having circular outlines in all cross sections parallel to said face sheets, said cells having their outer side surfaces, between said open ends, bulged in at least their medial portions, forming convex, arcuate, annular medial portion to abut adjacent cells, the maximum outer diameter of each cell being in said medial portion and being no more than substantially double the diameter of said annular end edges, whereby the face sheets bridge no greater distance between cells than across the open cell ends, said cells having said medial portions abutted on planes substantially tangential to the curves of the medial portions of each pair of abutted cells and said cells being brazed together at the points of abutment, the inner surfaces of said face sheets being brazed to said annular edges of said cells at said open ends.

3. A honeycomb type panel, comprising: a pair of superposed face sheets; a multiplicity of hollow cells between said face sheets having their ends open forming annular edges and said annular edges abutting said sheets forming a honeycomb panel; said cells having their outer side surfaces, between said open ends, bulged in at least their medial portions forming convex, arcuate, annular medial portions to abut adjacent cells; said cells having said medial portions abutted and secured together at the points of abutment, the inner surfaces of said face sheets being secured to said annular edges of said cells at said open ends; the maximum outer diameter of the medial portion of each cell being no more than substantially double the diameter of said annular end edges whereby the face sheets bridge no greater distance between cells than across the open cell ends.

4. A honeycomb type panel, comprising: a pair of superposed face sheets; a multiplicity of hollow cells between said face sheets having their ends open forming annular edges and said annular edges butting said sheets forming a honeycomb panel; said cells having their outer side surfaces, between said open ends, bulged in at least their medial portions, forming convex, arcuate, annular medial portions to abut adjacent cells; said cells having said medial portions abutted and secured together at the points of abutment, the inner surfaces of said face sheets being secured to said annular edges of said cells at said open ends; said panel having non-uniform density by having a first area in which the cell medial portions have a first diameter and a second area in which the cell medial portions have a second diameter less than said first diameter, the cells having the same height in both areas whereby said face sheets are parallel.

5. A honeycomb type panel, comprising: a pair of superposed face sheets; a multiplicity of hollow cells between said face sheets having their ends open forming annular edges and said annular edges abutting said sheets forming a honeycomb panel; said cells having their outer side surfaces, between said open ends, bulged in at least their medial portions, forming convex, arcuate, annular medial portions to abut adjacent cells; said cells having said medial portions abutted and secured together at the points of abutment, the inner surfaces of said face sheets being secured to said annular edges of said cells at said open ends; said panel being tapered, the points of abutment between cells all lying substantially in a common plane and all of said cells being substantially identical except the ends thereof being cut on a pair of converging planes, the inner surfaces of said face sheets lying in said pair of planes, the diameters of the medial portions of all cells being equal.

6. A honeycomb type panel, comprising: a pair of superposed face sheets; a multiplicity of hollow cells between said face sheets having their ends open forming annular edges and said annular edges abutting said sheets forming a honeycomb panel; said cells having their outer side surfaces, between said open ends, bulged in at least their medial portions, forming convex, arcuate, annular medial portions to abut adjacent cells; said cells having said medial portions abutted and secured together at the points of abutment, the inner surfaces of said face sheets being secured to said annular edges of said cells at said open ends; said panel having a curvature, said cells being secured together by brazing while said panel is flat, the brazing producing brazing fillets at said points of abutment and the brazing fillets in the area of the curvature being stressed due to rocking of said cells on the budged

medial portions into positions in which the axes thereof are directed generally as radials of the curvature.

7. A honeycomb type panel, comprising: a pair of superposed face sheets; a multiplicity of hollow cells between said face sheets having their ends open forming annular edges and said annular edges abutting said sheets forming a honeycomb panel; said cells having their outer side surfaces, between said open ends, budged in their medial portions, forming convex, arcuate, annular medial portions to abut adjacent cells; said cells having said medial portions abutted and secured together at the points of abutment, the inner surfaces of said face sheets being secured to said annular edges of said cells at said

open ends; said cells being cylindrical in their end portions and the bulging being restricted to said medial portions.

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