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(54) THICKNESS DIRECTION THREAD INSERTION NEEDLE, AND METHOD FOR PRODUCING THREE-DIMENSIONAL FIBROUS STRUCTURE

(57) Thickness direction thread insertion needles (11) each include a proximal end portion (12) and an insertion portion (13), which is formed thinner than the proximal end portion (12) and is selectively inserted in laminated fiber layers (23). The insertion portion (13) includes a distal end and a needle's eye formed close to the distal end. A coating (15) is formed on the insertion portion (13). The coating (16) has a surface roughness of 0.1 μm or more and 0.7 μm or less in terms of the center line average roughness Ra, and improves the wear resistance of the insertion portion (13). The thickness direction thread insertion needles (11) are used in producing a three-dimensional fibrous structure. The three dimensional fibrous structure includes the laminated fiber layers (23) formed by laminating fiber layers to be at least biaxially oriented, and thickness direction threads (P) inserted in a direction to intersect the fiber layers to connect the laminated fiber layers (23).

Fig.1 (a)

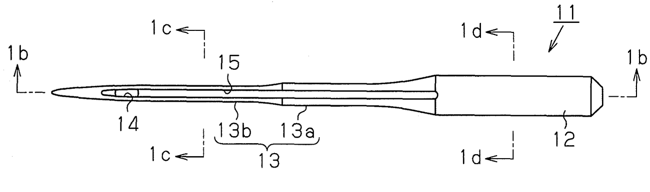


Fig.1 (b)

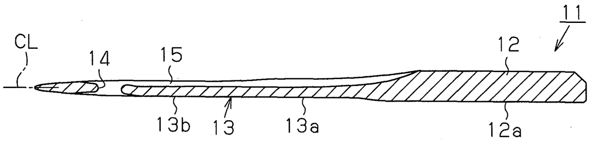


Fig.1 (c)

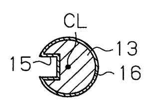
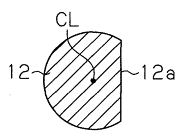


Fig.1 (d)



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Description

TECHNICAL FIELD

[0001] The present invention relates to a thickness direction thread insertion needle, and a method for producing a three-dimensional fibrous structure. More specifically, the present invention pertains to a thickness direction thread insertion needle used when inserting a thickness direction thread into laminated fiber layers to connect the laminated fiber layers, which are obtained by laminating fiber layers formed by arranging a thread (fiber bundle) while repetitively folding back the thread. The present invention further relates to a method for producing the three-dimensional fibrous structure that uses such a thickness direction thread insertion needle.

BACKGROUND ART

[0002] A reinforcement base material of a fiber reinforced composite material includes a three-dimensional fibrous structure, that is, a three-dimensional fabric. A method for producing the three-dimensional fibrous structure disclosed in Patent Document 1 includes forming a lamination (laminated fiber layers) that is at least biaxially oriented by laminating thread layers (fiber layers), and connecting the laminated fiber layers by thickness direction threads inserted so as to intersect the thread layers. The thread layers are arranged on a frame, on which pins are disposed at a predetermined pitch, so as to surround an area where the thickness direction threads are inserted and to be folded back between the pins. The thread layers are laminated to form the lamination. Thereafter, the thickness direction threads are inserted in the lamination held by the frame using thickness direction thread insertion needles arranged in a row.

[0003] The strength of the composite that includes the three-dimensional fibrous structure as the frame material is largely influenced by the three-dimensional fibrous structure. Thus, it is necessary to tighten the lamination by the thickness direction threads to obtain the composite with great strength. As shown in Fig. 6 of this application, thickness direction thread insertion needles 51 arranged in a row are thrust into a lamination F together with thickness direction threads z. In this state, loops L of the thickness direction threads z are formed on the side of the lamination F from which the thickness direction thread insertion needles 51 project. More specifically, the thickness direction thread insertion needles 51 penetrate the lamination F together with the thickness direction threads z until needle's eyes of the thickness direction thread insertion needles 51 reach the other side of the lamination F. After that, the loops L are formed by pulling back the thickness direction thread insertion needles 51 by a predetermined amount. Then, a lock yarn P is inserted in the loops L using a lock yarn insertion needle 52. Thereafter, the thickness direction threads z are pulled back from the lamination F with the thickness direction thread insertion needles 51 so that the thickness direction threads z tighten the lamination F via the lock yarn P. The lock yarn insertion needle 52 passes through the loops L, which are formed by the thickness direction threads z connected to the thickness direction thread insertion needles 51 that have penetrated the lamination F, without holding the lock yarn P when advancing in the arrow direction of Fig. 6. The lock yarn insertion needle 52 holds the lock yarn P when moving back, and reciprocates to pass through many loops L. A latch needle is used as the lock yarn insertion needle 52. Fig. 6 does not show the latch.

[0004] In the three-dimensional fibrous structure, in which the lamination that is at least biaxially oriented by laminating thread layers is connected by the thickness direction threads, the following is necessary when inserting the lock yarn P in the loops L of the thickness direction threads z, and connecting the lamination by pulling back the thickness direction threads z. That is, the loops L formed by the thickness direction thread insertion needles 51 arranged in a row need to be formed into a size greater than or equal to a predetermined size. However, a sizing agent is applied to a carbon fiber bundle used as the thickness direction threads z. Thus, when pulling back the thickness direction thread insertion needles 51 from the lamination F to form the loops L, the thickness direction threads z might adhere to the surface of the thickness direction thread insertion needles 51. The size of the loops L might be reduced as the thickness direction threads z return with the thickness direction thread insertion needles 51. Even if the size of one of the loops L of one row of the thickness direction threads z is reduced, the lock yarn insertion needle 52 cannot smoothly pass through the row of the loops L. In this case, an operator needs to manually adjust the loop L each time, which extends time to produce the three-dimensional fibrous structure.

Patent Document 1: Japanese Laid-Open Patent Publication No. 8-218249

DISCLOSURE OF THE INVENTION

[0005] Accordingly, it is an objective of the present invention to provide a thickness direction thread insertion needle that inhibits a thickness direction thread from adhering to the surface of the thickness direction thread insertion needle when inserting the thickness direction thread into laminated fiber layers, that is, a lamination. Furthermore, it is an objective of the present invention to provide a method for producing a three-dimensional fibrous structure that uses such a thickness direction thread insertion needle.

[0006] One aspect of the present invention provides a thickness direction thread insertion needle used for producing a three-dimensional fibrous structure. The three dimensional fibrous structure includes laminated fiber layers formed by laminating fiber layers to be at least two biaxially oriented, and a thickness direction thread inserted in a direction to intersect the fiber layers to connect the laminated fiber layers. The thickness direction thread insertion needle includes a proximal end portion and an insertion portion, which is formed to be thinner than the proximal end portion and is selectively inserted in the laminated fiber layers. The insertion portion includes a distal end and a needle's eye formed close to the distal end. A coating formed on the insertion portion. The coating having a surface roughness of 0.1 μm or more and 0.7 μm or less in terms of the center line average roughness Ra, and the coating improves the wear resistance of the insertion portion.

[0007] Another aspect of the present invention provides a thickness direction thread insertion needle, which includes a proximal end portion and an insertion portion, which is formed to be thinner than the proximal end portion and is selectively inserted in laminated fiber layers. The insertion portion includes a distal end and a needle's eye formed close to the distal end. The surface of the insertion portion includes grooves extending in an axial direction of the insertion portion. The surface of the insertion portion is coated with wear resistant plating.

[0008] Furthermore, another aspect of the present invention provides a method for producing a three-dimensional fibrous structure. The three-dimensional fibrous structure includes laminated fiber layers formed by laminating fiber layers to be at least biaxially oriented, and a thickness direction thread inserted in the laminated fiber layers to intersect the fiber layers thereby connecting the laminated fiber layers. The laminated fiber layers includes an insertion area in which the thickness direction thread is inserted. The production method includes arranging thickness direction thread insertion needles in a row. Each thickness direction thread insertion needle includes a proximal end portion, an insertion portion, and a coating. The insertion portion is formed to be thinner than the proximal end portion and is selectively inserted in the laminated fiber layers. The insertion portion includes a distal end and a needle's eye formed close to the distal end. The coating is formed on the insertion portion. The coating has a surface roughness of 0.1 μm or more and 0.7 μm or less in terms of the center line average roughness Ra. The coating improves the wear resistance of the insertion portion. Loops are formed by simultaneously thrusting thickness direction thread insertion needles arranged in a row into the laminated fiber layers with the thickness direction threads in a state where the laminated fiber layers are retained on a frame. The thickness direction thread insertion needles are thrust into the laminated fiber layers until the needle's eyes project outside of the laminated fiber layers. Loops are formed by the thickness direction threads on the side of the laminated fiber layers from which the thickness direction thread insertion needles project. A lock yarn is inserted in the loops along an arrangement direction of the thickness direction thread insertion needles. The laminated fiber layers are tightened by pulling back the thickness direction thread insertion needles from the laminated fiber layers after inserting the lock yarn in the loops. The thickness direction yarn is inserted in the insertion area of the laminated fiber layers by repeating the forming of loops, the insertion of the lock yarn, and the tightening of the laminated fiber layers. The laminated fiber layers are then removed from the frame.

[0009] Furthermore, another aspect of the present invention provides a method for producing a three-dimensional fibrous structure that uses different thickness direction thread insertion needles. Each thickness direction thread insertion needle includes a proximal end portion and an insertion portion, which is formed to be thinner than the proximal end portion and is selectively inserted in the laminated fiber layers. The insertion portion includes a distal end and a needle's eye formed close to the distal end. The surface of the insertion portion includes grooves extending in an axial direction of the insertion portion. The surface of the insertion portion is coated with wear resistant plating.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010]

Fig. 1(a) is a front view illustrating a thickness direction thread insertion needle according to one embodiment of the present invention;

Fig. 1(b) is a cross-sectional view taken along line 1b-1b of Fig. 1(a);

Fig. 1(c) is an enlarged cross-sectional view taken along line 1c-1c of Fig. 1(a);

Fig. 1(d) is an enlarged cross-sectional view taken along line 1d-1d of Fig. 1(a);

Fig. 2 is a schematic cross-sectional view illustrating a procedure for inserting the thickness direction thread insertion needle of Fig. 1(a) to laminated fiber layers;

Fig. 3 is a schematic perspective view illustrating a three-dimensional fibrous structure production apparatus including the thickness direction thread insertion needles of Fig. 1(a);

Fig. 4(a) is a partially enlarged view of Fig. 2;

Fig. 4(b) is a schematic cross-sectional view illustrating a state where loops of thickness direction threads are formed by penetrating the thickness direction thread insertion needles of Fig. 4(a) in the laminated fiber layers;

Fig. 5(a) is a front view illustrating a thickness direction thread insertion needle according to a modified embodiment;

Fig. 5(b) is an enlarged cross-sectional view taken along line 5b-5b of Fig. 5(a);

Fig. 5(c) illustrates a thickness direction thread insertion needle according to another modified embodiment,

and is a cross-sectional view illustrating a state where the intervals of grooves are changed from Fig.

5(b); and

Fig. 6 is a schematic diagram illustrating a state where a lock yarn is inserted in the loops of the thickness direction threads.

BEST MODE FOR CARRYING OUT THE INVENTION

[0011] Figs. 1 to 4 show one embodiment of the present invention.

[0012] First, the structure of a thickness direction thread insertion needle 11 will be explained with reference to Figs. 1(a) to 1(d). As shown in Figs. 1(a) and 1 (b), the thickness direction thread insertion needle 11, which is formed of carbon steel or alloy steel, includes a proximal end portion 12 and an insertion portion 13. The insertion portion 13 is formed to be thinner than the proximal end portion 12, and is selectively inserted in laminated fiber layers. A needle's eye 14 is formed close to the distal end of the insertion portion 13. The needle's eye 14 penetrates the insertion portion 13 in a direction perpendicular to an axis CL of the insertion portion 13. In the preferred embodiment, the axis CL of the insertion portion 13 represents the axis of the thickness direction thread insertion needle 11, and the direction of the axis CL of the insertion portion 13 represents the axial direction of the thickness direction thread insertion needle 11.

[0013] As shown in Fig. 1(d), the cross-section of the proximal end portion 12 is D-shaped, and part of the circumferential surface of a circular column is removed by a flat portion 12a. As shown in Figs. 1(a) and 1(b), the insertion portion 13 includes a large diameter portion 13a and a small diameter portion 13b. The thickness of the thickness direction thread insertion needle 11 changes roughly by two steps along the axis CL from the proximal end portion 12 to the large diameter portion 13a, and from the large diameter portion 13a to the small diameter portion 13b. The thickness direction thread insertion needle 11 includes a thread groove 15, which extends from the distal end of the insertion portion 13 to the proximal end portion 12. As shown in Fig. 1(b), the thread groove 15 is located on the opposite side of the insertion portion 13 from the flat portion 12a with respect to the axis CL of the insertion portion 13.

[0014] The thickness direction thread insertion needle 11 is subjected to heat treatment such as quenching and tempering so as to have necessary hardness. As shown in Fig. 1(c), a matte plating layer 16 is formed on the surface of the insertion portion 13. Figs. 1(a) and 1(b) do not show the matte plating layer 16. The matte plating layer 16 reduces or prevents, for example, adhesion of the thickness direction thread, on which the sizing agent is applied, to the surface of the insertion portion 13. That is, the matte plating layer 16 functions as a coating for providing the insertion portion 13 with non-adhesiveness against, for example, the thickness direction thread. The surface roughness of the matte plating layer 16 is formed such that the center line average roughness Ra is 0.1 μm or more and 0.7 μm or less.

[0015] The matte plating layer 16 is formed by roughening the surface of the needle material of the thickness direction thread insertion needle 11 by shot blasting, and then coating the surface of the needle material with plating. The roughening degree of the surface of the needle material by the shot blasting is set (adjusted) such that the surface roughness after the plating process becomes equal to a target roughness. The matte plating layer 16 of the preferred embodiment is formed by hard chrome plating such that the plating thickness is 20 μm. Since the hard chrome plating has excellent wear resistance, the matte plating layer 16 functions also as a coating to improve wear resistance.

[0016] Next, a method for producing a three-dimensional fibrous structure using the thickness direction thread insertion needles 11 formed as described above will now be explained. A production apparatus of the three-dimensional fibrous structure used in the preferred embodiment has basically the same structure as the production apparatus disclosed in Patent Document 1 except the thickness direction thread insertion needles 11, and produces the three-dimensional fibrous structure in the similar method. Thus, detailed explanation of the structure and the production procedures of the production apparatus is omitted as required.

[0017] As shown in Fig. 3, a production apparatus 20 of the three-dimensional fibrous structure uses a frame 22 on which a number of pins 21 are detachably mounted at predetermined pitch. The production apparatus 20 arranges laminated fiber layers 23 formed on the frame 22 such that the thickness direction of the laminated fiber layers 23 extends in the horizontal direction. An X-axis direction and a Y-axis direction of the laminated fiber layers 23 define a two-dimensional plane of the laminated fiber layers 23, and the X-axis direction extends in the horizontal direction while the Y-axis direction extends in the vertical direction. A Z-axis direction extends in the thickness direction of the laminated fiber layers 23. The production apparatus 20 simultaneously inserts one row of thickness direction threads z at a time along the Y-axis direction of the laminated fiber layers 23. That is, the laminated fiber layers 23 have an insertion area in which the thickness direction threads z are inserted. The term "thread" in the thickness direction threads z is not limited to twisted fibers, but may also include continuous fibers, that is, filaments that are tied in a bundle without being twisted.

[0018] As shown in Fig. 3, the production apparatus 20 includes a table 24, which is movable along a rail (not shown). A pair of support brackets (not shown) for supporting the frame 22 project on the table 24. A bolt insertion hole 22a is formed in each of corners of the frame 22, and the frame 22 is secured to the support brackets by bolts that penetrate the bolt insertion holes 22a. The laminated fiber layers 23 are formed on the frame 22 secured to the support brackets.

[0019] As shown in Figs. 2 and 3, the production apparatus 20 includes a needle support body 25, which supports the thickness direction thread insertion needles 11 secured in one row. That is, the arrangement direction of the thickness direction thread insertion needles 11 is the Y-axis direction in this embodiment. The thickness direction thread insertion needles 11 insert the thickness direction threads z in the laminated fiber layers 23 on the frame 22. A drive apparatus (not shown) moves the needle support body 25 between a standby position and an operational position. As shown in Figs. 2, 3, and 4(a), when the needle support body 25 is at the standby position, the thickness direction thread insertion needles 11 cannot engage with the laminated fiber layers 23 on the frame 22. As shown in Fig. 4(b), when the needle support body 25 is at the operational position, the thickness direction thread insertion needles 11 penetrate the laminated fiber layers 23, and the needle's eyes 14 reach the opposite side of the laminated fiber layers 23 from the needle support body 25.

[0020] As shown in Fig. 3, the production apparatus 20 includes perforation needles 26 the number of which is the same as that of the thickness direction thread insertion needles 11. The perforation needles 26 previously form bores 23a (shown in Fig. 4(b)) at predetermined positions of the laminated fiber layers 23 before thrusting the thickness direction thread insertion needles 11 into the laminated fiber layers 23. That is, the perforation needles 26 form the bores 23a in the laminated fiber layers 23 so that the thickness direction thread insertion needles 11 easily thrust the laminated fiber layers 23. A perforation needle support body 27 holds the perforation needles 26 secured in a row at the predetermined pitch corresponding to the thickness direction thread insertion needles 11. The drive apparatus (not shown) moves the perforation needle support body 27 between the standby position and the operational position while keeping the row of the perforation needles 26 to be parallel to the row of the thickness direction thread insertion needles 11. As shown in Figs. 2, 3, 4(a), and 4(b), when the perforation needle support body 27 is at the standby position, the perforation needles 26 cannot engage with the laminated fiber layers 23 on the frame 22. When the perforation needle support body 27 is at the operational position, the perforation needles 26 penetrate the laminated fiber layers 23 and form the bores 23a.

[0021] As shown in Figs. 2 and 3, the production apparatus 20 includes a press plate 28 for pressing the laminated fiber layers 23 on the frame 22. The press plate 28 presses the laminated fiber layers 23 from the side from which the thickness direction thread insertion needles 11 are inserted. The press plate 28 includes a support portion 28a, and comb teeth 28b, which are formed integrally with the support portion 28a. The support portion 28a extends in the direction in which the thickness direction thread insertion needles 11 are arranged, that is, in the Y-axis direction. The cross-section of the support portion 28a in the direction perpendicular to the Y-axis direction is L-shaped.

[0022] The comb teeth 28b the number of which is the same as that of the thickness direction thread insertion needles 11 are arranged in the Y-axis direction. The comb teeth 28b each include a recess 28c, which includes a surface that guides the associated thickness direction thread insertion needle 11 or the associated perforation needle 26. As shown in Fig. 4(b), the press plate 28 presses the laminated fiber layers 23 in a state where the thickness direction thread insertion needles 11 or the perforation needles 26 are sandwiched between the comb teeth 28b. The dimension of the press plate 28 in the Y-axis direction is formed slightly shorter than the interior width of the frame 22, and the press plate 28 presses the laminated fiber layers 23 without being engaged with the frame 22.

[0023] As shown in Figs. 2 and 3, the production apparatus 20 includes a pair of press blocks 29, 30. The press blocks 29, 30 are located on the opposite side of the frame 22 from the press plate 28. The cross-section of the press blocks 29, 30 in the direction perpendicular to the Y-axis direction is L-shaped, and the dimension in the Y-axis direction is the same as the press plate 28. The press blocks 29, 30 each include a contact portion, which contacts the laminated fiber layers 23, and the distance between the contact portions is greater than the pitch of the pins 21.

[0024] The press blocks 29, 30 are arranged to face the press plate 28. Furthermore, the press blocks 29, 30 are arranged close to each other so as to generate a gap at the position corresponding to the arrangement position of the recesses 28c. The gap of the press blocks 29, 30 permits the thickness direction thread insertion needles 11 or the perforation needles 26 to enter. An air cylinder (not shown) moves the press blocks 29, 30 between the standby position and the operational position. As shown in Fig. 3, when the press blocks 29, 30 are at the standby position, the press blocks 29, 30 cannot engage with the laminated fiber layers 23. As shown in Figs. 2 and 4(a), when the press blocks 29, 30 are at the operational position, the press blocks 29, 30 press the laminated fiber layers 23 in the retracting direction of the thickness direction thread insertion needles 11 or the perforation needles 26. That is, the press plate 28 and the press blocks 29, 30 sandwich and compress the laminated fiber layers 23.

[0025] As shown in Fig. 3, the table 24 includes a hole 24a, and the hole 24a is arranged to correspond to the lower end of the laminated fiber layers 23 on the frame 22 held by the support brackets. The production apparatus 20 includes a lock yarn insertion needle 31, which is movable in the direction in which the row of thickness direction thread insertion needles 11 are arranged, that is, the Y-axis direction. The lock yarn insertion needle 31 is arranged to correspond to the row of thickness direction thread insertion needles 11 that has penetrated the laminated fiber layers 23. The distal end of the lock yarn insertion needle 31 includes a latch (not shown). The drive apparatus (not shown) reciprocates the lock yarn insertion needle 31 between the operational position and the standby position. When the lock yarn insertion needle 31 is in the operational position, the lock yarn insertion needle 31 penetrates the loops formed by the thickness direction threads z connected to the row of thickness direction thread insertion needles 11. When the lock yarn insertion needle 31 is in the standby position, the lock yarn insertion needle 31 retracts from the position corresponding to the laminated fiber layers 23.

[0026] A method for producing the plate-like three-dimensional fibrous structure using the production apparatus 20 configured as described above will now be described. First, the laminated fiber layers 23 are formed using the rectangular frame 22 on which the pins 21 are detachably arranged at predetermined pitch as shown in Fig. 3. A fiber bundle, which is a carbon fiber bundle in this embodiment, is arranged in the longitudinal direction of the frame 22, which is the X-axis direction, while being folded back as the carbon fiber bundle is engaged with the pins 21. This forms a fiber layer, which is an X-thread layer in this embodiment. Furthermore, another fiber layer, which is a Y-thread layer in this embodiment, is formed by arranging the carbon fiber bundle in the Y-axis direction, which is the width direction of the frame 22. The carbon fiber bundle is arranged in a bias direction as required to further form another fiber layer, which is a bias thread layer. The bias direction intersects the X-axis direction and the Y-axis direction. When a predetermined number of the thread layers (fiber layers) are laminated on the frame 22, the laminated fiber layers 23 are formed. The term "fiber layer" may include one that is formed by arranging a fiber bundle that is not twisted and one that is formed by arranging a thread (twisted fiber bundle).

[0027] Next, the thickness direction threads z are inserted in the laminated fiber layers 23 while the frame 22 that holds the laminated fiber layers 23 is secured to the support brackets on the table 24 with bolts. Figs. 2 and 4(a) show the state where insertion of the thickness direction threads z and a lock yarn P have been performed two cycles, and insertion of the thickness direction threads z is being performed for the third time. Fig. 4(a) is a partially enlarged view of Fig. 2. Fig. 4(a) shows the state where the bores 23a have been formed by the perforation needles 26 at the position on the laminated fiber layers 23 where the thickness direction threads z are to be inserted, and the thickness direction thread insertion needles 11 are arranged at the position corresponding to the bores 23a.

[0028] To form the bores 23a with the perforation needles 26, the press plate 28 and the press blocks 29, 30 hold and compress the position of the laminated fiber layers 23 corresponding to the row of perforation needles 26. Advancing the perforation needles 26 from the standby position to the operational position in this holding state causes the perforation needles 26 to penetrate the laminated fiber layers 23, and form the bores 23a. Thereafter, the perforation needles 26 are retracted from the operational position to the standby position. The perforation needles 26 are guided by the recesses 28c of the comb teeth 28b so as to be inserted perpendicular to the laminated fiber layers 23. Since the laminated fiber layers 23 are arranged in close contact with each other to some extent by the compression of the press plate 28 and the press blocks 29, 30, the bores 23a are formed after the perforation needles 26 are removed.

[0029] After the press block 29 is arranged at the standby position as shown in Fig. 4(b) from the state shown in Figs. 2 and 4(a), the needle support body 25 is advanced to the operational position so that the thickness direction thread insertion needles 11 simultaneously thrust the laminated fiber layers 23. That is, the thickness direction thread insertion needles 11 arranged in a row in the Y-axis direction simultaneously thrust the laminated fiber layers 23 together with the thickness direction threads z. The thickness direction thread insertion needles 11 are inserted through the laminated fiber layers 23 until the needle's eyes 14 project to the outside of the laminated fiber layers 23. More specifically, the needle's eyes 14 are advanced until they project from the surface of the laminated fiber layers 23, on which the press block 30 abuts against, and come close to the press block 29.

[0030] After the thickness direction thread insertion needles 11 reach the advancing end, the thickness direction thread insertion needles 11 are slightly retracted. As a result, the thickness direction threads z form the loops L as shown in Fig. 4(b). That is, a loop forming process is performed. The loops L are formed by part of the thickness direction threads z that extend from the laminated fiber layers 23 to the needle's eyes 14. The loops L permit the lock yarn insertion needle 31 to pass therethrough. That is, the loops L are formed by the thickness direction threads z on the side of the laminated fiber layers 23 from which the thickness direction thread insertion needles 11 project. The side of the laminated fiber layers 23 from which the thickness direction thread insertion needles 11 project refers to the side of the laminated fiber layers 23 opposite from the needle support body 25, or to the side where the press blocks 29, 30 are located with respect to the laminated fiber layers 23.

[0031] When the thickness direction thread insertion needles 11 are inserted through the laminated fiber layers 23, the press block 29 is arranged at the standby position. Thus, the force by which the production apparatus 20 presses the laminated fiber layers 23 is slightly reduced. However, since the thickness direction thread insertion needles 11 are inserted through the bores 23a, which are previously formed by the perforation needles 26, the resistance caused when the thickness direction thread insertion needles 11 are inserted through the laminated fiber layers 23 is reduced. Thus, the arrangement of the thread of the laminated fiber layers 23 is not disturbed.

[0032] Next, the lock yarn insertion needle 31 is actuated in the state of Fig. 4(b). The lock yarn insertion needle 31 passes through a loop (not shown) of the lock yarn P that is previously inserted, and advances in the arrangement direction of the thickness direction thread insertion needles 11, that is, the Y-axis direction. That is, a lock yarn insertion process is performed. When the distal end of the lock yarn insertion needle 31 passes through the loops L of the thickness direction threads z held by the thickness direction thread insertion needles 11 and reaches the edge of the laminated fiber layers 23, the lock yarn insertion needle 31 is stopped. At this time, the lock yarn P that extends from a lock yarn feed portion (not shown) is latched on the distal end of the lock yarn insertion needle 31. When the latch at the distal end of the lock yarn insertion needle 31 is closed, the lock yarn insertion needle 31 is moved back so as not to pull in the loops L. As a result, the lock yarn P is inserted through the loops L of the thickness direction threads z while being folded back. That is, the loop of the lock yarn P that is latched on the lock yarn insertion needle 31 is inserted through the loop of the lock yarn P that is previously inserted.

[0033] Thereafter, the thickness direction thread insertion needles 11 are retracted away from the laminated fiber layers 23 from the state of Fig. 4(b), and are arranged at the standby position. The press block 29 is arranged at the operational position again. In this state, when a tension adjusting portion (not shown) pulls back the thickness direction threads z from the laminated fiber layers 23, the thickness direction threads z inserted in the laminated fiber layers 23 are tightened while being locked by the lock yarn P. That is, a laminated fiber layer tightening process is performed. Then, the row of perforation needles 26 and the row of thickness direction thread insertion needles 11 are returned to the initial position (standby position). The press plate 28 and the press blocks 29, 30 are also arranged at the standby position. As described above, one insertion cycle of the thickness direction threads z is completed.

[0034] Next, when the table 24 moves by an amount corresponding to the insertion pitch of the thickness direction threads z, the perforation needles 26 face the next insertion position of the thickness direction threads z into the laminated fiber layers 23. Hereinafter, the insertion cycle of the thickness direction threads z is successively executed in the same manner as described above, and the thickness direction threads z are inserted in the predetermined insertion area of the laminated fiber layers 23. That is, the loop forming process, the lock yarn insertion process, and the laminated fiber layer tightening process are repeated so that the thickness direction threads z are inserted in the insertion area of the laminated fiber layers 23. As a result, the thread layers forming the laminated fiber layers 23 are connected by the thickness direction threads z, and thus, the three-dimensional fibrous structure is produced. After insertion of the thickness direction threads z in the entire thickness direction thread insertion area of the laminated fiber layers 23 is finished, the pins 21 are detached from the frame 22, and the three-dimensional fibrous structure is removed from the frame 22. This completes the manufacture of the three-dimensional fibrous structure.

[0035] The sizing agent is applied to the carbon fiber bundle, which is used as the thickness direction threads z. Thus, conventionally, the thickness direction threads z undesirably adhered to the surface of the thickness direction thread insertion needles when forming the loops L by slightly pulling back the thickness direction thread insertion needles that are inserted in the laminated fiber layers 23. As the thickness direction threads z returns together with the thickness direction thread insertion needles, the size of the loops L are reduced. Even if the size of the loop L of one of the thickness direction threads z is reduced, the lock yarn insertion needle cannot smoothly pass through the entire one row of loops L, and an operator needs to manually adjust the loops L each time.

[0036] However, according to the preferred embodiment (the present invention), anti-adhesive treatment is performed on the surface of the insertion portions 13 of the thickness direction thread insertion needles 11 to prevent adhesion of the fiber bundle. More specifically, the matte plating layer 16 having a surface roughness of 0.1 μm or more and 0.7 μm or less in terms of the center line average roughness Ra is formed on the surface of each insertion portion 13 by hard chrome plating. As a result, when forming the loops L by slightly pulling back the thickness direction thread insertion needles 11, the fiber bundles are inhibited from adhering to the thickness direction thread insertion needles 11. Thus, the loops L having a predetermined size or more are stably formed. Therefore, the lock yarn P is smoothly inserted in the loops L using the lock yarn insertion needle 31. Furthermore, the laminated fiber layers 23 are tightened by the thickness direction threads z via the lock yarn P by pulling back the thickness direction threads z from the laminated fiber layers 23 together with the thickness direction thread insertion needles 11.

[0037] As an experiment, the surface roughness of the insertion portions 13 was changed, and the rate of loop forming was measured. The diameter of the small diameter portions 13b of the thickness direction thread insertion needles 11 used for measuring the loop forming rate was 1 mm, and the diameter of the thickness direction threads z was 0.5 mm. The loop forming rate shows by percentage the rate of the number of times the loops L that are successfully formed when insertion of the thickness direction threads z is executed 100 cycles. When the greatest distance between the loop L and the associated thickness direction thread insertion needle 11 is 3 mm or more, it was determined that the loop was successfully formed. As a result of the experiment, when the surface roughness was less than Ra 0.1 μm, that is, when the surface roughness of the thickness direction thread insertion needles was not modified from the conventional apparatus, the loop forming rate was 10% or less. However, when the surface roughness of the thickness direction thread insertion needles was changed, and the center line average roughness was set to Ra 0.5 μm, the loop forming rate was 100%. Also, even when the center line average roughness was Ra 0.1 μm or Ra 0.7 μm, the loop forming rate was 80% or more.

[0038] The preferred embodiment has the following advantages.

(1) The coating, which is the matte plating layer 16 in this embodiment, is formed on the insertion portions 13 of the thickness direction thread insertion needles 11 that are inserted in the laminated fiber layers 23. The surface roughness of the matte plating layer 16 is formed such that the center line average roughness Ra is 0.1 μm or more and 0.7 μm or less. Thus, when slightly pulling back the thickness direction thread insertion needles 11 that are thrust in the laminated fiber layers 23 from the laminated fiber layers 23, the thickness direction threads z are inhibited from adhering to the surface of the insertion portions 13. Thus, the loops L of the thickness direction threads z are stably formed to have a certain size or more for each row of the thickness direction thread insertion needles 11. Thus, the three-dimensional fibrous structure is smoothly produced.

(2) The matte plating layer 16 is formed by forming irregularities of a desired roughness on the surface of the needle material of the thickness direction thread insertion needles 11 by shot blasting, and then coating the surface of the needle material with plating. Thus, the matte plating layer 16 having the desired surface roughness is formed by changing the condition of the shot blasting.

(3) The matte plating layer 16 is formed by hard chrome plating having satisfactory wear resistance. Thus, the wear resistance of the thickness direction thread insertion needles 11 is improved.

(4) The laminated fiber layers 23 and the thickness direction threads z are formed by carbon fiber bundle. When forming the laminated fiber layers 23 and the thickness direction threads z by the carbon fiber bundle, several hundreds to several tens of thousands of thin fibers are put into a bundle to form one carbon fiber bundle. Thus, for example, when the sizing agent is not applied to the carbon fiber bundle, the arrangement of the fiber bundle and the insertion of the thickness direction threads z into the laminated fiber layers 23 are not smoothly performed. When using the thickness direction threads z to which the sizing agent is applied, the conventional thickness direction thread insertion needles cannot form the loops L of the thickness direction threads z stably to have a certain size or more. However, according to the thickness direction thread insertion needles 11 of the preferred embodiment, even if the laminated fiber layers 23 and the thickness direction threads z are formed by the carbon fiber bundle, the loops L of the thickness direction threads z are stably formed to have a certain size or more.

[0039] The preferred embodiment may be modified as follows.

[0040] The fiber that forms the laminated fiber layers 23 and the thickness direction threads z is not limited to a carbon fiber, but may be, for example, an aramid fiber, a poly-p-phenylene benzobisoxazole (PBO) fiber, an ultra-high molecular weight polyethylene fiber, a polyarylate fiber, a polyacetal fiber, or a high-strength polyvinyl alcohol (PVA) fiber.

[0041] The surface treatment for forming the matte plating layer 16 is not limited to forming desired irregularities on the surface of the needle material of the thickness direction thread insertion needles 11 by shot blasting, but the surface of the needle material may be subjected to honing.

[0042] Type of plating for forming the matte plating layer 16 is not limited to chrome plating such as hard chrome plating, but may be other wet plating or dry plating. Other wet plating includes nickel plating and electroless nickel plating. Dry plating includes forming a titanium nitride film by ion plating.

[0043] The method for forming the matte plating layer 16 on the surface of the insertion portions 13 is not limited to coating the surface of the needle material with plating after performing surface treatment for roughening the surface of the needle material by shot blasting or honing. The matte plating layer 16 may be formed by coating the surface of the needle material with composite plating without performing the surface treatment for roughening the surface of the needle material. The composite plating is a plating method in which particles are drawn into the coating by plating the surface of an object, that is, the insertion portion 13 in the preferred embodiment, in a state where particles are suspended in the plating bath. The surface roughness of the matte plating layer 16 is adjusted by adjusting the diameter of the particles suspended in the bath. When forming the matte plating layer 16 by composite plating, shot blasting and honing are not necessary, which reduces the number of processes. The composite plating preferably sustains particles of polytetrafluoroethylene (PTFE) in electroless nickel plating.

[0044] Particles used in composite plating do not need to be PTFE particles, but may be particles of aluminum oxide, silicon oxide, titanium oxide, zirconium oxide, silicon carbide, boron carbide, or boron nitride.

[0045] The structure in which non-adhesiveness against the thickness direction threads z is applied to the surface of the insertion portions 13 of the thickness direction thread insertion needles 11 is not limited to the coating treatment that makes the surface roughness of the insertion portions 13 to be 0.1 μm or more and 0.7 μm or less in terms of the center line average roughness Ra. Figs. 5(a) and 5(b) show a thickness direction thread insertion needle 11 of another embodiment. As shown in Fig. 5(b), grooves 17, which extend in the axial direction (the direction of the axis CL) of the thickness direction thread insertion needle 11, may be formed on the surface of the insertion portion 13 to be parallel to each other. The grooves 17 provide the surface of the insertion portion 13 with non-adhesiveness to the thickness direction thread z. The grooves 17 are formed on the surface of the insertion portion 13 except where the thread groove 15 is formed. The width of the grooves 17 is less than the width of the thread groove 15, and the depth of the grooves 17 is less than the depth of the thread groove 15. The width of the grooves 17 is set smaller than the diameter of the thickness direction threads z, and is preferably 0.5 mm or less. The pitch between the adjacent grooves 17 is substantially the same as the width of the grooves 17. Fig. 5(b) does not show the plating layer although plating is provided on the surface of the thickness direction thread insertion needles 11. Fig. 5(a) does not show the grooves 17.

[0046] The pitch between the adjacent grooves 17 may also be greater than the width of the grooves 17 as shown in Fig. 5(c).

[0047] The grooves 17 shown in Figs. 5(b) and 5(c) do not need to extend parallel to the axial direction of the thickness direction thread insertion needles 11, but may be formed to extend slightly inclined with respect to the axial direction of the thickness direction thread insertion needles 11.

[0048] The thread groove 15 provided on the insertion portion 13 may be omitted from the thickness direction thread insertion needles 11 of Figs. 1(c), 5(b), and 5(c).

[0049] The three-dimensional fibrous structure produced using the thickness direction thread insertion needles 11 may have shapes other than the plate-like shape. For example, thickness direction thread insertion needles 11 may be used in a method for producing the three-dimensional fibrous structure that has an angled shape, a rectangular cylinder shape, a circular cylinder shape, or a curved plate shape.

[0050] When inserting the perforation needles 26 and the thickness direction thread insertion needles 11 into the laminated fiber layers 23, the press plate 28 may be arranged at the standby position, and only the press blocks 29, 30 may be arranged at the operational position. In this case, since the perforation needles 26 and the thickness direction thread insertion needles 11 are inserted in the laminated fiber layers 23 in a state where the fiber layers are not compressed, the resistance when inserting the perforation needles 26 and the thickness direction thread insertion needles 11 into the laminated fiber layers 23 is reduced. This permits the perforation needles 26 and the thickness direction thread insertion needles 11 to be smoothly inserted in the laminated fiber layers 23.

[0051] The press blocks 29, 30 arranged on the side of the laminated fiber layers 23 from which the thickness direction thread insertion needles 11 project do not need to be a pair, but only either one of the press blocks 29, 30 may be provided.

[0052] The recesses 28c may be omitted by slightly increasing the size of the gaps between the comb teeth 28b of the press plate 28 than the outer diameter of the thickness direction thread insertion needles 11 and the perforation needles 26. The press plate 28 may be one that does not include the comb teeth 28b, and includes simply a straight pressing section extending along the row of thickness direction thread insertion needles 11.

[0053] Holes do not need to be previously formed in the laminated fiber layers 23 with the perforation needles 26, and the thickness direction thread insertion needles 11 may be directly inserted in the laminated fiber layers 23 depending on the thickness of the laminated fiber layers 23 and the type of the fiber.

[0054] The press plate 28 and the press blocks 29, 30 may be omitted, and the thickness direction thread insertion needles 11 may be directly inserted in the laminated fiber layers 23 depending on the thickness of the laminated fiber layers 23 and on the types of the fiber.

[0055] The loop portion of the lock yarn P does not need to be locked by successively inserting the loop portion of the lock yarn P into the loop portion of the previously inserted lock yarn P. The lock yarn P may be locked by simply tightening the thickness direction threads z.

[0056] The structure of the laminated fiber layers 23 shown in Fig. 3 may be changed as long as it is at least biaxially oriented in a plane. For example, the fiber layers 23 may be made biaxially oriented in a plane by omitting the bias thread, or may be made triaxially oriented in a plane by arranging the fiber bundles at an angle of 60° with respect to each other. The laminated fiber layers 23 may also be formed by laminating woven fabrics.

Claims

1. A thickness direction thread insertion needle used for producing a three-dimensional fibrous structure, the three-dimensional fibrous structure including laminated fiber layers formed by laminating a plurality of fiber layers to be at least biaxially oriented, and a thickness direction thread inserted in a direction to intersect the fiber layers to connect the laminated fiber layers, the thickness direction thread insertion needle being **characterized by**:

a proximal end portion;
an insertion portion, which is formed to be thinner than the proximal end portion and is selectively inserted in the laminated fiber layers, the insertion portion including a distal end and a needle's eye formed close to the distal end; and
a coating formed on the insertion portion, the coating having a surface roughness of 0.1 μm or more and 0.7 μm or less in terms of the center line average roughness Ra, and the coating improves the wear resistance of the insertion portion.

2. The thickness direction thread insertion needle according to claim 1, **characterized in that** the laminated fiber layers and the thickness direction thread are each formed by a carbon fiber bundle.

3. The thickness direction thread insertion needle according to claim 1 or 2, **characterized in that** the coating is formed by roughening the surface of needle material of the thickness direction thread insertion needle and then coating the surface with plating.

4. The thickness direction thread insertion needle according to claim 3, **characterized in that** treatment for roughening the surface of the needle material is performed by shot blasting.

5. The thickness direction thread insertion needle according to claim 1 or 2, **characterized in that** the coating is formed by composite plating.

6. A thickness direction thread insertion needle being **characterized by**:

a proximal end portion; and
an insertion portion, which is formed to be thinner than the proximal end portion and is selectively inserted in laminated fiber layers, the insertion portion including a distal end and a needle's eye formed close to the distal end, the surface of the insertion portion includes a plurality of grooves extending in an axial direction of the insertion portion, and the surface of the insertion portion is coated with wear resistant plating.

7. A method for producing a three-dimensional fibrous structure, the three-dimensional fibrous structure including laminated fiber layers formed by laminating a plurality of fiber layers to be at least biaxially oriented, and a thickness direction thread inserted in the laminated fiber layers to intersect the fiber layers thereby connecting the laminated fiber layers, the laminated fiber layers including an insertion area in which the thickness direction thread is inserted, the production method being **characterized by**:

arranging a plurality of thickness direction thread insertion needles in a row, each thickness direction thread insertion needle including a proximal end portion, an insertion portion, which is formed to be thinner than the proximal end portion and is selectively inserted in the laminated fiber layers, the insertion portion including a distal end and a needle's eye formed close to the distal end, and a coating formed on the insertion portion, the coating having a surface roughness of 0.1 μm or more and 0.7 μm or less in terms of the center line average roughness Ra, and the coating improves the wear resistance of the insertion portion;
simultaneously thrusting a plurality of thickness direction thread insertion needles arranged in a row into the laminated fiber layers with the thickness direction threads in a state where the laminated fiber layers are retained on a frame, so as to cause the needle's eyes of the thickness direction thread insertion needles to project outside of the laminated fiber layers, such that loops are formed by the thickness direction threads on the side of the laminated fiber layers from which the thickness direction thread insertion needles project;
inserting a lock yarn in the loops along an arrangement direction of the thickness direction thread insertion needles;
tightening the laminated fiber layers by pulling back the thickness direction thread insertion needles from the laminated fiber layers after inserting the lock yarn in the loops; and
inserting the thickness direction yarn in the insertion area of the laminated fiber layers by repeating the forming of loops, the insertion of the lock yarn, and the tightening of the laminated fiber layers, and then removing the laminated fiber layers from the frame.

8. A method for producing a three-dimensional fibrous structure, the three-dimensional fibrous structure including laminated fiber layers formed by laminating a plurality of fiber layers to be at least biaxially oriented, and a thickness direction thread inserted in the laminated fiber layers to intersect the fiber layers thereby connecting the laminated fiber layers, the laminated fiber layers including an insertion area in which the thickness direction thread is inserted, the production method being **characterized by**:

arranging a plurality of thickness direction thread insertion needles in a row, each thickness direction thread insertion needle including a proximal end portion and an insertion portion, which is formed to be thinner than the proximal end portion and is selectively inserted in the laminated fiber layers, the insertion portion including a distal end and a needle's eye formed close to the distal end, the surface of the insertion portion includes a plurality of grooves extending in an axial direction of the insertion portion, and the surface of the insertion portion is coated with wear resistant plating;
simultaneously thrusting a plurality of thickness direction thread insertion needles arranged in a row into the laminated fiber layers with the thickness direction threads in a state where the laminated fiber layers are retained on a frame, so as to cause the needle's eyes of the thickness direction thread insertion needles to project outside of the laminated fiber layers, such that loops are formed by the thickness direction threads on the side of the laminated fiber layers from which

the thickness direction thread insertion needles project;
inserting a lock yarn in the loops along the arrangement direction of the thickness direction thread insertion needles;
tightening the laminated fiber layers by pulling back the thickness direction thread insertion needles from the laminated fiber layers after inserting the lock yarn in the loops; and
inserting the thickness direction yarn in the insertion area of the laminated fiber layers by repeating the forming of loops, the insertion of the lock yarn, and the tightening of the laminated fiber layers, and then removing the laminated fiber layers from the frame.

Fig.1 (a)

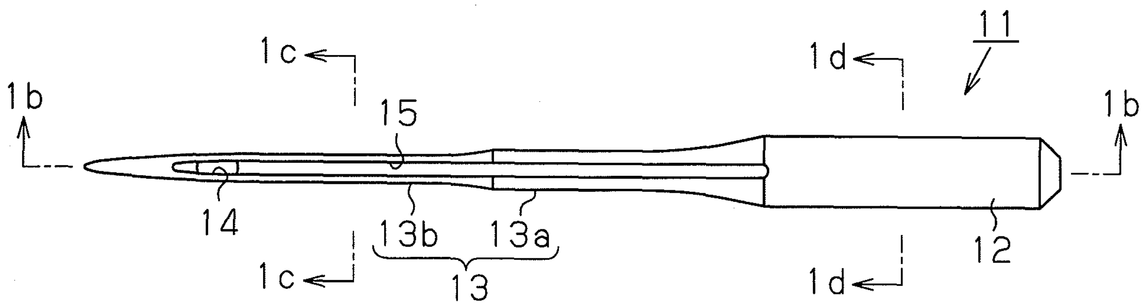


Fig.1 (b)

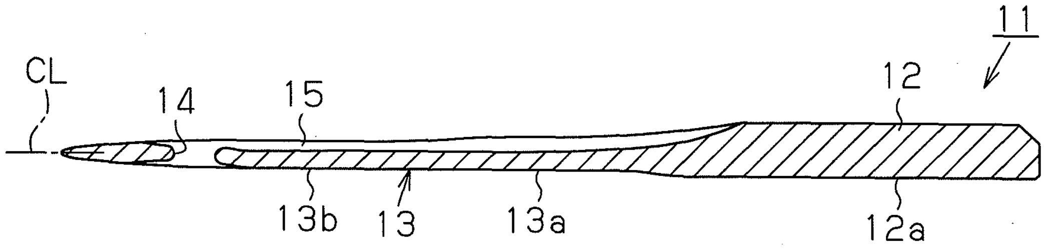


Fig.1 (c)

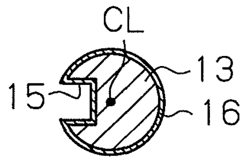


Fig.1 (d)

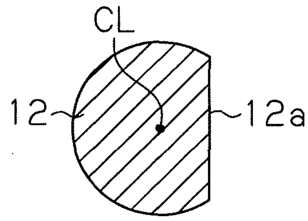


Fig.2

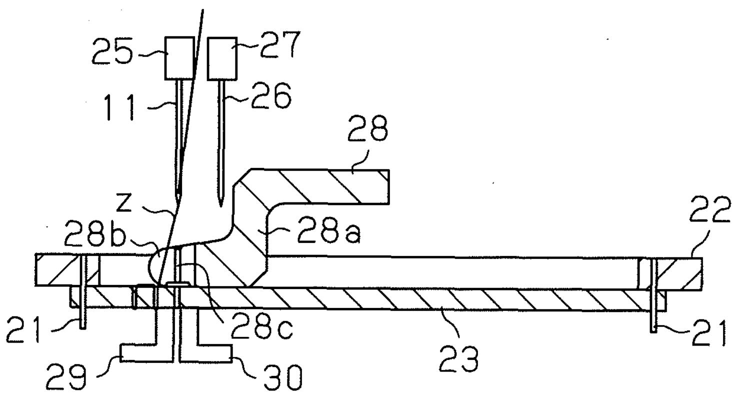


Fig.3

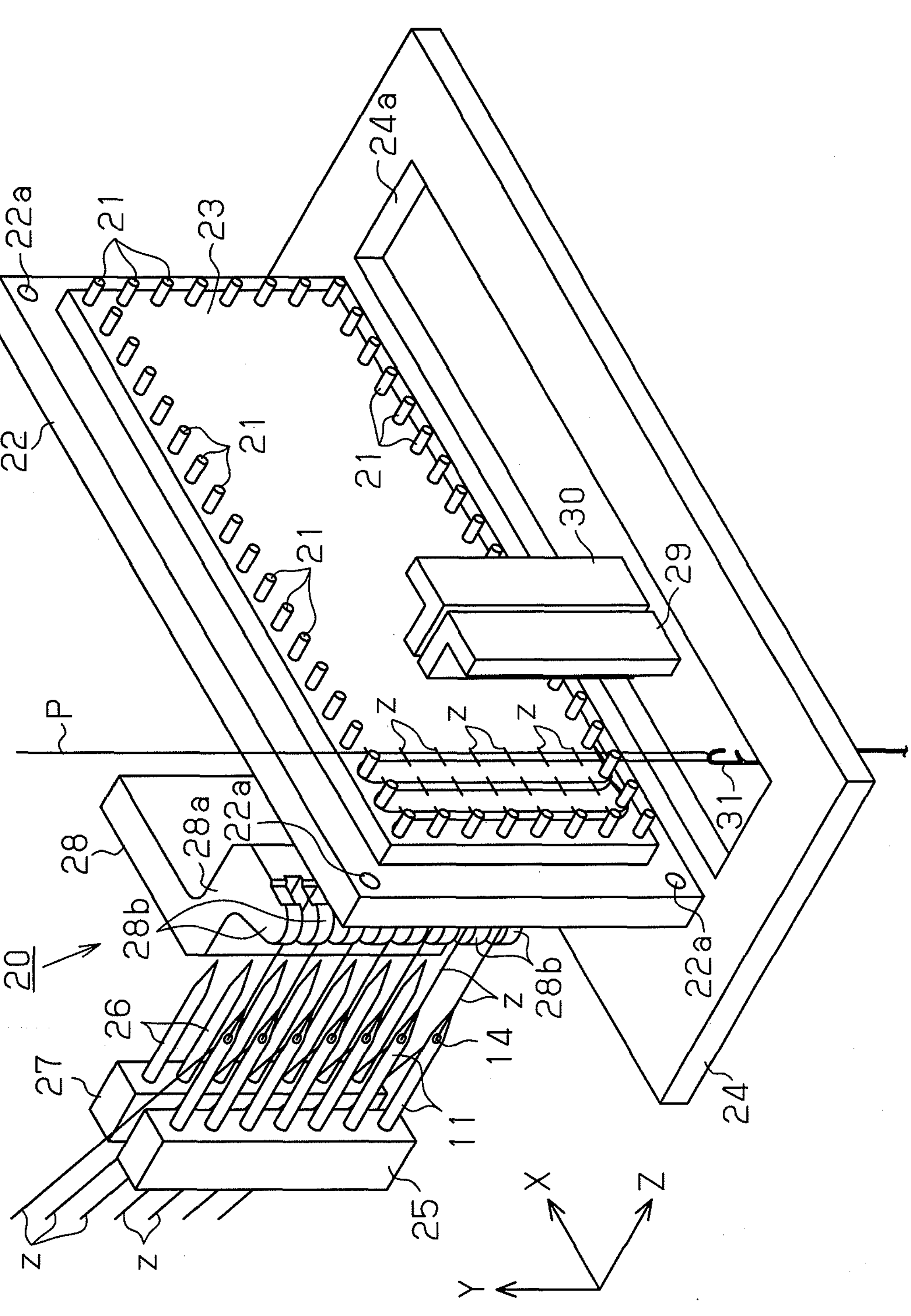

22a
21
23
22
24a
21
21
30
29
21
P
Z
Z
Z
31
28
28a
22a
28b
20
22a
28b
Z
26
14
27
11
24
25
Z
Z
X
Z
Y

Fig.4(a)

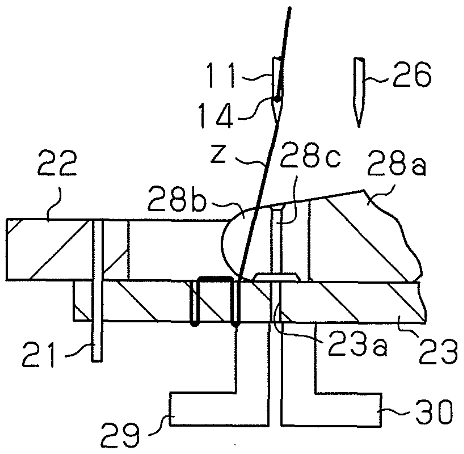


Fig.4(b)

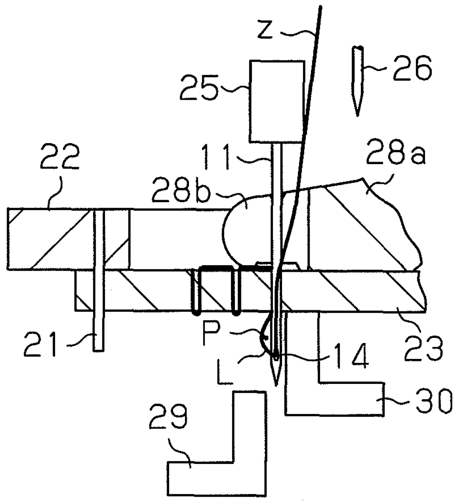


Fig.5(a)

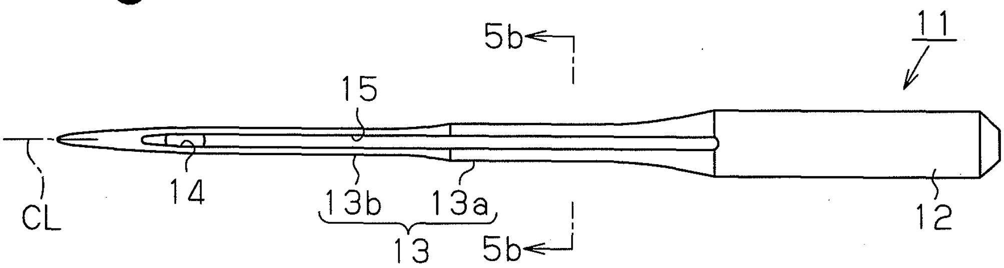


Fig.5(b)

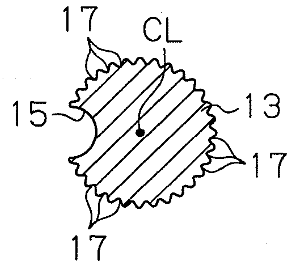


Fig.5(c)

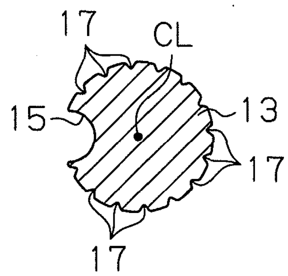
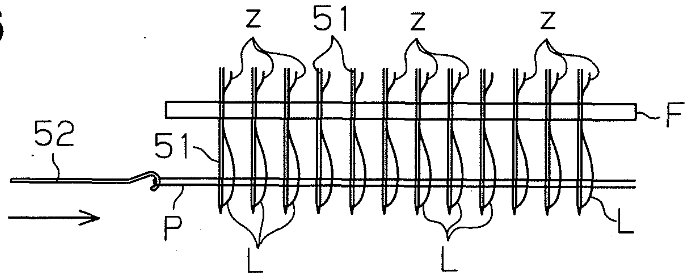


Fig.6



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2008/052249

A. CLASSIFICATION OF SUBJECT MATTER
D03D41/00(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
D03D41/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2008
Kokai Jitsuyo Shinan Koho	1971-2008	Toroku Jitsuyo Shinan Koho	1994-2008

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP 8-218249 A (Toyoda Automatic Loom Works, Ltd.), 27 August, 1996 (27.08.96), Par. Nos. [0033] to [0041]; Figs. 1 to 20 & US 5772821 A & FR 2730247 A	1-8
Y	JP 2003-326069 A (Brother Industries, Ltd.), 18 November, 2003 (18.11.03), Par. Nos. [0018] to [0021]; Fig. 3 & CN 1460741 A	1-5,7
Y A	JP 11-241256 A (Toyoda Automatic Loom Works, Ltd.), 07 September, 1999 (07.09.99), Par. No. [0023] (Family: none)	2-5 1,6-8

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
03 March, 2008 (03.03.08)	11 March, 2008 (11.03.08)
Name and mailing address of the ISA/ Japanese Patent Office Facsimile No.	Authorized officer Telephone No.

Form PCT/ISA/210 (second sheet) (April 2007)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2008/052249

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP 30-9753 Y1 (Kenji OKAMOTO), 15 July, 1955 (15.07.55), Figs. 1 to 5 (Family: none)	6,8
Y A	JP 51-146340 A (Rejin Seiki Kogyo Kabushiki Kaisha), 15 December, 1976 (15.12.76), Full text (Family: none)	6,8 1-5,7

Form PCT/ISA/210 (continuation of second sheet) (April 2007)

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

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