United States Patent

Lewis

[15] **3,670,397**

[45] **June 20, 1972**

[54] **METHOD OF FABRICATING A LAMINATED METAL MEMBER**

[72] Inventor: **Joseph C. Lewis**, Pasadena, Calif.

[73] Assignee: **North American Rockwell Corporation**

[22] Filed: **Feb. 24, 1970**

[21] Appl. No.: **13,743**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 604,270, Dec. 23, 1966, abandoned.

[52] **U.S. Cl.** **29/472.3,** 29/471.1, 29/493

[51] **Int. Cl.** **B23k 31/02**

[58] **Field of Search** 29/472.3, 497.5, 493, 471.1, 29/498

[56] **References Cited**

UNITED STATES PATENTS

1,744,588	1/1930	Strauss	29/472.3
2,700,632	1/1955	Ackerlind	29/493
2,998,646	9/1961	Hitz	29/497.5
3,133,346	5/1964	Allen	29/497.5
3,186,083	6/1965	Wright, Jr.	29/498 X
3,207,503	9/1965	Clover, Jr. et al.	29/493
3,345,735	10/1967	Nichols	29/471.1
3,393,445	7/1968	Ulam	29/497.5

Primary Examiner—John F. Campbell
Assistant Examiner—Richard Bernard Lazarus
Attorney—L. Lee Humphries

[57] **ABSTRACT**

A laminated, relatively massive metal member requiring a minimum of finish machining is made by cutting a number of thin metal laminae in the shape of the final member. The laminae are stacked into the shape of the member, and held therein by suitable restraining means. The laminae stack is then diffusion bonded together at an elevated temperature and pressure in a non-oxidizing environment.

4 Claims, 10 Drawing Figures

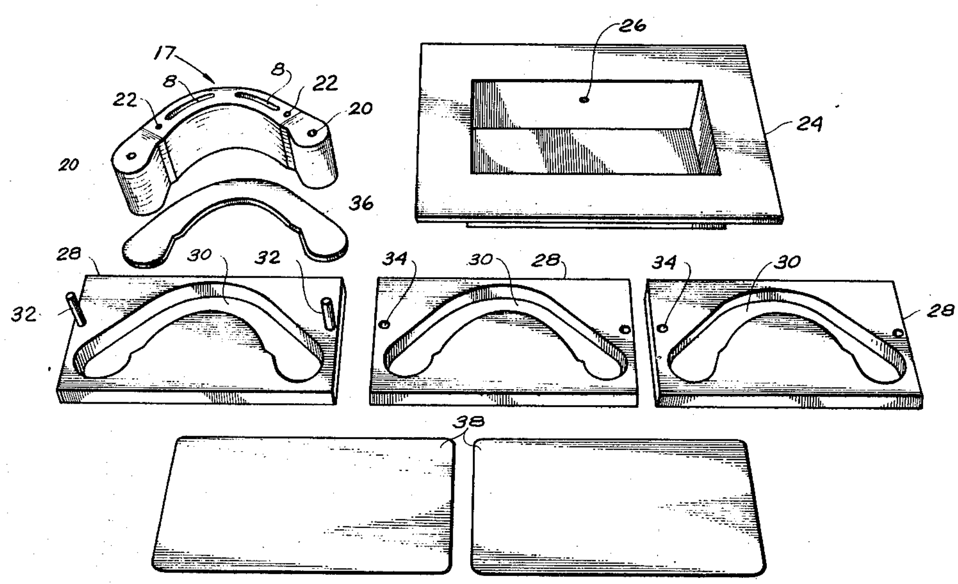


FIG. 1

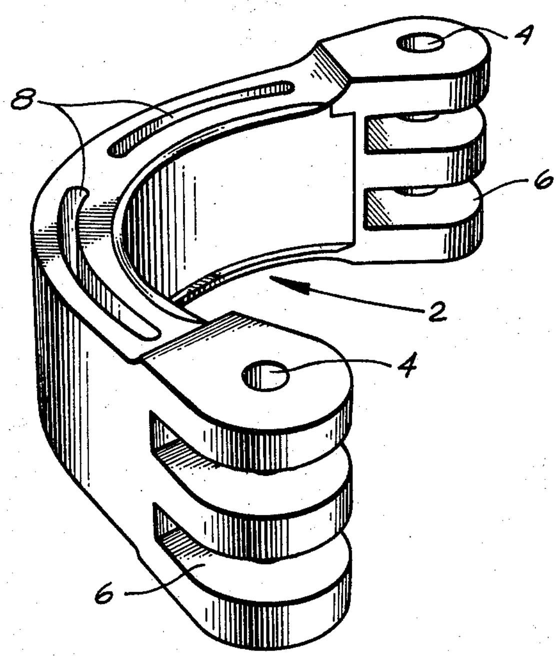


FIG. 2a

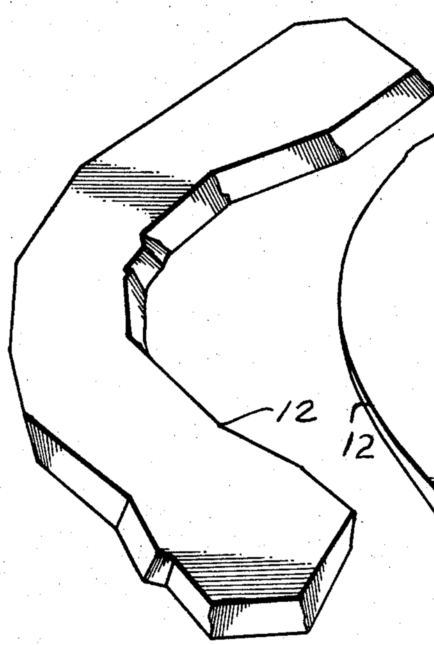


FIG. 2b

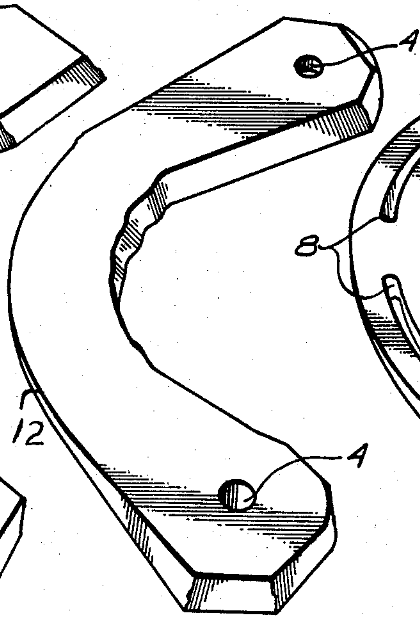
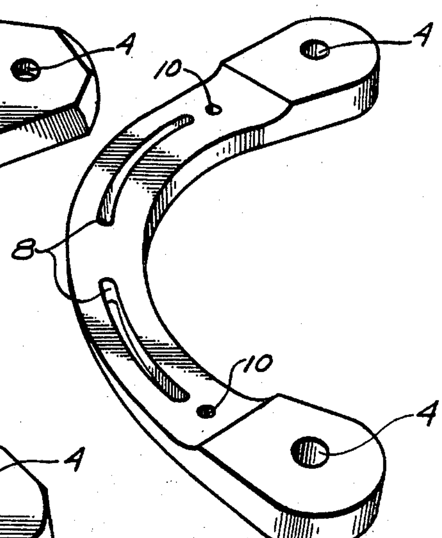


FIG. 2c

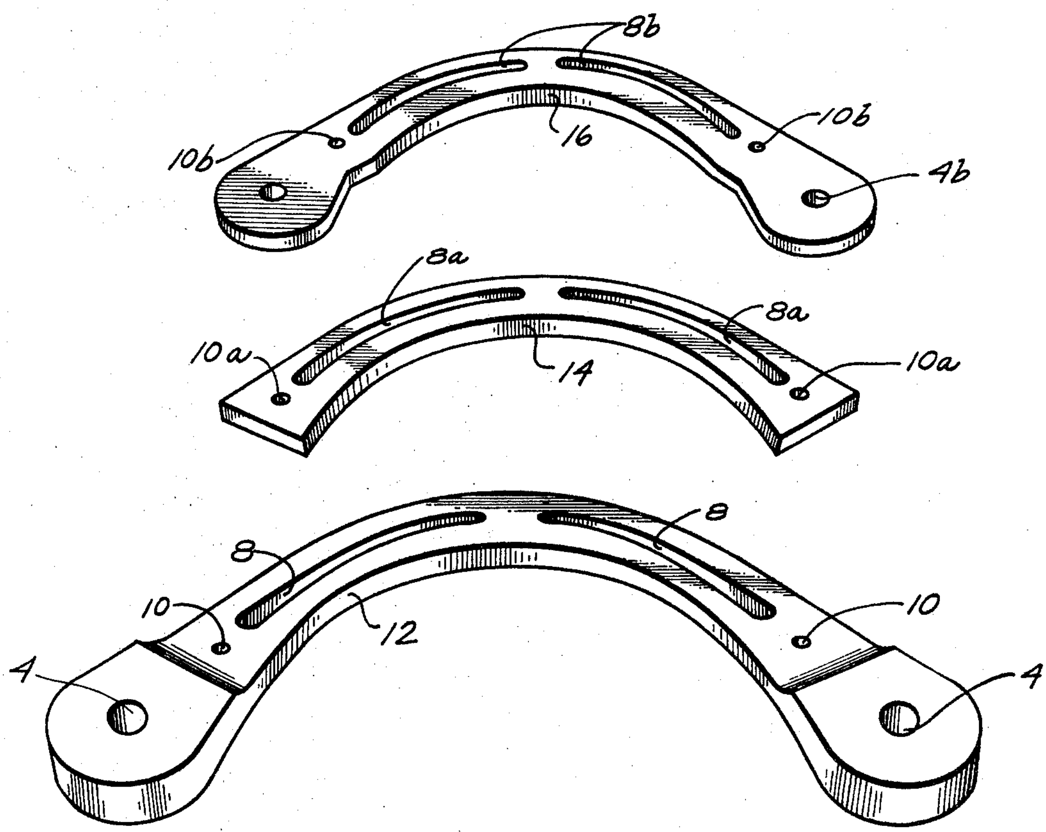


INVENTOR.
JOSEPH C. LEWIS

BY Gerald G. Koris

ATTORNEY

FIG. 3

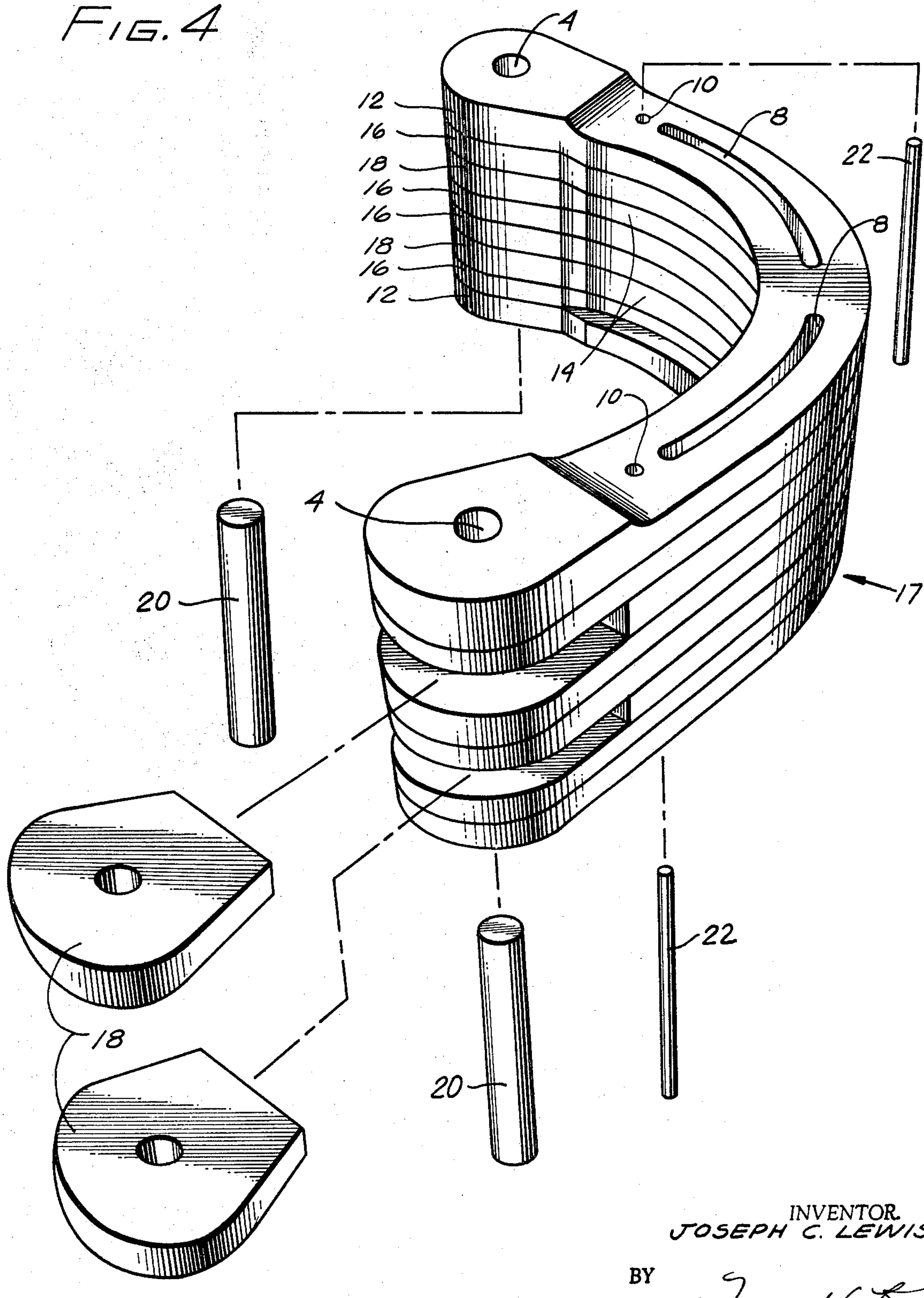


INVENTOR.
JOSEPH C. LEWIS

BY Gerald G. Koris

ATTORNEY

FIG. 4



INVENTOR.
JOSEPH C. LEWIS

BY

ATTORNEY

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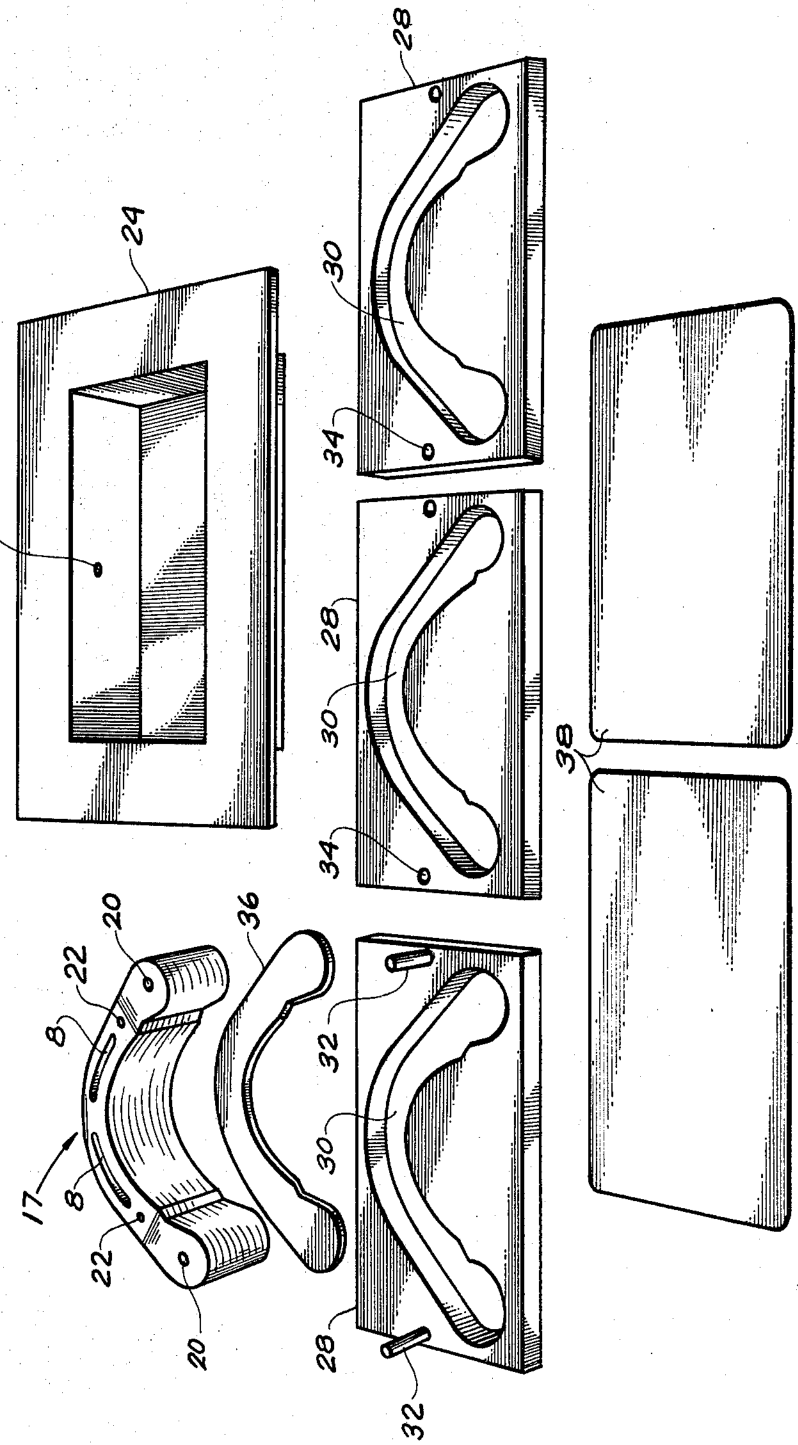


FIG. 5

INVENTOR.
JOSEPH C. LEWIS

BY Gerald A. Koris

ATTORNEY

FIG 6a

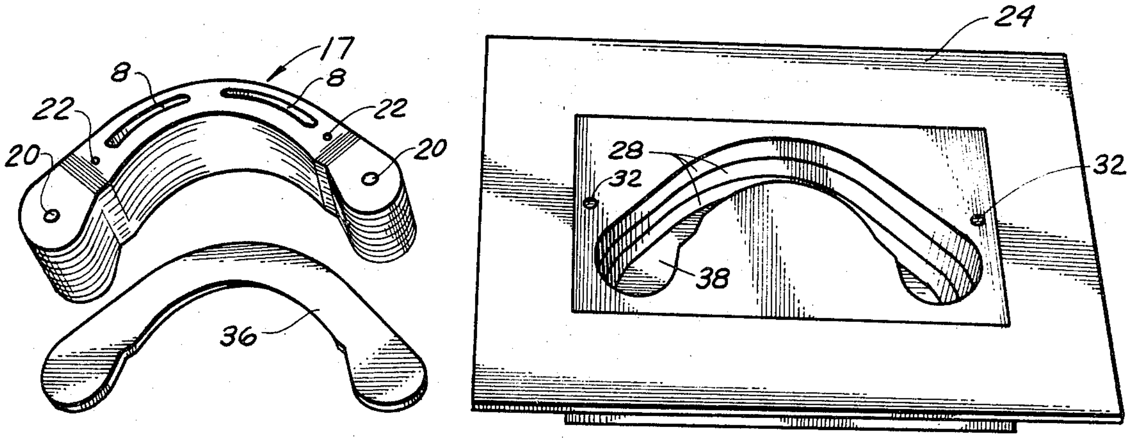
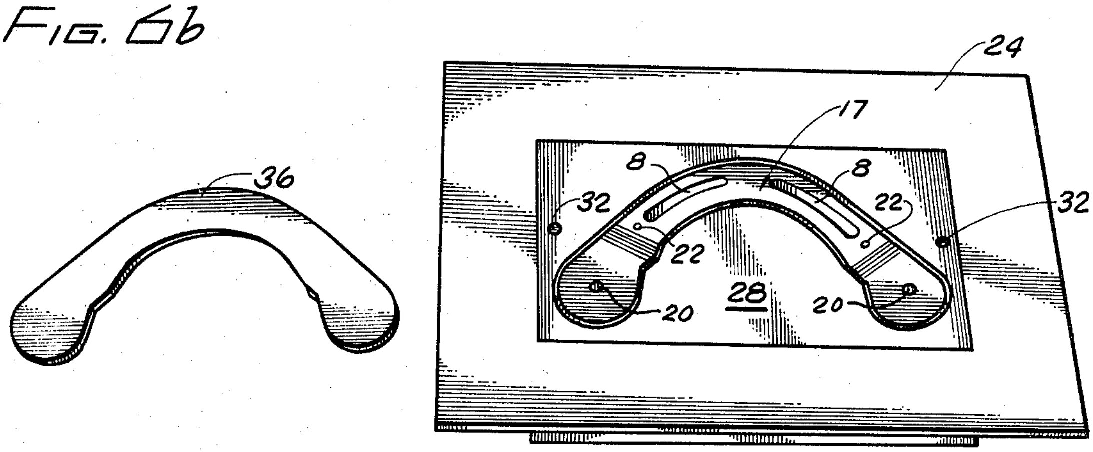


FIG. 6b



INVENTOR.
JOSEPH C. LEWIS

BY Gerald A. Koris
ATTORNEY

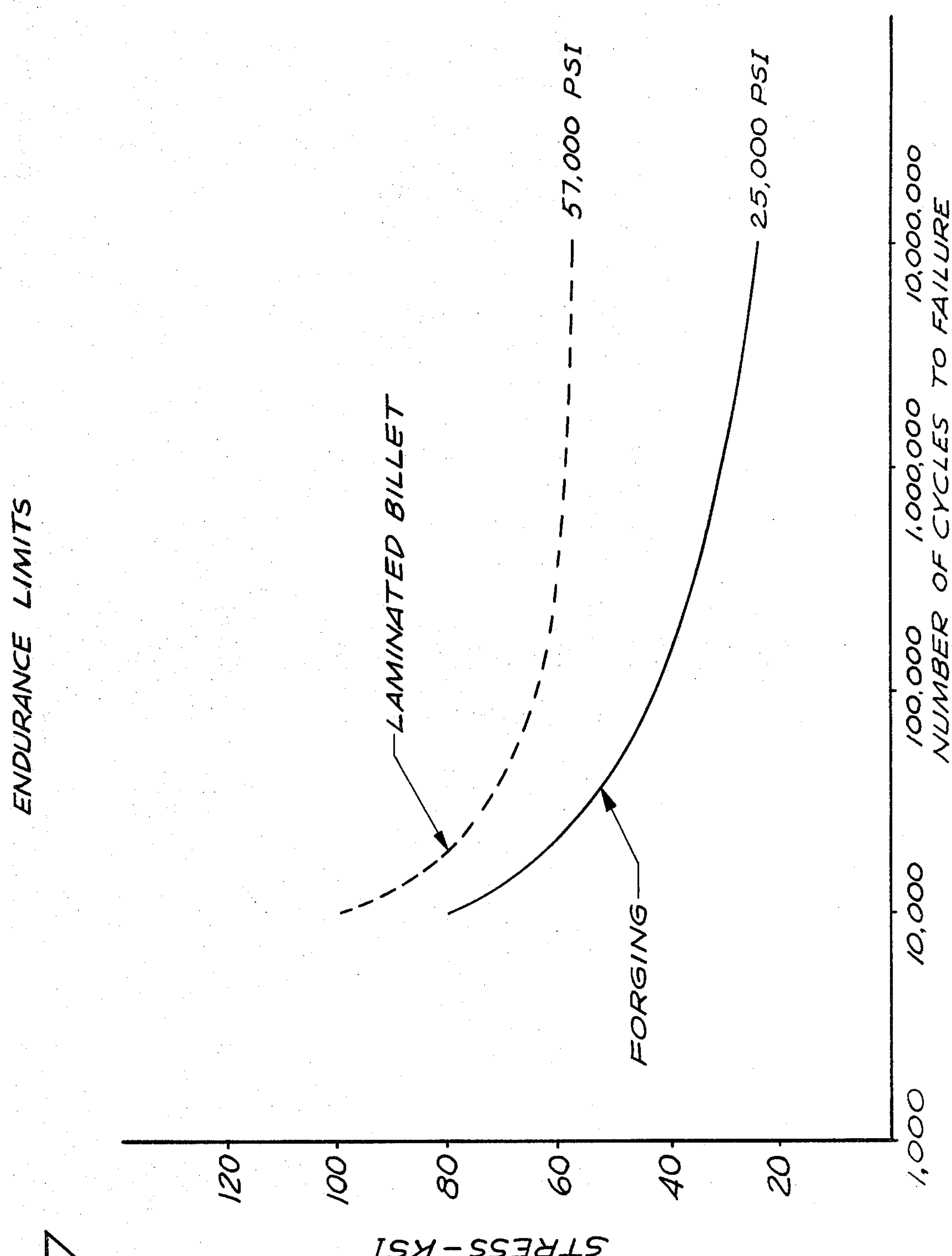


FIG. 7

INVENTOR.
JOSEPH C. LEWIS

BY Gerald G. Koris

ATTORNEY

METHOD OF FABRICATING A LAMINATED METAL MEMBER

CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation-in-part of the following:
Applicant: Joseph C. Lewis
Serial No: 604,270
Filed: Dec. 23, 1966, now abandoned,
For: Method of Fabricating A Laminated Metal Member

The present invention relates to a method of fabricating a laminated metal member.

Large, complex, heavy metal fittings and the like are generally manufactured either from castings or by forging a billet in a die having approximately the geometry of the final member. After forging, the billet is machined into the final desired dimensions. With complex parts having substantial mass non-uniformly distributed throughout the same, this frequently requires extensive precision machining. Initial costs of forgings are high and machining fittings of complex design frequently results in scrap losses of as much as 80 percent. Also, unacceptable weight penalties, particularly for aircraft and spacecraft applications, may result because forged billets have less than optimum metallurgical properties due to insufficient reduction of the metal during forging or rolling. Moreover, the extreme loads and temperatures experienced during supersonic flight require the use of costly, high strength metals such as titanium, hot-worked die steels, or maraging steels. In addition to scrap losses resulting from machining of costly metals, the investment in expensive forging dies is a significant economic factor when low production numbers are involved. Further, machining of complex shapes is expensive and time-consuming. Another limitation inherent in forging is that, since work is performed on a billet from the outside rather than from inside, structures with interior cavities cannot be fabricated. As is known, hollow box-type structures can be as strong as a solid structure and without the weight penalty.

Fittings produced by the initial forging of billets are characterized by anisotropic properties (extreme directionality) which tend to reduce the mechanical strength of the member and lead to failures under lesser loads. If compensation is made for poor metallurgical properties by increasing the weight of the members, the economic penalties of low strength-to-weight ratios are very severe in aircraft and spacecraft. Further, machining itself can introduce stresses and other weaknesses into a workpiece which may lead to failure thereof under heavy loads and temperatures. The difficulties of machining complex shapes from heavy forged billets additionally impose undesirable constraints on the design of such members.

The principal object of the present invention, therefore, is to provide an improved method of fabricating a metallic member consisting of a solid unitary mass.

Another object is to provide an improved method of fabricating a complex-shaped, relatively massive metal member which requires a minimum of final machining and produces smooth, bright surfaces.

Another object is to provide a method of fabricating a high quality structural fitting which is stronger than a similar structural member prepared by casting or forging and machining, and in which scrap losses are greatly reduced.

Still another object is to provide such a method which will produce fittings having greater strength than similar forged fittings.

Still another object is to provide a method of making a laminated fitting having improved strength and metallurgical uniformity wherein substantial savings in cost and production time can be achieved.

A further object is to provide such a method which permits versatility in the design of structural fittings and permits design changes without the capital investment losses in expensive dies.

Yet another object is to provide a method of fabricating fittings having hollow interior portions.

Other objects and advantages of the present invention will become clear from the following detailed description taken together with the accompanying drawings and the attached claims.

In the drawings,

FIG. 1 is an overall view of a laminated trunnion bearing cap prepared according to the present invention;

FIG. 2 shows an individual lamina in various stages of fabrication;

FIG. 3 is a grouping of individual laminae of different designs utilized in making the assembly of FIG. 1;

FIG. 4 shows the laminae of FIG. 3 in a complete assembly;

FIG. 5 shows the stack of laminae and associated equipment utilized in the bonding operation;

FIG. 6 shows the assembly of the laminae stack and of associated equipment in preparation for bonding; and

FIG. 7 is a graph comparing physical properties of forged and laminated billets.

The present invention provides a method of fabricating a laminated, complex-shaped, metal member requiring a minimum of final machining, which comprises providing a plurality of shaped, relatively thin, metal laminae designed to be arranged into said member, stacking the laminae to form the shape of said member, and diffusion bonding the stack of laminae together at an elevated temperature and pressure in an inert environment.

The stack of thin sheet material is bonded into a precision laminated form of uniform properties having the exact configuration of the final part, which requires minimal, if any, final machining. The sheet laminae have better metallurgical properties, which result in a fitting of improved strength and metallurgical uniformity over fittings machined from large billets, castings and heavy forgings. For example, a member produced by practice of the present invention has on test shown an endurance limit of over twice that of a similar forged member. By alternating the grain direction of each laminae, fittings having isotropic properties can be produced from materials that exhibit extreme directional properties in wrought form. Material losses are greatly minimized, which contributes to the economic effectiveness of the process. Further, design flexibility is provided, and favorable strength-to-weight ratios are obtained.

Enclosing the laminae stack in a restraining means produces a fitting having smooth and bright surfaces, equivalent to those of the restraining metal. This important benefit results from plastic flow at the edges of the laminae under heat and pressure. Therefore, a restraining means serves not only to maintain alignment and prevent distortion during diffusion bonding, but also to polish the surfaces of the member.

The present method is further readily adapted to making hollow box-like members of high strength-to-weight ratios. This may be accomplished by utilizing interior laminae with aligned, cut-out portions and solid laminae for exterior surfaces. The present method is also useful for solid workpieces, particularly those having a thickness greater than maximum thickness of commercially available rolled plate.

Diffusion bonding is known to the art for joining members, for example, tubular or rib members, in point-to-point contact (usually not surface-to-surface). It is generally considered as an alternative joining method, superior in a number of regards to brazing or welding. Diffusion bonding is characterized by the formation of a metal-to-metal bond between contacting surfaces at suitable pressures and at temperatures below the melting point of the metal. Bonds which approach the strength of the parent metal can be obtained. In certain cases a thin interleaf material, or eutectic former, is provided, and in other forms of diffusion bonding no interleaf material is utilized.

The mechanism of diffusion bonding is believed to involve plastic deformation of the metal, followed by surpassing of the compressive yield strengths. This characteristic of plastic deformation under pressure and temperature may be taken advantage of in the present invention to produce a finished part having smooth surfaces without further work. Inserting the laminae stack in a restraining die of conforming shape causes creep flow at the ends of the laminae to proceed along the edges of the stack. This has a smoothing and polishing effect on edges which otherwise might be relatively rough and dull.

A number of metals may be joined by diffusion bonding, and illustrative of these are aluminum, stainless steel, titanium, nickel, tantalum, molybdenum, zirconium, and columbium, and alloys of the foregoing. For further information on diffusion bonding, reference is made to such representative U.S. Pat. Nos. as 3,145,466; 3,180,022; 3,044,160; 2,850,798; 3,158,732; 3,170,234; and 3,242,565.

The present invention will be particularly illustrated with reference to the accompanying drawings which disclose the preparation of a trunnion bearing cap for a supersonic aircraft from a 6 Al – 4 V – titanium alloy. This fitting had previously been made by forging the titanium alloy in a suitable die, and then machining the resulting billet. Referring to FIG. **1**, it is seen that the bearing cap **2** is massive and generally arcuate; it is about 12.25 in. long by 3.25 in. high. (Two such bearing caps are joined to enclose the bearing.) The fitting has clevis bores **4** and slots **6** at its extremities and elongated slots **8** extending through its body, in order to reduce its weight, but is essentially a solid unitary mass with non-uniform mass distribution, since it is wider and thicker at each end than in its mid-portion. It is apparent that a hollow, box-type structure of the same or other designs may be made, when required, by not slotting the top and bottom laminae. The method of making this bearing cap to semi-finish dimensions requiring minimum machining will be described with reference to FIGS. **2–6**.

FIG. *2a–c* illustrates the sequence for fabricating a lamina **12**. The lamina is made from 6 Al – 4 V – Ti plate stock approximately three-eighths in. thick; it is friction sawed oversize, drilled, and profiled to the finish dimensions of the part except for an undercut. The slots **8** are obtained by use of a 0.312 in. mill cutter, and small alignment bores **10** are drilled. As seen in FIG. *2a*, sharp edges are not removed by sawing but by machining (FIG. *2b* and *2c*). The lamina is lapped flat and parallel to a surface finish of 20 micro inches RMS.

In FIG. **3** are shown, next to lamina **12**, laminae **14** and **16** of other shapes, which are required to make the configuration of FIG. **1**; these are made by the procedure described with respect to FIG. **2**. Lamina **12** is an outer lamina, lamina **14** a shortened spacer, and lamina **16** an interior lamina which, together with lamina **14**, serves to define extremity slots **6**. Lamina **14** and **16** have longitudinal slots *8a* and *8b* and bores *10a*, *10b*, and *4b*, respectively, which align with the corresponding slots **8** and bores **10** and **4** of lamina **12**. Eight such laminae (two laminae **12**, two laminae **14**, and four laminae **16**) are utilized to form the bearing cap.

FIG. **4** shows the assembled laminae configuration **17**, prior to bonding, including the positions of laminae **12**, **14** and **16**. This configuration is supported by means of spacer blocks **18** of Type 321 stainless steel which are inserted in slots **8**. These blocks serve to prevent warpage of the extremities of the assembly under high loads during diffusion bonding. Stainless steel pins **20** pass through clevis bores **4** and spacer blocks **18** to maintain alignment of the laminae. Pins **22** pass through the smaller alignment bores **10**. The stainless steel pins and spacer blocks are coated with a step-off compound which will prevent bonding to the titanium laminae. For example, aluminum oxide may be flame-sprayed thereon for this purpose. Likewise, the stainless steel members shown in FIG. **5** are coated with aluminum oxide.

FIG. **5** shows the associated apparatus employed in the diffusion bonding operation. A rectangular retort **24** is fabricated from Type 321 stainless steel sheet of 0.035 in. thickness. A three-eighths in. diameter stainless steel purge tube, 36 in. long (not shown) is welded onto a port **26** of the retort.

A tooling stack consisting of three Type 321 stainless steel plates **28** with their centers **30** cut out to conform with the shape of and receive the stack of laminae is made to fit inside retort **24**. The tooling stack provides mass for uniform heating and prevents the retort from collapsing around the laminated billet during diffusion bonding under vacuum. The tooling stack also aligns and constrains the laminae stack in the manner of a constraining die. Stainless steel alignment pins **32** are provided to fit the alignment holes **34** in plates **28**. A stainless steel pressure plate **36**, one-fourth in. thick, is cut to the shape of the laminae with one-sixteenth in. overlap on all edges.

Two other stainless steel plates **38**, one-fourth in. thick, are also provided, one to fit the bottom of retort **24** and the other as a top cover plate for the entire assembly.

Turning to FIG. **6**, the arrangement of the tooling stack and the laminae stack in the retort is seen. FIG. *6a* illustrates tooling plates **28** disposed in retort **24**, the plates being aligned by means of the stainless steel pins **32**. Prior to lay-up in the retort, the stainless steel members are cleaned, for example, with an alkaline degreasing agent, followed by water and organic (e.g., methylethylketone) rinses. The laminae stack **17** is then positioned in the tooling stack as shown in FIG. *6b*. The flame-sprayed stainless steel pressure plate **36** shown outside the retort in FIG. *6b* is put into position over laminae stack **17** by tack welding stainless steel tabs between the pressure plate and the tooling stack. The laminae stack is maintained at a height approximately one-eighth in. above the height of the tooling stack for all diffusion bonding operations so that the applied load is transmitted only through the stack.

Following lay-up, a top cover plate **38** (FIG. **5**) is welded onto the retort. The closed retort is then leak tested under full vacuum, using a helium leak detector to locate any leaks. All leaks are closed by welding. The retort is hot purged at a temperature of about 600° F. in an electric furnace by alternately flooding with dry argon and evacuating to a full vacuum. The vacuum is maintained during all subsequent heating and cooling periods.

After hot purging, the retort is removed from the electric furnace and placed in a hydraulic press of 500 tons capacity which is equipped with ceramic heating platens. Diffusion bonding is accomplished by heating under unidirectional compressive force for a sufficient period to achieve such bonding. The time-temperature-pressure relationships to achieve satisfactory bonding are coordinated and will vary with the metallurgical characteristics of the metal being bonded and the thickness of the laminae stack. Such bonded parameters may be determined by those skilled in the art for different laminating applications from available information concerning the diffusion bonding of particular metals and their alloys. Generally, for the fabrication of the above described titanium member, it is found that coordinated time-temperature-pressure relationships of about 3½ – 4½ hours, 1,500°–1,650° F. and 250–800 psi are satisfactory.

After the bonding operation is completed, the retort is removed from the press and the diffusion bonded laminated stack removed from the retort. Any necessary finish machining, such as that required to achieve the dimensions of the trunnion bearing cap shown in FIG. **1** from the configuration of FIG. **4**, is then performed. The pins **20** and **22** and spacer blocks **18** utilized to maintain alignment of the laminae stack **17** (FIG. **4**) are readily removed after the diffusion bonding step, since bonding does not occur between the aluminum oxide-coated steel and the titanium.

The laminated fitting generally has properties closely approaching those of the parent metal, particularly with regard to small grain size achieved in thin rolled sheets and not obtainable in massive castings or forgings. The bearing caps are tested by placing the fittings in a test fixture so that a contoured plunger can apply a bearing load against the back of the cap. This bearing load is reacted by pins through the clevises, placing the bearing cap in hoop tension. The clevises undergo bearing failure at about 350,000 pounds load.

Additional data comparing the metallurgical properties of similar members fabricated by the present invention and by forging will now be presented. FIG. **7** displays the notched fatigue data or endurance limits (i.e., the maximum stress load which can be maintained without failure under repeated cycling) of forged and of laminated billets of 6Al–6V–2Sn–Ti alloy prepared by the present method. It is seen that the endurance limit of the laminated billet is over twice that of the forged (57,000 psi vs. 25,000 psi).

The following table presents a comparison of the notch properties of a 3 × 3 × 6 inches laminated and forged billet of the foregoing titanium alloy. The better notch properties and notch strength to yield strength ratios (although not yield strengths) of the laminated billet are clearly apparent.

TABLE I

Material	Notch Strength (KSI)	Yield Strength (KSI)	Notch Strength/ Yield Strength
Forged Billet	72.9	160.6	0.45
	74.7		0.47
Laminated Billet	165.0	154.4	1.07
	169.6		1.10
	172.9		1.12
	160.1		1.04

I claim:

1. A method of fabricating a laminated, complex-shaped, metal member requiring a minimum of final machining which comprises fabricating a plurality of shaped, relatively thin metal laminae designed to be arranged into said member, stacking said laminae substantially parallel to each other to form the shape of said member, placing the resulting laminae stack within an enclosed metal retort having disposed therein a restraining die shaped to receive and to conform with the shape of said laminae stack, drawing a vacuum on the resulting assembly, and then applying suitable heat and pressure to said assembly in order to diffusion bond said laminae together.

2. The method of claim 1 wherein the said laminae are of titanium, and said diffusion bonding is conducted under coordinated time-temperature-pressure conditions of about 3½ – 4½ hours, 1,500°–1,650° F, and 250–800 psi.

3. The method of claim 1 wherein said laminae are of titanium and said retort and said restraining die are of stainless steel, and wherein surfaces of said stainless steel contacting said titanium are treated to prevent bonding therewith.

4. The method of claim 1 wherein said heat and pressure are applied by placing said retort assembly between heating platens and then applying unidirectional compressive force to the resulting assembly.

* * * * *