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(54) Fabric for arresting ballistic articles

(57) In the field of aircraft engines, it is known to provide a so-called rigid fabric barrier for containing ballistic articles such as fragments of engine components liberated by mechanical failure in the engine. However, known rigid fabrics of plain woven form suffer from high elongation per unit length.

The disclosure relates to a rigid fabric (10) comprising a plurality of elongate interstices (16) each containing one or more elongate warp yarns (15). The interstices (16) permit the warp yarns to lie in an uncrimped condition, thereby improving the elongation characteristics of the fabric (10).

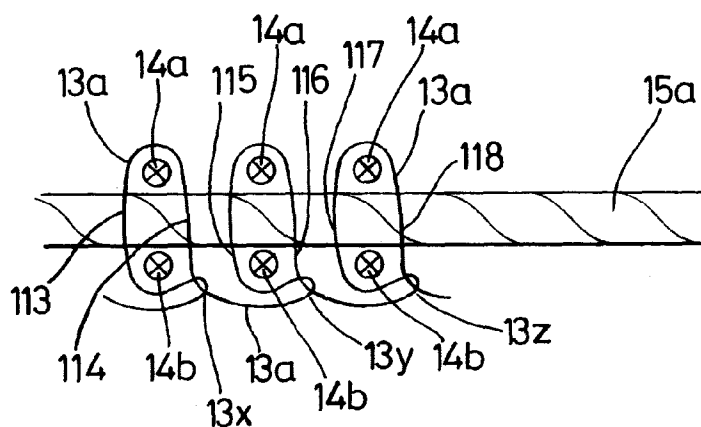


Fig. 3

Description

This invention relates to improvements in or relating to fabrics, in particular fabrics having physical characteristics suitable for arresting ballistic articles. Such articles typically include fragments of compressor fan blades from aircraft engines such as turbofans. However, the term 'ballistic article' is also intended to embrace eg; bullets and shells, or fragments thereof.

It has for some years been common practice for manufactures of aircraft engines having rotating parts to provide within the engine a barrier capable of arresting ballistic articles arising from mechanical failure within the engine. The object of this practice is to minimise the damage to the remainder of the engine that may be caused by such articles.

In the early days of aviation, such barriers were provided by rigid, metal components. However, these are of limited utility because of the tendency of metal barriers to transmit impulses directly to other parts of the engine, thereby causing potentially catastrophic damage.

The development of aramid fibres led to replacement of the rigid barriers by barriers comprised essentially of woven fabrics made of aramid yarns. Typically, the woven fabrics are produced in widths of up to 1000mm that are wrapped several times about an annular frame defining eg the periphery of the compressor stage of a turbofan engine. The thus-wound fabric is effectively exposed, on the inner face of the barrier, to the interior of the compressor stage, so that high velocity articles resulting from mechanical failure within the compressor stage tend to be thrown outwardly into the fabric wrap. The fabric absorbs the resulting impulse.

This method of arresting ballistic articles is successful because aramid fibres possess almost no elasticity yet are flexible and have extremely good tensile strength characteristics. Typically, the elongation to failure of an aramid fibre is less than 3%, yet the fibre can withstand huge tensile loads before such failure occurs. Thus, a woven fabric consisting of aramid fibres is most unlikely to rupture when it experiences the impulse from a ballistic article in an aircraft engine; yet the energy of such an impulse is successfully absorbed by the woven fabric structure without any significant part of the energy being transferred to the remainder of the engine components.

In this way, woven aramid fibre barriers have prevented many instances of catastrophic aircraft engine failure.

The high strength/low elasticity characteristics of aramid fibres also make them highly suitable as ballistic barriers in eg; flak jackets and bullet-proof vests.

In view of their characteristics, fabrics woven from aramid fibres are known as 'rigid fabrics'. There are other fibres (including high-density polypropylene and polyethylene) that are also potentially suitable in such applications. The weaving of such alternative fibres also results in so-called rigid fabrics. The term "rigid fabric" also embraces fabrics made from mixes of fibres, not all

of which need necessarily possess low elasticity/high strength characteristics.

Tests have revealed that in typical instances of aircraft engine component failure, known rigid fabric barriers exhibit extensions significantly greater than the approximately 3% figure mentioned above. The precise performance characteristics depend in part on the engine in which the fabric is installed.

There is a constant effort to improve the efficiency of aircraft engines, by reducing their specific fuel consumption characteristics. One way of achieving this is to increase the compressor fan area, thereby permitting a higher charge compression ratio to be used. However, for reasons of weight saving and because it is often not possible simply to increase the overall dimensions of an engine, such increases in fan area are usually accomplished at the expense of reducing the size of other components constituting the generally annular shape of the compressor chamber. Thus there is a need for a rigid fabric that offers comparable performance to previous rigid fabrics, whilst occupying a reduced volume and/or possessing reduced mass.

There is also a need for a rigid fabric that has a generally improved characteristic in terms of its overall elongation when impacted by a ballistic article.

According to a first aspect of the invention, there is provided a fabric for arresting ballistic articles, comprising a woven or interlooped assembly of fibres defining a plurality of elongate interstices containing one or more elongate, substantially inextensible warp yarns extending along each interstice.

Thus preferred embodiments of the invention may include warp yarns of e.g. aramid; and weft and (where present) wale yarns of another material not necessarily having low elongation/high strength characteristics. Alternatively the weft and wale yarns (if present) may also possess such characteristics and indeed be aramid yarns.

An example of an aramid yarn suitable for use in the invention is Kevlar™.

An advantage of a fabric according to the invention is believed to lie in the presence of the elongate interstices. These permit the warp fibres of the fabric to be applied in a completely flat, uncrimped condition. This contrasts with the situation in previous, plain woven, rigid fabrics, in which, as a result of the weaving process, there is a significant degree of crimp in both the warp and weft fibres thereof. When a ballistic article strikes a plain woven rigid fabric, the crimps in the yarns tend to straighten before the low elongation/high strength characteristics of the yarns become effective. This is believed to be the primary reason that plain woven rigid fabrics have an elongation greater than that of the yarns from which they are formed.

In preferred embodiments, the warp fibres are the principal working fibres in the sense of conferring the favourable characteristics of the fabric. Since in the fabric of the invention the warp fibres are not crimped, the

low elongation/high strength characteristics of the warp fibres are available almost immediately a ballistic article strikes the fabric.

In preferred embodiments of the invention, the substantially inextensible warp yarns are or include aramid fibres. However, in other embodiments of the invention it is thought possible to use other low elongation/high strength yarns, such as high density polypropylene fibres and high density polyethylene fibres.

Preferably the fabric is crocheted. When the fabric is crocheted, it preferably includes first and second weft fibres, disposed respectively on opposite sides of each or the warp fibre. The use of such first and second weft fibres so disposed advantageously assists in defining the elongate interstices.

Conveniently, when the fabric is crocheted, the wales are interlooped with the weft fibres only. This permits the fabric to be a self-sustaining structure in which there is virtually no possibility of the warp fibres becoming crimped.

Preferably when the fabric is crocheted, the weft fibres constrain the warp fibres in a first direction and the wale fibres constrain the warp fibres in a second direction generally perpendicular to the first said direction. This feature ensures that the warp fibres remain in their preferred locations, even though in preferred embodiments they are not interlooped with any other fibre.

Conveniently the woven or interlooped assembly comprises substantially inextensible yarns. Preferably the substantially inextensible fibres are or include aramid fibres.

In embodiments of the invention including weft fibres on opposite sides of the warp fibres, the use of substantially inextensible fibres for the weft fibres advantageously increases the density of such fibres in the fabric assembly, thereby improving the performance of the fabric.

It is also preferable that the wales include or are of a substantially inextensible yarn, not least because under conditions of ballistic impact the wales are likely to suffer tensile stresses of comparable magnitude to the warp and weft yarns.

Conveniently the fabric includes a plurality of overlapping widths of weft yarn. This advantageously allows manufacture of the fabric in virtually any width.

In particularly preferred embodiments, the count of the or each warp fibre is up to approximately 6000 D'TEX, in particular 1600-2400 D'TEX. Similarly, the stitch density preferably lies in the range of approximately 4-20 per cm, in particular 9.5 per cm $\pm$ 25%; the yarn count of the weft fibres lies in the range of approximately 200-2000 D'TEX, in particular 800-1270 D'TEX; and the yarn count of the wale fibres is up to approximately 1000 D'TEX, in particular 110-330 D'TEX.

There are inherent difficulties associated with knitting substantially inextensible fibres. The use of fibre diameters, stitch densities and yarn counts as defined hereinabove has been found advantageously to permit

formation of a self-sustaining, crocheted knit when aramid or other fibres are used.

The invention is also considered to reside in a ballistic article containment barrier for an aircraft engine, including a fabric as defined hereinabove.

Further, the invention is considered to reside in a ballistic article containment barrier for a protective garment (such as a flak jacket, bullet-proof vest or safety helmet).

According to a second aspect of the invention there is provided a method of manufacturing a fabric as defined hereinabove, comprising the steps of:

forming a woven or interlooped assembly of fibres defining a plurality of elongate interstices; and placing one or more elongate, substantially inextensible warp yarns in each interstice, extending along the length thereof.

Conveniently, the step of placing one or more inextensible warp yarns occurs generally contemporaneously with the step of forming a woven or interlooped assembly. This advantageously allows the fabric of the invention to be manufactured on a crocheting machine.

Preferably, the step of crocheting the assembly of fibres includes the step of interlooping the weft and wale yarns only, in order to create the preferred fabric.

Manufacture of the fabric may also optionally include the step of disposing first and second weft yarns respectively on opposite sides of each warp fibre. This confers the high density/low elongation properties characteristic of the preferred form of the fabric of the invention.

Conveniently the method includes the step of forming the fabric using a stitch density in the range 4-20 per cm.

In its simple form, the invention is considered to reside in an interlooped fabric formed of or comprising a substantially inextensible yarn.

There now follows a description of a preferred embodiment of the invention, by way of example, with reference being made to the accompanying drawings in which:

Figure 1 is a schematic representation of a prior art, plain woven, rigid fabric;

Figure 2 shows a preferred form of crocheted knit employed in the fabric of the invention;

Figure 3 is a cross sectional view, on a reduced scale, of the fabric of Figure 2; and

Figure 4 is an exploded view of a second embodiment of the invention, including a multi-weft, knitted construction.

Referring to the drawings, there is shown in Figure 1 a prior art, plain woven, rigid fabric 10. Fabric 10 comprises a plurality of generally parallel, aramid warp fibres 11a to 11f, and a corresponding plurality of interwoven,

generally mutually parallel weft fibres 12a to 12f extending generally perpendicular to the warp fibres 11a to 11f.

This is the construction of rigid fabric that has conventionally been used in eg aircraft ballistic containment members. As is evident by the respective warp and weft end elevational views figures 1a and 1b, both the warp and weft fibres adopt a generally sinusoidal appearance, by virtue of the plain weaving process. In other words, all the fibres in the fabric of Figure 1 are crimped. Such crimping causes the linear extension of the fabric, on impact of a ballistic article, to be considerably greater than the extension of each individual fibre.

Referring now to Figure 2, there is shown on an enlarged scale a preferred form of crocheted rigid fibre in accordance with the invention.

The fabric of Figure 2 includes a series of wales 13a to c looped into chains extending generally parallel to one another in the warp direction of the fabric.

Interlooped with the wale fibres 13a to 13c are respective top and bottom weft fibres 14a and 14b. In Figure 2, the upper weft fibre 14a is shown as a solid line and the lower weft fibre 14b as a dotted line.

A series of parallel warp yarns 15a, 15b are lain into the elongate interstices denoted generally by reference numeral 16 between adjacent chains of wale yarn 13a, 13b, 13c etc. The warp threads 15a, 15b, etc are not interlooped with any other threads of the fabric. Instead they are constrained within the interstices 16 by virtue of the chains of wale yarn 13a, 13b, 13c constraining their movement from side to side in the plane of Figure 2; and by virtue of the upper 14a and lower 14b weft yarns constraining their movement perpendicular to the plane of Figure 2.

Thus it will be seen that the warp threads exist in a completely uninked condition. This effect is also illustrated in Figure 3, which is a detailed cross sectional view, on an enlarged scale, of part of the fabric of Figure 2, viewed on arrows 3-3.

As is evident from Figure 3, the wales, such as wale 13 shown, loop around the upper surface the upper weft yarn 14a, and around the lower surface of the lower weft yarn 14b. The wale yarn is looped through itself in a *per se* known chain repeat, eg. as shown at 13x, 13y, 13z of Figure 3.

The downwardly extending portions 113-118 of the wale 13a shown in Figure 3 between them define generally upstanding side wall portions of one of the interstices 16; whereas the upper 14a and lower 14b weft yarns respectively define upper and lower walls thereof. The downwardly extending portions (not visible in Figure 3) of adjacent wale yarns such as yarn 13b of Figure 2 between them also define upstanding side wall portions of the interstices 16, in a like manner to those shown in Figure 3.

Thus the wale yarns constrain the warp threads 15a, 15b, etc against movement from side to side in the sense of Figure 2; while the weft threads 14a, 14b constrain the warp threads against movement in the up and

down direction of Figure 3. Thus each warp thread 15a, 15b is supported within the interstice 16 in a completely uninked condition, ready to absorb energy from an impacting ballistic article.

Since the warp threads 15a, 15b etc constitute the principal working fibres of the fabric, they are of enlarged diameter compared with the weft and wale yarns.

Referring now to Figure 4, there is shown a second embodiment of a fabric 10 according to the invention. The fabric 10 is shown in an exploded view, from which the wale yarns have been omitted, for ease of viewing. In reality, fabric 10 of Figure 4 would of course be an integral construction including wale yarns (similar or identical to the wale yarns 13 of Figures 2 and 3) binding the warp (15) and weft (14) yarns together.

As is evident from Figure 4, the weft portions of the fabric comprise face weft 50 and back weft 60. This is in principle similar to the upper and lower weft yarns 14a and 14b of the Figure 2 embodiment, but in Figure 4 the front face 50 comprises a series of overlapping weft widths 50a, 50b, 50c each of a similar construction to the weft 14a of Figure 2. Similarly the back face weft 60 comprises a series of overlapping weft widths 60a, 60b each of which is in the embodiment shown of the same width as each of the front face wefts 50a, 50b, 50c.

The adjacent widths of back face weft 60 overlap one another, as do the adjacent widths of front face weft 50. The zones of overlapping are misaligned as between the front and back faces.

Thus when the wale yarns 13 are present in the Figure 4 embodiment, the multiple weft structure defines therewith a plurality of elongate interstices that contain the inextensible warp yarns. The offsetting, or misalignment, of the zones of overlap of the multiple wefts forming the front and back faces confers strength on the fabric. The use of multiple wefts allows the manufacture of a wider fabric than if only single front and back wefts are used.

The number of weft widths is limited only by the width of the bed of the crocheting machine employed to make the fabric. Also, it is not essential that the weft widths 50a, 50b etc. and 60a, 60b, etc are all of the same width.

Successful results have been achieved in both embodiments of the invention using warp thread counts of up to approximately 6000 D'TEX, particularly 1600-2400 D'TEX; weft yarn counts in the range approximately 200-2000 D'TEX, in particular 860-1270 D'TEX; wale yarn counts up to approximately 1000 D'TEX, particularly 110-330 D'TEX; and stitch densities of approximately 4-20 per cm, particularly 7.1-11.9 per cm. However, other yarn counts and densities could be used if desired.

Also it is possible to lay more than one warp yarn such as yarns 15a, 15b in the interstices 16, the dimensions of which could be selected appropriately.

Furthermore, it is believed possible to define the interstices 16 using a multi-layered weave instead of a

knitted assembly. Such embodiments are considered to be within the scope of the invention.

Although the invention has been described in relation to the use of aramid fibres, any of the fibres in Figures 2 and 3 and described herein could be replaced by eg high density polypropylene or polyethylene fibres. Although such fibres may have poorer resistance to high temperatures than aramid fibres, they are generally more stable to ultraviolet light and generally are considerably lighter than the equivalent aramid fibres.

Claims

1. A fabric for arresting ballistic articles, comprising a woven or interlooped assembly of fibres defining a plurality of elongate interstices containing one or more elongate, substantially inextensible warp yarns extending along each interstice. 15
2. A fabric according to Claim 1 wherein the substantially inextensible warp yarns are or include aramid fibres. 20
3. A crocheted fabric according to Claim 1 or Claim 2. 25
4. A fabric according to Claim 3 including first and second weft fibres, disposed respectively on opposite sides of the or each warp fibre. 30
5. A fabric according to Claim 3 or Claim 4, wherein the wales are interlooped with the weft fibres only. 35
6. A fabric according to any of Claims 3 to 5 wherein the weft fibres constrain the warp fibres in a first direction and the wale fibres constrain the warp fibres in a second direction generally perpendicular to the first said direction. 40
7. A fabric according to any preceding claim wherein the woven or interlooped assembly comprises substantially inextensible fibres. 45
8. A fabric according to Claim 7 wherein the substantially inextensible fibres are or include aramid fibres. 50
9. A fabric according to any preceding claim wherein the count of the or each warp fibre is up to 6000 D'TEX. 55
10. A fabric according to any of Claims 3 to 9 wherein the stitch density lies in the range 4-20 per cm.
11. A fabric according to any of Claims 3 to 10 wherein the yarn count of the weft fibres lies in the range 200-2000 D'TEX.
12. A fabric according to any of Claims 3 to 11 wherein the yarn count of the wale fibres is up to 1000 D'TEX.
13. A fabric according to any preceding claim including a plurality of overlapping widths of weft yarn.
14. A ballistic article containment barrier for an aircraft engine including a fabric according to any preceding claim.
15. A ballistic article containment barrier for a protective garment including a fabric according to any preceding claim.
16. A method of manufacturing a fabric according to any preceding claim, comprising the steps of:
 - forming a woven or interlooped assembly of fibres defining a plurality of elongate interstices; and
 - placing one or more elongate, substantially inextensible warp yarns in each interstice, extending along the length thereof.
17. A method according to Claim 16 wherein the step of placing one or more inextensible warp yarns occurs generally contemporaneously with the step of forming a woven or interlooped assembly.
18. A method according to Claim 16 or Claim 17 including the step of crocheting the assembly of fibres.
19. A method according to Claim 18 wherein the step of crocheting the assembly of fibres includes the step of interlooping the weft and wale yarns only.
20. A method according to any of Claims 16 to 19 including the step of disposing first and second weft yarns respectively on opposite sides of each warp fibre.
21. A method according to any of Claims 16 to 20 including the step of forming the fabric with a stitch density in the range 4-20 per cm.
22. An interlooped fabric formed of or comprising a substantially inextensible yarn.

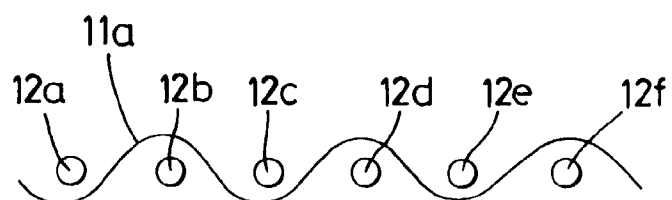


Fig. 1b

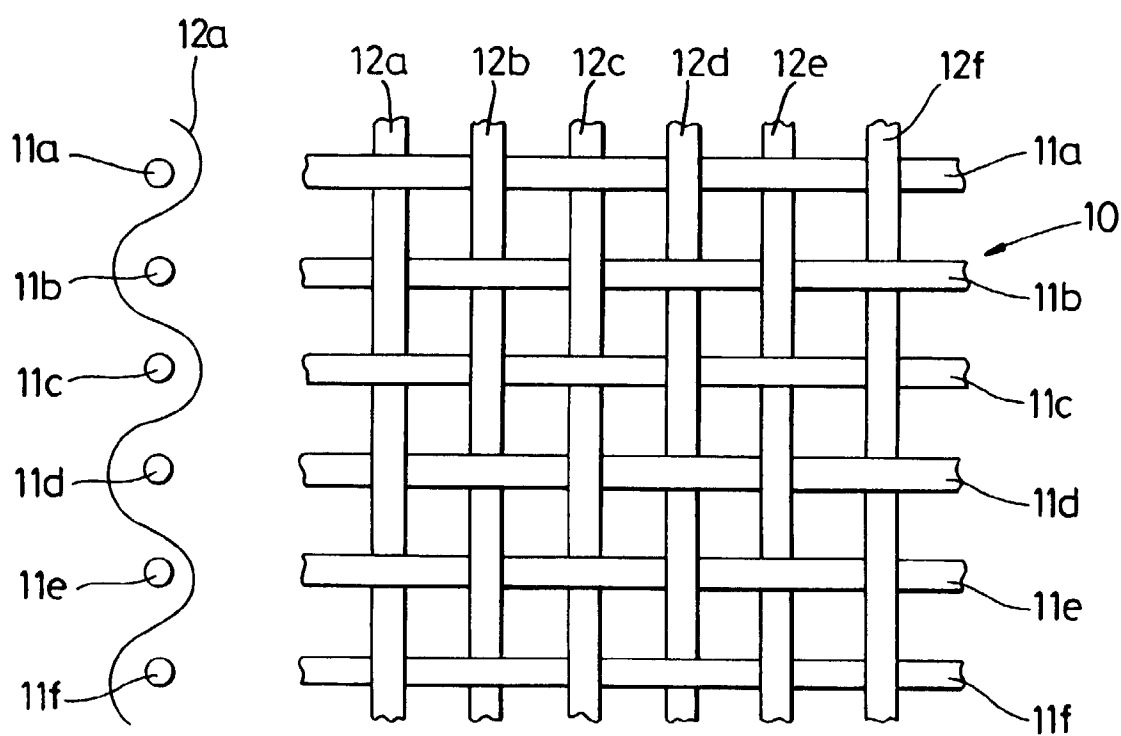


Fig. 1a

Fig. 1

PRIOR ART

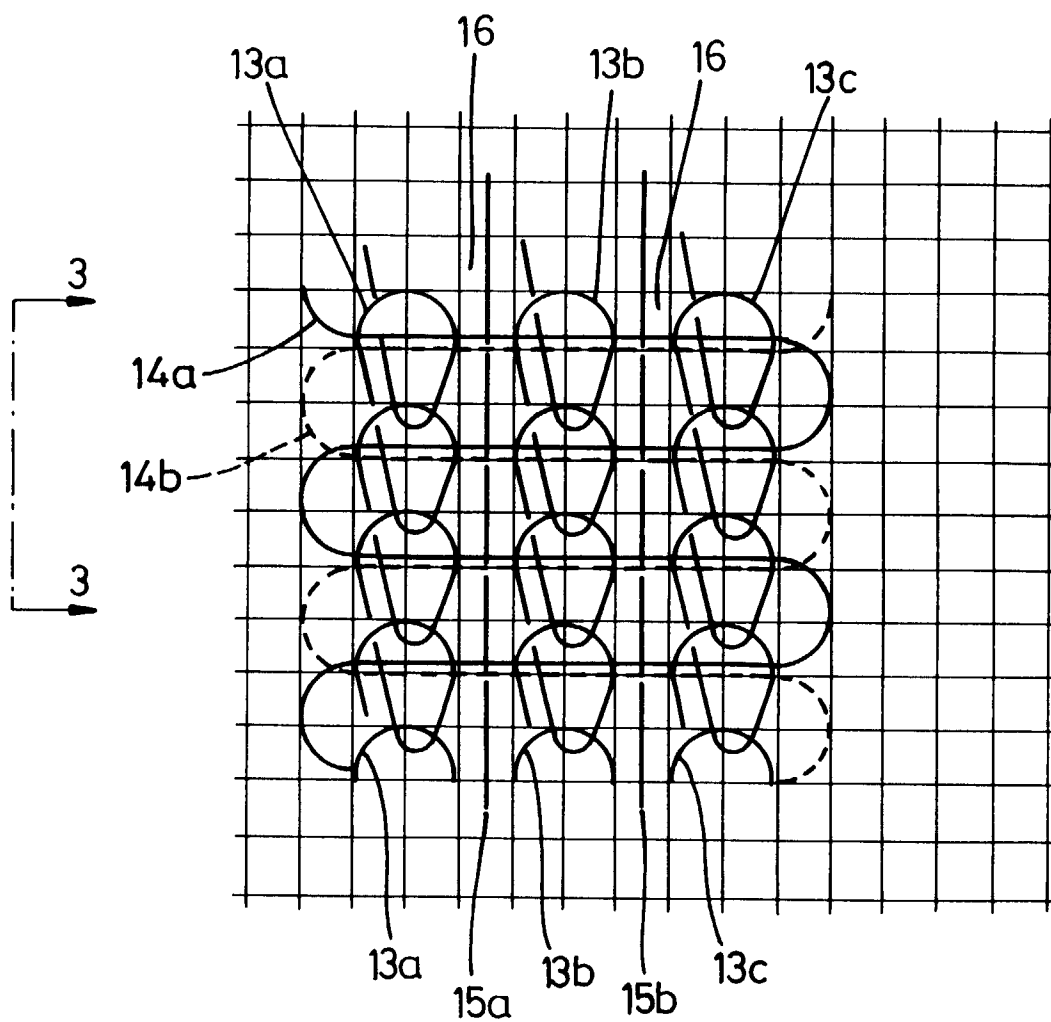


Fig. 2

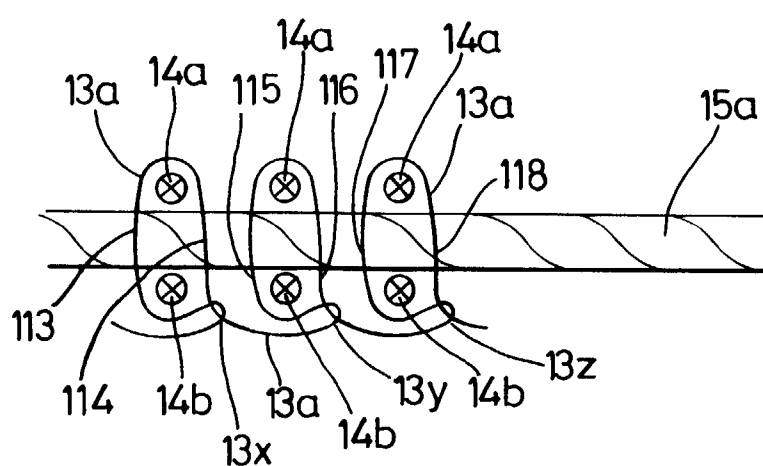


Fig. 3

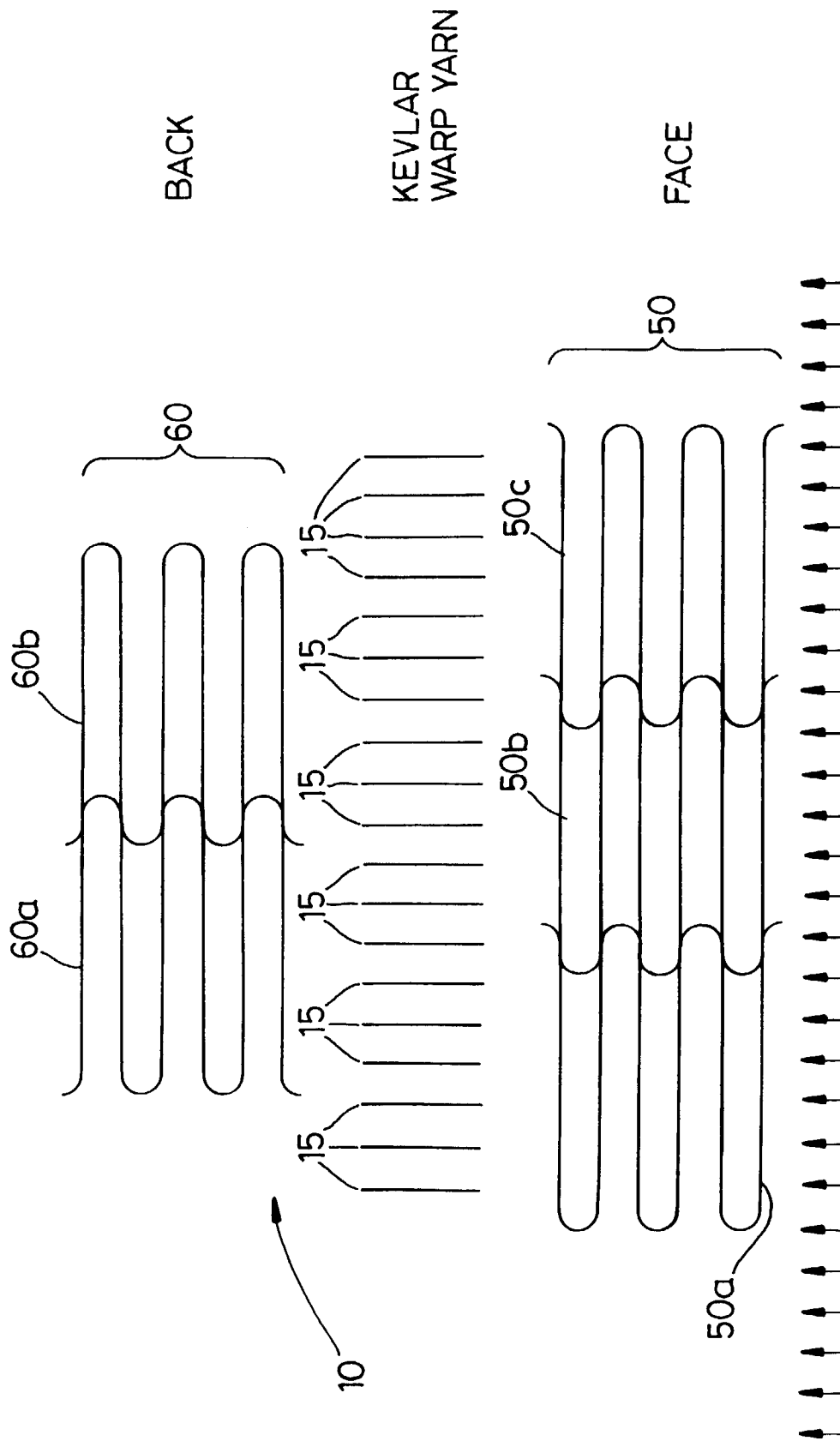


Fig. 4