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(54) Title: TAPE LAYING AND CUTTING SYSTEM FOR FIBER REINFORCED PLASTIC MANUFACTURING

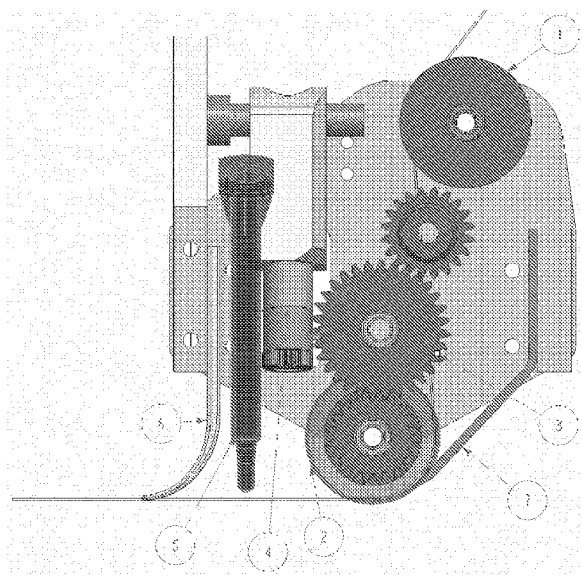


Fig 1.

(57) Abstract: This patent application focuses on the cutting, laying and impregnating the fiber tape using a tape laying and cutting head. The head contains a stationary or moving laser system with an in-situ mixing of resin and hardener, rollers (1,2) and a spreader (6) for pressing. The head enables manufacturing of small fiber reinforced parts avoiding the problems in manufacturing them.



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Tape laying and cutting system for fiber reinforced plastic manufacturing

Field of the invention

- 5 The invention concerns in general the technical field of material laying, machining and forming. More particularly, the invention concerns a laying device and a cutting device for fiber tapes.

Background

10

Fiber reinforced plastic (FRP) parts are increasingly used in automotive and aerospace industries due to their lightweight and high strength [1-3]. However, due to their high cost and specialized manufacturing processes, they have mainly been restricted to aerospace and high-end automotive industries. The future of
15 manufacturing for lightweight composite structures relies strongly on automation to bring down the overall cost of FRP parts [4, 5].

20

Manufacturing of these FRP parts is gradually becoming automated using 5-axis Automated Tape Laying (ATL) machines which are used for manufacturing big size parts. These ATL system employs a tape laying head for laying down the carbon fiber prepreg tapes. Prepregs are fibers which have been pre-impregnated with a resin system (typically epoxy). In the process of laying, after each pass of laying tape, the tape is cut using an ultrasonic blade. However, these cutting systems are bulky, require frequent maintenance and blade replacements after an average of
25 about 6000 cuts [6].

Summary of the invention

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In this patent application, a new invention for a compact tape laying system for feeding, positioning, and impregnating the tape, with a stationary or moving miniaturized cutting sub-system to cut the dry fiber tape is disclosed. The system is not limited to the width of the tape. The system has one or more rollers for guiding, feeding and laying the tape, a stationary or moving cutter, a resin impregnation and mixing system and a spreading and compacting system for uniform and thorough
35 resin impregnation. The resin and hardener are mixed in-situ before impregnating

the tape. The system is able to move in X-Y-Z axes (linear movements) and in A-B-C axes (rotating movements). Thus, fibers can be laid on a 3-dimensional surface over a mould of complex geometry. The system is able to trim every layer of the FRP to an almost-finished part, reducing post-processing. Repeating the process layer upon
5 layer in a controlled layup sequence and with a chosen fiber direction for each layer, the desired parts are obtained.

Brief description of figures

10 The embodiments of the invention are illustrated by way of example and not by way of limitation, the figures of accompanying drawings.

Figure 1 illustrates the laser cutting and laying head.

15 Figure 2 illustrates the head moving directions.

Detailed description

In this patent application, an embodiment of a tape laying system for feeding,
20 positioning, impregnating and cutting a tape is presented. Also a method for manufacturing fiber reinforced plastic parts is presented.

The system of Figure 1 comprises three major subsystems:

- a. Tape rolling subsystem
- 25 b. Tape impregnation subsystem
- c. Tape cutting subsystem

Part No.	Item
1	Upper roller
2	Lower Roller
3	Gear train
4	Laser cutter
5	Resin mixer
6	Spreader
7	Tape pressing plate

Table 1. The part No. and items in figure 1.

X axis	Fiber direction, and tape laying passes direction
Y axis	Perpendicular direction to fiber (tape width)
Z axis	Perpendicular direction to fiber and tape width
A, B and C	Rotation about X,Y and Z axis respectively

5 Table 2. The head moving directions.

- In this system, a tape laying head moves in planar motion (XZ plane) while placing one segment of tape on the mould for every pass before cutting the tape and moving one tape width on Y direction. The planar motion in XZ plane is only an example which helps to understand the concept of this embodiment. The tape laying head of the system could also be moved in linear motion, in planar motion in any other plane or following a path defined in a three-dimensional space. The tape-laying head has a rolling system comprising one or more rollers. In an embodiment, the rolling system consists of two rollers, upper roller 1 and lower roller 2 to keep the tape in tension. The upper roller 1 is idler and lower roller 2 is rotated by rotating a motor connected to gear train 3 which in turn rotates the lower roller 2. The lower roller 2 follows the XZ profile of the part, with the total head movement in the X direction. The lower roller 2 is applying certain force towards the mould and can be rigid or elastic to ensure better placement of fibers on complex moulds. In an embodiment the upper roller 1 can be omitted and the tension can be controlled with other means, e.g. by controlling the feeding or releasing of the tape from a roll. Tape pressing plate 7 ensures consistent contact of the tape and the lower roller.
- After laying a pass of tape, the tape is cut with a tape cutting sub-system and the tape-laying head is shifted one tape width to a direction perpendicular to the direction of the previously laid tape. In other words, the tape-laying head lays the tapes next to each other with each pass until a defined surface is covered with the tape. After that a second layer of tape can be laid on top of the first layer of tape.

Preferably, either the mould or the tape-laying head is rotated between successive layers to achieve crosswise direction of tapes between successive layers. The fiber orientation in each layer can be chosen by rotating the mould platform (rotates $\pm C$ direction) or the tape-laying head itself. The head can be used for laying up on
5 mould with free form surfaces. Repeating the process and building layer by layer it forms desired layup sequence and the parts. The term tape refers in this patent application to a dry or lightly bounded spread fiber tow. Preferably a spread tow consisting of unidirectional fibers with or without a binder is used. The tape can also consist of unidirectional fibers with crimps. In an embodiment, the binder
10 component constitutes less than 10 % of the total volume of the tape and preferably less than 5 % of the total volume. In an embodiment, the binder component constitutes less than 10 % of the total mass of the tape and preferably less than 5 % of the total mass. The fibers of the tape can be any fibers that are used as reinforcing fibers, such as carbon fiber, aramid fiber, glass fiber, or a
15 combination of two or more types of fibers.

As the tape-laying head moves and lays the tape, an impregnation subsystem impregnates the tape with a mixture of multi-component epoxy thereby creating a multi-component layer consisting of the fibers of the tape and the epoxy
20 impregnated into the tape. A two-component epoxy consisting of a resin component and a hardener component is used as an example but also other multi-component matrices can be used, such as three-part methyl methacrylate adhesive system or a two-component epoxy with an accelerator component.

25 The impregnation subsystem comprises two or more containers for epoxy components, at least one container for each epoxy component. The components are pumped from said containers with pumps into a mixing unit. Preferably the number of pumps is equal to the number of containers or equal to the number of epoxy components. For example, a system using two-component epoxy, resin and
30 hardener, can have total of two containers, one container for the resin component and one container for the hardener component and two pumps, one for each container. The components are preferably moved through tubing with the use of a metering pump (e.g. piston pump, peristaltic pump or screw pump). The pumps are configured to pump the two or more components into a mixing unit which is
35 preferably a static mixer 5. Mixing ratio of the epoxy components varies between

component combinations and the pumps are configured to pump the components from the containers to the mixing unit according to the mixing ratio of said components. Pumping of the epoxy components in desired ratio to the static mixer 5 moves the epoxy components through the mixer and at the same time mixes the components thoroughly.

The mixed epoxy coming out from the mixer 5 can be applied on the tape that has been laid and rolled against the mould. Typically multi-component epoxies have such a high viscosity that proper impregnation of the tape doesn't take place without assistance. Therefore the impregnation sub-system comprises a spreader or a spreader system which can have one or more functions. In an embodiment the mixed multi-component epoxy coming out from the mixer 5 flows through a wide spreading mechanism which spreads the epoxy and forms a layer of epoxy onto the tape covering most of the tape width, for example more than 50 %, more than 70 % or more than 90 % of the tape width. In another embodiment, the epoxy is applied directly from the static mixer on the tape. Once the epoxy has been applied on the tape, either directly or through a spreading mechanism, the epoxy is pressed into the tape in order to fully impregnate the tape and to remove any air bubbles. The pressing can be realized with a roller or flap 6 or a similar device which exerts a force on the epoxy towards the tape.

At the end of each pass, the fiber tape is cut using a cutter of a tape cutting sub-system. Preferably a laser 4 is used where a laser beam, either converted into a stationary line, perpendicular to the fiber direction, or with a focused beam moving perpendicular to the fiber direction cuts the tape. With a stationary laser cutter, a uniform-power distribution line generating lens or lens system can be used for converting the focused laser point into a line matching or exceeding the tape width. Preferably the width of this laser line is adjustable to match different tape widths. The adjustment can be realized e.g. by changing the distance between the lens and the laser source.

A first aspect of the invention is a method of manufacturing fiber reinforced plastic parts. The method comprises using a tape rolling system to perform steps of placing a segment of a tape on a mould by moving a tape-laying head of the tape rolling system in planar motion; mixing a mixture of resin and hardener; impregnating the

tape with the mixture of resin and hardener; distributing and compressing the mixture of resin and hardener within the tape using a spreading mechanism of the tape rolling system; cutting the tape with a laser cutter of the tape rolling system; and moving the tape laying head of the tape rolling system one tape width to a
5 direction perpendicular to said planar motion and repeating the process again for multiple layers of different fiber orientation.

In an embodiment of the first aspect of the invention, said laser cutter is a stationary laser comprising a lens generating a uniform power distribution line. In
10 an embodiment of the first aspect of the invention, said laser cutter is a moving laser unit.

In an embodiment of the first aspect of the invention, said tape is a carbon fiber tape.
15

In an embodiment of the first aspect of the invention, said cutting step is performed on a dry carbon fiber tape.

In an embodiment of the first aspect of the invention, said mixing step and said
20 impregnating step are performed in-situ.

In an embodiment of the first aspect of the invention, the method further comprises a step of rotating the mould in relation to the tape laying head between layers of tape for altering fiber orientation between layers.
25

A second aspect of the invention is a tape-laying system for manufacturing fiber reinforced plastic parts. The system comprises a tape rolling sub-system comprising a movable tape-laying head having a rotatable roller for tensioning and placing a tape; a tape impregnation subsystem comprising means for mixing resin and
30 hardener with each other and a spreader for impregnating the tape with said mixture; and a cutting sub-system comprising a laser cutter configured to cut the tape with a laser beam.

In an embodiment of the second aspect of the invention, said cutting sub-system comprises a lens configured to convert said laser beam into a stationary line perpendicular to the fiber direction.

- 5 In an embodiment of the second aspect of the invention, said cutting subsystem is configured to cut the tape using a focused beam moving perpendicular to a direction of fibers in the tape.

10 A third aspect of the invention is a method of manufacturing fiber reinforced plastic parts. The method comprises using a tape rolling system to perform steps of: placing a segment of a tape on a mould by moving a tape-laying head of the tape rolling system; providing components of a multi-component epoxy in defined ratios to a mixer; mixing a mixture of multi-component epoxy with the mixer; spreading the mixture of multi-component epoxy on the placed segment of the tape;

15 impregnating the mixture of multi-component epoxy into the tape; cutting the tape with a cutter of the tape rolling system; and moving the tape-laying head of the tape rolling system one tape width to a direction perpendicular to fiber direction of the placed tape segment.

- 20 In an embodiment of the third aspect of the invention, said cutter is a stationary laser cutter comprising a laser source and a lens generating a uniform power distribution line.

In an embodiment of the third aspect of the invention, said cutter is a moving laser

25 unit comprising a laser source.

In an embodiment of the third aspect of the invention, said tape is a spread tow of fibers, wherein the fibers are selected from the following fibers: carbon fiber, aramid fiber and glass fiber.

30

In an embodiment of the third aspect of the invention, said cutting step is performed on a dry portion of the tape.

In an embodiment of the third aspect of the invention, said mixing step and said

35 impregnating step are performed in-situ.

In an embodiment of the third aspect of the invention, the method further comprises a step of rotating the mould in relation to the tape laying head between layers of tape for altering fiber orientation between layers.

5

A fourth aspect of the invention is a tape-laying system for manufacturing fiber reinforced plastic parts. The system comprises a tape rolling sub-system comprising a movable tape-laying head having one or more rotatable rollers 1, 2 for tensioning and placing a tape; a tape impregnation subsystem comprising a container for each component of a multi-component epoxy, a plurality of pumps for pumping said components to a mixer 5 for mixing components of a multi-component epoxy with each other, and a spreader 6 for impregnating the tape with said mixture; and a cutting sub-system comprising a cutter 4 configured to cut the tape.

10 In an embodiment of the fourth aspect of the invention, said cutting sub-system is a laser cutter 4 comprising a laser source and a lens configured to convert a laser beam from the laser source into a stationary line perpendicular to a fiber direction of the tape.

15 In an embodiment of the fourth aspect of the invention, said cutting sub-system is a laser cutter 4 comprising a laser source configured to cut the tape using a focused beam moving perpendicular to a direction of fibers in the tape.

In an embodiment of the fourth aspect of the invention, said cutting sub-system 4 is located between said tape rolling subsystem and said tape impregnation subsystem for cutting a dry, non-impregnated, tape.

25 The system enables manufacturing of small fiber reinforced parts without human intervention. Thus, consistent quality can be achieved and manufacturing costs can be reduced. In addition, the system avoids human exposure to carcinogenic material (epoxy resins are typically used) while manufacturing FRP parts thus reducing the health hazard to the laborer. The system provides manufacturing freedom as of additive manufacturing with strength of FRP composites, allowing manufacturing of high strength quality parts with ease.

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Claims

1. A method of manufacturing fiber reinforced plastic parts, the method comprising using a tape rolling system to perform steps of:
 - 5 placing a segment of a tape on a mould by moving a tape-laying head of the tape rolling system;
 - providing components of a multi-component epoxy in defined ratios to a mixer;
 - mixing a mixture of multi-component epoxy with the mixer;
 - spreading the mixture of multi-component epoxy on the placed segment of the
 - 10 tape;
 - impregnating the mixture of multi-component epoxy into the tape;
 - cutting the tape with a cutter of the tape rolling system; and
 - moving the tape-laying head of the tape rolling system one tape width to a direction perpendicular to fiber direction of the placed tape segment.
- 15 2. The method of claim 1, **characterized** in that said cutter is a stationary laser cutter comprising a laser source and a lens generating a uniform power distribution line.
- 20 3. The method of claim 1, **characterized** in that said cutter is a moving laser unit comprising a laser source.
4. The method of any one of claims 1 to 3, **characterized** in that said tape is a spread tow of fibers, wherein the fibers are selected from the following fibers:
 - 25 carbon fiber, aramid fiber and glass fiber.
5. The method of any one of claims 1 to 4, **characterized** in that said cutting step is performed on a dry portion of the tape.
- 30 6. The method of any one of claims 1 to 5, **characterized** in that said mixing step and said impregnating step are performed *in-situ*.
7. The method of any one of claims 1 to 6, **characterized** in that the method further comprises a step of rotating the mould in relation to the tape laying head
- 35 between layers of tape for altering fiber orientation between layers.

8. A tape-laying system for manufacturing fiber reinforced plastic parts, wherein the system comprises
a tape rolling sub-system comprising a movable tape-laying head having one or
5 more rotatable rollers (1, 2) for tensioning and placing a tape,
a tape impregnation subsystem comprising a container for each component of a multi-component epoxy, a plurality of pumps for pumping said components to a mixer (5) for mixing components of a multi-component epoxy with each other, and
a spreader (6) for impregnating the tape with said mixture, and
10 a cutting sub-system comprising a cutter (4) configured to cut the tape.
9. The system of claim 8, **characterized** in that said cutting sub-system is a laser cutter (4) comprising a laser source and a lens configured to convert a laser beam from the laser source into a stationary line perpendicular to a fiber direction of the
15 tape.
10. The system of claim 8, **characterized** in that said cutting sub-system is a laser cutter (4) comprising a laser source configured to cut the tape using a focused beam moving perpendicular to a direction of fibers in the tape.
20
11. The system of any one of claims 8 to 10, **characterized** in that said cutting sub-system (4) is located between said tape rolling subsystem and said tape impregnation subsystem for cutting a dry, non-impregnated, tape.

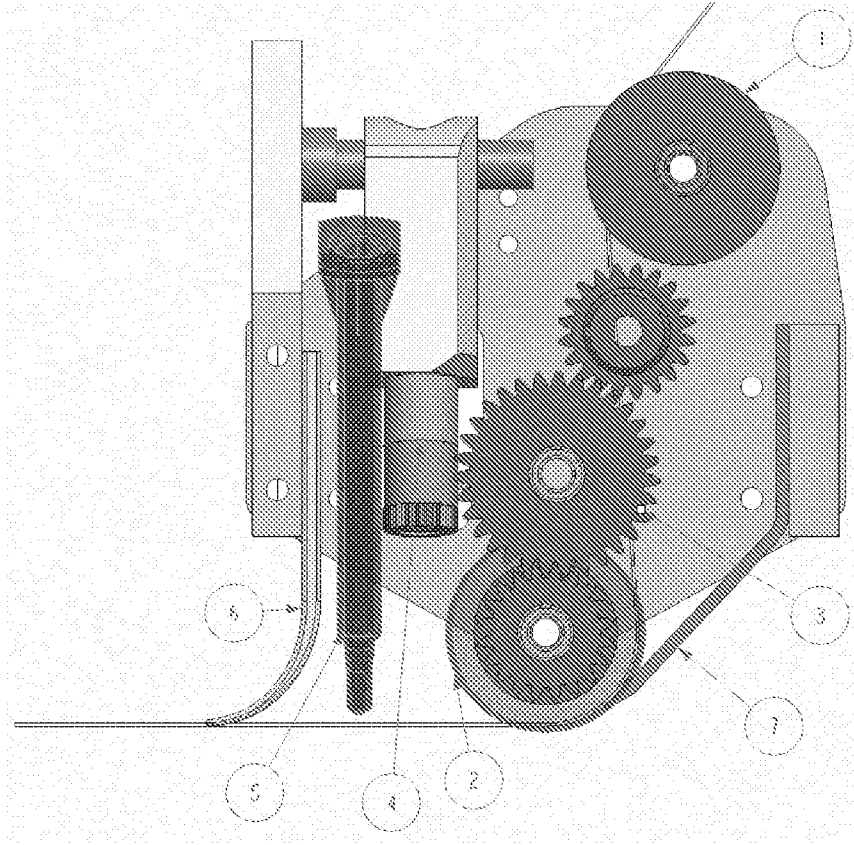


Fig 1.

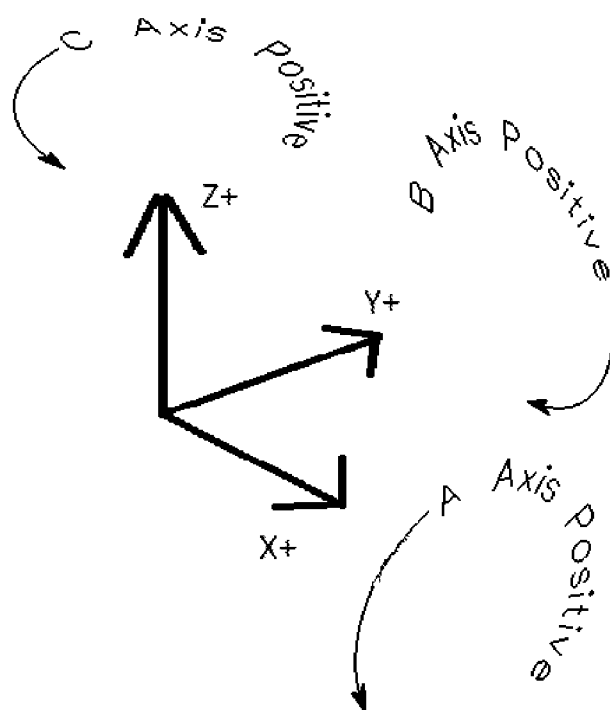


Fig 2.

INTERNATIONAL SEARCH REPORT

International application No
PCT/FI2017/050251

A. CLASSIFICATION OF SUBJECT MATTER
INV. B29C70/38 B29C70/54 B29B15/12
ADD. B29K63/00

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)
B23K B29K B29C B29B

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 2 345 530 A1 (KRAUSS MAFFEI TECH GMBH [DE]) 20 July 2011 (2011-07-20)	1,4-8,11
Y	paragraphs [0021], [0024]; claim 1; figure column 3, lines 45-49	2,3,9,10
A	----- WO 2007/045088 A1 (STATEMIX LTD [CA]; TOWFIGH PAYAM [CA]; DERWIN JON P [CA]; O'CONNOR JOH) 26 April 2007 (2007-04-26) page 7, paragraph 4 - page 8, paragraph 2 claims 28,31; figures 1,2	1,8
Y	----- EP 0 881 026 A2 (HAUNI MASCHBAU AG) 2 December 1998 (1998-12-02) column 3, line 18 - column 4, line 13; figure 2	2,9
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Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

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Name and mailing address of the ISA/

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INTERNATIONAL SEARCH REPORT

International application No

PCT/FI2017/050251

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

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