METHOD FOR MACHINING AND FORMING A PRE-FORMED OPENING IN A FIBRE-REINFORCED COMPOSITE MATERIAL

The invention relates to a method for machining and forming transcurrent openings in fibre-reinforced composite materials. Openings with damage-free edges can be formed with high precision by positioning a rotating milling tool (5) in a preformed hole (3). In conjunction with this the material is arranged in such a way that the axis of rotation (7) of the grinding tool (5) is essentially perpendicular to the longitudinal direction of the fibres at the edge of the hole. The opening is machined and formed by causing the milling tool (5) on the one hand to rotate about its own axis (7) and on the other hand to describe an orbital motion relative to the edge of the hole. Any damage/defects (4) caused in the course of preforming are removed in this way.
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METHOD FOR MACHINING AND FORMING A PRE-FORMED OPENING
IN A FIBRE-REINFORCED COMPOSITE MATERIAL.

The present invention relates to a method for machining and
forming a transcurrent opening in a fibre-reinforced
composite material starting form a preformed hole, in
conjuction with which at least one rotatable milling tool
with a wear-resistant outer working surface and with a
diameter considerably smaller than that of the preformed
hole is positioned in the hole, and the hole is machined
and formed by causing the milling tool on the one hand to
rotate about its own axis and on the other hand to describe
a translation motion relative to the edge of the hole.

Polymer composite materials have been known since the
1950s. These materials are composed of a protective and
consolidating polymer, either thermoplastic or thermosetting
resin plastic, usually referred to as the matrix, and
fibres (e.g. glass, carbon or aramide fibres), which may be
regarded as reinforcing material. The fibres may be
continuous and oriented in certain directions, or may be
relatively short and arranged at random in the matrix.

Composites with continuous and oriented fibres give
products with superior mechanical characteristics to
conventional polymer and metallic materials, in particular
with regard to their weight-related strength and rigidity.
Composites with shorter fibres find applications where
their characteristics are subject to rather low require-
ments. One inhibiting factor for the increased use of
composite materials is the absence of effective methods of
cutting machining. The physical and chemical properties of
composite materials mean that familiar machining methods
cannot be applied generally with successful results.

Composite materials for practical applications often
contain holes for various purposes. The holes may be
required, for example, to accommodate wiring or to permit
assembly or inspection. One particularly important
category of hole is bolt holes. Structures for practical
applications are often built up from components which have
been joined together to produce a finished product. The purpose of the joint is to transmit the load from one part of the structure to another. A common method of joining is the bolted joint in which the load is transmitted via either shearing forces or tensile forces in the bolt. The strength of a bolted joint is influenced to a considerable degree by the quality and accuracy of the holes. Reference can be made here to three particular problem areas which can arise in conjunction with making holes in polymer composite materials:

Low interlaminar strength.

When machining laminated composite materials, the risk is present of the layers separating (delaminating) due to the low interlaminar strength. Extensive delamination damage can reduce the strength of the material.

Low heat-and-cold resistance of certain thermoplastics.

The heat release during machining can cause the matrix to soften and to block the tool, making further machining impossible. In order to achieve good hole quality, therefore, effective cooling of the tool/hole edge is required, and the cut material (shavings, chips and grinding dust) must be removed continuously from the hole.

High resistance to wear of fibres.

When composite fibres are machined by a process involving cutting, severe tool wear occurs as a consequence of the high wear-resistant characteristics of the fibre materials. This leads to high wear costs, especially when making holes with high precision requirements.

The methods used to make holes in composite laminates traditionally involve drilling, milling, sawing and grinding. The problem associated with these hole forming
methods as they are applied at the present time is that they are not sufficiently effective from a technical/financial point of view.

One general problem associated with cutting machining with traditional metal-based tools is the high wear costs. Drilling calls for considerable care to be taken in order to avoid delamination damage on both the entry side and the exit side. In order to achieve the required hole quality, cutters made of special materials are needed, and special procedures must be worked out. In order to avoid extensive delamination damage to the exit side of the laminate, it is necessary for local lateral pressure to be applied around the edge of the hole. Another previously disclosed method of protecting the exit side from damage is to provide the laminate with an extra protective layer.

Sawing is a manifestly unsuitable method for producing holes with high accuracy requirements. Making holes by grinding involves the use of a hollow tubular body in the form of a cylinder, the cutting end of which is coated with a wear-resistant surface layer. Holes are produced by grinding the surface of the material transversally by causing the grinding tool to rotate. This method is slow and provides low precision.

The purpose of the proposed invention is to eliminate the shortcomings and limitations associated with previously disclosed methods and to permit the efficient (cost-effective) making of holes with high precision without causing damage with an adverse effect on strength, thereby ensuring repeatable and high quality. This is achieved through the invention by positioning the fibre-reinforce material in such a way that the axis of rotation of the milling tool lies essentially perpendicular to the longitudinal direction of the fibres at the edge of the hole, that the size/geometry of the finished hole differs significantly compared with the preformed hole, and that
the cutting tool is in the form of a milling tool, in conjunction with which the radial extent of any damage/defects caused when making the preformed hole define a lower limit for the quantity of material to be removed by cutting machining.

It should be pointed out in this context that methods for machining holes in which a tool caused to rotate about an axis of rotation is also caused to describe an orbital motion (i.e. the axis of rotation is displaced so that the tool is able to move relative to the edge of the hole) are previously disclosed. Previously disclosed in SE 173 899 is a machine tool with a tool holder rotating eccentrically about a main shaft, in which the distance between the tool holder and the main shaft is adjustable. A guide component, which rotates about the main shaft together with the tool holder, is used to adjust the distance between the tool holder and the main shaft. The guide component rotating together with the tool holder is arranged at right angles to the main shaft and is executed as a curved sheet capable of rotating about the main shaft in relation to the tool holder, with the guiding curved surface of which the tool holder is in direct engagement. The advantages of the present invention are, amongst other things, the absence of free play and the space-saving design of the guide component. SE 382 506 discloses a combined cutting tool which is caused to rotate for the purpose of making holes in stationary workpieces, which holes can be provided with a conical entrance chamfer.

What is not previously disclosed, however, is that such a method can be used to form damage-free holes in fibre-reinforced materials by arranging the axis of rotation of the milling tool perpendicular to the longitudinal direction of the fibres at the edge of the hole. The proposed method also differs from previously disclosed surface-modifying hole-machining methods in that the amount of material removed by cutting machining is considerably
larger. When forming holes by the radial removal of material, the amount of material removed by cutting machining is proportional to the change in radius before and after machining. In the case of traditional surface-modifying machining, the profile depth of the edge of the hole is a characteristic indicator of the change in radius. When machining by the proposed method, the radial extent of any damage defines a lower limit for the difference in the radius before and after machining. This lower limit is generally considerably greater than the profile depth of the edge of the hole. It will be appreciated from the above that the size of the finished formed opening differs significantly compared with the preformed hole.

The method exhibits a number of essential advantages compared with previously disclosed methods.

The method permits transcurrent openings to be made to without causing damage with an adverse effect on strength (damage in the preformed hole is removed by cutting machining).

The method permits transcurrent openings to be made to within close tolerances. The dimensional accuracy of the opening is determined essentially by the accuracy of positioning of the milling tool in the opening. No particularly strict requirements are imposed, however, on the geometry of the milling tool, since an individual is easily able to calibrate before use.

The method reduces the risk of blocking the milling tool. Because the milling tool is considerably smaller than the opening, the method permits material which has been removed by cutting machining to be removed simply, for example with compressed air. The method also permits effective cooling of the milling tool and the edge of the hole.

The method largely reduces wear costs compared with
previously disclosed methods, thanks to the ability to impart a wear-resistant material, e.g. diamond coating.

The method requires a preformed hole. This hole, which may be considerably smaller than the final formed transcurrent opening can be made by a previously disclosed method. Low requirements are imposed on the quality of the preformed hole, however, for which reason traditional tools can be used for a much longer period without having to be scrapped/reground than would be the case if they were to be used traditionally.

The invention is described in more detail below with reference to the accompanying drawing. Fig. 1 in the drawing shows the direction of the fibres in a laminated, fibre-reinforced composite sheet, and Figs. 2b and 2c illustrate how a transcurrent opening is formed in the sheet with the help of a rotating milling tool.

A flat sheet 1 (a laminate) is built up from a number of laminae 2 (layers) with continuous fibres, which laminae are arranged one on top of the other. The fibres are arranged in planes parallel with the plane of the laminate. The directions of the fibres (0, 90, +45 och -45 grader) are represented schematically in Fig. 1. An opening in the laminate is formed by making a preformed circular hole 3 by a traditional method. This causes damage/defects 4 at the edge of the hole 3. A rotating milling tool 5 with a wear-resistant outer working surface 6 is positioned in the preformed hole 3. In conjunction with this, the laminate is positioned in such a way that the axis of rotation 7 of the milling tool 5 is perpendicular to the longitudinal directions 8 of the fibres, i.e. so that cutting machining takes place in planes parallel to the plane of the laminate. The opening is machined by causing the milling tool on the one hand to rotate about its own axis and on the other hand to describe a translation motion relative to the edge of the opening. The damage/defects 4 are removed in
the course of machining. The size of the finished formed opening differs significantly in comparison with the preformed hole 3.
Patent Claims

1. Method for machining and forming a transcurrent opening in a fibre-reinforced composite material (1) starting from a preformed hole (3), in conjunction with which at least one rotatable milling tool (5) with a wear-resistant outer working surface (6) and with a diameter considerably smaller than that of the preformed hole (3) is positioned in the hole, and the hole (3) is machined and formed by causing the milling tool (5) on the one hand to rotate about its own axis (7) and on the other hand to describe a translation motion relative to the edge of the hole (3), characterized in that the fibre-reinforce material (1) is positioned in such a way that the axis of rotation (7) of the milling tool (5) lies essentially perpendicular to the longitudinal direction of the fibres at the edge of the hole (3), in that the size/geometry of the finished opening differs significantly compared with the preformed hole (3), and in that the cutting tool (5) is in the form of a milling tool, in conjunction with which the radial extent of any damage/defects (4) caused when making the preformed hole (3) define a lower limit for the quantity of material to be removed by cutting machining.

2. Method in accordance with Claim 1, characterized in that the rotating milling tool (5) is used both for the preforming of the hole (3) and for the final forming of the opening.
**INTERNATIONAL SEARCH REPORT**

**International application No.**
PCT/SE 93/00444

**A. CLASSIFICATION OF SUBJECT MATTER**

IPC5: B23C 3/12, B23B 35/00, B24B 1/00

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)

**IPC5: B23B, B23C, B24B**

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

SE, DK, FI, NO classes as above

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

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

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Date of the actual completion of the international search: 4 August 1993

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