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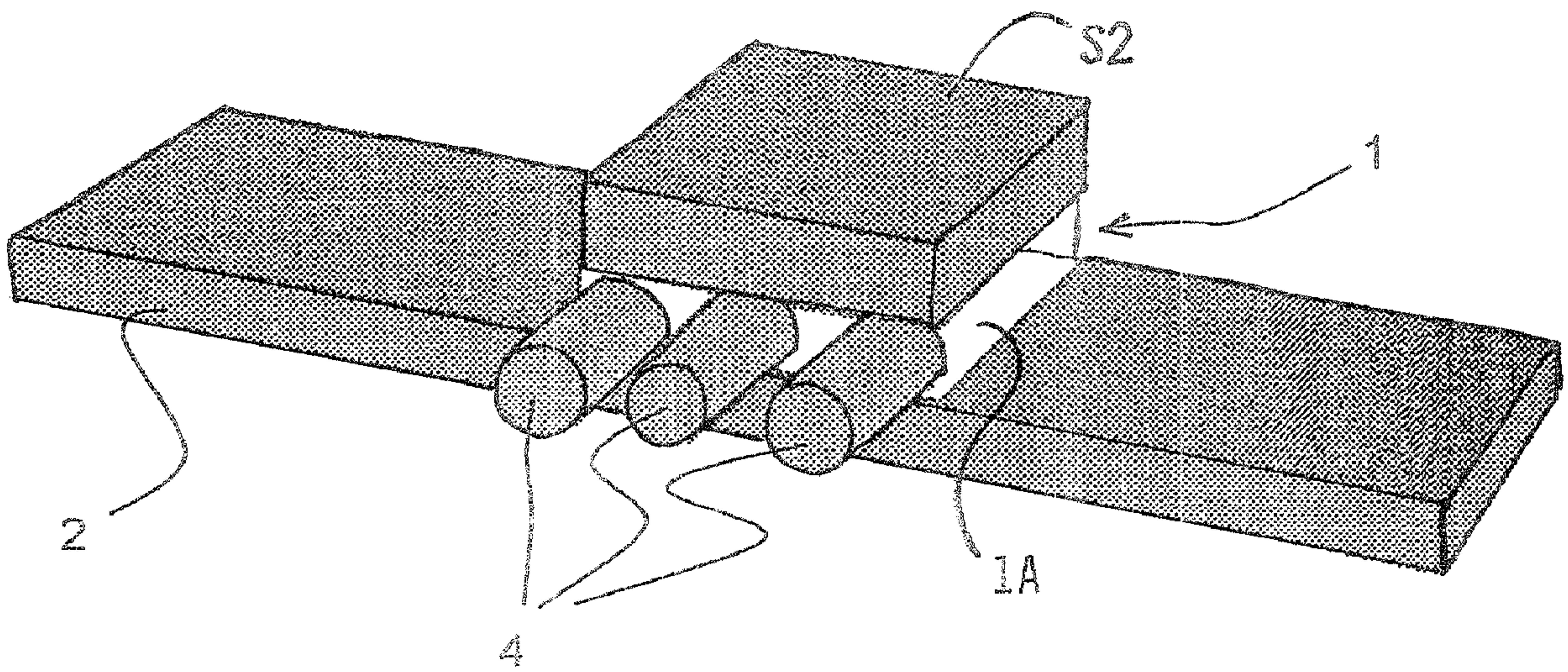
(54) Titre : STRUCTURE LEGERE PARTICULIEREMENT ADAPTEE AUX AERONEFS ET METHODE DE FABRICATION CONNEXE

(54) Title: LIGHTWEIGHT STRUCTURE ESPECIALLY FOR AN AIRCRAFT AND METHOD FOR MAKING SUCH A STRUCTURE



(57) Abrégé/Abstract:
An additional fiber reinforced layer reduces crack propagation in a lightweight structure of an outer skin adhesively bonded to a reinforcing frame. For this purpose the additional fiber reinforced layer is interposed between the outer skin and the frame and adhesively bonded to the outer skin and to the frame. The additional layer has reinforcing fibers extending in parallel to each other or the reinforcing fibers are woven into a fabric embedded in a synthetic adhesive bonding material. The embedding of the parallel fibers or of the fiber fabric in the bonding material is performed either prior to the bonding or during the bonding of the additional layer to the outer skin and to the reinforcing frame.

TITLE OF THE INVENTION

Lightweight Structure Especially for an Aircraft and Method for Making Such a Structure

ABSTRACT OF THE DISCLOSURE

An additional fiber reinforced layer reduces crack propagation in a lightweight structure of an outer skin adhesively bonded to a reinforcing frame. For this purpose the additional fiber reinforced layer is interposed between the outer skin and the frame and adhesively bonded to the outer skin and to the frame. The additional layer has reinforcing fibers extending in parallel to each other or the reinforcing fibers are woven into a fabric embedded in a synthetic adhesive bonding material. The embedding of the parallel fibers or of the fiber fabric in the bonding material is performed either prior to the bonding or during the bonding of the additional layer to the outer skin and to the reinforcing frame.

FIELD OF THE INVENTION

Lightweight structures are used primarily in aircraft construction, particularly aircraft bodies including an outer skin adhesively bonded to a framework. The invention also relates to a method for constructing such a lightweight structure by adhesive bonding.

BACKGROUND INFORMATION

Lightweight structures for use in the aircraft and spacecraft technologies include an outer skin which is strengthened on its inner surface by a reinforcement or stiffening framework. Such a framework is in fact a three dimensional structure but may be referred to as being "two-dimensional" to distinguish the framework from a three-dimensional aircraft or spacecraft body. An aircraft body, for example, is constructed as a lightweight structure with an outer skin that is reinforced by longitudinally extending stringers and circumferentially extending ribs. The stringers and ribs are adhesively bonded to the inner surface of the outer skin. In designing such lightweight structures, particularly in the aircraft industry, a special value is allocated to reducing weight while simultaneously keeping in mind, depending on the particular type of use, the strength requirement, the fatigue requirement, and the tolerance against damages, referred to herein as damage tolerance. Further, lightweight structures used in the aircraft construction must meet special requirements regarding the damage tolerance that lightweight aircraft components must have for safety reasons.

Increasing the damage tolerance of such lightweight structures can be accomplished in different ways. One example involves increasing the entire skin thickness, or providing different skin thicknesses in different locations throughout the lightweight structure so that the skin is thicker in locations exposed to higher loads while the skin is thinner in locations exposed to lesser loads. Strengthening the skin by increasing the thickness of the skin even only locally, increases the overall weight more than is acceptable. Another possibility of increasing the skin strength resides in using materials which themselves have an improved damage tolerance. Such materials are disclosed in German Patent Publication DE 102 38 460 A1, which describes metallic laminated materials or fiber composite laminates which are on the market under the Trademark GLARE®.

Fiber reinforced laminates have the advantage of a very good damage tolerance combined with a relatively small density compared to monolithic metallic materials. However, presently fiber reinforced laminates have a lower static strength characteristic compared to monolithic materials. As a result, a weight reduction of the lightweight structure is only possible in a few areas where the particular component is primarily designed with regard to damage tolerant characteristics rather than strength characteristics. Furthermore, the production of fiber reinforced laminates is relatively expensive compared to the production of monolithic materials due to the, at least partially, complicated pretreatment required for the subsequent adhesive bonding operation and due to the use of additional prepreg films and the need for manually positioning and preparing the individual laminae for the subsequent adhesive bonding operation. As a result, the production costs can be significantly higher than the production costs of monolithic sheet metals. Significantly smaller costs are involved in the production of metallic laminate materials without fiber reinforcement as described in the above mentioned German Patent Publication DE 102 38 460 A1.

OBJECTS OF THE INVENTION

In view of the foregoing it is the aim of the invention to achieve the following object singly or in combination:

to improve the damage tolerance of fiber reinforced laminated materials and of monolithic sheet metal materials;

to improve the fatigue characteristics of such materials by reducing crack formation and by retarding crack propagation in these materials;

to significantly reduce the crack propagation speed so that the structure remains serviceable for a longer period of time than was possible heretofore; and to provide a method for the production of such materials or lightweight structures made of these materials.

The invention further aims to avoid or overcome the disadvantages of the prior art, and to achieve additional advantages, as apparent from the present specification. The attainment of these objects is, however, not a required limitation of the present invention.

SUMMARY OF THE INVENTION

The above objects have been achieved according to the invention in a lightweight structure by adhesively bonding a fiber strengthened reinforcing layer between the outer skin and the strengthening support structure also referred to herein simply as frame. The reinforcing layer effectively retards the formation and propagation of cracks in the outer skin. The present lightweight structures are produced by embedding the fibers of the reinforcing layer either prior to or during the adhesive bonding into a synthetic material matrix which is preferably an adhesive bonding material.

It has been found that the teaching of the invention is equally applicable to outer skins made of fiber reinforced laminated materials or of sheet metal laminated materials, or of monolithic sheet metal materials. These materials are used to form the outer skin of lightweight structures.

The use of reinforcing layers according to the invention between an outer skin of metallic laminates and the ribs and/or stringers of a frame, as compared to an embodiment with an outer skin made of a monolithic sheet metal layer, has substantially reduced the propagation of cracks as long as the cracks do not get longer than approximately the spacing between two neighboring stringers. However, if the crack length approaches a length of about twice said spacing, the crack propagation reduction is more effective in a structure with an outer skin of a monolithic sheet metal material. Generally, the retardation of the crack propagation according to the invention can increase the useful life of a lightweight structure up to five times compared to conventional structures without an additional reinforcing layer between the outer skin and the stringers and/or ribs of the frame.

According to the invention not only the damage tolerance has been increased due to the retardation of the crack propagation, a weight reduction has also been achieved because it has been found that the use of the reinforcing layers between the outer skin and the ribs and/or stringers permits the use of thinner sheet metal layers for forming the outer skin. As a result the sheet metal thickness can be reduced up to 20% compared to conventionally used sheet metal thicknesses, thereby correspondingly reducing the total weight of the lightweight structure such as an aircraft body. This important advantage is particularly significant in connection with upper body shell sections of an aircraft body.

BRIEF DESCRIPTION OF THE DRAWINGS

In order that the invention may be clearly understood, it will now be described in connection with example embodiments thereof, with reference to the accompanying drawings, wherein:

Fig. 1 is a perspective view in a direction toward a plane I-I shown in Fig. 6 showing a reinforcing layer of matrix embedded fibers between a stringer and an outer monolithic sheet metal skin;

Fig. 2 is a view similar to that of Fig. 1, illustrating an outer skin of laminated sheet metals;

Fig. 3 is a view similar to that of Fig. 1, showing a reinforcing layer made of a matrix embedded woven fiber fabric and a single layer outer skin;

Fig. 4 is a view similar to that of Fig. 3, with a laminated outer skin;

Fig. 5 shows two characteristic curves illustrating a half crack length as a function of applied load cycles; and

Fig. 6 shows a broken away plan view of ribs and stringers of an aircraft body lightweight structure with the view extending radially outwardly to clarify the position of the present reinforcing layer shown in Figs. 1 to 4.

DETAILED DESCRIPTION OF A PREFERRED EXAMPLE EMBODIMENT AND OF THE BEST MODE OF THE INVENTION

Fig. 6 shows a view onto a broken away section of an aircraft lightweight body structure including a frame or framework FW of ribs R1, R2, R3 extending circumferentially around the longitudinally aircraft axis while stringers S1, S2, S3 extend parallel to the longitudinal aircraft axis. The ribs and stringers are adhesively bonded to the inwardly facing surface of an outer skin 2. A plane extending perpendicularly to the plane of the sheet of the drawing and designated by arrows I-I illustrates the position of a reinforcing layer in the perspective view of Fig. 1 between the outer skin 2 and a stringer S2 in the framework FW. More specifically, the reinforcement layers according to the invention are positioned between the outer skin 2 and the ribs, or between the outer skin and the stringers or between the outer skin and the ribs and stringers.

Fig. 1 shows a reinforcing layer 1 bonded by an adhesive matrix 1A to an outer skin 2 and to a stringer S2. The reinforcing layer 1 comprises fibers 4 arranged in parallel to each other and embedded in the matrix 1A. The outer skin 2 is made of a monolithic sheet metal. The matrix 1A is an adhesive that, after curing, bonds the reinforcing layer 1A to the stringer S2 and to the outer skin. The fibers 4 in the matrix 1A retard any crack propagation thereby improving the damage tolerance and thus the service life of the lightweight structure.

In Fig. 2 the outer skin 12 is a sandwich or laminated structure of two sheet metal layers 12A and 12B bonded to each other by an adhesive 12C. The reinforcing layer 11 is made of damage tolerant fibers 14 adhesively bonded in a matrix 11A between the outer skin 12 and the stringer 13. Crack propagation in the outer skin 12 is retarded or slowed down significantly by the present reinforcing layer as will be explained below with reference to Fig. 5.

Fig. 3 shows an embodiment in which the outer skin 22 is a monolithic member as in Fig. 1. The reinforcing layer 21 comprises a fiber fabric with weft fibers and warp fibers 24 embedded in an adhesively bonding matrix 21A which simultaneously bonds the reinforcing layer 21 to the outer skin 22 and to the stringer 23.

Fig. 4 shows an embodiment in which the outer skin 32 is a laminated structure including for example two monolithic sheet metal layers 32A and 32B bonded to each other by an adhesive bonding layer 32C. Fiber composite layers strengthened by the bonding layer 32C may alternatively be used instead of sheet metal layers. Epoxy resin may be used for the bonding of the layers 32A and 32B to each other. Epoxy resin may also be used to embed the reinforcing fiber fabric 34 in a respective matrix

31A which, upon curing, bonds the stringer 33 to the reinforcing layer 31 and the latter to the outer skin 32.

In each of Figs. 1, 2, 3 and 4 the reinforcing layers 1, 11, 21 and 31 perform the function of increasing the damage tolerance characteristics of the entire lightweight structure, particularly the outer skin since the crack formation and crack propagation in the outer skin is at least retarded or slowed down. For this purpose the fibers of the reinforcing layers should be oriented to cross a crack propagation direction.

In all embodiments shown in Figs. 1 to 4, the width of the reinforcing layers 1, 11, 21 and 31 preferably corresponds to the width of the respective stringer or rib. Such width is preferably within the range of about 10mm to about 80 mm. The reinforcing layers 1 and 11 shown in Figs. 1 and 2 are preferably made of a monolithic material, particularly an aluminum lithium alloy containing preferably 1% to 3% by weight of lithium or other high strength aluminum alloys.

In addition to the layer width within the range of 10 to 80 mm, the reinforcing layers 1, 11, 21, 31 have a layer thickness including the bonding adhesive forming the matrix 1A, 11A, 21A and 31A within the range of 0.05 mm to 0.3 mm. This layer thickness is smaller than the thickness of the stringers and ribs which is within the range of 0.6 mm to 2.0 mm.

The fibers are preferably made of glass fibers, carbon fibers, polyaromatic amide fibers, aluminum oxide fibers, silicon carbide fibers or basalt fibers. The fibers may also be metal wires such as aluminum wires, titanium wires or magnesium wires. Any type of fibers are embedded in a synthetic material matrix that is preferably also an adhesive bonding material such as epoxy resin. The embedding step may be performed prior or during the adhesive bonding. The fibers have a length of at least 10 mm and a diameter within the range of 0.001 mm to 0.3 mm.

Any adhesive bonding systems compatible with the fibers, stringers and ribs may be used for the present purposes. The reinforcing layers are preferably secured to the inner surface of the outer skin together with the ribs and/or stringers of the framework in a single adhesive bonding operation.

The outer skin is preferably formed of aluminum alloys particularly aluminum lithium alloys with about 1% to 3% by weight of lithium, magnesium alloys, and titanium alloys. Laminated materials comprising two or more adhesively bonded plies or such plies with an intermediate sheet metal layer are also suitable for producing the outer skin 2. Fiber reinforced plies combined with sheet metals or vice versa are equally suitable as outer skin for the present purpose.

Fig. 5 shows two curves A and B illustrating the crack propagation or halt crack length in mm as a function of applied load cycles. Curve A shows a rapid propagation of a crack in a conventional lightweight structure even well prior to 5000 load cycles. Curve B represents a lightweight structure with reinforcing layers 1, 11, 21, 31 between the outer skin and the framework FW. Curve B shows a significant retarding of the propagation of a fatigue crack H, whereby the damage tolerance and the useful life of the lightweight structure is correspondingly increased. The improvement has been achieved for monolithic and for laminated skin structures.

Although the invention has been described with reference to specific example embodiments, it will be appreciated that it is intended to cover all modifications and equivalents within the scope of the appended claims. It should also be understood that the present disclosure includes all possible combinations of any individual features recited in any of the appended claims.

WHAT IS CLAIMED IS:

1. A lightweight structure comprising a reinforcing frame including ribs and stringers, an outer skin adhesively bonded to said reinforcing frame and an additional fiber reinforced layer for retarding crack propagation interposed between said outer skin and said reinforcing frame, and an adhesive bond between said additional fiber reinforced crack propagation retarding layer and said outer skin and said reinforcing frame.

2. The lightweight structure of claim 1, wherein said additional fiber reinforced crack propagation retarding layer comprises fibers embedded in a matrix, said fibers extending in parallel to each other.

3. The lightweight structure of claim 1, wherein said additional fiber reinforced crack propagation retarding layer comprises fibers woven into a fabric embedded in a matrix, said fibers crossing each other.

4. The lightweight structure of claim 1, wherein said additional fiber reinforced crack propagation retarding layer comprises fibers embedded in a matrix having a damage tolerant characteristic.

5. The lightweight structure of claim 4, wherein said fibers having a crack propagation retarding characteristic are selected from the group consisting of glass fibers, carbon fibers, polyaromatic amide fibers, aluminum oxide fibers, silicon carbide fibers and basalt fibers.

6. The lightweight structure of claim 4, wherein said fibers having a crack propagation retarding characteristic are metal wires selected from the group of aluminum wires, titanium wires, magnesium wires, and wires of alloys of these metals including aluminum lithium alloy wires.

7. The lightweight structure of claim 6, wherein said metal wires have a diameter within the range of 0.001 mm to 0.3 mm.

8. The lightweight structure of claim 4, wherein said fibers having a crack propagation retarding characteristic have a diameter within the range of 0.001 mm to 0.3 mm.

9. The lightweight structure of claim 1, wherein said additional fiber reinforced crack propagation retarding layer is a strip having a strip width within the range of 10 mm to 80 mm.

10. The lightweight structure of claim 1, wherein said additional fiber reinforced crack propagation layer comprises fibers having a length of at least 10 mm.

11. The lightweight structure of claim 1, wherein said outer skin is constructed of a monolithic sheet metal.

12. The lightweight structure of claim 11, wherein said monolithic sheet metal is any one of an aluminum alloy, a magnesium alloy, and a titanium alloy.

13. The lightweight structure of claim 12, wherein said aluminum alloy is an aluminum lithium alloy.

14. The lightweight structure of claim 13, wherein said aluminum lithium alloy comprises 1% to 3% by weight of lithium.

15. The lightweight structure of claim 1, wherein said outer skin comprises a laminated material.

16. The lightweight structure of claim 1, wherein said additional fiber reinforced crack propagation retarding layer has a layer thickness, following its adhesive bonding to said reinforcing frame, within the range of 0.05 mm to 0.3 mm.

17. The lightweight structure of claim 1, wherein said additional fiber reinforced crack propagation retarding layer comprises strips interposed between said outer skin and said ribs and stringers and adhesively bonded to said outer skin and to said ribs and stringers.

18. A method for producing a lightweight structure, comprising a reinforcing frame including ribs and stringers, an outer skin adhesively bonded to said reinforcing frame and at least one fiber reinforced layer for retarding crack propagation interposed between said outer skin and said reinforcing frame, and an adhesive bond between said fiber reinforced crack propagation retarding layer and said outer skin and said reinforcing frame, said method comprising the following steps:

a) embedding fibers in a matrix material to form said crack propagation retarding fiber reinforced layer as a fiber composite layer; and

b) adhesively bonding said fiber composite layer to said outer skin and to said reinforcing frame.

19. The method of claim 18, further comprising using in said embedding step an adhesive material as said matrix material to form an adhesive prepreg, inserting said prepreg between said outer skin and said reinforcing frame and adhesively bonding said prepreg to said outer skin and to said reinforcing frame by curing said prepreg.

20. The method of claim 18, further comprising forming said fiber composite layer as a cured layer and then adhesively bonding said cured layer to said outer skin and to said reinforcing frame.

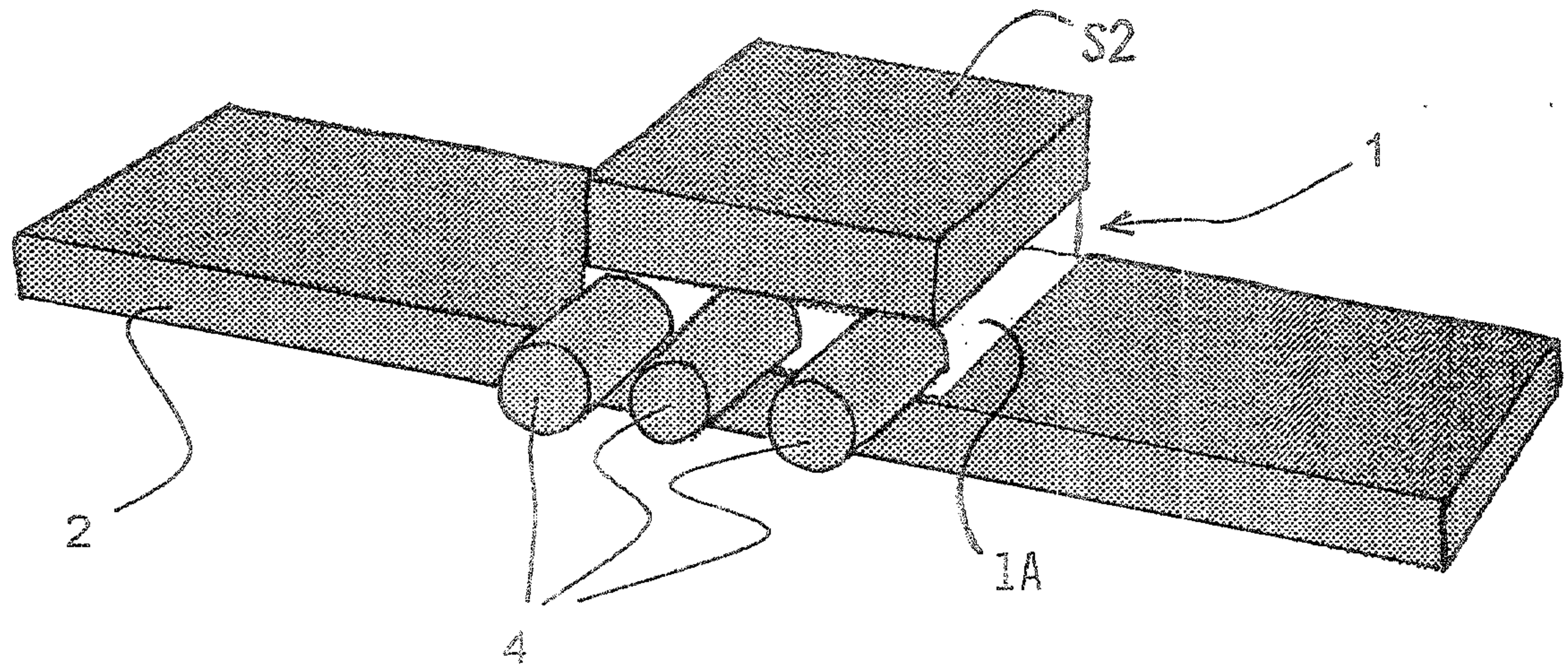


Fig. 1

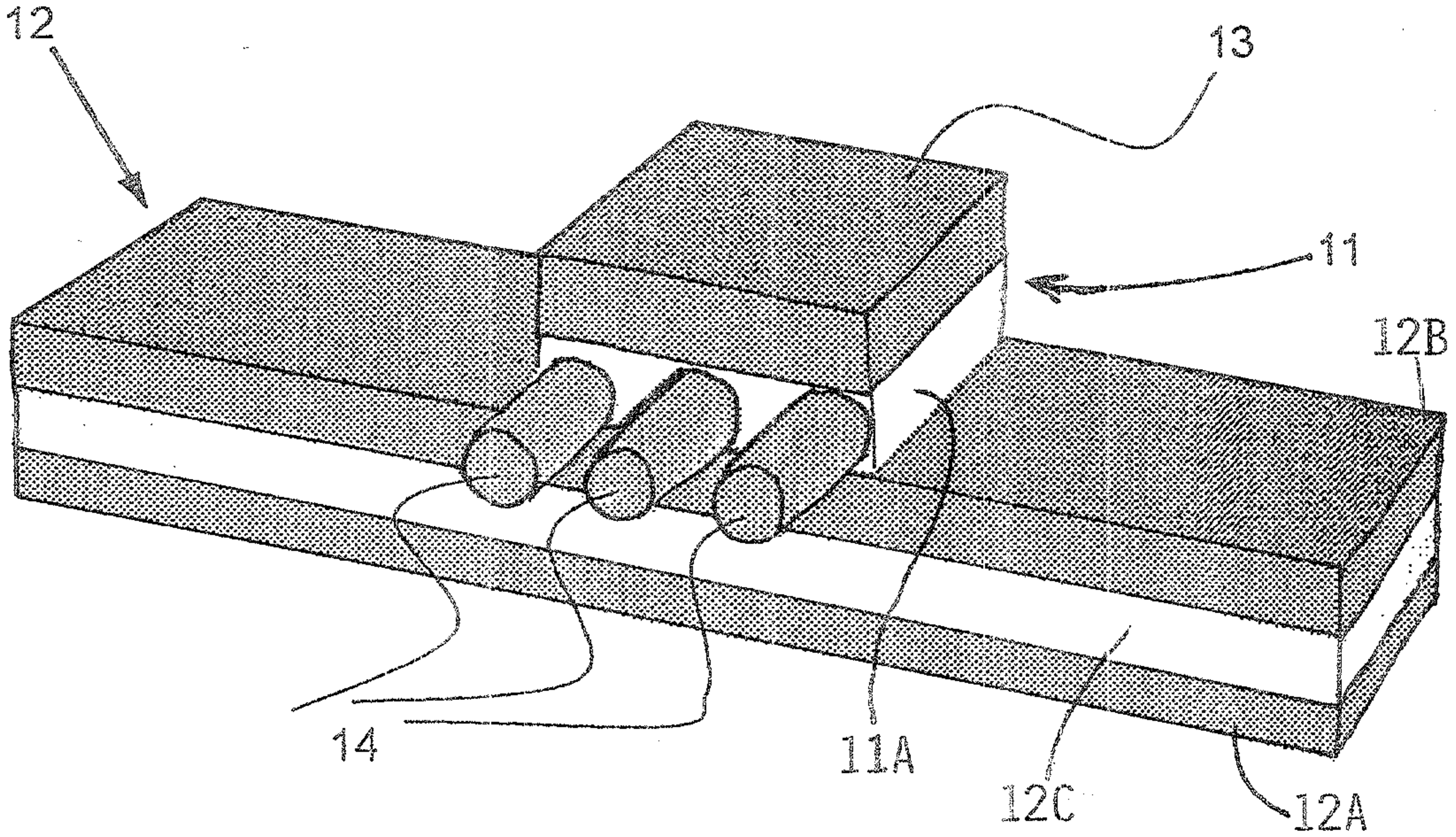


Fig. 2

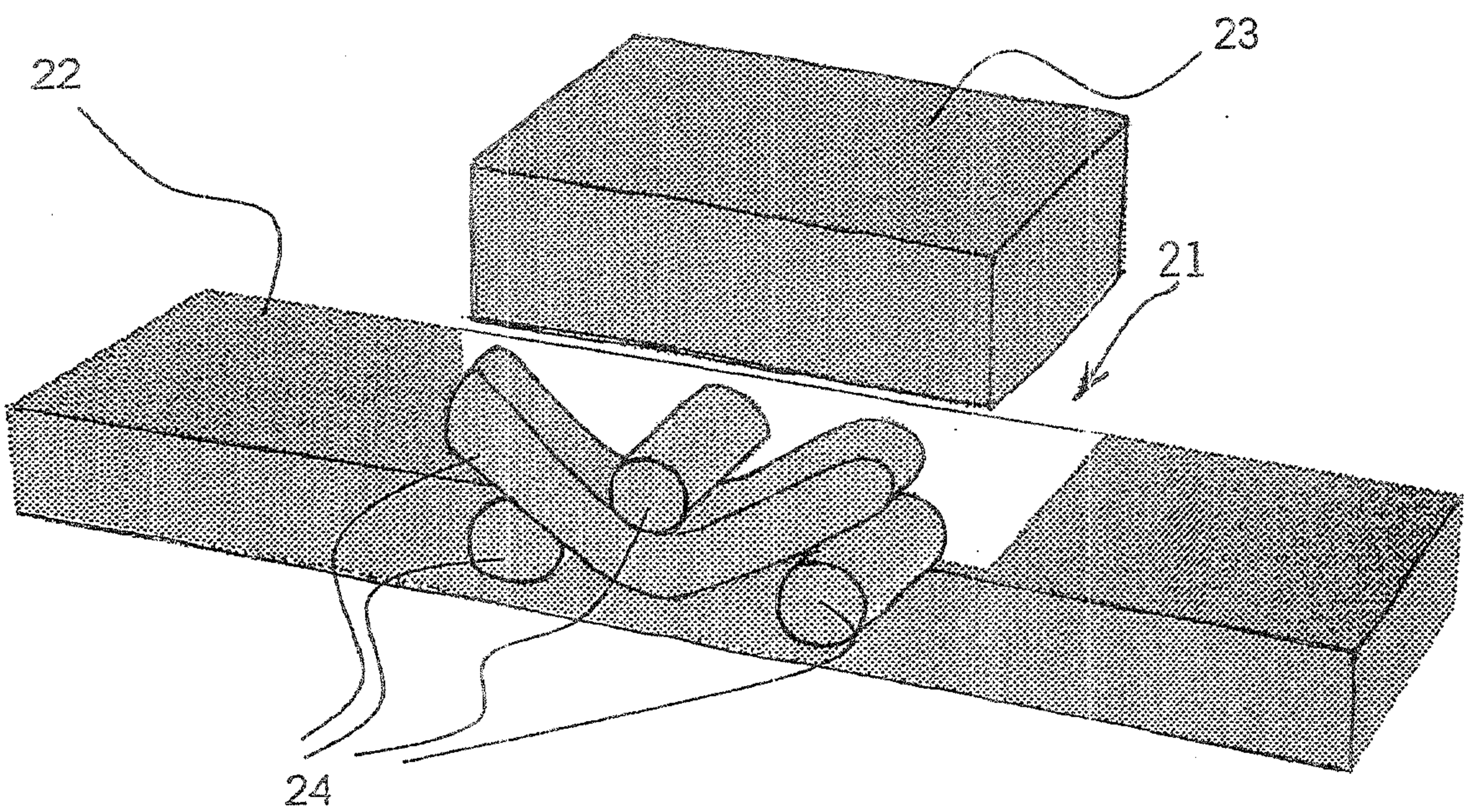


Fig. 3

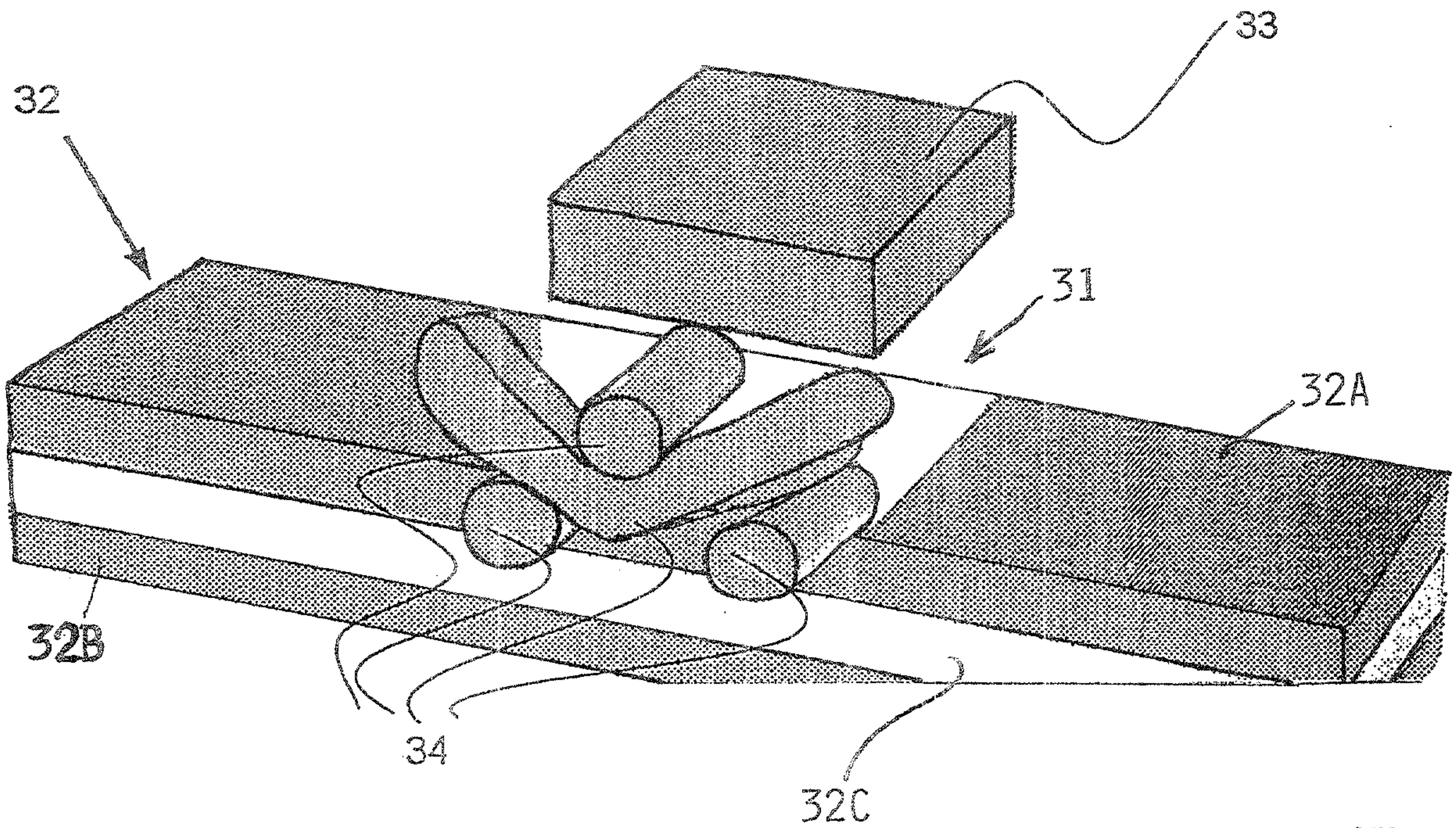
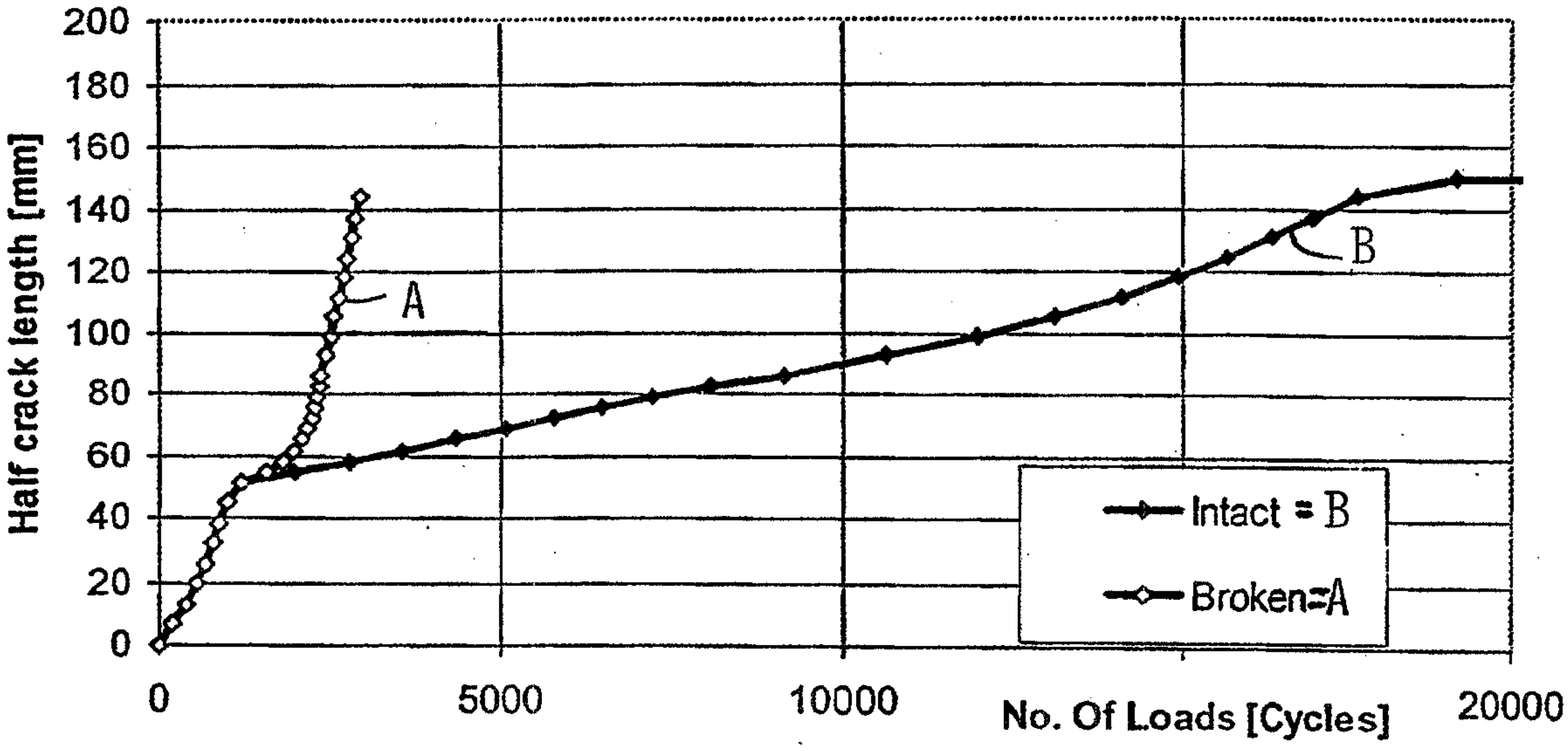
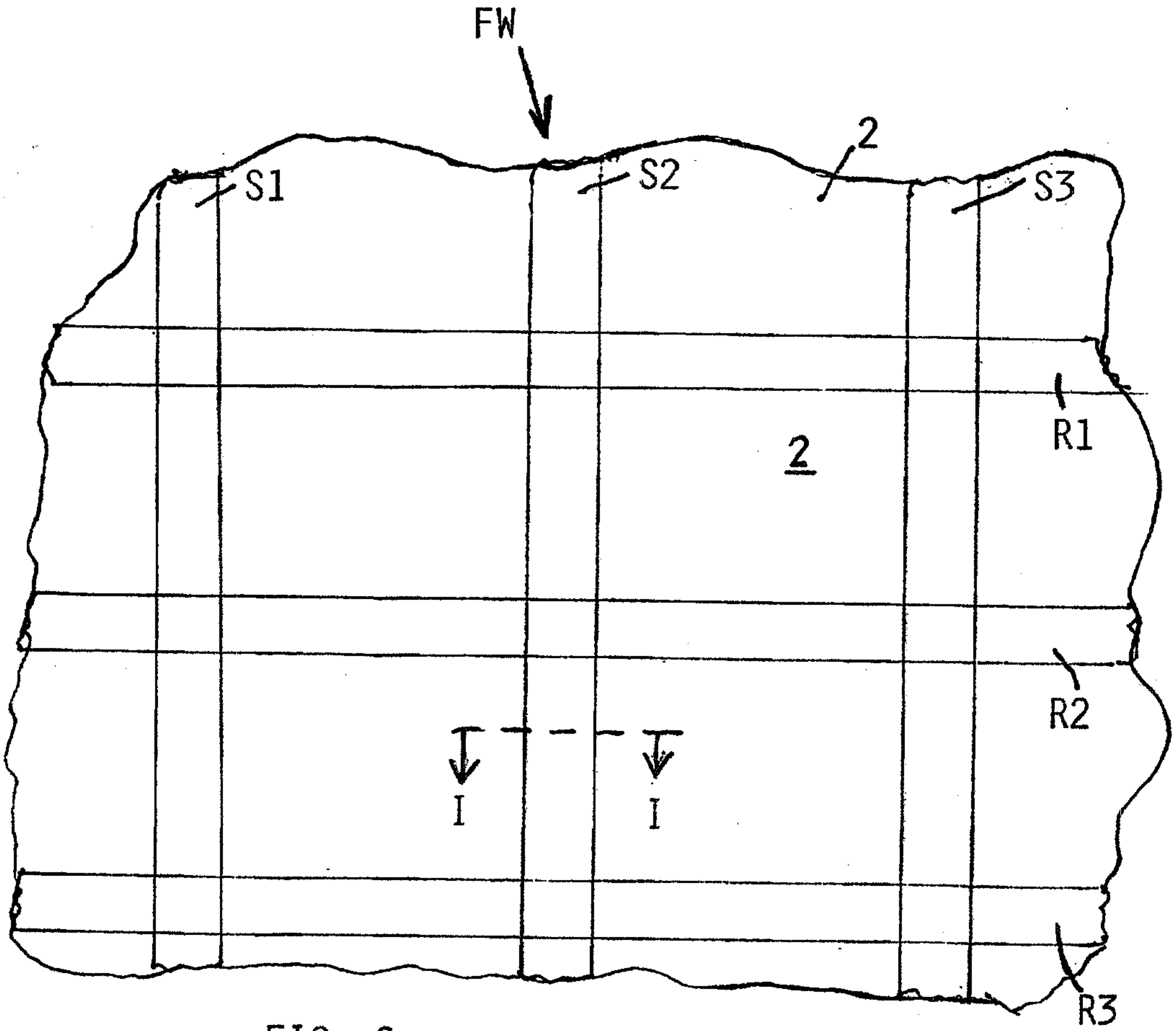


Fig. 4



Half crack length [mm]
200
180
160
140
120
100
80
60
40
20
0
0
5000
10000
No. Of Loads [Cycles]
20000
A
B
Intact = B
Broken=A

FIG. 5



FW
2
S1
S2
S3
2
R1
R2
R3
I
I

FIG. 6


S2
1
2
1A
4