United States Patent [19]

Fremont et al.

[11] **3,922,899**

[45] **Dec. 2, 1975**

[54] **METHOD OF FORMING SANDWICH MATERIALS**

[75] Inventors: **Maurice, Henri, Louis Fremont,** Massy; **Jean-Francois Denis,** Lesigny; **Serve, Yvan Dzalba-Lyndis,** Villejuif, all of France

[73] Assignee: **Societe Nationale Industrielle Aerospatiale,** Paris, France

[22] Filed: **July 8, 1974**

[21] Appl. No.: **486,428**

[30] **Foreign Application Priority Data**

July 10, 1973 France 73.25292

[52] **U.S. Cl.** **72/128;** 72/342

[51] **Int. Cl.**[2] **B21D 47/00**

[58] **Field of Search** .... 72/128, 342; 29/455 LM

[56] **References Cited**

UNITED STATES PATENTS

622,282	4/1899	Smith	72/128
2,737,224	3/1956	Jones	72/342
3,788,117	1/1974	Chester et al.	29/455

FOREIGN PATENTS OR APPLICATIONS

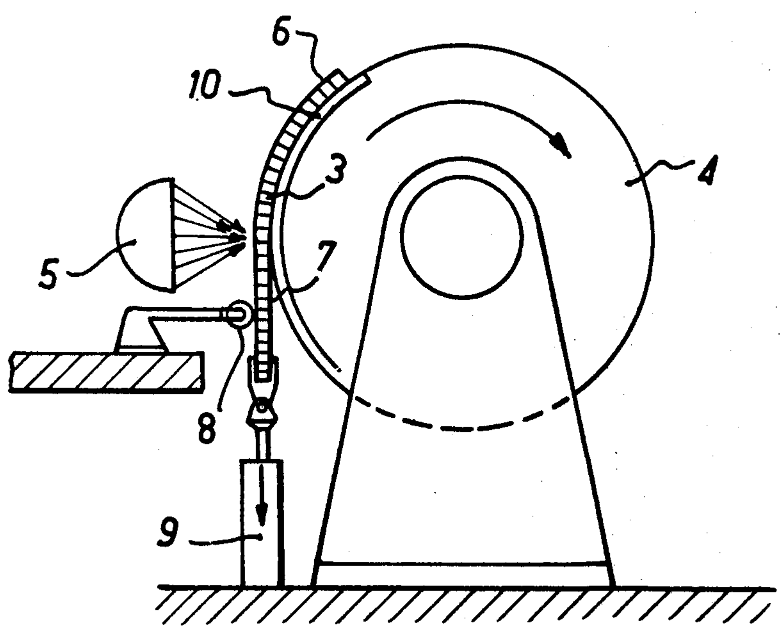
6,742	1965	Japan	72/128

Primary Examiner—Lowell A. Larson
Attorney, Agent, or Firm—Karl W. Flocks

[57] **ABSTRACT**

The invention provides a method of forming sandwich materials. The area subjected to forming stresses is heated locally in such manner that the strength properties of the skin metals governing the permissible stress limits in that area are constantly monitored without the structure as a whole being subjected to oxidation.

4 Claims, 13 Drawing Figures



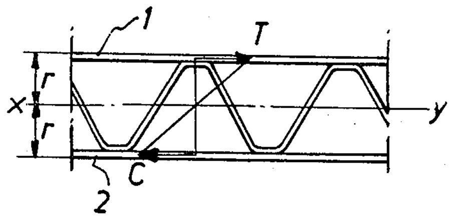


FIG.1

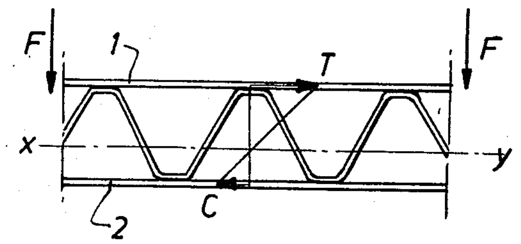


FIG.3

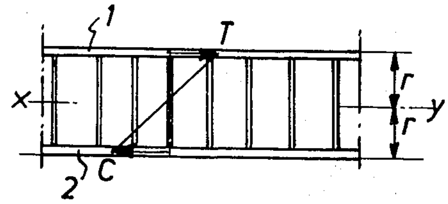


FIG.2

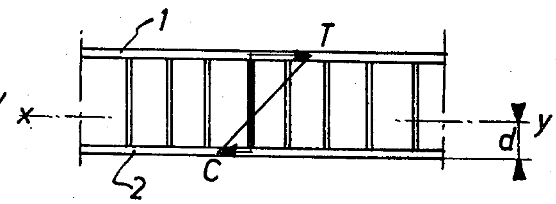


FIG.4

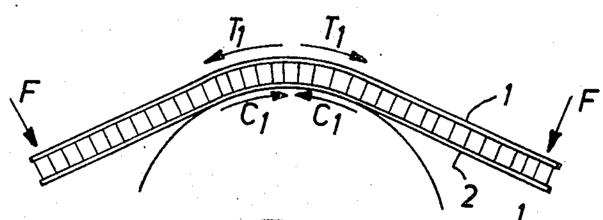


FIG.5

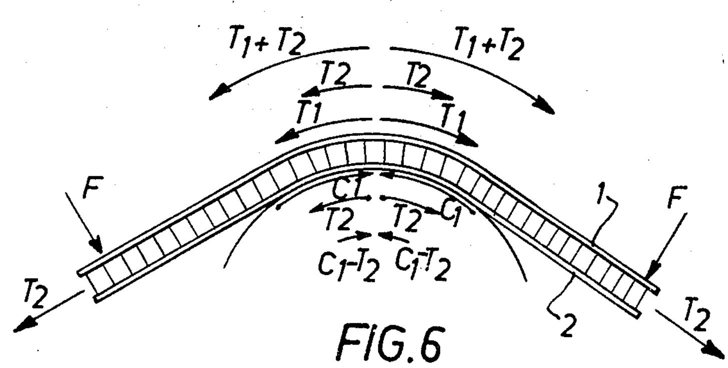
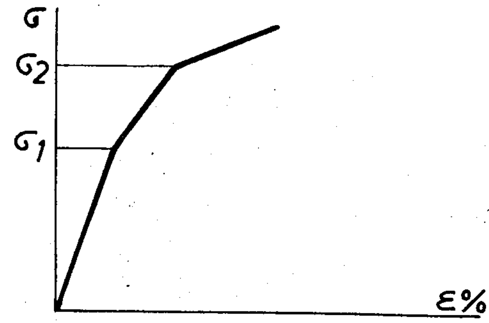
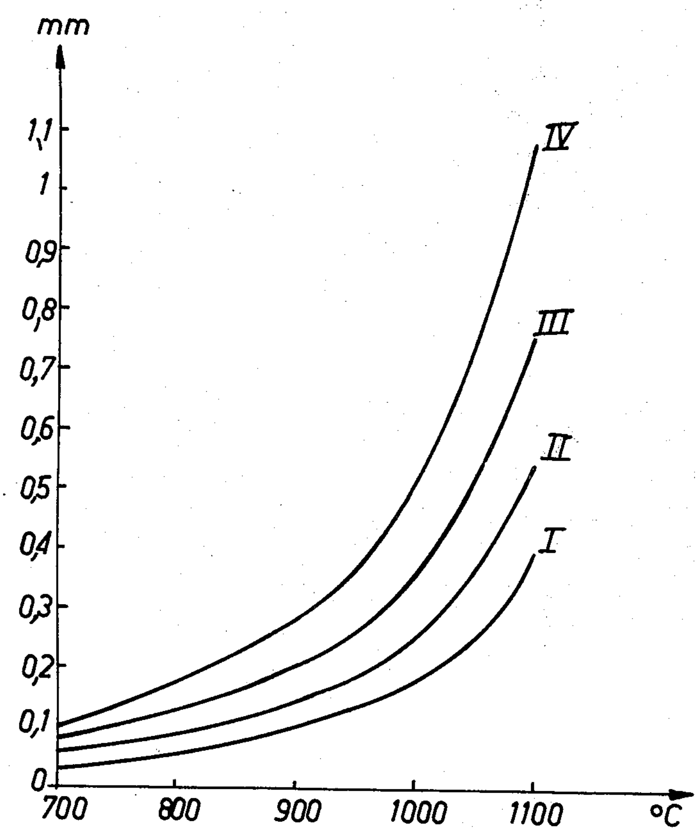


FIG.6



σ
σ2
σ1
ε%

FIG.7



mm
1,1
1
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
700
800
900
1000
1100
°C
IV
III
II
I

FIG.8

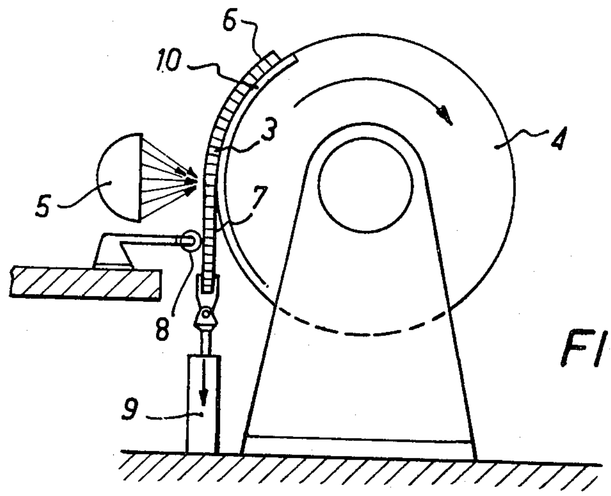


FIG.9

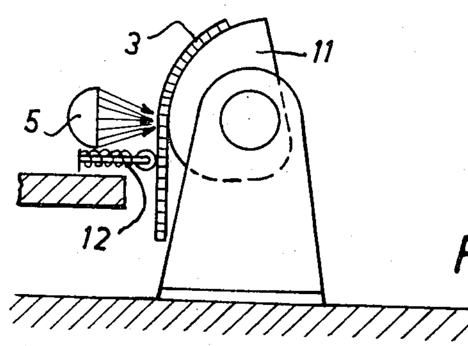


FIG.13

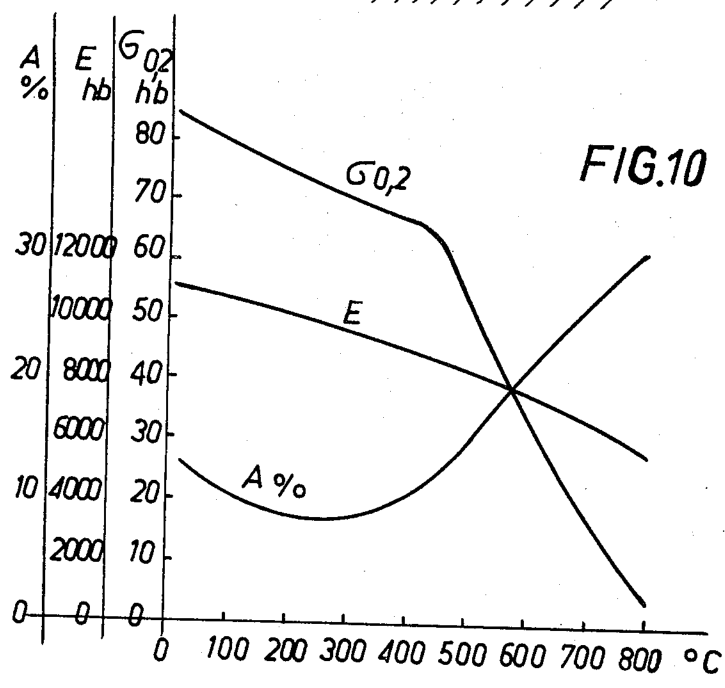


FIG.10

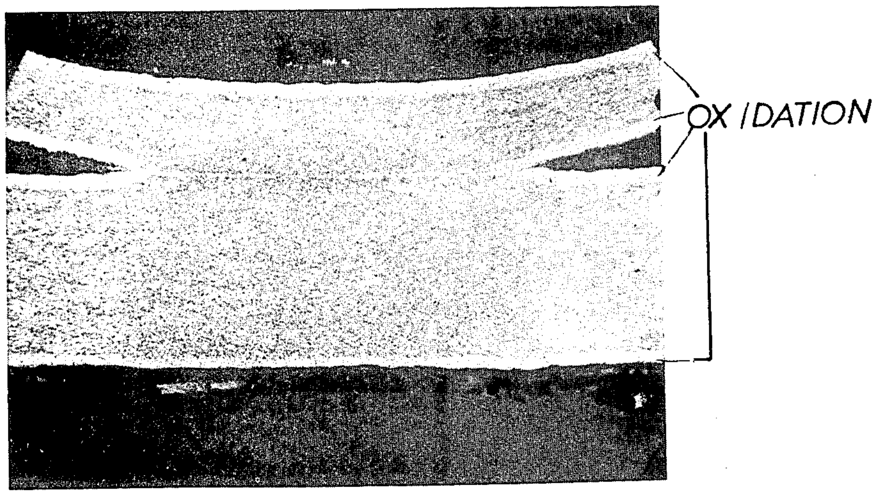


FIG. 11

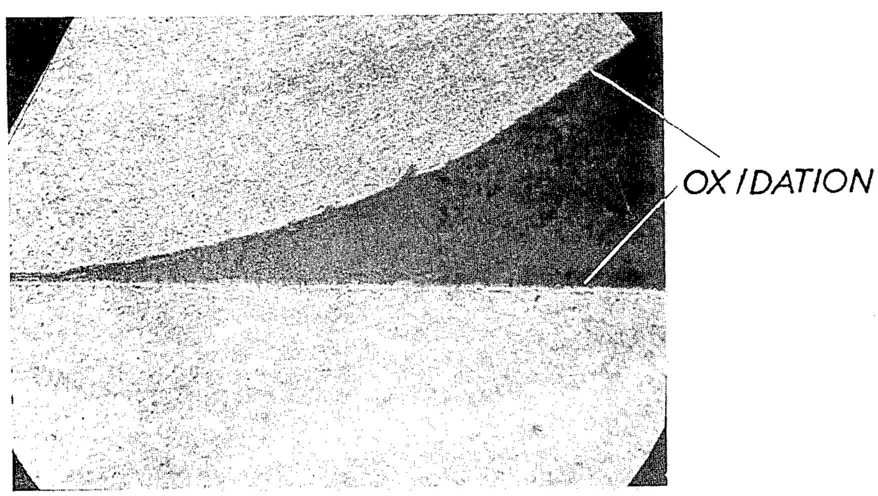


FIG. 12

METHOD OF FORMING SANDWICH MATERIALS

The present invention relates to a method of forming sandwich materials.

The difficulties of forming the so-called sandwich materials used in the aerospace industry, in which two thin sheets of metal are maintained in mutually spaced relationship by a spacing element or web, are well known. For example, this spacing element may be either a corrugated element as used in the materials employed by the Applicant under the trade-name "Norsial", or a honeycomb type of element as used in the materials employed by the Applicant under the trade-name "Nida".

These difficulties are mainly due to the fact that it is not always possible to impart shape to such materials directly or to form them from flat panels because local buckling phenomena tend to cause the compressed face (or skin) to wrinkle while the stretched face (or skin) is subjected to high tensile stresses.

However, when the neutral or zero-stress fibre passes midway through the thickness of the material, the tensile and compressive stresses in the two skins are of equal and opposite values, and therefore a knowledge of these values can determine the magnitude of the deformation which can be applied to the panel.

Indeed, by applying appropriate overall heating it is even possible to so modify the principal characteristics of materials as to make it possible to increase the obtainable extent of deformation. However, although this heating method is applicable to many metals such as stainless steel, nickel, etc., this is not so in the case of many other special metals like titanium and its alloys, molybdenum, magnesium, beryllium and their alloys, which metals do not stand up well to protracted overall heating because of their great sensitivity to oxidation.

Obviously, protection against oxidation can be obtained by carrying out such heating in an evacuated enclosure or in a neutral atmosphere, but this is an inconvenient and costly solution when the items to be formed are of considerable size.

The present invention provides a method of forming sandwich materials of the above-mentioned kind, made of oxidizable metals, that overcomes the drawbacks of the prior art.

In the method according to this invention, the area subjected to forming stresses is heated locally in such manner that the strength properties of the skin metals governing the permissible stress limits in that area are constantly monitored without the structure as a whole being subjected to oxidation.

The description which follows with reference to the accompanying non-limitative exemplary drawings will give a clear understanding of how the invention can be carried into practice.

In the drawings:

FIGS. **1** and **2** are sectional side elevation views of Norsial and Nida type sandwich panels, respectively, in which the neutral fibre (x-y) lies in the median plane through the thickness of the panel;

FIGS. **3** and **4** are illustrations corresponding to FIGS. **1** and **2**, for the case where the neutral fibre (x-y) is offset and does not lie in the median plane through the thickness of the panel;

FIGS. **5** and **6** are diagrammatic illustrations showing the stress distribution when a sandwich panel is subjected to bending and tension respectively;

FIG. **7** is a graph for illustrating the local buckling phenomenon in a sandwich panel;

FIG. **8** is a graph showing the effect of oxidation on a metal oxidizable in free air, as a function of time and temperature;

FIG. **9** diagrammatically illustrates a first possible arrangement for performing the subject method of this invention;

FIG. **10** is a graph in which the strength properties of a titanium alloy are plotted against temperature;

FIG. **11** is a micrographic image of the effect of oxidation under protracted heat in an assembly of titanium alloy sheets;

FIG. **12** is a micrographic image of the effect of oxidation under heat in a titanium alloy assembly treated in accordance with the present invention; and

FIG. **13** diagrammatically illustrates an alternative possible arrangement for performing the subject method of this invention.

One of the difficulties encountered in operations for forming Norsial or Nida type sandwich panels stems from the fact that it is almost mandatory to resort to a bending load F (see FIG. **5**). The effect of such bending is to produce a tensile stress T_1 on the stretched face (or skin) **1** and a compressive stress C_1 on the compressed face (or skin) **2**, but these stresses will be of equal magnitude provided that the neutral fibre is equidistant from the external faces of the panel. (For greater clarity, FIGS. **1** and **2** represent equal stresses T and C for the case where the neutral fibre x-y lies at equal distances r from the external faces **1** and **2** of Norsial and Nida type panels respectively, and FIGS. **3** and **4** represent unequal stresses T and C for the case where the neutral fibre x-y is offset in relation to the median planes of said panels).

The strain in each case can readily be calculated from the elementary formula:

$$\sigma = \frac{M}{I/r}$$

where σ is the strain,

M the bending moment,

I the inertia of the material

and r the distance of the external faces (or skins) from the neutral fibre x-y.

In practice, the tensile stress T does not present a major drawback provided that the metal possesses adequate capacity for elongation. On the other hand, the compressive stress in the compressed skin **2** soon results in a local buckling effect which produces increasingly accentuated wrinkling. This phenomenon will be seen to be virtually inevitable from and examination of the graph in FIG. **7**, in which Σ is the deformation,

σ the strain,

σ_1 the strain beyond which local buckling of the compressed skin occurs,

and σ_2 the strain at the elastic limit of the metal for an 0.2% elongation.

If it is desired to deform the material permanently, it is indispensable to greatly exceed the metal's elastic limit at 0.2% elongation, a limit which is usually greater than the strain σ_1 producing the local buckling phenomenon.

This drawback can often be avoided, in particular through the use of so-called stretch-forming methods in which a tensile force T_2 is exerted on the panel prior to deformation by bending, as shown in FIG. 6. This stress T_2 comes in deduction of the compressive stress (C_1-T_2) that appears in the internal skin 2 and sets back the onset of the local buckling phenomenon correspondingly. Contrariwise, it is added ($T_1 + T_2$) to the tensile stress in the outer skin 1 and therefore limits the deformation possibilities by reason of the high stresses involved, which could result in rupturing of the stretched skin 1.

As is well-known, the forming of oxidizable parts, especially titanium or titanium alloy parts, is facilitated if it can be carried out under heat; for in addition to the fact that the rise in temperature improves the basic strength characteristics, it enables the elastic restoring or resilience effect, which is particularly strong in such materials when they are cold, to be avoided. Unfortunately however, in order to be effective, the temperature must be high (in excess of 600°C) and it is well-known that at such temperatures all these oxidizable metals are very seriously contaminated by the atmosphere, resulting in a notably diminished resisting section and in the appearance of oxidized cracks. In consequence, a conventional forming operation would require a fairly long time during which oxidation and contamination would develop by the process shown in FIG. 8, in which the temperature in degrees centigrade is plotted along the X-axis and the oxidization depth in millimeters along the Y-axis. Curves I, II, III and IV in FIG. 8 correspond to heating times of ½ hour, 1 hour, 2 hours and 4 hours respectively, and it may be noted that the depth of oxidization as a function of temperature and time does indeed vary between about 0.03 mm and 1.1 mm.

When it is remembered that the skins of sandwich panels to be formed are no more than a few tenths and sometimes a few hundredths of a millimeter thick as a rule, it will be clear that with such an operation there would be virtually no "sound" metal left, making it impossible to treat such materials by conventional open-air methods.

The solution consisting in placing the parts to be shaped in an evacuated enclosure or in a neutral atmosphere, though valid for small parts, would be difficult to apply in the case of items of substantial size.

The forming method according to this invention enables all the drawbacks mentioned hereinbefore to be overcome.

The subject method of the invention firstly allows of very substantially delaying the onset of local buckling of the compressed inner skin and therefore increases the forming possibilities for any given panel, and secondly authorizes the forming of oxidizable parts, and especially titanium alloy parts, in very short times during which oxidation has very little chance to develop, even without gaseous protection. It should be noted that such "short-time" forming by no means implies high deformation speeds, but quite the opposite, thereby enabling advantage to be taken of the relaxation phenomena well-known in metallurgy.

Essentially, this method is characterized by the fact that it consists in heating the skins of a metal sandwich panel locally and differentially in such manner as to ensure that the tensile and compression stresses engendered therein during forming are optimal having regard for the strength characteristics of the metals in question.

In accordance with further teachings of this invention:

— the local heating zone is proximate the instantaneous deformation zone;

— the forming is carried out by applying the panel against a rotatable former and by providing local heating means in immediate proximity to the points at which the panel to be formed is tangential to said former;

— and in the specific case of titanium and its alloys, the temperature of the "hotter" skin is approximately 770°C, thereby providing a modulus of elasticity of about 6200 hb, and the temperature of the "colder" skin is approximately 480°C, thereby providing a modulus of elasticity in the region of 8500 hb.

The invention likewise relates to arrangements and means for performing the said method, which arrangements are described hereinbelow for exemplary purposes with reference to FIGS. 9 and 13.

Reference is first had to FIG. 9, which illustrates a first way of performing the subject method of this invention.

The panel to be formed 3 is placed with its inner face 7 against any convenient rotating former 4. Local heating means 5, such as an iodine vapour or infrared-tube radiator heats the metal locally on the outer skin 6, in proximity to the line of instantaneous deformation, that is to say at the points where the panel to be formed is tangential to the former. A roller-type restraining device 8 prevents the panel from lifting, and possible tensioning means 9 exert a traction on the panel in order to produce additional overall stretching.

The surface of former 4 can be coated at 10 with insulating substances such as asbestos or melted ceramic, or alternatively with metals like copper or aluminium so that the good heat-conducting properties thereof may ensure optimum heat distribution through the panel.

Using the subject method of this invention and the above-described arrangement, the Applicant has been able to make a circular cylinder with an inner diameter of 100 mm, made of welded Norsial sandwich material consisting of a corrugated web in 0.15 mm-thick sheet with corrugations pitched at 6 mm and two 0.3 mm-thick skins in TA6V4 titanium alloy (6% of aluminium and 4% of vanadium). The panel had a total thickness of 4.3 mm and the wrapping rate was 6 mm per minute.

The local heating was provided by an iodine-vapour radiator with a linear heating zone, positioned in such manner that the area heated on the outer skin 6 was a generatrix of the cylinder approximately 3 mm wide.

The temperature noted on the heated outer skin was 770°C and that of the inner skin in contact with the former (which was made of insulating material) was 480°C.

The curves in FIG. 10 (obtained by plotting the temperature along the X-axis and the strength characteristics $\sigma_{0.2}$, E and A as hereinbelow defined along the Y-axis) give the values of these strength characteristics in the case of TA6V4 titanium alloy sheet 0.3 mm thick. It may be noted from FIG. 10, where

$\sigma_{0.2}$ is the tensile strength at the conventional elastic limit for 0.2% elongation.

E is Young's modulus of elasticity, and

A% is the ultimate elongation,

that the elastic limit and Young's modulus decrease with rising temperature and that, conversely, the permissible elongation increases considerably, albeit after a small transitory decrease.

Thus when the area of the sandwich material being formed at any given instant is uniformly heated, the surface of the neutral fibres extends midway along the panel by reason of the thermal symmetry achieved, and the tensile and compressive stresses are accordingly equal in absolute value.

When however, in accordance with this invention, there is thermal asymmetry by reason of preferential heating of the outer skin, the latter's modulus of elasticity becomes less than that of the inner skin and the surface of the neutral fibres shifts towards the compressed skin and the tensile and compressive stresses are no longer equal.

For instance, when the outer "hot" skin is tensioned to a modulus of elasticity of 6200 hb at 770°C, the inner "cooled" skin is compressed to 8500 hb at 480°C and the downward shift of the neutral-fibre surface then corresponds to the ratio 8500 hb/6200 hb or 1.37, as schematically illustrated in FIGS. **3** and **4.**

The compression in the inner skin is thus considerably less than in the case of uniform stress referred to precedingly, and this skin furthermore possesses high rigidity (8500 hb). It is accordingly lightly stressed and will withstand buckling, and the unacceptable drawbacks of local buckling are thus eliminated. Another consequence of the shifted position of the neutral fibres is to increase the tension in the outer skin, or in other words the elongation required to achieve a permanent set. However, this increase is offset by the fact that that face is at high temperature, and that at that temperature the permissible elongation, which is then 30% as shown in FIG. **10,** is over-abundant and easily covers most foreseeable contingencies for the sandwich materials considered by the present invention.

FIG. **11** shows for exemplary purposes, in the case of 0.27 mm and 0.14 mm thick TA6V4 titanium alloy, the corrosion effect obtained in air during protracted heating at 800°C. The micrographic image shows clearly, with its magnification of 125 times, that the oxidized layer is very thick.

Conversely, the micrograph image in FIG. **12** (which shows the joining area of other such sheet metals of similar nature forming a sandwich panel processed by the subject method of this invention) clearly reveals the thinness of the oxidized layer even though the image is magnified 340 times in this case.

By way of an alternative arrangement for obtaining a panel in accordance with this invention, FIG. **13** shows an arrangement similar to that in FIG. **9,** in which the rotating former **11** is non-cylindrical and the panel **3** is heated by a radiator **5** having infrared tubes and is restrained by a thrust roller **12.**

All the aforementioned embodiments, regardless of whether they involve the use of a cylindrical or non-cylindrical mandrel, employ the same method of this invention, which provides for suitably adapting local stresses in materials by locally heating the two skins of a "Norsial" or "Nida" type sandwich panel symmetrically.

It goes without saying that the present invention has been described for non-limitative exemplary purposes only and that changes and substitutions may be made without departing from the scope of the invention as defined in the appended claims.

We claim:

1. A method of forming a metallic panel sandwich comprising two thin metal sheets maintained in mutually spaced relationship by a spacer element of honeycomb structure, corrugated elements, or the like, wherein the said method includes:

a. placing one sheet of a metallic panel sandwich against a rotating former of rounded surface;

b. applying radiant heat to the immediate proximity of points where said metallic panel sandwich is tangential to said rotating former whereby a localized and differential heating effect is provided in the two thin sheets passing thereby; and

c. simultaneously rotating said former to thereby effect formation of said metallic panel sandwich.

2. The method of claim **1** wherein said radiant heat is obtained from an iodine vapour or infrared-tube radiator.

3. The method of claim **1** wherein said heat is supplied from a source spaced from and not contacting said metallic panel sandwich.

4. The method of claim **1** wherein said application of radiant heat is set to provide a temperature of 770°C in one of said two sheets and a temperature of 480°C in the other of said two sheets, where said two sheets are of titanium or titanium alloys.

* * * * *

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,922,899 Dated December 2, 1975

Inventor(s) Maurice Henri Louis Fremont, Jean-Francois Denis, Serge Yvan Dzalba-Lyndis

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

In column 1, the third inventor's first name should read: Serge

Signed and Sealed this

thirtieth Day of *March 1976*

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents and Trademarks

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,922,899 Dated December 2, 1975

Inventor(s) Maurice Henri Louis Fremont, Jean-Francois Denis, Serge Yvan Dzalba-Lyndis

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

In column 1, the third inventor's first name should read: Serge

Signed and Sealed this

thirtieth Day of March 1976

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents and Trademarks