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FIBER STRUCTURE AND FIBER-REINFORCED COMPOSITE MATERIAL

Abstract

A fiber structure includes multiple fiber layers and multiple interlayer binding yarns. The fiber layers include multiple first yarn layers and one or more second yarn layers. Each of the first yarn layers includes multiple first yarns each having a yarn main axis extending in a first direction. Each of the second yarn layers includes an end second yarn located at an end of the central region. The interlayer binding yarns located in an end region include two of the interlayer binding yarns that pass through mutually different paths in a cross section of the fiber structure orthogonal to the first direction, so as to interlace with the first yarns. A pitch in the first direction between the interlayer binding yarns in the end region is smaller than a pitch in the first direction between the interlayer binding yarns in the central region.

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Background/Summary

TECHNICAL FIELD

[0001] The present disclosure relates to a fiber structure and a fiber-reinforced composite material.

BACKGROUND ART

[0002] For example, a fiber structure described in Patent Literature 1 includes multiple first yarns each having a yarn main axis extending in a first direction, and multiple second yarns each having a yarn main axis extending in a second direction orthogonal to the first direction. The first yarns are arranged in the second direction. The second yarns are arranged in the first direction. Additionally, the fiber structure described in Patent Literature 1 includes thermofusible yarns that contain thermofusible fibers. By fusing the thermofusible yarns at intersections of the first and second yarns, the first and second yarns are prevented from being displaced in the fiber structure.

CITATION LIST

Patent Literature

[0003] Patent Literature 1: Japanese Laid-Open Patent Publication No. 2011-58119

SUMMARY OF INVENTION

Technical Problem

[0004] It is desirable to suppress fraying of the second yarns from the ends of the fiber structure in the first direction. For example, fraying of the second yarns can be suppressed by providing thermofusible yarns described in Patent Literature 1 at the ends of the fiber structure in the first direction and fusing these thermofusible yarns to the first and second yarns. However, this approach requires an additional step of fusing the thermofusible yarns to the first and second yarns, in addition to the weaving process used to produce the fiber structure. This results in an increase in the number of steps involved in manufacturing the fiber structure. Therefore, it is desirable to suppress fraying from the ends of the fiber structure while minimizing the increase in the number of steps required for the manufacture of the fiber structure.

Solution to Problem

[0005] In one general aspect of the present disclosure, a fiber structure includes multiple fiber layers stacked in a stacking direction, and multiple interlayer binding yarns binding the multiple fiber layers in the stacking direction. The fiber layers include multiple first yarn layers and one or more second yarn layers located between the first yarn layers in the stacking direction. Each of the first yarn layers includes multiple first yarns each having a yarn main axis extending in a first direction. The first yarns are arranged in a second direction orthogonal to the first direction. One of the first yarn layers is located at each of opposite ends of the fiber structure in the stacking direction. Each of the second yarn layers includes multiple second yarns each having a yarn main axis extending in the second direction. The second yarns are arranged in the first direction without interlacing with the first yarns. Each of the interlayer binding yarns is adjacent to one of the second yarns in the first direction, has a yarn main axis extending in the second direction, and is engaged with the first yarns of the first yarn layers located at the opposite ends of the fiber structure in the

stacking direction. The fiber structure further includes a central region including a center of the fiber structure in the first direction, and two end regions respectively including opposite ends of the fiber structure in the first direction. Each of the end regions is adjacent to the central region in the first direction. The second yarns include multiple end second yarns located at an end of the central region in the first direction. Each of the second yarn layers includes the end second yarns. Each of the central region and the two end regions includes the interlayer binding yarns. The interlayer binding yarns located in each of the end regions include the interlayer binding yarn located at an endmost position in the first direction among the interlayer binding yarns included in the fiber structure, and two of the interlayer binding yarns that pass through mutually different paths in a cross section of the fiber structure orthogonal to the first direction, so as to interlace with the first yarns. A pitch in the first direction between the interlayer binding yarns in the end regions is smaller than a pitch in the first direction between the interlayer binding yarns in the central region. [0006] In another general aspect of the present disclosure, a fiber-reinforced composite material includes the above-described fiber structure and a matrix material impregnated into the fiber structure.

Description

BRIEF DESCRIPTION OF DRAWINGS

[0007] FIG. 1 is a perspective view showing a fiber-reinforced composite material according to an embodiment.

[0008] FIG. 2 is a perspective view showing a fiber structure according to the embodiment.

[0009] FIG. 3 is a top view of the fiber structure shown in FIG. 2.

[0010] FIG. 4 is an end view taken along line 4-4 of FIG. 3.

[0011] FIG. 5 is an end view taken along line 5-5 of FIG. 3.

[0012] FIG. 6 is a cross-sectional view taken along line 6-6 of FIG. 3.

[0013] FIG. 7 is a top view showing a fiber-reinforced composite material according to a first modification.

[0014] FIG. 8 is an explanatory top view showing a method for manufacturing a fiber structure according to a second modification.

DESCRIPTION OF EMBODIMENTS

[0015] A fiber structure and a fiber-reinforced composite material according to an embodiment will now be described with reference to FIGS. 1 to 6.

Fiber Reinforced Composite

[0016] As shown in FIG. 1, a fiber-reinforced composite material **10** includes a fiber structure **11** and a matrix resin Ma as a matrix material impregnated into the fiber structure **11**. The fiber structure **11** serves as a reinforcing substrate of the fiber-reinforced composite material **10**. The matrix resin Ma is, for example, a thermosetting resin. Examples of the thermosetting resin include an epoxy resin, a vinyl ester resin, an unsaturated polyester resin, and a phenol resin. For example, the fiber-reinforced composite material **10** is formed by impregnating the fiber structure **11** with a thermosetting resin using a resin transfer molding (RTM) method.

Fiber Structure

[0017] As shown in FIG. 2, the fiber structure **11** includes multiple fiber layers **20**. The fiber layers **20** are stacked in a stacking direction Z. The fiber structure **11** does not change in configuration before and after thermal curing of the matrix material.

[0018] In the following description, the fiber structure **11** is described as being placed horizontally. In the drawings, directions along a horizontal plane are indicated by an X-axis and a Y-axis, and a direction orthogonal to the horizontal plane is indicated by a Z-axis. The X-axis, the Y-axis, and the Z-axis are orthogonal to each other. A direction parallel to the X-axis is also referred to as a first

direction X. A direction parallel to the Y-axis is also referred to as a second direction Y. The second direction Y is a direction orthogonal to the first direction X. The stacking direction Z is a direction parallel to the Z-axis.

[0019] The fiber layers **20** include multiple first yarn layers **21** and one or more (multiple in this example) second yarn layers **22**. The first yarn layers **21** and the second yarn layers **22** are stacked in the stacking direction Z. Each first yarn layer **21** includes multiple first yarns **31**, and the first yarns **31** are arranged in the second direction Y. The first yarns **31** each have a yarn main axis extending in the first direction X. Each second yarn layer **22** includes multiple second yarns **32**, and the second yarns **32** are arranged in the first direction X. The second yarns **32** each have a yarn main axis extending in the second direction Y.

[0020] Each of the first yarns **31** and the second yarns **32** is, for example, a fiber bundle in which multiple reinforcing continuous fibers are bundled. The reinforcing fibers may be organic fibers or inorganic fibers. Instead, the reinforcing fibers may be mixed fibers in which different types of organic fibers, different types of inorganic fibers, or organic fibers and inorganic fibers are mixed. Examples of the organic fibers include acrylic fibers, nylon fibers, polyester fibers, aramid fibers, poly-p-phenylenebenzobisoxazole fibers, and ultra-high-molecular weight polyethylene fibers. Examples of the inorganic fibers include carbon fibers, glass fibers, and ceramic fibers. The first yarns **31** and the second yarns **32** of the present embodiment are made of carbon fibers.

[0021] One of the first yarn layers **21** is located at each of the opposite ends of the fiber structure **11** in the stacking direction Z. Specifically, one of the multiple first yarn layers **21** is located at an end **11a**, which is one end (lower end in FIG. 2) of the fiber structure **11** in the stacking direction Z. Another of the first yarn layers **21** is located at an end **11b**, which is the other end (upper end in FIG. 2) of the fiber structure **11** in the stacking direction Z. The first yarn layer **21** located at the end **11a** of the fiber structure **11** is also referred to as a first end layer **21a**. The first yarn layer **21** located at the end **11b** of the fiber structure **11** is also referred to as a second end layer **21b**.

[0022] Each second yarn layer **22** is located between the corresponding first yarn layers **21** in the stacking direction Z. Each of the first end layer **21a** and the second end layer **21b** is adjacent to one of the second yarn layers **22** in the stacking direction Z. Two of the first yarn layers **21** are located between the corresponding second yarn layers **22** in the stacking direction Z. One second yarn layer **22** and two first yarn layers **21** are alternately stacked in that order in the stacking direction Z between the first end layer **21a** and the second end layer **21b**. In this manner, the multiple first yarn layers **21** and the multiple second yarn layers **22** are stacked in the stacking direction Z, so that the multiple fiber layers **20** are stacked in the stacking direction Z.

[0023] The first yarns **31** extend linearly in the first direction X. The first yarn layers **21** are stacked such that the first yarns **31** are arranged in the stacking direction Z. The first yarns **31** arranged in the stacking direction Z are collectively referred to as a first yarn group **31a**. Multiple first yarn groups **31a** are arranged in the second direction Y.

[0024] The second yarns **32** do not interlace with the first yarns **31**. In each of one first yarn layer **21** and the corresponding second yarn layer **22** adjacent to each other in the stacking direction Z, each second yarn **32** in the second yarn layer **22** extends linearly in the second direction Y across the first yarns **31** in the first yarn layer **21**.

[0025] The fiber structure **11** includes a central region Ra and two end regions Rb. The central region Ra includes a center of the fiber structure **11** in the first direction X. Each of the end regions Rb is adjacent to the central region Ra in the first direction X. The two end regions Rb include ends **11c** and **11d** of the fiber structure **11** in the first direction X, respectively.

[0026] Each second yarn layer **22** includes multiple end second yarns **32a**. The end second yarns **32a** are the second yarns **32** located at ends Rc of the central region Ra in the first direction X. Among the multiple second yarns **32** in each second yarn layer **22**, the second yarn **32** located at one end in the first direction X and the second yarn **32** located at the other end correspond to the end second yarns **32a**. The end second yarns **32a** are located at the opposite ends of the central

region Ra in the first direction X. The central region Ra includes the end second yarns **32a** located at the opposite ends in the first direction X, and multiple second yarns **32** located between the end second yarns **32a** at one end in the first direction X and the end second yarns **32a** at the other end. [0027] The end regions Rb are regions of the fiber structure **11** located outside the end second yarns **32a** in the first direction X. In each of the multiple first yarn layers **21**, the opposite ends of the first yarns **31** protrude beyond the end second yarns **32a** toward the outside of the fiber structure **11**. Each end region Rb thus includes the ends of the first yarns **31** protruding beyond the end second yarns **32a**. The parts of the first yarns **31** other than the parts located in the end regions Rb are located in the central region Ra.

Interlayer Binding Yarns

[0028] As shown in FIGS. **2** and **3**, the fiber structure **11** includes multiple interlayer binding yarns **35** that bind the multiple fiber layers **20** in the stacking direction Z. Each of the interlayer binding yarns **35** is, for example, a fiber bundle in which multiple reinforcing continuous fibers are bundled. The interlayer binding yarns **35** are included in the fiber structure **11** by binding the multiple fiber layers **20** with the interlayer binding yarns **35** in the weaving process used to produce the fiber structure **11**.

[0029] The interlayer binding yarns **35** are adjacent to the second yarns **32** in the first direction X. The interlayer binding yarns **35** each have a yarn main axis extending in the second direction Y. The interlayer binding yarns **35** engage with the first yarns **31** in the first end layer **21a** and the first yarns **31** in the second end layer **21b**. In other words, the interlayer binding yarns **35** engage with the first yarns **31** of the first yarn layers **21** located at the opposite ends in the stacking direction Z of the multiple fiber layers **20**.

[0030] Multiple interlayer binding yarns **35** are located in each of the central region Ra and the two end regions Rb. The interlayer binding yarns **35** located in the central region Ra include multiple first interlayer binding yarns **36a** and multiple second interlayer binding yarns **36b**. The first interlayer binding yarns **36a** and the second interlayer binding yarns **36b** are disposed alternately in the first direction X.

[0031] As shown in FIGS. **4** and **5**, each of the first interlayer binding yarns **36a** and the second interlayer binding yarns **36b** alternately engages with the first yarns **31** located in the first end layer **21a** and the first yarns **31** located in the second end layer **21b**, from one end to the other end in the second direction Y of the fiber structure **11**. The first yarns **31** with which the first interlayer binding yarns **36a** are engaged in the first end layer **21a** and the first yarns **31** with which the first interlayer binding yarns **36a** are engaged in the second end layer **21b** are located in the first yarn groups **31a** adjacent to each other in the second direction Y. Similarly, the first yarns **31** with which the second interlayer binding yarns **36b** are engaged in the first end layer **21a** and the first yarns **31** with which the second interlayer binding yarns **36b** are engaged in the second end layer **21b** are located in the first yarn groups **31a** adjacent to each other in the second direction Y. Each of the first interlayer binding yarns **36a** and the second interlayer binding yarns **36b** extends in the second direction Y, alternating the engaged first yarn **31** between the first yarn **31** in the first end layer **21a** and the first yarn **31** in the second end layer **21b** for each first yarn group **31a**. Each of the first interlayer binding yarns **36a** and the second interlayer binding yarns **36b** extends in the stacking direction Z between any two of the first yarn groups **31a** adjacent to each other in the second direction Y.

[0032] The first interlayer binding yarns **36a** and the second interlayer binding yarns **36b** pass through mutually different paths in a cross section of the fiber structure **11** orthogonal to the first direction X, so as to interlace with the first yarns **31**. Each first interlayer binding yarn **36a** alternately engages with the first yarn **31** located in the first end layer **21a** and the first yarn **31** located in the second end layer **21b**, from one end to the other end of the fiber structure **11** in the second direction Y. Each second interlayer binding yarn **36b** alternately engages with the first yarn **31** located in the second end layer **21b** and the first yarn **31** located in the first end layer **21a**, from

one end to the other end of the fiber structure **11** in the second direction Y. In a first yarn group **31a** in which the first interlayer binding yarn **36a** engages with the first yarn **31** located in the first end layer **21a**, the second interlayer binding yarn **36b** engages with the first yarn **31** located in the second end layer **21b**. In a first yarn group **31a** in which the first interlayer binding yarn **36a** engages with the first yarn **31** located in the second end layer **21b**, the second interlayer binding yarn **36b** engages with the first yarn **31** located in the first end layer **21a**.

[0033] As shown in FIG. **3**, the interlayer binding yarns **35** located in each end region Rb include a first end interlayer binding yarn **37a** and a second end interlayer binding yarn **37b**. The first end interlayer binding yarn **37a** and the second end interlayer binding yarn **37b** are adjacent to each other in the first direction X. One first end interlayer binding yarn **37a** is located in the end region Rb at each of the ends **11c** and **11d** of the fiber structure **11**. One second end interlayer binding yarn **37b** is located in the end region Rb at each of the ends **11c** and **11d** of the fiber structure **11**.

[0034] The first end interlayer binding yarns **37a** and the second end interlayer binding yarns **37b** are thinner than the second yarns **32**. In other words, the multiple interlayer binding yarns **35** located in each end region Rb are thinner than the second yarns **32**. All the interlayer binding yarns **35** provided in the fiber structure **11** may have the same thickness. In this case, the first interlayer binding yarns **36a** and the second interlayer binding yarns **36b**, which are the interlayer binding yarns **35** located in the central region Ra, are also thinner than the second yarns **32**.

[0035] The second end interlayer binding yarns **37b** are the interlayer binding yarns **35** located at the endmost positions in the first direction X among the interlayer binding yarns **35** provided in the fiber structure **11**. In other words, the interlayer binding yarns **35** located in the end regions Rb include the interlayer binding yarns **35** located at the endmost positions in the first direction X among the interlayer binding yarns **35** provided in the fiber structure **11**.

[0036] As shown in FIG. **6**, each of the first end interlayer binding yarn **37a** and the second end interlayer binding yarn **37b** alternately engages with the first yarn **31** located in the first end layer **21a** and the first yarn **31** located in the second end layer **21b** from one end to the other end of the fiber structure **11** in the second direction Y. The first yarns **31** with which the first end interlayer binding yarn **37a** is engaged in the first end layer **21a** and the first yarns **31** with which the first end interlayer binding yarn **37a** is engaged in the second end layer **21b** are located in the first yarn groups **31a** adjacent to each other in the second direction Y. Similarly, the first yarns **31** with which the second end interlayer binding yarn **37b** is engaged in the first end layer **21a** and the first yarns **31** with which the second end interlayer binding yarn **37b** is engaged in the second end layer **21b** are located in the first yarn groups **31a** adjacent to each other in the second direction Y. Each of the first end interlayer binding yarn **37a** and the second end interlayer binding yarn **37b** extends in the second direction Y, alternating the engaged first yarn **31** between the first yarn **31** in the first end layer **21a** and the first yarn **31** in the second end layer **21b** for each first yarn group **31a**. Each of the first end interlayer binding yarn **37a** and the second end interlayer binding yarn **37b** extends in the stacking direction Z between any two of the first yarn groups **31a** adjacent to each other in the second direction Y.

[0037] The first end interlayer binding yarn **37a** and the second end interlayer binding yarn **37b** pass through mutually different paths in a cross section of the fiber structure **11** orthogonal to the first direction X, so as to interlace with the first yarns **31**. The first end interlayer binding yarn **37a** alternately engages with the first yarn **31** located in the first end layer **21a** and the first yarn **31** located in the second end layer **21b**, from one end to the other end of the fiber structure **11** in the second direction Y. The second end interlayer binding yarn **37b** alternately engages with the first yarn **31** located in the second end layer **21b** and the first yarn **31** located in the first end layer **21a**, from one end to the other end of the fiber structure **11** in the second direction Y. In a first yarn group **31a** in which the first end interlayer binding yarn **37a** engages with the first yarn **31** located in the first end layer **21a**, the second end interlayer binding yarn **37b** engages with the first yarn **31** located in the second end layer **21b**. In a first yarn group **31a** in which the first end interlayer

binding yarn **37a** engages with the first yarn **31** located in the second end layer **21b**, the second end interlayer binding yarn **37b** engages with the first yarn **31** located in the first end layer **21a**. [0038] In FIG. **6**, a path through which each first interlayer binding yarn **36a** passes is schematically shown as a first path **R1** indicated by a long-dash double-short-dash line, and a path through which each second interlayer binding yarn **36b** passes is schematically shown as a second path **R2** indicated by a long-dash short-dash line. In a cross section of the fiber structure **11** orthogonal to the first direction **X**, the first end interlayer binding yarn **37a** passes through the first path **R1**, and the second end interlayer binding yarn **37b** passes through the second path **R2**. Therefore, the first end interlayer binding yarn **37a**, which is the interlayer binding yarn **35** located in each end region **Rb**, passes through the same first path **R1** as the first interlayer binding yarn **36a** in the cross section of the fiber structure **11** orthogonal to the first direction **X**, so as to interlace with the first yarns **31**. The second end interlayer binding yarn **37b**, which is the other interlayer binding yarn **35**, passes through the same second path **R2** as the second interlayer binding yarn **36b** in the cross section of the fiber structure **11** orthogonal to the first direction **X**, so as to interlace with the first yarns **31**.

Pitches

[0039] As shown in FIG. **3**, a pitch between the first interlayer binding yarn **36a** and the second interlayer binding yarn **36b**, which are adjacent to each other in the first direction **X**, is referred to as a first pitch **L1**. In the central region **Ra**, the interlayer binding yarns **35** are separated from each other in the first direction **X**.

[0040] A pitch between the first end interlayer binding yarn **37a** and the second end interlayer binding yarn **37b**, which are adjacent to each other in the first direction **X**, is referred to as a second pitch **L2**. The first end interlayer binding yarn **37a** and the second end interlayer binding yarn **37b**, which are adjacent to each other in the first direction **X**, are in contact with each other in the first direction **X**. Therefore, the second pitch **L2**, which is the pitch in the first direction **X** between the interlayer binding yarns **35** in each end region **Rb**, is smaller than the first pitch **L1**, which is the pitch in the first direction **X** between the interlayer binding yarns **35** in the central region **Ra**.

Operation

[0041] Operation of the present embodiment will now be described.

[0042] The first interlayer binding yarns **36a** and the second interlayer binding yarns **36b**, which are located in the central region **Ra**, pass through mutually different paths in a cross section of the fiber structure **11** orthogonal to the first direction **X**, so as to interlace with the first yarns **31**. Thus, the parts of the first yarns **31** located in the central region **Ra** are engaged with the first interlayer binding yarns **36a** and the second interlayer binding yarns **36b** from the opposite sides in the stacking direction **Z**. The engagement of the interlayer binding yarns **35** in the central region **Ra** allows the second yarns **32** located in the central region **Ra** in the first direction **X** to be supported by being sandwiched from the opposite sides in the stacking direction **Z** by the first yarns **31** adjacent to the second yarns **32** in the stacking direction **Z**. Thus, the parts of the fiber layers **20** located in the central region **Ra** are bound together by the first interlayer binding yarns **36a** and the second interlayer binding yarns **36b**.

[0043] The first end interlayer binding yarn **37a** and the second end interlayer binding yarn **37b** located in each end region **Rb** interlace with the first yarns **31** through mutually different paths in a cross section of the fiber structure **11** orthogonal to the first direction **X**. Thus, parts of the first yarns **31** located in each end region **Rb** are engaged with the first end interlayer binding yarn **37a** and the second end interlayer binding yarn **37b** from the opposite sides in the stacking direction **Z**. The engagement of the interlayer binding yarns **35** in each end region **Rb** allows the end second yarns **32a** adjacent to the end region **Rb** in the first direction **X** to be supported to be sandwiched from the opposite sides in the stacking direction **Z** by the first yarns **31** adjacent to the end second yarns **32a** in the stacking direction **Z**. Thus, the parts of the fiber layers **20** located in each end region **Rb** are bound together by the first end interlayer binding yarn **37a** and the second end

interlayer binding yarns **37b**.

[0044] The second pitch **L2**, which is the pitch between the first end interlayer binding yarn **37a** and the second end interlayer binding yarn **37b** in each end region **Rb**, is smaller than the first pitch **L1**, which is the pitch between the first interlayer binding yarn **36a** and the second interlayer binding yarn **36b** in the central region **Ra**. Therefore, the fiber layers **20** are more firmly bound together by the interlayer binding yarns **35** in each end region **Rb** than in the central region **Ra**. Such engagement of the interlayer binding yarns **35** in each end region **Rb** allows the end second yarns **32a** to be more strongly sandwiched from the opposite sides in the stacking direction **Z** by the first yarns **31** adjacent in the stacking direction **Z** than the other second yarns **32** located in the central region **Ra**.

Advantages

[0045] The above-described embodiment has the following advantages.

[0046] (1-1) The pitch in the first direction **X** between the interlayer binding yarns **35** in each end region **Rb** is smaller than the pitch in the first direction **X** between the interlayer binding yarns **35** in the central region **Ra**. Therefore, the fiber layers **20** are more firmly bound together by the interlayer binding yarns **35** in each end region **Rb** than in the central region **Ra**. The end second yarns **32a**, which are the second yarns **32** located at the ends **Rc** of the central region **Ra** in the first direction **X**, are less likely to fray from the ends **11c**, **11d** of the fiber structure **11** in the first direction **X** due to the interlayer binding yarns **35** in the end regions **Rb**. Further, since such fraying is suppressed by binding the fiber layers **20** with the interlayer binding yarns **35** in the weaving step, it is not necessary to add a step other than the weaving step in order to suppress fraying. Therefore, fraying from the ends **11c**, **11d** of the fiber structure **11** is suppressed while also preventing an increase in the manufacturing steps required for the fiber structure **11**.

[0047] (1-2) Some of the interlayer binding yarns **35** located in each end region **Rb** pass through the same first path **R1** as the first interlayer binding yarns **36a** in a cross section of the fiber structure **11** orthogonal to the first direction **X**, so as to interlace with the first yarns **31**. The other interlayer binding yarns **35** pass through the same second path **R2** as the second interlayer binding yarn **36b** in the cross section of the fiber structure **11** orthogonal to the first direction **X**, so as to interlace with the first yarns **31**. Therefore, the interlayer binding yarns **35** located in the central region **Ra** and the interlayer binding yarns **35** located in the end regions **Rb** share common paths in the cross section of the fiber structure **11** orthogonal to the first direction **X**. This facilitates the manufacture of the fiber structure **11**.

[0048] (1-3) The interlayer binding yarns **35** located in each end region **Rb** are thinner than the second yarns **32**. Thus, as compared with a case in which the interlayer binding yarns **35** located in each end region **Rb** are thicker than the second yarns **32**, meandering of the first yarns **31** due to engagement of the interlayer binding yarns **35** is less likely to occur. This limits a decrease in the strength of the fiber structure **11** caused by meandering of the first yarns **31**.

[0049] (1-4) Fraying from the ends **11c**, **11d** of the fiber structure **11** in the first direction **X** can also be prevented by forming interlacing yarns at the ends **11c**, **11d** of the fiber structure **11**. However, this approach requires additional tools specifically for forming the interlacing yarns. According to the above-described embodiment, the interlayer binding yarns **35** located in the central region **Ra** and the interlayer binding yarns **35** located in the end regions **Rb** share common paths in the cross section of the fiber structure **11** orthogonal to the first direction **X**. Consequently, there is no need to increase the number of tools for the interlayer binding yarns **35** in the end regions **Rb**. This prevents fraying from the ends **11c**, **11d** of the fiber structure **11** while also minimizing the increase in the number of tools used in the weaving process.

Modifications

[0050] The above-described embodiment may be modified as follows. The above-described embodiment and the following modifications can be combined as long as the combined modifications remain technically consistent with each other.

[0051] As in a first modification shown in FIG. 7, the interlayer binding yarns **35** located in each end region Rb may be melted by impregnating the fiber structure **11** with the matrix resin Ma as a thermosetting resin by using the RTM method. In this case, for example, a resin having a property of melting at the curing temperature of the matrix resin Ma can be used as the material of the interlayer binding yarns **35** located in the end regions Rb. When an epoxy resin is used as the matrix resin Ma, for example, a phenoxy resin, a methyl methacrylate resin, or the like can be used as the material of the interlayer binding yarns **35** located in the end regions Rb. When the fiber structure **11** is heated by the RTM method, the matrix resin Ma impregnated into the fiber structure **11** is thermally cured. At the same time, the interlayer binding yarns **35** located in the end regions Rb disappear from the fiber structure **11**. As a result, as shown in FIG. 7, a fiber structure **11e** in which the interlayer binding yarns **35** are not present in the end regions Rb is obtained. In this modification, the fiber structure **11e** serves as the reinforcing substrate of the fiber-reinforced composite material **10**.

[0052] The first modification has the following advantages.

[0053] (2-1) The interlayer binding yarns **35** located in the end regions Rb are melted by impregnating the fiber structure **11** with the thermosetting resin using the RTM method. Even if the first yarns **31** meander due to the engagement of the interlayer binding yarns **35** in the end regions Rb, the meandering of the first yarns **31** is eliminated since the interlayer binding yarns **35** located in the end regions Rb are melted by impregnating the fiber structure **11** with the thermosetting resin using the RTM method. This limits a decrease in the strength of the fiber structure **11** caused by meandering of the first yarns **31**.

[0054] As in a second modification shown in FIG. 8, fiber structures **11** may be manufactured by cutting a fiber body **11f**, which is a precursor of the fiber structures **11**. The fiber body **11f** in this case has the first yarns **31**, the second yarns **32**, and the interlayer binding yarns **35** similar to those of the fiber structure **11**. In the fiber body **11f**, central regions Ra and end regions Rb are arranged in the first direction X. Two end regions Rb are adjacent to each other in the first direction X between the central regions Ra in the first direction X. The first yarns **31** of the end regions Rb adjacent to each other in the first direction X are continuous. The first yarns **31** extend in the first direction X between the opposite ends of the fiber body **11f** in the first direction X. After the fiber body **11f** is manufactured, the fiber body **11f** is cut along a cutting position C indicated by the long-dash short-dash line in FIG. 8. Accordingly, since the fiber body **11f** is cut between the end regions Rb adjacent to each other in the first direction X, the fiber structures **11** are manufactured from the fiber body **11f**.

[0055] In the fiber structure **11**, the number of the first yarn layers **21** located between the second yarn layers **22** in the stacking direction Z may be one or three or more.

[0056] The second yarns **32** may be located in each end region Rb. In this case as well, fraying of the end second yarns **32a** from the ends **11c**, **11d** of the fiber structure **11** in the first direction X is suppressed by the interlayer binding yarns **35** in the end portion regions Rb.

[0057] In a cross section of the fiber structure **11** orthogonal to the first direction X, the first interlayer binding yarns **36a** may pass through a path different from the first path R1. In a cross section of the fiber structure **11** orthogonal to the first direction X, the second interlayer binding yarns **36b** may pass through a path different from the second path R2. In summary, the paths of the first interlayer binding yarns **36a** and the second interlayer binding yarns **36b** may be changed as long as they pass through mutually different paths in a cross section of the fiber structure **11** orthogonal to the first direction X and interlace with the first yarns **31**.

[0058] In a cross section of the fiber structure **11** orthogonal to the first direction X, the first end interlayer binding yarns **37a** may pass through a path different from the first path R1. In a cross section of the fiber structure **11** orthogonal to the first direction X, the second end interlayer binding yarns **37b** may pass through a path different from the second path R2. In summary, the interlayer binding yarns **35** located in the end regions Rb may pass through a path different from

that of the interlayer binding yarns **35** located in the central region Ra in a cross section of the fiber structure **11** orthogonal to the first direction X.

[0059] The number of the interlayer binding yarns **35** located in each end region Rb may be three or more. For example, two or more first end interlayer binding yarns **37a** may be located in each end region Rb. Two or more second end interlayer binding yarns **37b** may be located in each end region Rb.

[0060] The fiber structure **11** may be provided with interlayer binding yarns **35** having different thicknesses. For example, the thickness of the interlayer binding yarns **35** located in the central region Ra may be different from the thickness of the interlayer binding yarns **35** located in the end regions Rb.

[0061] The thickness of the interlayer binding yarns **35** located in the central region Ra may be greater than or equal to the thickness of the second yarns **32**.

[0062] The thickness of the interlayer binding yarns **35** located in the end regions Rb may be greater than or equal to the thickness of the second yarns **32**.

[0063] In each end region Rb, the interlayer binding yarns **35** may be separated from each other in the first direction X. In this case also, the second pitch L2, which is the pitch in the first direction X between the interlayer binding yarns **35** in each end region Rb, is smaller than the first pitch L1, which is the pitch in the first direction X between the interlayer binding yarns **35** in the central region Ra.

[0064] The fiber structure **11** may be manufactured using first yarns **31** and second yarns **32** impregnated with the matrix resin Ma.

[0065] At least one of the first yarns **31**, the second yarns **32**, and the interlayer binding yarns **35** may be fiber bundles formed by bundling multiple non-reinforcing fibers. The phrase “at least one of” as used in this description means “one or more” of desired options. As an example, the expression “at least one” as used in this description means “only one option” or “both two options” if the number of options is two. In another example, the phrase “at least one of” as used in this description means “only one single option” or “any combination of two or more options” if the number of options is three or more.

Claims

1. A fiber structure, comprising: multiple fiber layers stacked in a stacking direction; and multiple interlayer binding yarns binding the multiple fiber layers in the stacking direction, wherein the fiber layers include multiple first yarn layers and one or more second yarn layers located between the first yarn layers in the stacking direction, each of the first yarn layers includes multiple first yarns each having a yarn main axis extending in a first direction, the first yarns being arranged in a second direction orthogonal to the first direction, one of the first yarn layers is located at each of opposite ends of the fiber structure in the stacking direction, each of the second yarn layers includes multiple second yarns each having a yarn main axis extending in the second direction, the second yarns being arranged in the first direction without interlacing with the first yarns, each of the interlayer binding yarns is adjacent to one of the second yarns in the first direction, has a yarn main axis extending in the second direction, and is engaged with the first yarns of the first yarn layers located at the opposite ends of the fiber structure in the stacking direction, the fiber structure further comprises: a central region including a center of the fiber structure in the first direction; and two end regions respectively including opposite ends of the fiber structure in the first direction, each of the end regions being adjacent to the central region in the first direction, the second yarns include multiple end second yarns located at an end of the central region in the first direction, each of the second yarn layers includes the end second yarns, each of the central region and the two end regions includes the interlayer binding yarns, the interlayer binding yarns located in each of the end regions include: the interlayer binding yarn located at an endmost position in the first direction

among the interlayer binding yarns included in the fiber structure, and two of the interlayer binding yarns that pass through mutually different paths in a cross section of the fiber structure orthogonal to the first direction, so as to interlace with the first yarns, and a pitch in the first direction between the interlayer binding yarns in the end regions is smaller than a pitch in the first direction between the interlayer binding yarns in the central region.

2. The fiber structure according to claim 1, wherein the interlayer binding yarns located in the central region include a first interlayer binding yarn and a second interlayer binding yarn, the first interlayer binding yarn and the second interlayer binding yarn pass through mutually different paths in a cross section of the fiber structure orthogonal to the first direction, so as to interlace with the first yarns, and among the interlayer binding yarns located in the end regions, one or more of the interlayer binding yarns pass through the same path as the first interlayer binding yarn in a cross section of the fiber structure orthogonal to the first direction, so as to interlace with the first yarns, and other interlayer binding yarns pass through the same path as the second interlayer binding yarn in a cross section of the fiber structure orthogonal to the first direction, so as to interlace with the first yarns.

3. The fiber structure according to claim 1, wherein the interlayer binding yarns located in the end regions are thinner than the second yarns.

4. The fiber structure according to claim 1, wherein the interlayer binding yarns located in the end regions are melted by impregnating the fiber structure with a thermosetting resin using an RTM method.

5. A fiber-reinforced composite material, comprising: the fiber structure according to claim 1; and a matrix material impregnated into the fiber structure.
