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(72) Inventeurs/Inventors:
MCKAGUE, ELBERT LEE JR., US;
SCHMIDT, RONALD P., US

(73) Propriétaire/Owner:
LOCKHEED MARTIN CORPORATION, US

(74) Agent: FINLAYSON & SINGLEHURST

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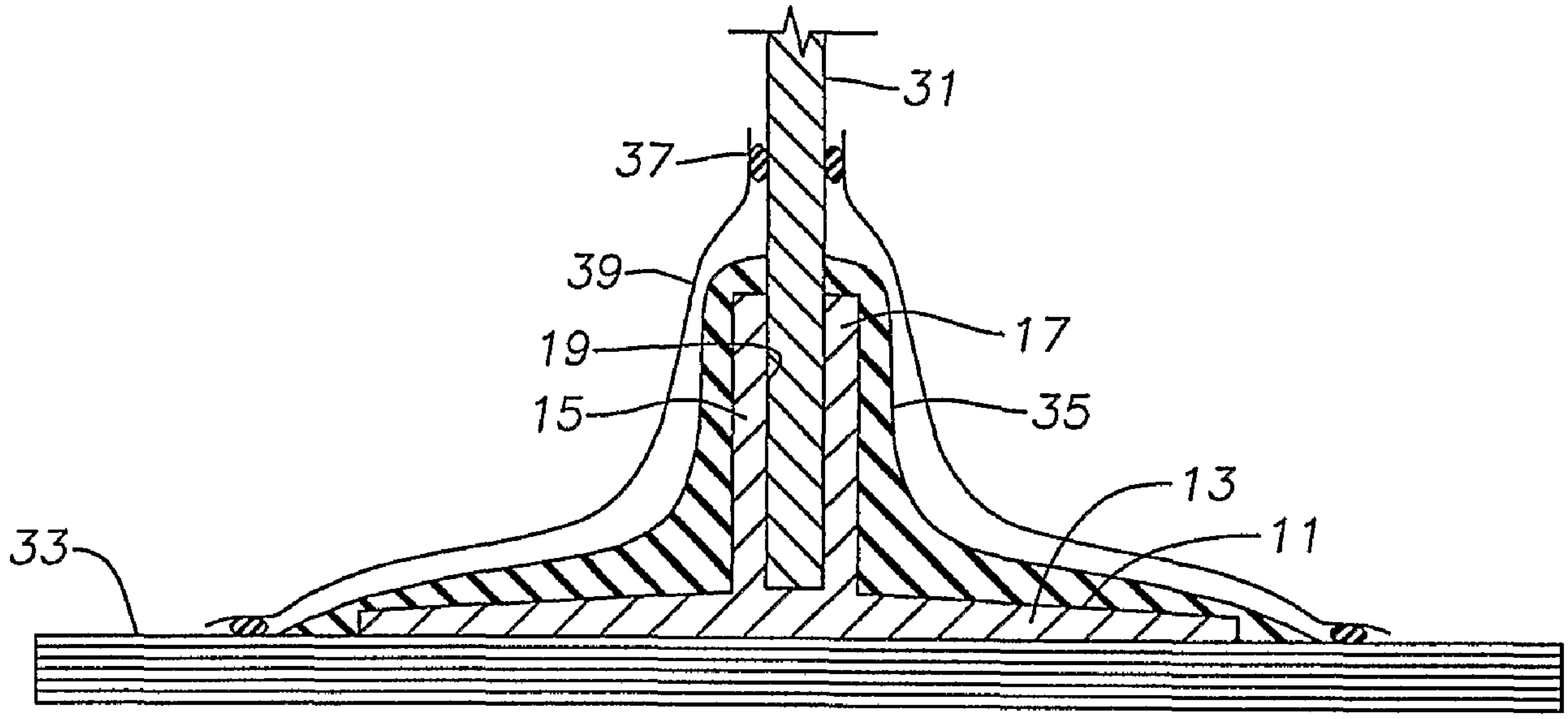
(54) Title: APPARATUS AND METHOD FOR JOINING DISSIMILAR MATERIALS TO FORM A STRUCTURAL SUPPORT MEMBER



(57) Abrégé/Abstract:
A preformed component or "preform" (11) for a structural member has a planar base with two longitudinal legs (15, 17) extending in parallel from the base (13). A channel (19) is defied between the legs (15, 17) for insertion of a plat panel (31) that forms the web of the structural member. The preform (11) is a composite material having continuous filaments of woven or braided fiber (21). The preform (11) is impregnated with a thermoset resin that bonds the web of the flange of the structural member. The perform (11) provides excellent structural support even if the web of the flange are formed from dissimilar materials such as metallic and composite. The resin is structurally reinforced with oriented fibers in such a manner as to provide coupling strength between the joined members.

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(71) Applicant: LOCKHEED MARTIN CORPORATION [US/US]; 6801 Rockledge Drive, Bethesda, MD 20817 (US).

(72) Inventor: MCKAGUE, Elbert, Lee, Jr.; 5000 Birch Hollow Lane, Fort Worth, TX 76132 (US).

(74) Agent: BRADLEY, James, E.; Bracewell & Patterson, L.L.P., P.O. Box 61389, Houston, TX 77208-1389 (US).

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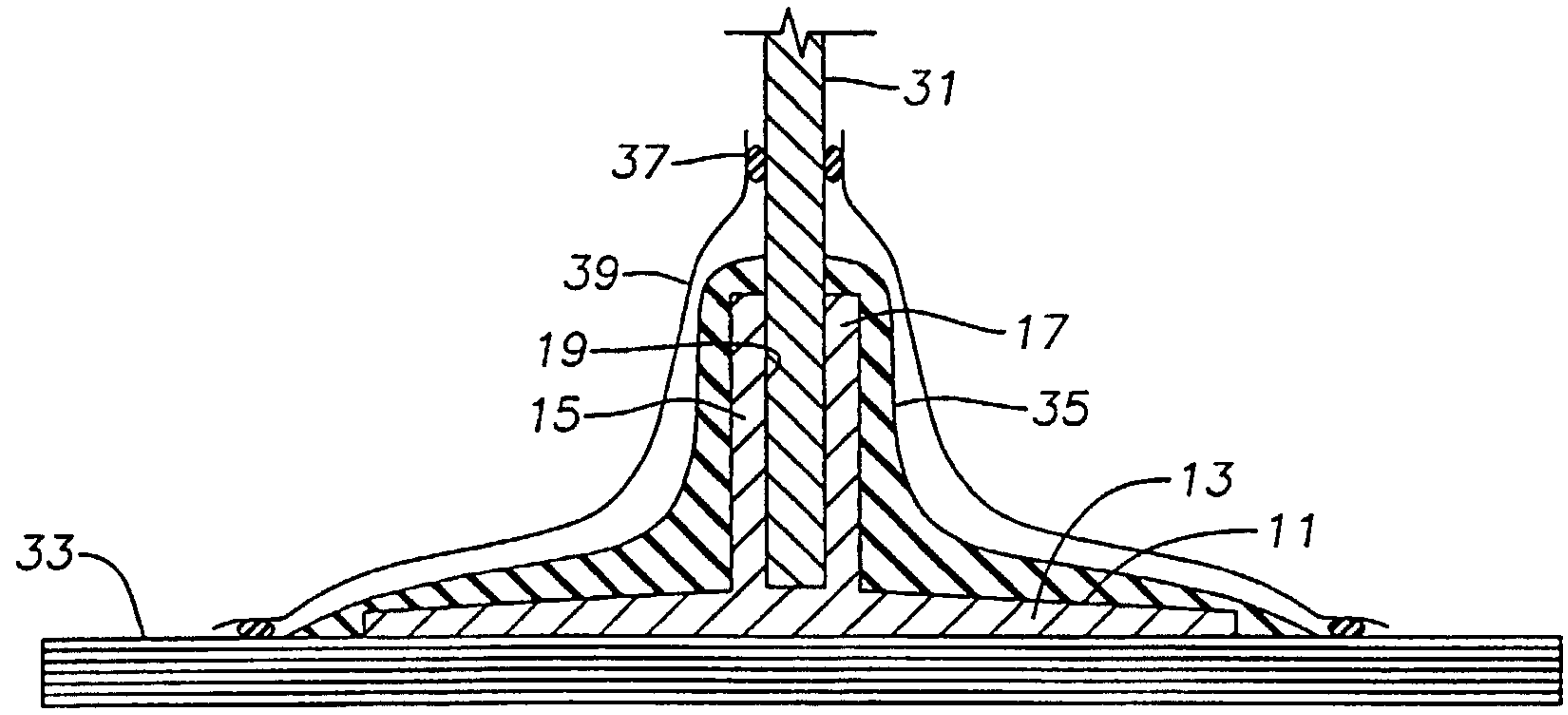
(54) Title: APPARATUS AND METHOD FOR JOINING DISSIMILAR MATERIALS TO FORM A STRUCTURAL SUPPORT MEMBER



(57) Abstract: A preformed component or "preform" (11) for a structural member has a planar base with two longitudinal legs (15, 17) extending in parallel from the base (13). A channel (19) is defied between the legs (15, 17) for insertion of a plat panel (31) that forms the web of the structural member. The preform (11) is a composite material having continuous filaments of woven or braided fiber (21). The preform (11) is impregnated with a thermoset resin that bonds the web of the flange of the structural member. The perform (11) provides excellent structural support even if the web of the flange are formed from dissimilar materials such as metallic and composite. The resin is structurally reinforced with oriented fibers in such a manner as to provide coupling strength between the joined members.

APPARATUS AND METHOD FOR JOINING DISSIMILAR MATERIALS TO FORM A STRUCTURAL SUPPORT MEMBER

BACKGROUND OF THE INVENTION

1. Technical Field:

The present invention relates in general to an improved structural member, and in particular to an improved structural beam, made by joining dissimilar materials. Still more particularly, the present invention relates to a structural composite preform for joining the web of a structure with flanges formed from dissimilar materials.

2. Description of the Prior Art:

Structural support spars or beams may have dissimilar materials joined to each other . For example, one type of beam has a web formed from a first material (such as a metal) secured to panels formed from a second, dissimilar material (such as a composite material). This type of beam has been pursued through a variety of design and manufacturing approaches since these structures offer the potential of providing excellent stiffness and strength-to-weight performance.

Prior approaches to joining dissimilar materials such as metals and composites have generally relied on mechanical fastening if the two elements are at an angle. As shown in **Figure** 1, a spar 1 having an inverted T-shaped metal panel 3 with a flange 5 is joined to a flat composite plate 7 with mechanical fasteners 9 such that metal panel 3 and composite plate 7 are perpendicular to each other. In such an arrangement, metal panel 3 must have flange 5 to enable fastening to composite plate 7. Moreover, the necessity of having flange 5 on metal panel 3 adds considerable cost to its fabrication since flange 5 significantly increases the volume of metal that must be purchased and then machined away. In addition, mechanical fastening involves drilling and countersinking holes, installing fasteners and, in some cases, treating the fastener heads to achieve a desired surface smoothness. These steps are expensive and can contribute an additional 25% to 60% to the overall cost of the spar assembly. Thus, an improved apparatus and method for forming a structural support member by joining dissimilar materials at an angle is needed.

SUMMARY OF THE INVENTION

A preformed component or "preform" for a structural support beam has a planar base with two longitudinal legs extending in parallel therefrom. A channel is defined between the legs of the preform, and a flat panel that forms the web of the structural support beam is inserted into the channel. The preform is a composite material having continuous filaments of woven or braided fiber. The preform is impregnated with a thermoset resin that joins and bonds the web to the flange of the structural support beam. The preform provides excellent structural support even if the web and the flange are formed from dissimilar materials such as metal and composite. The resin is structurally reinforced with oriented fibers in such a manner as to provide coupling strength between the joined members.

When a single filament is chosen for the preform, its properties are selected to minimize the difference in thermal expansion coefficients of the metal web and the composite flange. However, the preform may have two or more types of filaments with different properties. The filament in the base of the preform is chosen such that its axial thermal expansion coefficient matches that of the composite flange. The filament in the legs of the preform is chosen such that its axial thermal expansion coefficient matches that of the metal web. These filaments are used in combination to provide coupling strength between the joined metal web and composite flange by having the best structural fiber oriented parallel to the legs of the preform, and by its being interwoven into the base of the preform.

The foregoing and other objects and advantages of the present invention will be apparent to those skilled in the art, in view of the following detailed description of the preferred embodiment of the present invention, taken in conjunction with the appended claims and the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

So that the manner in which the features, advantages and objects of the invention, as well as others which will become apparent, are attained and can be understood in more detail, more particular description of the invention briefly summarized above may be had by reference to the embodiment thereof which is illustrated in the appended drawings, which drawings form a part of this specification. It is to be noted, however, that the drawings illustrate only a preferred embodiment of the invention and is therefore not to be considered limiting of its scope as the invention may admit to other equally effective embodiments.

Figure 1 is an isometric view of a conventional, prior art spar formed from dissimilar materials.

Figure 2 is an isometric view of a structural preform constructed in accordance with the invention.

Figure 3 is a sectional end view of the structural preform of **Figure 2**.

Figure 4 is an exploded, isometric view of the structural preform of **Figure 2**, a composite flange, and a metallic web.

Figure 5 is a schematic end view of the preform, flange, and web of **Figure 4** during fabrication.

Figure 6 is an exploded, isometric view of an alternate version of the structure of **Figure 4**, a metallic flange, and a composite web.

Figure 7 is an end view of a beam constructed from the components of **Figure 4** in accordance with the invention.

Figure 8 is an end view of an alternate embodiment of a beam constructed in accordance with the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to **Figures 2 and 3**, a preformed component or "preform" **11** for a structural support beam is shown. When viewed from the end or in cross-section, preform **11** resembles the Greek letter Π or "pi" having a longitudinal crossbar or base **13** with two longitudinal legs **15, 17** extending therefrom. A groove or channel **19** is defined between legs **15, 17**. Preform **11** is a composite material that is formed by weaving or braiding continuous bundles or tows of structural fibers **21** (**Figure 3**). The tows of fibers **21** are oriented to extend continuously throughout each segment of preform **11** including base **13** and legs **15, 17**. The fiber preforms may be formed to provide any desired fiber architecture needed to impart chosen load-carrying capability and to accommodate any desired web panel thickness. Preform **11** may be impregnated with a suitable thermoset resin that acts as an adhesive to bond together two dissimilar materials. The resin is structurally reinforced with the filaments and/or fibers oriented in x, y, and z directions in such a manner as to provide coupling strength between the joined members.

Alternatively, preform **11** may be unimpregnated so that resin may be infused at a later step of the overall manufacturing process. In the latter embodiment, preform **11** is constructed by weaving or braiding the filaments in such a way that the process is not inhibited. After curing, preform 11 may be machined as needed by an appropriate method to provide desired edge straightness, smoothness, and dimensional control.

Referring now to **Figure 4**, preform **11** is used to join a first member, such as a flat metallic panel or plate **31** to a flat composite plate or panel **33** at an angle. Metallic plate **31** has a zone **32** that is prepared for bonding to preform **11**. Preparation may be any suitable, established method appropriate to the selected metal alloy, such as chemical etching. The composite may also be prepared, in the zone to be mated with the preform, by a suitable method such as removal of a peel ply. In the embodiment shown, metallic panel **31** forms the web of a structural support member and composite plate **33** is perpendicular. However, composite plate **33** may form the web of the spar with metallic panel **31** as the other surface of the structural member, and the angle between the members may be acute (see **Figure 8**). The members can be joined at other angles relative to each other because the fibrous preform **11** is flexible prior to curing the resin. In **Figure 8**, a beam **71** has a metallic plate **77** secured at a non-orthogonal angle between upper and lower panels **73,75**. The bases **79** of the preforms **81** are substantially flat and parallel relative to panels **73, 75**, while the legs **83** of preforms **81** are inclined at the non-orthogonal angle relative to bases **79**. These concepts are not limited to I-beam type structural support members, but may be readily adapted for use in beams having other shapes as well, such as U-shaped, C-shaped, L-shaped, or Z-shaped beams, depending on the application.

During assembly, one of the longitudinal edges of metallic panel **31** is fully inserted into channel **19** of preform **11** until it bottoms out as shown in **Figure 5** or is appropriately close to bottoming out. The two legs **15, 17** closely receive and straddle the thickness of panel **31**. The vertical sides or edges of panel **31** are not attached to preform **11**. Next, a composite plate **33** of appropriate thickness, fiber orientation, and geometry is positioned against the base 13 of preform 11 opposite panel 31. Composite plate 33 may be either cured or uncured, but in the preferred embodiment of the invention, it is already cured to provide the desired configuration and dimensional tolerances in order to simplify the assembly tooling that is required.

The fastenerless assembly of the metallic and composite elements also may be accomplished via the following steps. (1) The base 13 of the uncured, resin-impregnated preform 11 is placed at the desired joining location onto the base plate or panel (usually composite plate 33) after it has been suitably cleaned or prepared for bonding. (2) Using appropriate fixtures, the metallic panel 31 is placed in channel 19 of uncured preform 11 at the desired angle relative to composite plate 33. (3) Appropriate boundary tooling, such as conventional molded shapes of silicone rubber or other suitable pressure intensifier/transmitter 35 (Figure 5), is positioned against each side of preform 11. (4) Vacuum bagging materials 39 are placed around the resulting assembly, sealed with sealant beads 37, and a vacuum is pulled under the bag. If the preform was previously unimpregnated, a selected resin is infused therein. (5) The total structure is heated according to a thermal profile suitable for curing the thermosetting resin that impregnates preform 11, thereby creating structural bonds that integrally link preform 11 to metallic panel 31 to create a desired structure. If desired or required, autoclave pressure can be simultaneously applied to provide compaction of preform 11 during cure of the resin. The resin and the maximum cure temperatures are selected to provide a cured glass transition temperature greater than the intended use temperature of the assembly. Alternatively, a resin can be used which has a suitable chemistry, such as free-radical polymerization, so that an energetic beam of electrons can initiate and complete the cure (a process known in the industry as electron beam curing). (6) Following completion of the required cure cycle, the bagging materials and positioning fixtures are removed, yielding a completed assembly.

Alternatively, it should be readily apparent to one skilled in the art that all of the curable materials may be uncured at the time of assembly of metallic panel 31, preforms

11, and composite plate **33**. After the respective components are assembled and placed in suitable tooling, the resin in preform **11** can be injected in a resin transfer molding type of process, or infused by placing a thick layer of resin over the preform and applying a vacuum bag. Although this reduces the number of cure cycles required, it significantly complicates the assembly cure tooling requirements, thereby increasing both cost and risk. By still another means, a co-bonding of preform **11** with an uncured composite plate **33** can be accomplished. Although the process was described for only one end of panel **31**, this series of steps may be performed simultaneously on both ends of panel **31** to form the end product spar or beam **41** (**Figure 7**).

Depending upon the actual use temperature of the assembly and the chemistry of the selected resin, it may be necessary to expose the assembly to resin cure temperatures as high as 350 degrees F. At such temperatures, the dimensional growth of each plate or panel **31, 33** is governed by its respective thermal expansion coefficient. An aluminum panel **31**, having an expansion coefficient of approximately **12** micro-inch/inch/degree F, will expand by about 3300 micro-inch/inch of length. In contrast, a composite plate **33** formed from carbon fiber impregnated with epoxy resin has negligible expansion. This difference in expansion imparts a significant strain on the joined panel and plate **31, 33**, thereby degrading the mechanical performance of the assembly and making it difficult to achieve the desired dimensional control of the assembly because of bowing induced by the thermal mismatch. In the legs **15, 17** of preform **11**, an axial fiber having a thermal expansion coefficient much closer to that of aluminum panel **31** would reduce the amount of strain built into the assembly by the curing operation.

In **Figure 6**, an alternate embodiment depicts a preform **51** having two (or more) types of filaments and/or fibers having different properties. Base filament **53**, which is oriented parallel to the length of the preform, is chosen such that its axial thermal expansion coefficient matches that of composite plate **33** as closely as possible. Leg filament **55**, which also is oriented parallel to the length of the preform, is chosen such that its axial thermal expansion coefficient matches that of metallic panel **31** having bonding zone **32** as closely as possible. Filaments **53, 55** are used in combination to provide coupling strength to the joined metallic panel **31** and composite plate **33** by being oriented parallel to the legs **57, 59** of preform **51** (in the direction of arrow **61**), and by being interwoven into the base **63** of preform **51**. The fiber or filament **53** chosen to provide coupling strength is oriented orthogonal to the fiber and/or filaments **55** chosen for thermal expansion characteristics. These orthogonal fibers **53** traverse the width of preform **51**, following its shape back and forth in a manner resulting from weaving of woof fibers, i.e., those fibers which are perpendicular to the lengthwise direction of the preform.

The extent and pattern, if any, for blending the two axial fibers **53, 55** in the area where the legs **57, 59** intersect base **63** are determined on an application-specific basis through analysis and/or empirical methods. When a single filament is chosen for preform **51 (Figure 4)**, its properties are selected in order to minimize its difference in thermal expansion coefficients with metallic panel **31** and composite plate **33**. However, in all cases the filaments are oriented parallel to the axis and continuous length of the preform.

An example of filament or fiber selections would be E-glass® or S-glass® fibers for the axial direction of preform **11**, and high strength carbon fibers such as Hexcel AS4® or Toray T300® for the coupling strength direction (parallel to the vertical direction of legs **15, 17**). Glass fibers provide a thermal expansion coefficient on the order of 6 micro-inch/inch/degree F, whereas carbon fibers have an expansion coefficient near zero. Thus, glass fibers are a better thermal strain match with aluminum than with carbon fiber. Alternatively, metallic filaments in the axial direction impart a smaller difference in thermal strains between the legs **15, 17** of preform **11** and metallic panel **31**. High modulus carbon fibers such as Hexcel IM7® or Amoco T600M® may be used for the coupling strength direction, where the total distance over which strain differences are multiplied is very small.

During the cure of the resin, temperature is controlled so that the resin gels at as low a temperature as is practical. This step is followed by a slow rise in temperature to levels necessary to achieve the required glass transition temperature of the cured resin. Gelling the resin at a lower temperature aids the establishment of a stress-free temperature point that is lower than that required to achieve the needed glass transition temperature. The rise in temperature after gellation must be very slow so that resin cross-link density is increased at such a rate that increasing levels of thermally-induced strain does not break down the tender bond. After completing the maximum temperature dwell, cool down preferably occurs at as slow a rate as practical until a temperature is reached that is at least **50** degrees F lower than the gellation temperature. This slow cool down allows some relaxation to occur in the polymer and helps to preserve the lowest possible stress-free temperature. The difference in stress-free temperature and ambient temperature, multiplied by the difference between thermal expansion coefficient of metallic panel **31** and that of the axial fibers in preform **11**, determine the amount of thermally-induced strain in the resulting assembly.

The present invention has several advantages. Woven or braided pi-shaped preforms join metallic and composite plates or panels at angles relative to each other without the use of mechanical fasteners. The preforms provide much greater strength than conventional adhesive bonding techniques while simplifying and reducing the cost of manufacturing. The present invention does not require drilling, countersinking, fastener installation, or fastener head treatments. Whereas mechanical fastening involves incremental work progressing along the joint length, the present invention treats the entire joint in one step. This enables a very large reduction of 20% to 55% in the total cost of the assembly. In addition, the present invention is also lighter in weight than prior art solutions because the resin-impregnated preform weighs less than the number of fasteners that would be required to provide an equivalent strength joint. Moreover, the metallic member can be a flat plate or panel without a flange, thereby significantly reducing the cost of fabricating the metal detail for many complex, high performance structures such as those used for aircraft.

While the invention has been shown or described in only some of its forms, it should be apparent to those skilled in the art that it is not so limited, but is susceptible to various changes without departing from the scope of the invention.

CLAIMS

What is claimed is:

1. A structural member, comprising:

a first member formed from one of a metallic material and a composite material, the first member having a pair of longitudinal edges extending in an axial direction;

a second member formed from the other of the metallic and composite materials;

a preform formed from composite materials and having a base with a pair of axially elongated legs extending therefrom to define a channel therebetween, wherein the preform is formed from filaments that extend through the base and legs; and wherein

one of the longitudinal edges of the first member is bonded in the channel of the preform and the second member is bonded to a surface of the base of the preform.

2. The structural member of claim 1 wherein the filaments of the preform include axially oriented filaments that are selected to minimize a difference in thermal expansion coefficients of the first member and the second member.

3. The structural member of claim 1 wherein the preform has a pi-shaped cross-section.

4. The structural member of claim 1 wherein the axial filaments are oriented parallel to an axial, continuous length of the preform.

5. The structural member of claim 1 wherein the second member and the base of the preform are inclined at a non-orthogonal angle relative to the first member.

6. The structural member of claim 1 wherein the preform is impregnated with a thermoset resin that acts as an adhesive to bond together the first member and the legs.

7. The structural member of claim 1 wherein the filaments of the preform include axial filaments that are oriented parallel to an axial continuous length of the preform and orthogonal filaments that are perpendicular to the axial filaments.

8. The structural member of claim 1 wherein the preform has a first type of axial filament in the base, and a second type of axial filament in the legs.

9. The structural member of claim 8 wherein the first and second types of axial filaments are blended in an area where the legs intersect the base.

10. The structural member of claim 8 wherein the first type of axial filament has an axial thermal expansion coefficient that substantially matches an axial thermal expansion coefficient of the second member, and wherein the second type of axial filament has an axial thermal expansion coefficient that substantially matches an axial thermal expansion coefficient of the first member.

11. A structural member, comprising:

a first member formed from one of a metallic material and a composite material, the first member having a pair of longitudinal edges extending in an axial direction;

a second member formed from the other of the metallic and composite materials;

a generally pi-shaped preform formed from composite materials and having a base with a pair of axially elongated legs extending therefrom to define a channel therebetween, the preform being formed from axial filaments that extend through the base and legs, wherein the axial filaments are oriented parallel to the axial direction and a continuous length of the preform, and the axial filaments minimize a difference in thermal expansion coefficients of the first member and the second member; and wherein

one of the longitudinal edges of the first member is bonded in the channel of the preform and the second member is bonded to a surface of the base of the preform.

12. The structural member of claim 11 wherein the second member and the base of the preform are inclined at a non-orthogonal angle relative to the first member.

13. The structural member of claim 11 wherein the preform is impregnated with a thermoset resin that acts as an adhesive to bond together the first member and the second member.

14. The structural member of claim 13 further comprising orthogonal filaments extending through the base and the legs perpendicular to the axial filaments.

15. The structural member of claim 11 wherein the preform has a first type of axial filament in the base, and a second type of axial filament in the legs, and wherein the first and second types of axial filaments are blended in an area where the legs intersect the base.

16. The structural member of claim 15 wherein the first type of axial filament has an axial thermal expansion coefficient that substantially matches an axial thermal expansion coefficient of the second member, and the second type of axial filament has an axial thermal expansion coefficient that substantially matches an axial thermal expansion coefficient of the first member.

17. A method for fabricating a structural member, comprising the steps of:

(a) providing a first member formed from one of a metallic material and a composite material and having a longitudinal edge extending in an axial direction, and a second member formed from the other of the metallic and composite materials;

(b) forming a preform from composite materials, the preform having a base with a pair of legs extending therefrom to define a channel therebetween, wherein the preform has filaments that extend through the base and the legs;

(c) positioning boundary tooling on the preform, first member, and second member and heating the structural member;

(d) bonding the longitudinal edge of the first member in the channel of the preform such that the legs of the preform closely receive the longitudinal edge of the first member; and

(e) bonding the base of the preform to the second member to form a structural member.

18. The method of claim 17 wherein steps (d) and (e) comprises heating the first member, second member, and preform to create structural bonds therebetween.

19. The method of claim 17, further comprising the step of impregnating the preform with a thermoset resin.

20. The method of claim 17 wherein the preform of step (b) is unimpregnated, and further comprising the step of infusing or injecting the unimpregnated preform with resin.

21. The method of claim 17, further comprising the step of applying autoclave pressure to provide compaction of the preform.

22. The method of claim 17, further comprising the step of curing said one of the first member and the second member formed from the composite material.

23. The method of claim 17 wherein step (c) comprises placing a sealed pressure intensifier over the preform inside a vacuum bag.

24. The method of claim 17, further comprising the step of inclining the first member of the preform at a non-orthogonal angle relative to the second member and the base of the preform.

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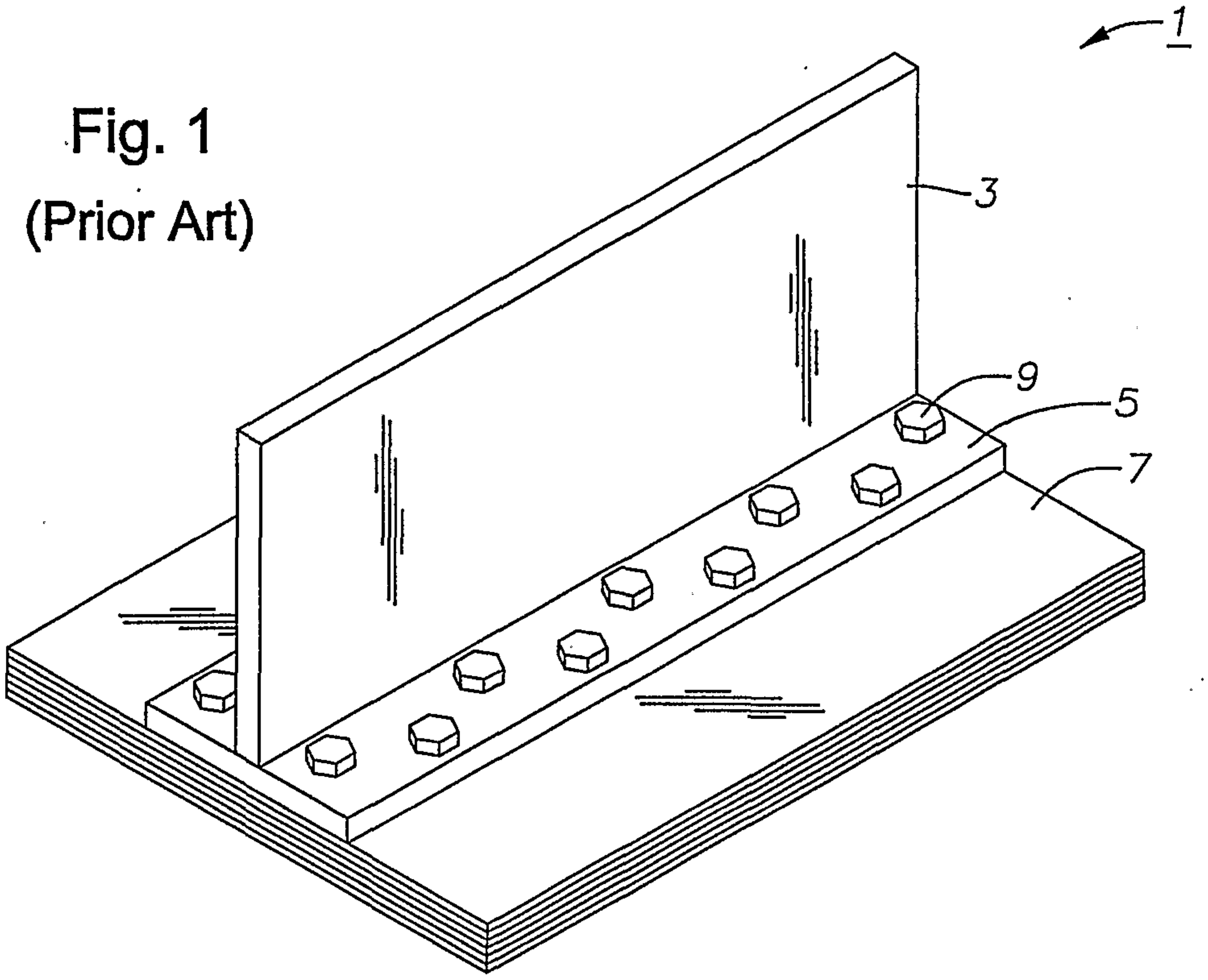
Fig. 1
(Prior Art)



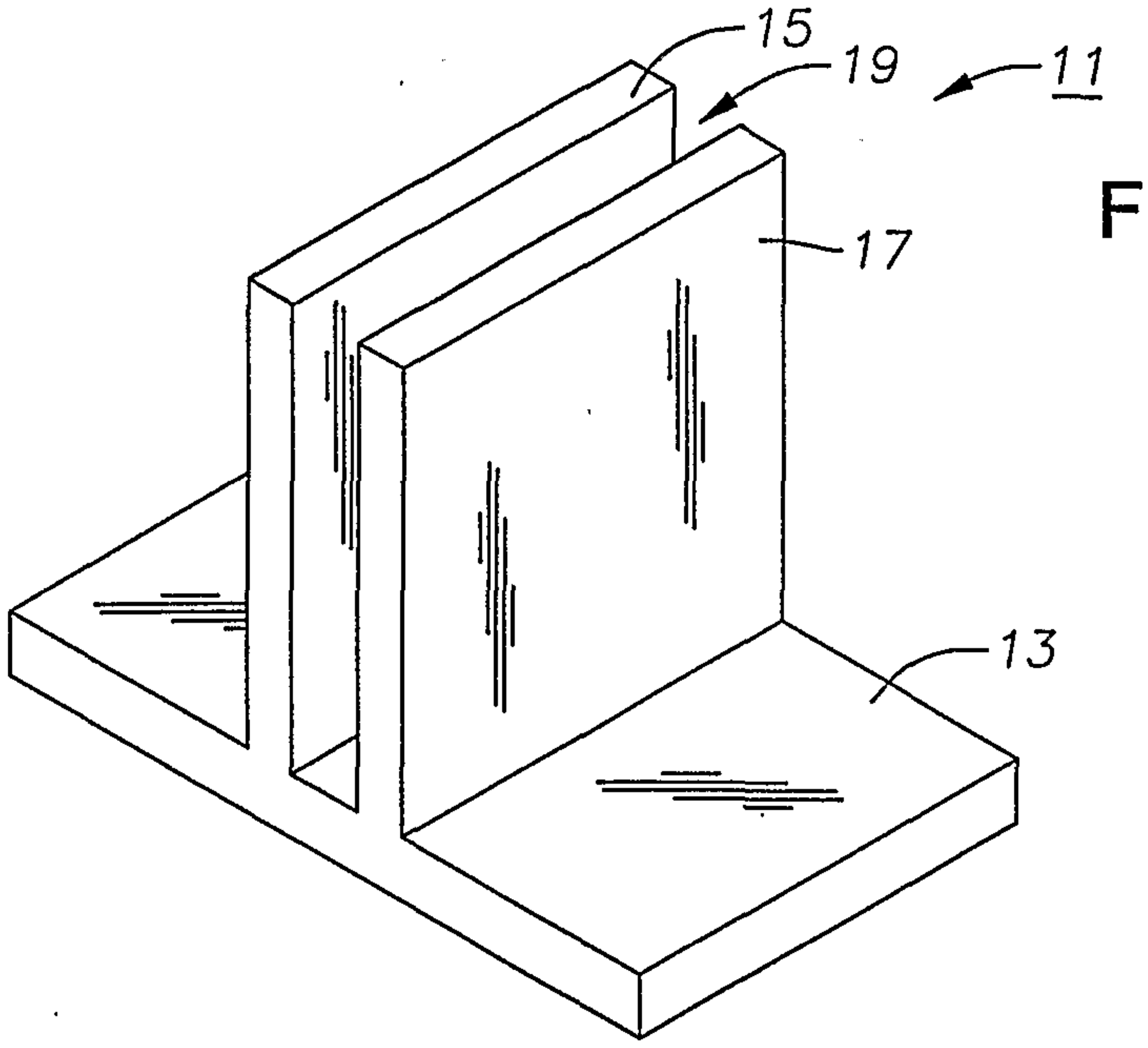


Fig. 2

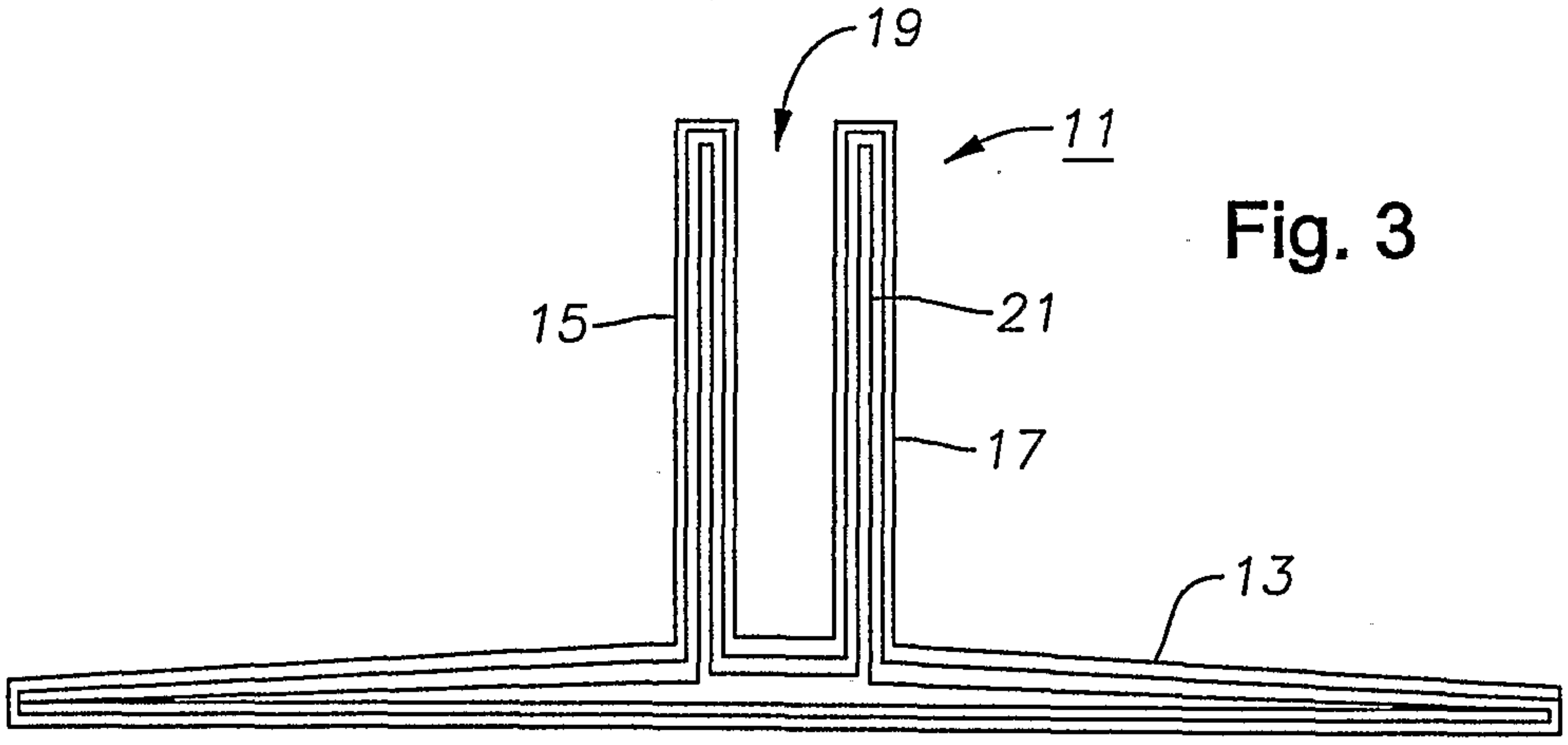


Fig. 3

Fig. 4

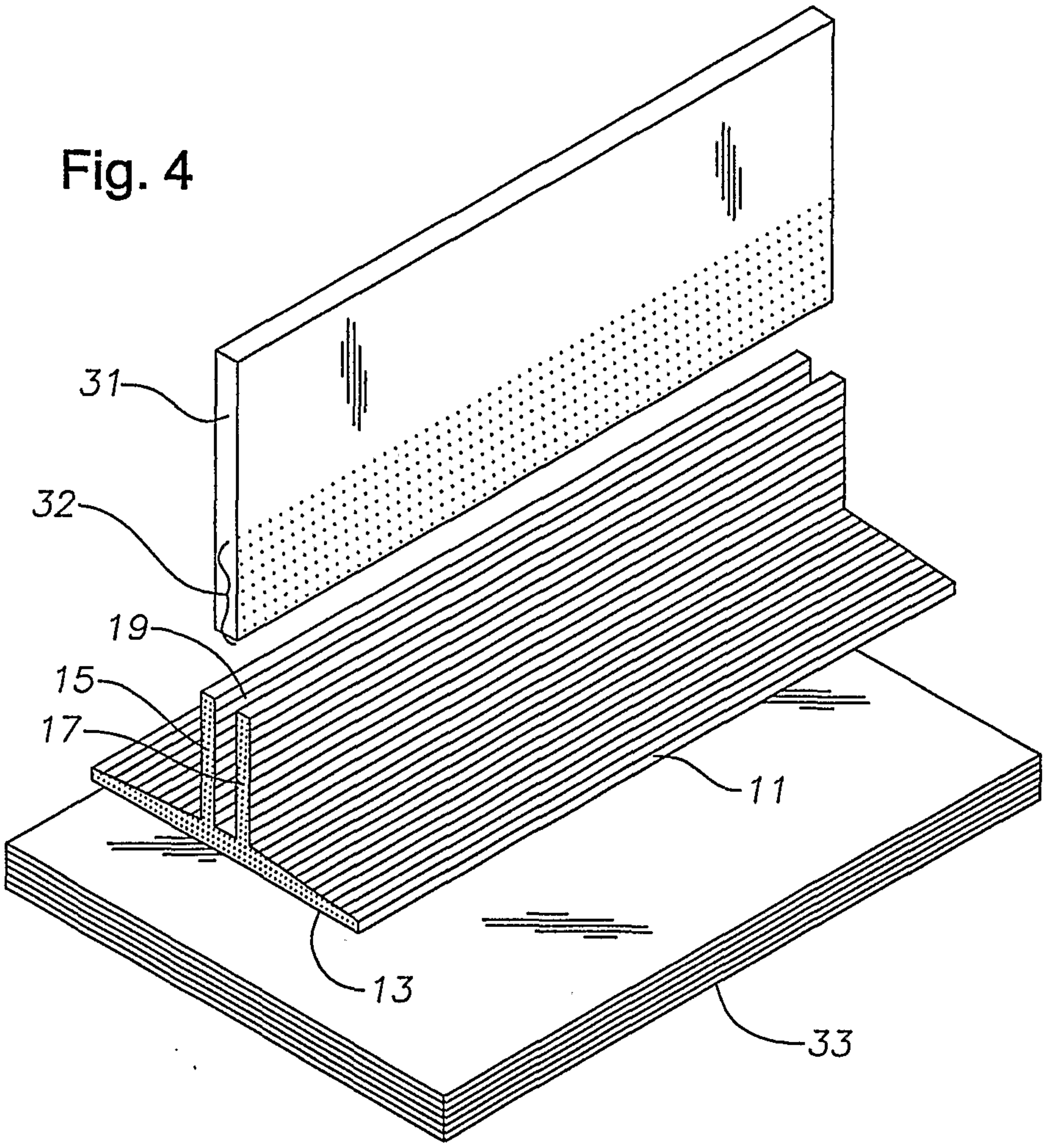


Fig. 5

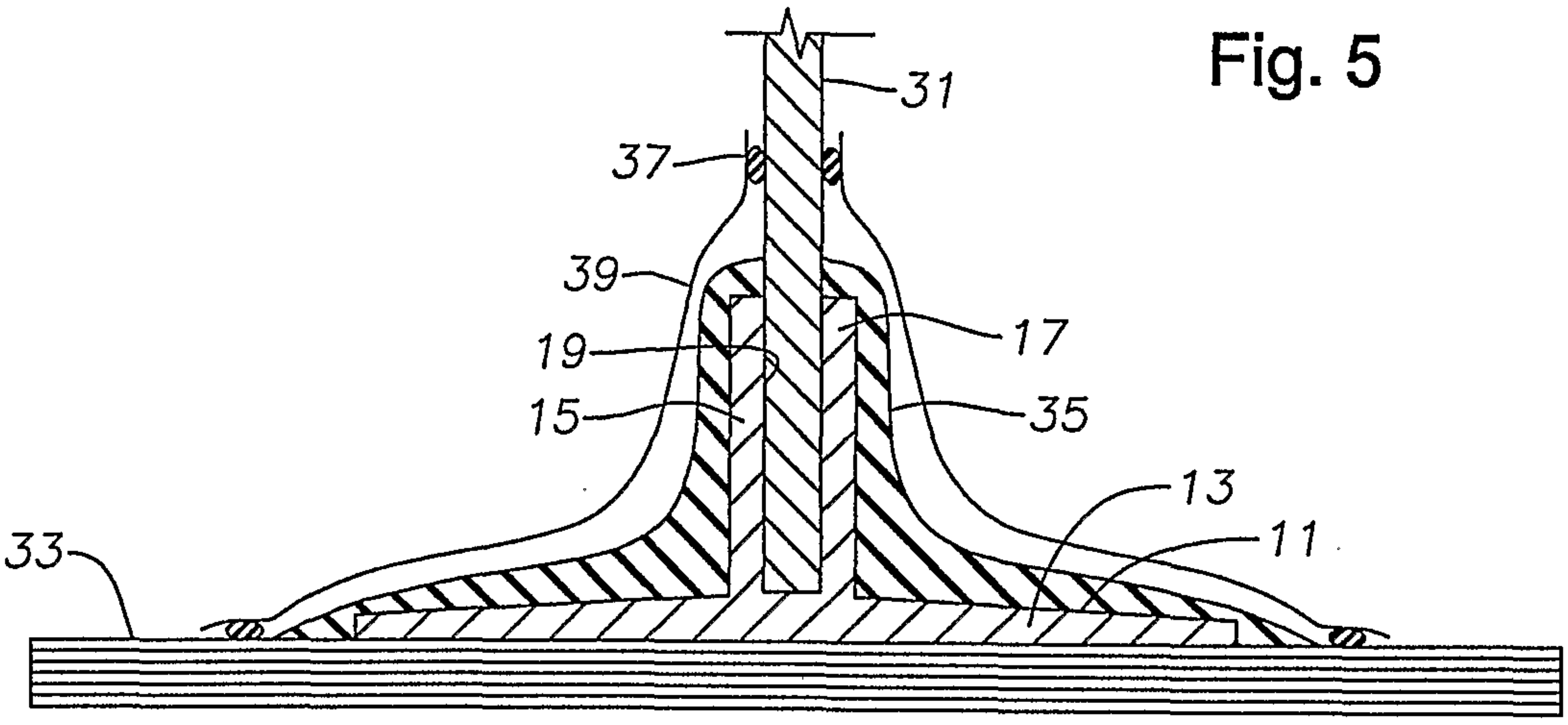


Fig. 6

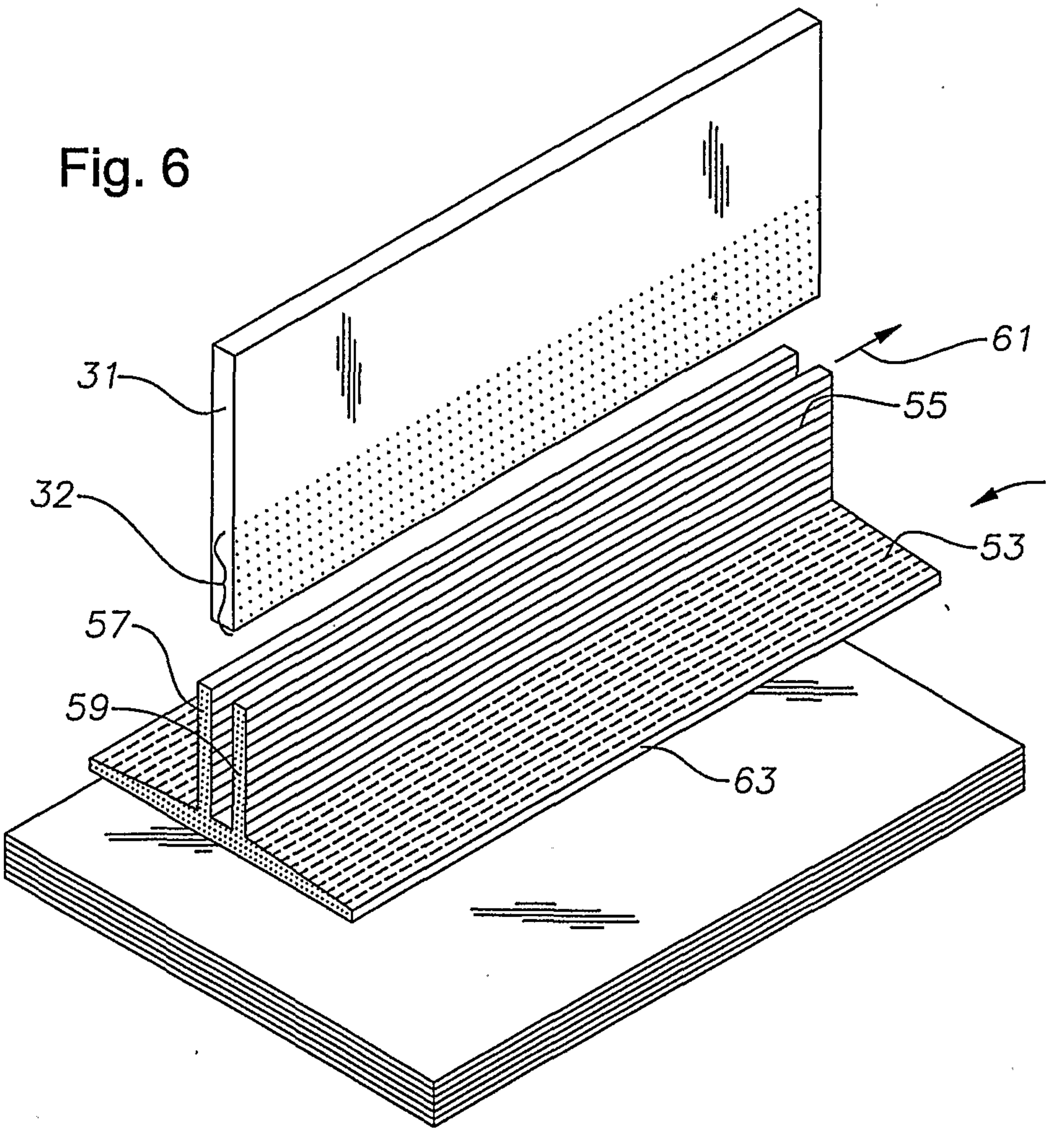


Fig. 7

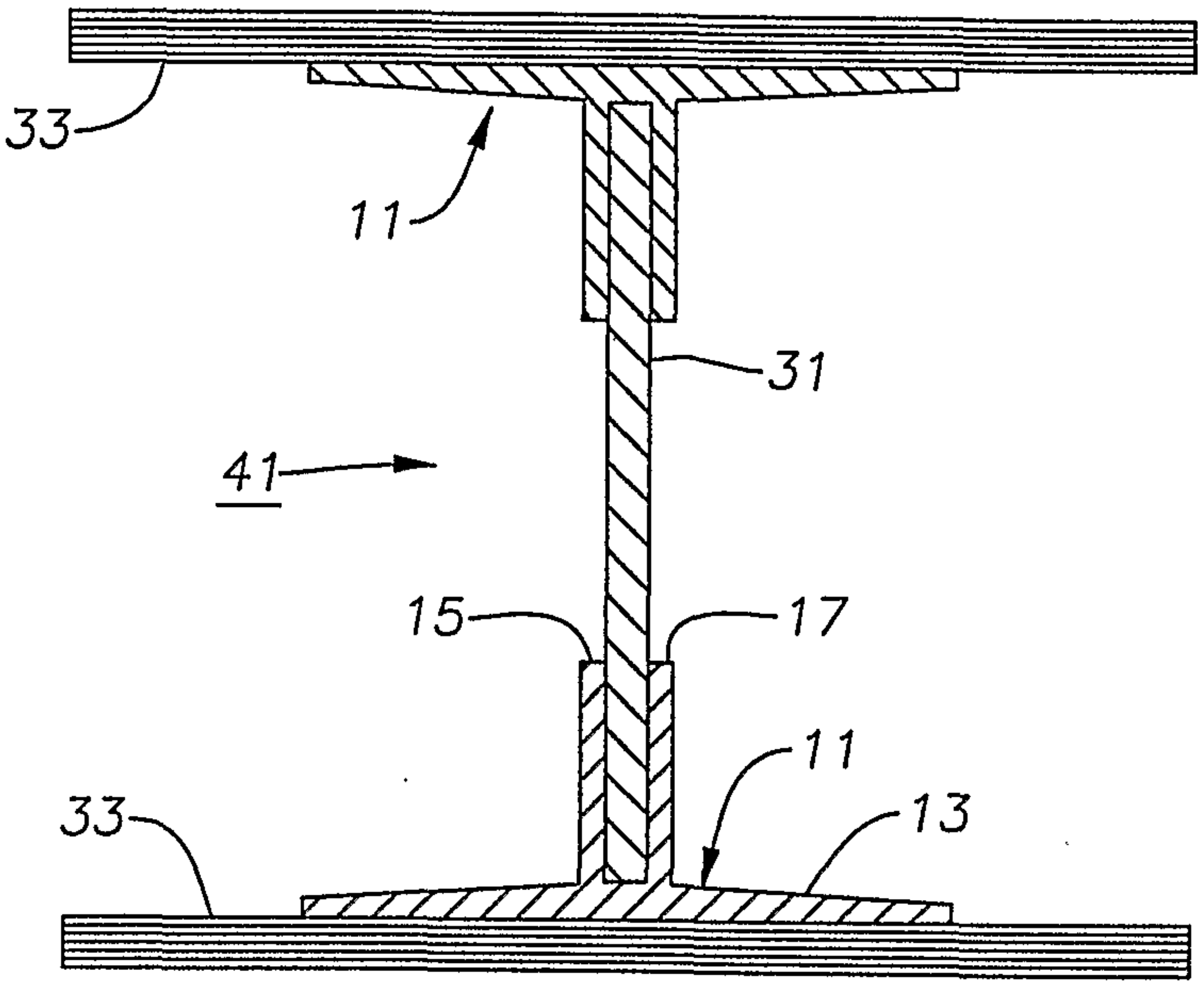
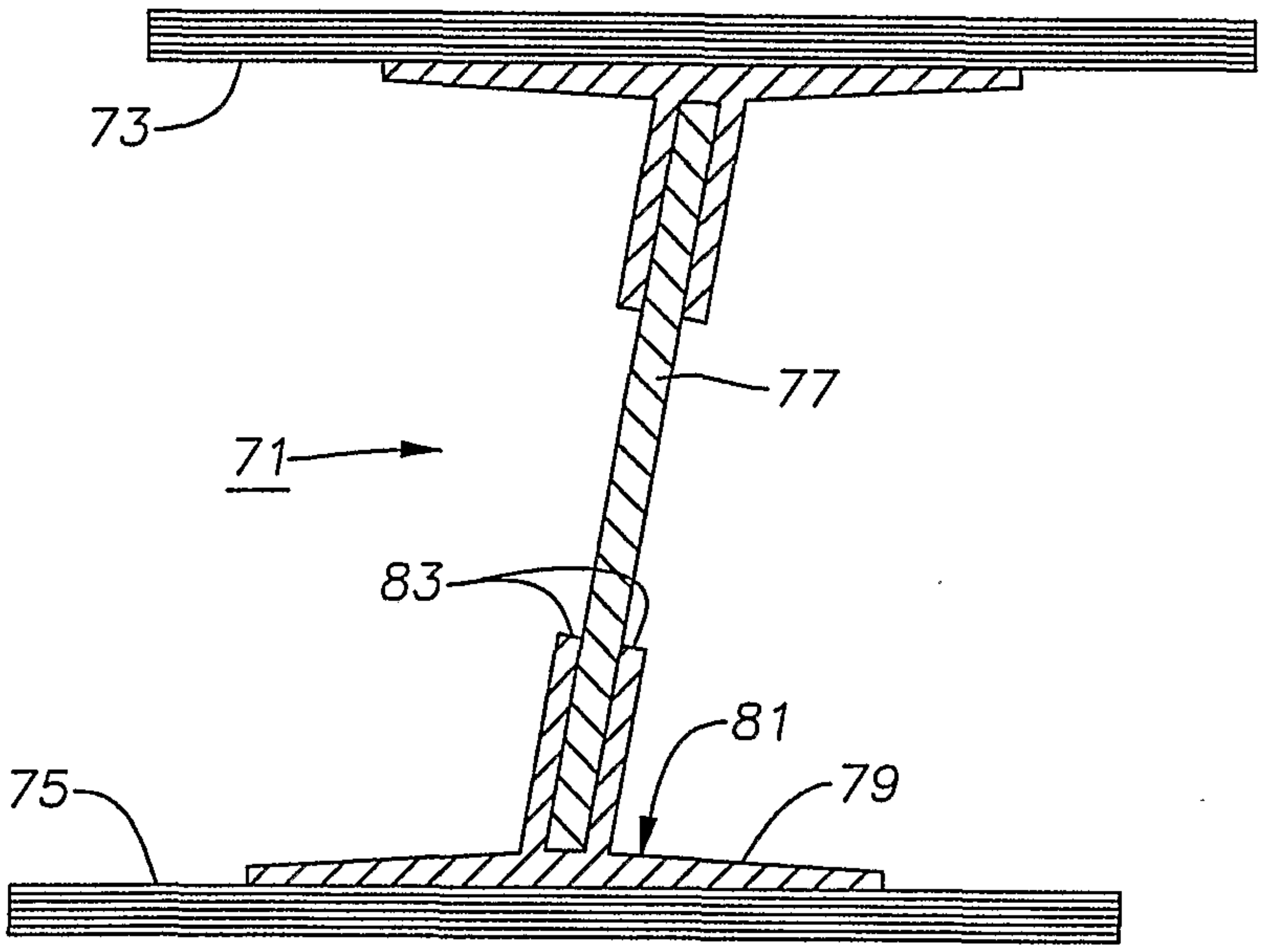


Fig. 8

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