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(54) Titre : METHODE DE FABRICATION D'UN STRATIFIE METAL-FIBRE DE VERRE 3D ET PANNEAU STRUCTURAL STRATIFIE 3D

(54) Title: METHOD OF MAKING A 3D GLASS FIBER METAL LAMINATE AND 3D LAMINATE STRUCTURAL PANEL

(57) Abrégé/Abstract:
A new assembled glass fiber metal laminate has a 3D E-glass fiber fabric core layer, which contains two bidirectional fabrics knitted together by vertical braided glass fiber pillars. Application of resin to core faces and interior fibers creates spaces and voids in the fabric, which are filled by injection of foam to increase strength and stiffness. Thin magnesium alloy sheets comprise the outer layers on the two sides of the core layer. In addition, core and laminate structural strength and stiffness can be increased through the optional step of inserting thin fiberglass cloth layers between the core layer and outer metal alloy layers. A new type of structural laminate panel is formed by bonding together two or more of the new component laminates. The new laminate and structural panel are suitable for use in automobiles, marine vessels and other applications particularly requiring optimal impact resistance and minimization of delamination occurrence.

METHOD OF MAKING A 3D GLASS FIBER METAL LAMINATE AND 3D LAMINATE STRUCTURAL PANEL

Abstract

A new assembled glass fiber metal laminate has a 3D E-glass fiber fabric core layer, which contains two bidirectional fabrics knitted together by vertical braided glass fiber pillars. Application of resin to core faces and interior fibers creates spaces and voids in the fabric, which are filled by injection of foam to increase strength and stiffness. Thin magnesium alloy sheets comprise the outer layers on the two sides of the core layer. In addition, core and laminate structural strength and stiffness can be increased through the optional step of inserting thin fiberglass cloth layers between the core layer and outer metal alloy layers. A new type of structural laminate panel is formed by bonding together two or more of the new component laminates. The new laminate and structural panel are suitable for use in automobiles, marine vessels and other applications particularly requiring optimal impact resistance and minimization of delamination occurrence.

Description

FIELD OF THE INVENTION

The present invention relates to a novel fiber-metal laminate comprising mutually 3D foam impregnated fiber-reinforced composite layers and magnesium metal sheets. More particularly, the invention relates to a fiber-metal laminate comprising mutually bonded foam impregnated 3D glass fiber-reinforced composite layers and magnesium metal sheets having an optimal configuration.

BACKGROUND OF THE INVENTION

Fiber-reinforced composites offer considerable weight advantage over other materials, such as metals. Generally, the weight savings are obtained at the sacrifice of other important material properties such as; ductility, toughness, bearing strength, conductivity and cold forming capability. In order to overcome these deficiencies, new hybrid materials called fiber-metal laminates have been developed to combine the best attributes of metal and composites.

Fiber-reinforced polymer (FRP) composites have been extensively utilized in various industries over recent years. The relatively high specific-strength and stiffness and noteworthy fatigue and corrosion endurance characteristics have made them useful materials for numerous applications, particularly in automotive fabrication. The weakest link in the FRPs has been their inter-laminar shear capacity, which makes them susceptible to impact loading. Thus, previous researchers have tried to improve the impact resistance of FRPs over the last over the last few decades. One of the most effective means of improving the impact resistance of FRPs has been to incorporate thin sheets to form so-called fiber-metal laminates (FMLs).

WO 2007/145512A1 discloses a FML comprising metal plates with an individual thickness of 1mm. Patent EP0312150 A1 and EP0312151 describe other useful FMLs. US Patent 7446064 B2 employs a glass fabric reinforcing layer and a polymer core but no 3D fabric and uses aluminum alloy instead of magnesium alloy. US patent 6824851 B1 employs a glass fabric that is not a 3D fabric and the use a honeycomb, not a 3D fabric. The present invention would be less costly to obtain similar to greater strength. US patent 8334055 B2 is a typical sandwich type composite with the exception that there use longitudinal fibers not through-thickness fibers dispersed within the epoxy resin as in the much stronger 3D fabric of the present invention.

Impact characterization of FMLs has been studied based on aluminum as the constituent metal. GLARE (Glass Laminate Aluminum Reinforced Epoxy, US Patent 5039571 A) FML, is composed of several very thin layers of metal (usually aluminum) interspersed with layers of glass-fiber "pre-preg", bonded together with a matrix such as epoxy. GLARE5 FMLs were developed with emphasis upon the effects of FML thickness and impactor mass on the impact response. It was determined that specimen thickness had a significant effect upon the failure modes of FMLs, such that an increase in panel thickness significantly enhanced the energy absorption capacity of the FMLs.

US Patent 4,500,589 describes the material under trade name ARALL, which is fabricated by putting fiber reinforcement in the adhesive bond lines between aluminum alloys. The main difference between ARALL and GLARE was that GLARE consists of glass fibers instead of the ARALL aramid fibers and that GLARE exhibits higher tensile and compressive, greater impact behavior and greater residual strength than ARALL. Currently, GLARE materials are commercialized in six different standard

grades based upon unidirectional glass fibers embedded with epoxy adhesive resulting in pre-pregs with a normal fiber volume fraction of 60%. It has been found that ARALL exhibits poor compressive strength, which represents a major limitation. CARAL materials have exhibited an improvement over ARALL materials, such that they contain different amounts of carbon/epoxy pre-pregs instead of amarmid/epoxy pre-pregs.

Compared with aramid/epoxy, the carbon/epoxy composites possess higher specific modulus, but relatively low values of specific impact strength and strain to failure. In terms of fatigue, it was recognized that aramid fiber composites exhibit better low cycle fatigue performance but worse high cycle fatigue performance than carbon fiber composites. Moreover, the high stiffness of carbon fibers allows for extremely efficient crack bridging and therefore very low crack growth rates.

Fiber-metal laminates or FMLs, such as described in US 4,500,589. For instance, are obtained by stacking alternating sheets of metal (most prefer aluminum) and the fiber-reinforced pre-pregs and curing the stack under heat and pressure, for example, in ships, cars, trains aircraft and spacecraft. They can also be used as sheets and/or a reinforcing element and/or and or as a stiffener for (body) structures of these transports, like for aircraft for wings, fuselage and tail panels and/or skin panels and structural elements of aircraft.

3D fiberglass (3DEG) fabric (ex. PATENT US 6338367 B1) is a newly developed fiberglass woven/braided fabric consisting of two bi-directional woven fabrics knitted together by vertical braided glass pillars. Besides glass fibers, carbon and even basalt fibers as well as hybridizations of these fibers could be used to form 3D clothes. The unique configuration of fibers in 3D clothes have been claimed to provide excellent impact resistance. However, there is little evidence to support any claims to date.

Polyurethane liquid foam is comprised of a two-part liquid that yields a high strength, rigid, closed-cell foam for cavity filling and buoyancy applications. The liquid is extremely simple to use. Immediately after mixing the two component parts, it is poured into cavities, then left to quickly cure. The foam imparts considerable stiffness with only minimal increase in weight. Optimal results require use of appropriate mixing procedures. The majority of foam use is used behind other materials for domestic and commercial uses, such as constructing furniture and preparing thermal insulation panels for the building industry.

US Patent 5547735 describes a metal-polymer laminate that has a bidirectional reinforcing layer containing roughly 45-70 volume per cent high strength glass fibers. The bidirectional reinforcing layer includes a center layer containing glass fibers oriented generally parallel to a first direction and first and second outer layers each reinforced with glass fibers oriented in a second direction extending generally transverse to the first direction. The bidirectional laminate is suitable for use in aircraft flooring and other applications requiring improved impact strength. This approach lacks the additional strength and stiffness character gained by employing a 3D glass fiber fabric with reinforcing layers.

The use of magnesium alloys in various engineering applications has been increasing steadily in recent years, especially in the automotive industry. One of the primary reasons is due to the low density of magnesium (roughly 25% that of steel and 35% lower than aluminum, which makes the weight of magnesium alloy structural components very comparable to that of FRPs. Magnesium alloy-based fiber metal laminates several advantages over other metal base complexes such as; a high strength to weight ratio, improved electromagnetic shielding capability, relatively density and lower cost compared to aluminum and superior corrosion resistance. Previous studies have found that compared

to 2024-T3-based GLARE5, the impact resistance of magnesium-based FMLs was lower than that of GLARE5 when damage in the form of cracking of magnesium plates was taken as the failure criterion. However, when comparing the perforation limit, the specific impact energy of the magnesium-based FMLs was observed to be approximately equal to GLARE5.

In addition, it has been found that magnesium-based alloys exhibit higher specific tensile strength than aluminum-based FMLs. Also the specific tensile strengths of magnesium-based FMLs has been found to be higher than that of 2024-TO aluminum alloy-based FMLs. It has also been suggested that the relatively lower elastic modulus and fracture properties exhibited by magnesium-based FMLs may be mitigated by selection of an appropriate volume of the composite constituents. One of the most common modes of damage for conventional FML configurations subjected to low velocity impact is the delamination that could develop within their FRP layers and/or within FRP/metallic interfaces. Current testing has shown that due to the resilient structure of the 3D fabric, no delamination has occurred. It has been determined that impact energy is absorbed mainly by crushing vertical fibers and the supporting foam beneath the region of impact, which leads to magnesium oxide which has found some current uses in the marketplace that include Ecomag magnesium boards and in boards and panels used employed by MoonrakerSIPS building systems, whereas the uses for magnesium alloy as a strengthening and reinforcing agent are very limited. US patent 7087317 describes a Glare type composite laminated sandwich panel comprised of aluminum with adhesive where at least one of the aluminum sheets is preferably made of an aluminum non-heat treatable alloy type Al-Mg with a magnesium content of between 4 and 6%.

OBJECTIVES OF THE INVENTION

It is an object of the invention to provide a fiber metal laminate composite comprised of mutually bonded 3D glass fiber fabric layers and metal alloy sheets as layers exhibiting optimal impact and strength characteristics. It is a further object of the invention to provide a laminate comprised of 3D E-glass foam-injected fiber fabric core, layers of magnesium metal alloy sheets and optional fiberglass cloth layers all bonded by an appropriate epoxy resin/adhesive. Another objective of the invention is to show that the unique configuration of 3D E-glass fiber, foam, adhesive and magnesium alloy sheets will enable assembly of superior low velocity impact resistant panels. Another object of the invention is to show that the performance of the FMLs comprised of 3D fiber fabric, foam, adhesive, magnesium alloy sheets and optional fiberglass cloth will minimize delamination that could occur within laminate layers and/or within fiber fabric or fiberglass cloth/metallic interfaces. Another object of the invention is to advise of uses of such laminate panel as a structural element, particularly in automobile and marine vessel construction and repair.

Additional objects, features and advantages of the invention will be set forth in the description, which follows and in part will be obvious from the description or may be learned by practice of the invention. The objects, features and advantages of the invention may be realized and obtained by means of the instrumentalities and combination particularly pointed out in the appended claims.

SUMMARY OF THE INVENTION

In one aspect, a structural laminate is provided having a layered composition of first and second metal alloy sheets as opposing outer layers.

In another aspect, liquid resin is applied to a 3D glass fiber fabric, which creates expansion of the through-thickness fibers of the fabric, which in turn creates spacing and voids in the body of the 3D glass fiber fabric core. The spacing is then filled with a polymeric foam.

In another aspect, the foam injected 3D glass fiber fabric layer is fitted between the opposing metal alloy sheets and bonded to the sheets using an adhesive material.

In another optional aspect, a thin layer of fiberglass cloth is fitted between the 3D glass fiber fabric layer and metal alloy sheet layers on one or opposing sides and bonded to the 3D fiber fabric layer and sheet layers using an adhesive material.

In yet another aspect of the invention, a method of forming a structural 3D fiber fabric metal laminate panel from 3D fiber fabric metal alloy laminate components is provided.

The Steps involved in integration of the present invention comprise;

1) Step one involves sanding the surfaces of metal alloy sheets, blowing surfaces clean and wiping with acetone.

2) Step two involves applying a liquid polymeric resin onto 3D fiber fabric and its core fibers and permit to cure with addition of a hardener.

3) Step three involves injecting a liquid polymer foam (or alike) into the 3D fiber core and permitting it to solidify.

4) Step four involves the option of bonding a layer of fiberglass cloth to the top and bottom or either of the foam injected 3D glass fiber fabric core layer.

5) Step five involves applying adhesive/resin to the inside faces of the outer metal alloy sheets to the mating sides of the 3D core for bonding the constituents together.

6) Step six involves bonding two 3D glass fiber fabric metal alloy laminate components together using and an adhesive material to form a 3D glass fiber fabric metal alloy laminate panel.

Needless to mention, in all the above described steps of 3D fiber fabric metal laminate and 3D fiber fabric metal laminate panel assembly, other completing operations of the process will be carried-out at the appropriate moments of the fabrication to produce a satisfactory laminate component and laminate panel of the required specifications. It will be apparent to those skilled in the art that it is possible to alter or modify the various details and steps of this invention without departing from the spirit of the invention. Therefore, the foregoing description is for the purpose of illustrating the basic idea of this invention and it does not limit the claims which are listed in this patent.

BRIEF DESCRIPTION OF THE FIGURES

The invention is described in reference to the following illustrations.

Figure 1 is a top view in perspective of a magnesium alloy sheet layer according to an embodiment of the present invention.

Figure 2 is a top view of 3D glass fiber fabric material with applied resin according to an embodiment of the present invention.

Figure 3 is a front view of a 3D glass fiber fabric material with applied resin according to an embodiment of the present invention.

Figure 4 is a front view of 3D glass fiber fabric material with applied resin and injected foam forming a layer within the 3D glass fiber fabric material according to an embodiment of the present invention.

Figure 5 is a front view of 3D glass fiber fabric material with applied resin, injected foam forming a layer within the 3D glass fiber fabric, optional fiberglass cloth layer and outer magnesium alloy sheet layers that bonded together by epoxy resin form a 3D E-glass fiber fabric laminate component according to an embodiment of the present invention.

Figure 6 is a front view of two 3D E-glass fiber fabric laminate components bonded together to form a 3D E-glass fiber fabric laminate panel.

Figure 7 is a depiction in graphical form of the residual deformation of a 3D E-glass fiber fabric laminate test specimen being compared to woven fabric test specimens having several different layers (e.g. 4, 7 and 16 layers, respectively).

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS OF THE INVENTION

In the following description, reference is made to the accompanying drawings, which form a part hereof, and which show, by way of illustration, specific embodiments in which the invention may be practiced. The present invention, however, may be practiced without the specific details or with certain alternative equivalent methods to those described herein. The method of producing an innovative 3D fiber fabric metal laminate component and 3D fiber fabric laminate panel therefrom, using a 3D glass fiber fabric injected with foam between thin sheets of magnesium alloy, with or without a fiberglass cloth layer reinforcing layer, will now be described in reference to the above stated drawings. The working principle of the laminate component will be described first and then the particular way of constructing the laminate component and associated laminate panel through a combination of the laminate components will be described.

In the description of the present invention and elsewhere the 3D E-glass fiber fabric magnesium alloy sheet laminate may occasionally be called a laminate or laminate component or FML (fiber metal laminate) or 3D glass fiber fabric metal laminate or 3D-E glass fiber metal laminate or 3D glass fiber fabric metal alloy laminate or 3D glass fiber fabric laminate or 3D laminate or glass fiber fabric metal laminate or glass fiber metal laminate or similar for the sake of brevity, while still maintaining the accuracy and intent of the description and the spirit of the present invention. The 3D E-glass fiber fabric magnesium alloy sheet panel may in the same vein within the context of the description of the present invention be called a 3D E-glass fiber metal alloy panel or 3D glass fiber metal alloy panel or a 3D glass fiber metal panel or 3D laminate panel or similar for the sake of brevity, while still maintaining the accuracy and intent of the description and the spirit of the present invention. In addition, for the sake of brevity, the 3D E-glass fiber fabric material may be called 3D glass fiber fabric or 3D fiber fabric or 3D fabric or similar, while still maintaining the accuracy and intent of the description and the spirit of the present invention.

The basis of the present invention is a unique arrangement of 3D E-glass fiber fabric-reinforced composite layers, magnesium metal sheets, fiberglass cloth, foam and adhesive. In accordance with the invention, a 3D E-glass fiber fabric metal alloy laminate is provided comprising fiber-reinforced composite layers and magnesium metal sheets, the fiber properties relate to the metal sheet properties in a specific manner. It has been previously stated in this submission that the preferred 3D glass fiber for the invention is 3D E-glass fiber although other types of 3D glass fiber could be employed to achieve potentially similar results. It is stated and has also been previously stated in this submission that other types of fiber material could be employed in this invention.

The present invention comprises the assembly of a new 3D E-glass fiber fabric metal laminate as a component or article and a new 3D E-glass fiber fabric metal laminate panel by bonding together two or more of the new 3D E-glass fiber metal laminate components. More specifically, the new 3D laminate is comprised of a 3D E-glass fiber fabric (core) layer, an optional fiberglass layer or layers bonded to one or either side of the core layer and outer layers comprised of magnesium sheets bonded to the core or optional fiberglass layers. The core layer is comprised of 3D E-glass fiber fabric material with epoxy resin (adhesive) applied to the surface and used to impregnate interior fibers of the core plus a foam injected into the core material, which forms a layer within the core material. The core material itself constitutes a layer of the invention. An optional fiberglass cloth layer is bonded to the core layer using adhesive for further reinforcement.

In the present invention, fiber-reinforced composite layers preferably comprise fibers treated with a bonding system, preferably a metal adhesive. The system of adhesive, composite layers and metal sheets preferably provides its own internal heat development along with pressure supplied by a vacuum pressure system for curing the adhesive and forming a solid laminate component and laminate panel. The preferred epoxy resin (adhesive) as applied to the 3D glass fiber fabric, is also used to adhere the various layers of metals, fiberglass cloth and 3D fiber fabric material structures together. The preferred range in thickness for a 3D glass fiber fabric material is from 2 mm to 10 mm, thus the 3D glass fiber fabric laminate component can display various thicknesses dependent upon the number of 3D glass fiber fabric materials and their individual thicknesses employed to assembly one new 3D laminate or 3D laminate panel.

In the present invention, the laminate outer magnesium alloy sheet layers can be formed of one or more magnesium alloy sheets of varying thicknesses dependent upon the desired structural character or the application of the new 3D laminate component or new 3D laminate panel. The preferred range for thickness of a single magnesium alloy sheet is 0.4 mm to 50 mm. The total thickness of a magnesium alloy sheet layer is contingent upon the number of sheets chosen to be employed for a particular design or application. In addition, the number of optional fiberglass cloth layers employed in the new 3D laminate component or 3D laminate panel can also vary from one to more layers dependent upon the desired structural character or the application of the new 3D laminate or new 3D laminate panel. The preferred range for thickness of a singular optional fiberglass cloth is 0.2 mm to 0.4 mm. The total thickness of a fiberglass cloth layer is contingent upon the number of units of fiberglass cloth that are chosen to be employed in a particular design or application.

In the present invention, preferably, when applying adhesive to join two separate surfaces/layers of the 3D laminate component and 3D laminate panel, an appropriate amount of adhesive is applied to both surfaces to be joined simultaneously. It has been discovered by the inventors that 3D glass fiber fabric metal laminates with described fiber fabric properties have better structural properties respecting joint strength as well as in fatigue, in particular a higher resistance against low velocity impact and fabric

delamination than conventional fiber-metal laminates of which the relevant properties are not in accordance with the methods of assembling the present invention.

In accordance with the invention and Figure 1, AZ31B magnesium alloy sheets (1) ranging in thickness from 0.4 to 50 mm are employed to form the outer layers of the new 3D glass fiber fabric laminate component and 3D glass fiber fabric laminate panel. The magnesium alloy sheets (1) as shown in Figures 1, 4, 5 and 6 are sandblasted and treated with acetone to ensure clean surfaces for application of a bonding agent. Magnesium alloy is useful for its high strength to weight ratio, low density and corrosion resistance, all features useful in a laminate and structural panel.

In accordance with the invention and Figure 2, 3D E-glass fiber fabric (2) material consists of two bi-directional woven fabrics connected in a uniform specific distance by vertical column-like fibers. The 3D E-glass fiber fabric (2) preferably ranges in thickness from 2 to 10 mm and was acquired from China Beihai Fiberglass Co. Ltd. An innovative step in assembly of the present innovation includes the application of epoxy resin (3) to the surfaces of the 3D glass fiber fabric (2) and resin (3) impregnation of the interior fibers of the 3D glass fiber fabric (2), which encourages the fibers connecting the top and bottom cloth of the fabric (2) to expand through the thickness direction, thus creating spacing and voids in the fabric (2). In addition, Araldite Y564 (Bisphenole-A) epoxy resin (3) plus Aradus 2954 (cycloaliphatic polyamine) hardener from Huntsman Co. were employed. Considering the present invention, the aforementioned resin and hardener together comprise the aforementioned epoxy resin or resin.

In accordance with the invention and Figure 3, 3D E-glass fiber fabric (2) material is shown with impregnating resin (3) that creates voids and spacing within the 3D E-glass fiber fabric (2) material. The resin (3) is applied to the surfaces and interior fibers of the 3D E-glass fiber fabric, which creates the spacing and voids in the 3D fabric.

In accordance with the invention and Figure 4, foam (4) material is injected into the 3D E-glass fiber fabric (2) material to fill the spacing and voids and to reinforce the strength and provide stiffness to the 3D E-glass fiber fabric (2) material. To create the present invention, 8lb density pour type urethane foam (4) from US Composites was preferably used. The 3D E-glass fiber fabric (2) material along with resin (3) and injected foam (4) form the core layer of the present invention.

In addition, magnesium alloy sheets (1) are bonded with resin (adhesive)(3) to the outer sides of the 3D E-glass fiber fabric (2) material to form the exterior covering for the new laminate component and to provide additional strength and stiffness to the laminate component. The aforementioned epoxy resin (adhesive) (3) used as a bonding agent and impregnating agent are the same material in the present invention, although varying bonding agents could be employed, although perhaps not with the same optimal results. The resin is used with a hardening agent to perform the curing process, thus the hardening agent is considered part of the epoxy resin or adhesive for the purposes of the present invention. The adhesive (3) dries in a matter of minutes, thus it is applied and the layers bonded together while the new laminate is under vacuum pressurization, to ensure a strong bond. It was found from lab testing, respecting the present invention that the optimal thickness range of 3D glass fiber fabric material (2) with resin (3) and foam (4), which form the core layer of the laminate or laminate component, is from 2 to 10 mm, with a preferred thickness of 4 mm to gain greater cost and impact integrity advantages.

In accordance with the invention and Figure 5 an optional step in the assembly of a 3D E-glass fiber fabric laminate component is the insertion of a thin layer of fiberglass cloth (5) as a reinforcing layer

between the interior 3D E-glass fiber fabric core (2) layer and the outer magnesium alloy sheet (1) layer to increase strength and stiffness in the laminate. The fiberglass cloth layer (5) is bonded to the core fabric (2) layer using adhesive (3) material. The fiberglass reinforcing (5) layer may be employed on one or both sides of the 3D E-glass fiber fabric (2) and one or more magnesium alloy sheets (1) may be used on one or both sides of the 3D E-glass fiber fabric (2) layer. A new 3D E-glass fiber fabric (2) magnesium alloy sheet (1) laminate is assembled by bonding together using adhesive (3) all layers noted in Figure 5.

In accordance with the present invention and Figure 6, two 3D E-glass fiber fabric (2) magnesium alloy sheet (1) laminates (laminate components) are bonded together with adhesive (3) to form a new 3D fiber fabric (2) magnesium alloy sheet (1) laminate panel. For the purposes of the present invention the new laminate panel may be formed by bonding together two or more of the laminate components with adhesive (2) material. All laminate layers are bonded together under vacuum pressurization or similar pressure application using adhesive (2) to ensure optimal bond strength and optimal structural characteristics of the present invention. Testing by the inventors has revealed that the new 3D E-glass fiber metal laminate panel exhibits superior structural properties to the new 3D E-glass fiber metal laminate component alone.

In accordance with the present invention and Figure 7, there is displayed herein a graph depicting the residual deformation of the new 3D E-glass fiber fabric metal laminate compared to conventional woven fabric laminates. The energy levels used for testing specimens were directed to generate damage: (i) on the impact surface (ii) to the reverse side and (iii) in the form of full perforation through test specimens. The three types of damage generated are depicted as mode 1, mode 2 and mode 3, respectively. In the present invention, testing has shown that due to the resilient structure of 3D glass fiber fabric, no delamination has occurred. In addition, it has been determined through testing that impact energy is absorbed mainly by the crushing of vertical fibers and the supporting foam beneath the region of impact, which leads to higher impact resistance exhibited by the 3D glass fiber fabric metal alloy laminate and a smaller damage area.

Low velocity impact response and failure modes for the present invention are investigated experimentally and computationally. The performance of the new 3D glass fiber fabric metal laminates (FMLs) are compared to that of conventional FMLs (fiber metal laminates) made with various numbers of layers of biaxial woven fabrics. The failure modes of the 3D laminate test specimens are characterized by being based upon the quantitative measurements of shape, type and extent of damage inflected upon the FMLs structure.

The impact characteristics of new assembled 3D FMLs are examined by characterizing and comparing; their energy absorption capacities, residual deformation and maximum deformation due to low velocity impact. Test results reveal that; the FMLs based upon the 3D glass fiber fabric exhibit outstanding impact absorption capacity, although the impact energy resistance is lower than FMLs based upon woven fabrics. In addition, a finite element analysis (FEA) framework constructed using the commercial finite element code ABAQUS so as to simulate the response of such complex structures. Results from running the FEA demonstrate that the simulation framework can be used to optimize the configuration of 3D FMLs for different loading situations and provide a useful quality control check during 3D FML assembly. Results of laboratory testing relevant to the present invention are summarized in the following Tables.

Table 1 displays a comparison of the flexural stiffness of FMLs made by existing industry woven fabric, compared to values for those made by the new 3D fiber fabric FMLs particular to the invention. The comparison shows that the new 3D FMLs exhibit a notably better performance on weight and material cost basis. The details of the FMLs noted in Table 1 are reported in Table 2.

Table 1. Flexural stiffness of the FMLs

Specimen ID	Flexural Stiffness ($N\text{-}m^2$)	Specific Flexural Stiffness ($N\text{-}m^2/g.mm^{-3}$)
3DF-FML	269.28	5729.53
4-layer FML	178.23	1916.40
7-layer FML	356.96	2189.96
16-layer FML	1287.25	3460.34

Table 2. Specifics of the different FMLs

Specimen ID	Overall Thickness (mm)	Overall Density (g/mm^3)	Reinforcement Fabric type	Number of layers of fabrics
3DF-FML	14.40	0.047	3DFGF	1
4-layer FML	4.87	0.093	biaxial woven	4
7-layer FML	6.53	0.163	biaxial woven	7
16=layer FML	10.16	0.372	biaxial woven	16

The present invention also incorporates new research data that shows the 3D E-glass fiber fabric metal alloy laminate exhibits a bending stiffness greater than conventional FMLs. Employing four layers resulted in flexural stiffness of the 3D glass fiber fabric FML that was found to be greater than the previously mentioned biaxial woven layers of FRPs. It was also determined that the 3D glass fiber fabric metal laminate could absorb the highest impact energy in comparison to the aforementioned woven layers of FRPs.

Many modifications may be made in the structures and processes to alter or modify the various details of this invention without departing from the spirit and scope thereof, which are defined only in the appended claims. For Example, one skilled in the art may discover that a certain combination of components, i.e. a particular core, etc., may give a sandwich panel with certain advantages. Further, certain dimensions or designs other than those disclosed here could be produced for a particular installation, but laminate components and laminate panels of these designs or dimensions would nevertheless fall within the scope of the claims herein, may prove advantageous.

Needless to mention, in all the above described methods of 3D laminate and 3D laminate panel production, the other complementing operations of the assembly process will be carried out at the

appropriate moments of the assembly to produce a satisfactory laminate of the required specification. It will be apparent to those skilled in the art that it is possible to alter or modify the various details of this invention without departing from the spirit of the invention. Therefore, the foregoing description is for the purpose of illustrating the basic idea of this invention and it does not limit the claims which are listed herein.

We believe that using the combination of: a 3D glass fiber fabric core material; resin to create spacing and voids in the laminate core that can be filled by injecting liquid foam to cure and notable increase structural strength and stiffness; employing an optional fiberglass cloth layer as reinforcement dependent upon product demand requirements of the laminate and laminate panel; and using thin magnesium metal alloy sheets as the outer layers of the new laminate and derived new panel to increase low velocity impact resistance and minimize delamination of layering is new and truly innovative.

What is believed to be the best mode of the invention has been described above. However, it will be apparent to those skilled in the art that these and other changes could be made to the present invention without departing from the spirit of the invention. The scope of the present invention is indicated by the broad general meaning of the terms in which the claims are expressed.

The research employed herein was funded by the National Science and Engineering Research Council of Canada (NSERC) and AUT021, a Network Center of Excellence in automotive grant.

References:

Low-velocity Impact Response of Fiberglass/Magnesium FMLs with a New 3D Fiberglass Fabric, Zohreh Asaee, Shahin Shadlou and Farid Taheri, In Press.

Claims

We Claim

1. A method of assembling a 3D glass fiber metal laminate or laminate component or article and a subsequent 3D glass fiber metal laminate panel, each comprising: a 3D E-glass fiber fabric material; a resin coating residing upon the opposing surfaces of said 3D E-glass fiber fabric material and said resin impregnating said 3D E-glass fiber fabric material; a liquid foam used as a filler in said 3D E-glass fiber fabric material; thin optional fiberglass cloth inner layers; thin magnesium alloy sheet outer layers and; an adhesive material to form a bond between all said layers and materials.

2. The 3D laminate according to Claim1, wherein a core layer is preferably comprised of said 3D E-glass fiber fabric, a surface coating of said resin upon opposing sides of said core, said core fabric fibers impregnated with said resin and foam injected into said fabric material.

3. The 3D laminate according to Claims 1, 2 wherein said core fabric is caused to expand and form spacing and voids due to the action of said resin applied upon the opposing surfaces of and within the fibers of said core fabric.

4. The 3D laminate according to Claims1, 2, 3 wherein said core layer fabric may also be made from other types of 3D glass and other types of organic and inorganic fibers.

5. The 3D laminate according to Claims 1, 2, 3 wherein said resin may be epoxy, vinyl ester, polyester or alike and is 2-part such that it produces its own heat energy to foster the curing process.

6. The 3D laminate according to Claims 1,2,3,4 wherein said liquid foam is injected into said core layer so as to fill upon, curing, said spacing and voids in order to increase the structural strength and stiffness of said laminate component.

7. The 3D laminate according to Claims 1, 6 wherein said liquid foam may be polyurethane or the like.

8. The 3D laminate according to Claims 1, 2, 3, 4 wherein different thicknesses of said laminate or laminate component are formed by employing various thicknesses of said 3D E-glass fiber fabric, where said fiber fabric will preferably range from 2 mm to 10 mm in thickness.

9. The 3D laminate according to Claim 1 wherein said thin magnesium alloy sheets are preferred as said outer layers of said laminate component and as such are either bonded to said 3D E-glass fiber fabric core and or to said optional fiberglass cloth layer/s.

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10. The 3D laminate according to Claims 1, 9 wherein said thin magnesium alloy sheets have a preferred range in individual sheet thickness from 0.4 mm to 50 mm.

11. The 3D laminate according to Claims 1, 9, 10 wherein said magnesium alloy sheets are effective in preventing corrosion of said laminate component.

12. The 3D laminate according to Claims 1, 2, 3, 4, 9, 10 wherein said optional fiberglass cloth layer is inserted between said core and either or both of said magnesium alloy sheets as a reinforcing layer.

13. The 3D laminate according to Claims 1, 9, 10, 11 wherein the preferred thickness of said magnesium alloy sheets may range from 0.4 mm to 50mm.

14. The 3D laminate according to Claims 1, 12 wherein the preferred thickness for said individual fiberglass cloth units ranges from 0.2 mm to 0.4 mm.

15. The 3D laminate according to Claims 1, 2, 3, 4, 12 wherein a preferred adhesive material (i.e. epoxy resin) is disposed between said core and said optional fiberglass cloth layer/s to form a bond and increase the structural strength and stiffness of said laminate component.

16. The 3D laminate according to Claims 1, 9, 12, 15 wherein said adhesive material is disposed between said optional fiberglass cloth layer and said outer thin magnesium alloy sheet layers.

17. The 3D laminate according to Claims 1, 2, 3, 4, 9 wherein said adhesive material is disposed directly between said outer magnesium alloy sheet layers and said core layer to form a bond and increase structural strength and stiffness of said laminate.

18. The 3D laminate according to Claims 1, 2, 3, 4, 9, 12, 15, 16, 17 wherein said preferred adhesive (i.e. epoxy resin), as applied to and within said 3D E-glass fiber fabric core, is also used to adhere the various layers of said metal sheets, fiberglass cloth layers and said 3D E-glass fiber fabric core structures together.

19. The 3D laminate according to Claims 1 through 18 wherein said 3D glass fiber fabric metal laminate or laminate component is comprised of said 3D E-glass fiber fabric core, said optional fiberglass cloth layer/s, said magnesium alloy outer sheet layers, said foam filler and said adhesive material.

20. The 3D laminate according to Claims 1 through 18 wherein said 3D E-glass fiber fabric metal laminate or laminate component is comprised of said 3D E-glass fiber fabric core, said optional fiberglass cloth layer/s, said magnesium alloy outer sheet layers, said foam filler and said adhesive material.

21. The 3D laminate according to Claims 1, through 20 wherein said 3D E-glass fiber fabric magnesium alloy laminate or laminate component may be bonded, using said adhesive material, to another said 3D E-glass fiber fabric magnesium alloy laminate component of similar dimensions and character, or otherwise, to form a 3D E-glass fiber fabric magnesium alloy laminate panel, which would greatly increase the structural strength and stiffness, optimize the impact resistance and minimize delamination occurrences of the new innovative panel.

22. The 3D laminate according to Claims 1, through 20 wherein said 3D E-glass fiber fabric magnesium alloy laminate or laminate component may be bonded, using said adhesive material, to another said 3D E-glass fiber fabric magnesium alloy laminate or laminate component of similar dimensions and character, or otherwise, to form a 3D E-glass fiber fabric magnesium alloy laminate panel system, which would greatly increase the structural strength and stiffness, optimize the impact resistance and minimize delamination occurrences of the new innovative panel.

23. The 3D laminate according to Claims 1, through 20 wherein said 3D E-glass fiber fabric laminate or laminate component may be bonded, using said adhesive material, to more than one said 3D E-glass fiber fabric laminates or laminate components of similar dimensions and character, or otherwise, to form a 3D E-glass fiber fabric magnesium alloy laminate panel system, which would greatly increase the structural strength, optimize the impact resistance and minimize delamination occurrences of the new innovative panel.

24. The 3D laminate according to Claim 1 through 21 wherein said 3D E-glass fiber fabric magnesium alloy laminate panel system may be comprised of two or more of said 3D E-glass fiber fabric laminate panels to comprise a panel system of greater thickness.

25. The 3D laminate according to Claims 1 through 24 wherein said 3D E-glass fiber fabric magnesium alloy laminate component and said 3D E-glass fiber fabric magnesium alloy laminate panel and said 3D E-glass fiber fabric magnesium alloy panel system are subjected to vacuum pressure or other pressurization procedures to ensure optimal bond strength is achieved.

While particular embodiments of this invention are shown and described herein, it will be understood, of course, that the invention is not to be limited thereto since many modifications may be made, particularly by those skilled in this art, in light of this disclosure. It is contemplated therefore, by the appended claims, to cover any such modifications as fall within the true spirit and scope of this invention.

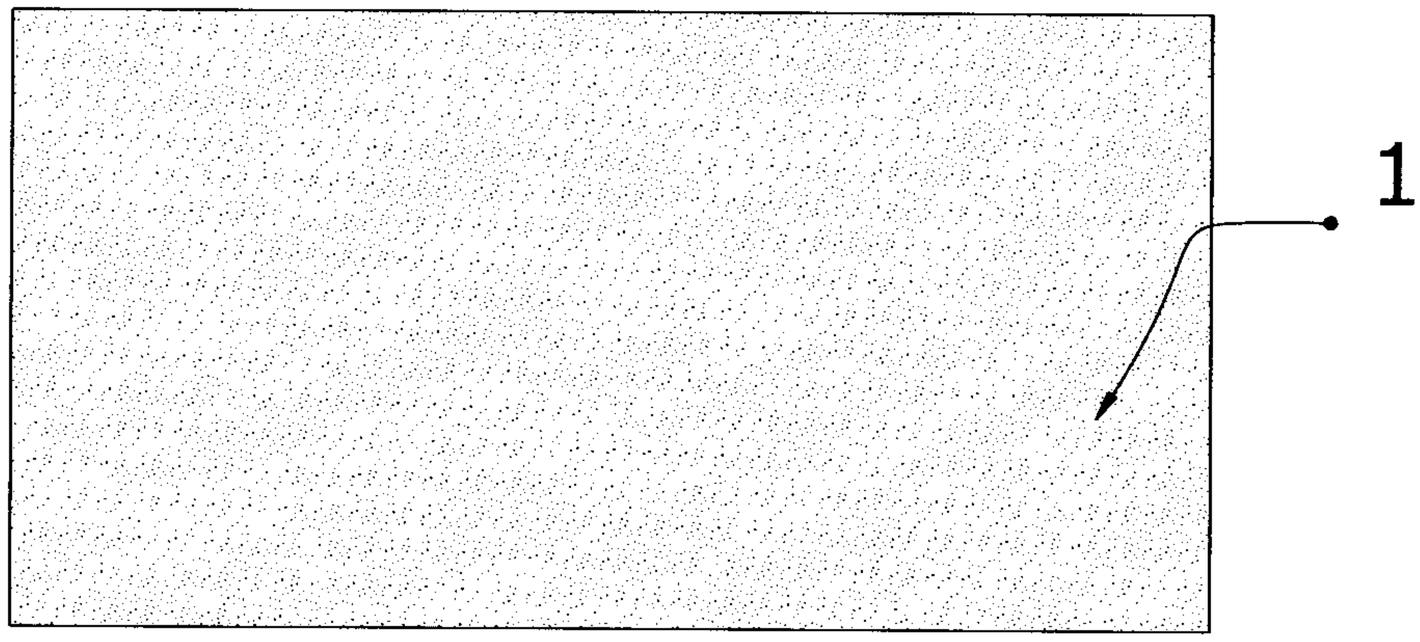

Fig. 1

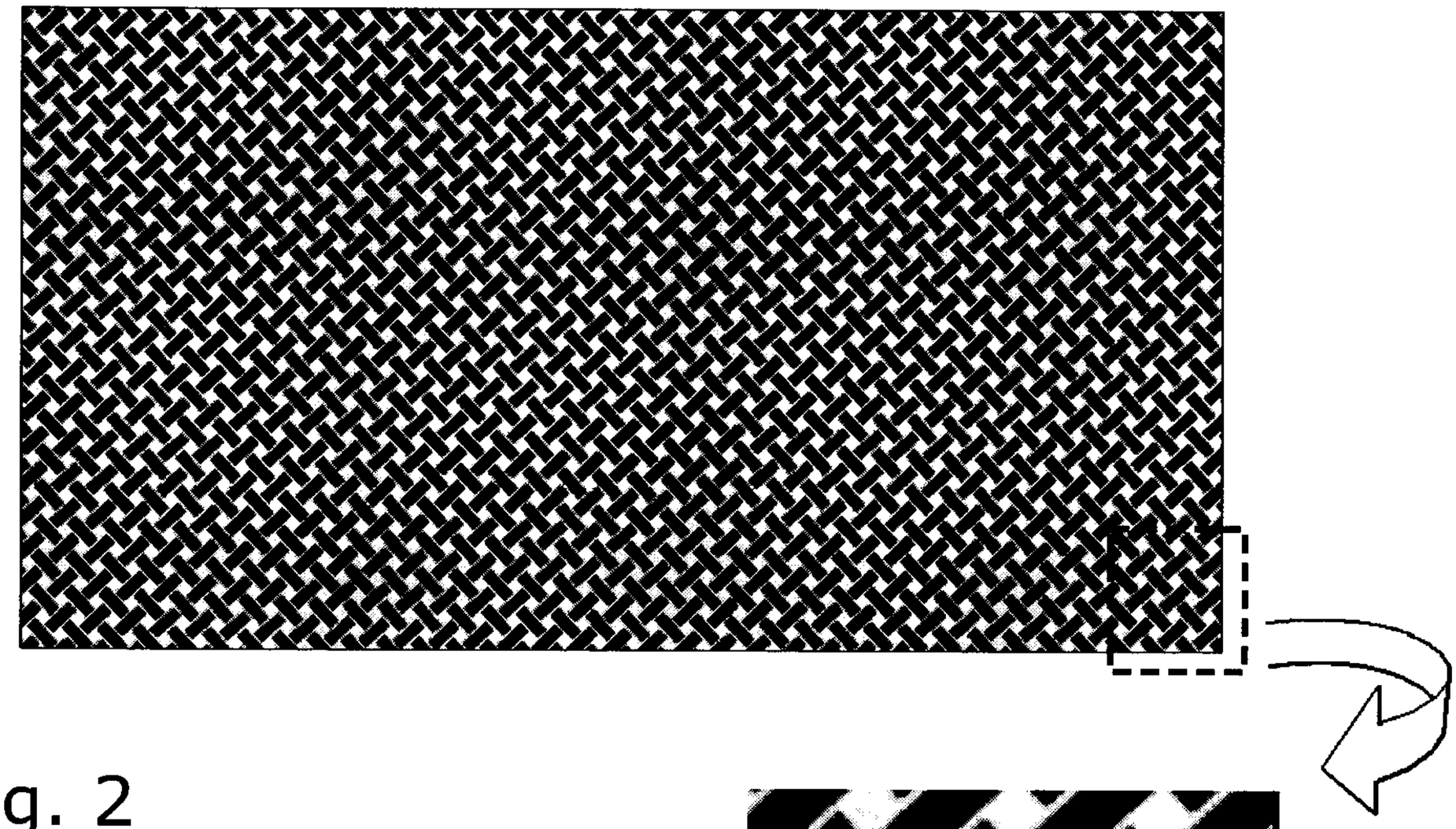

Fig. 2

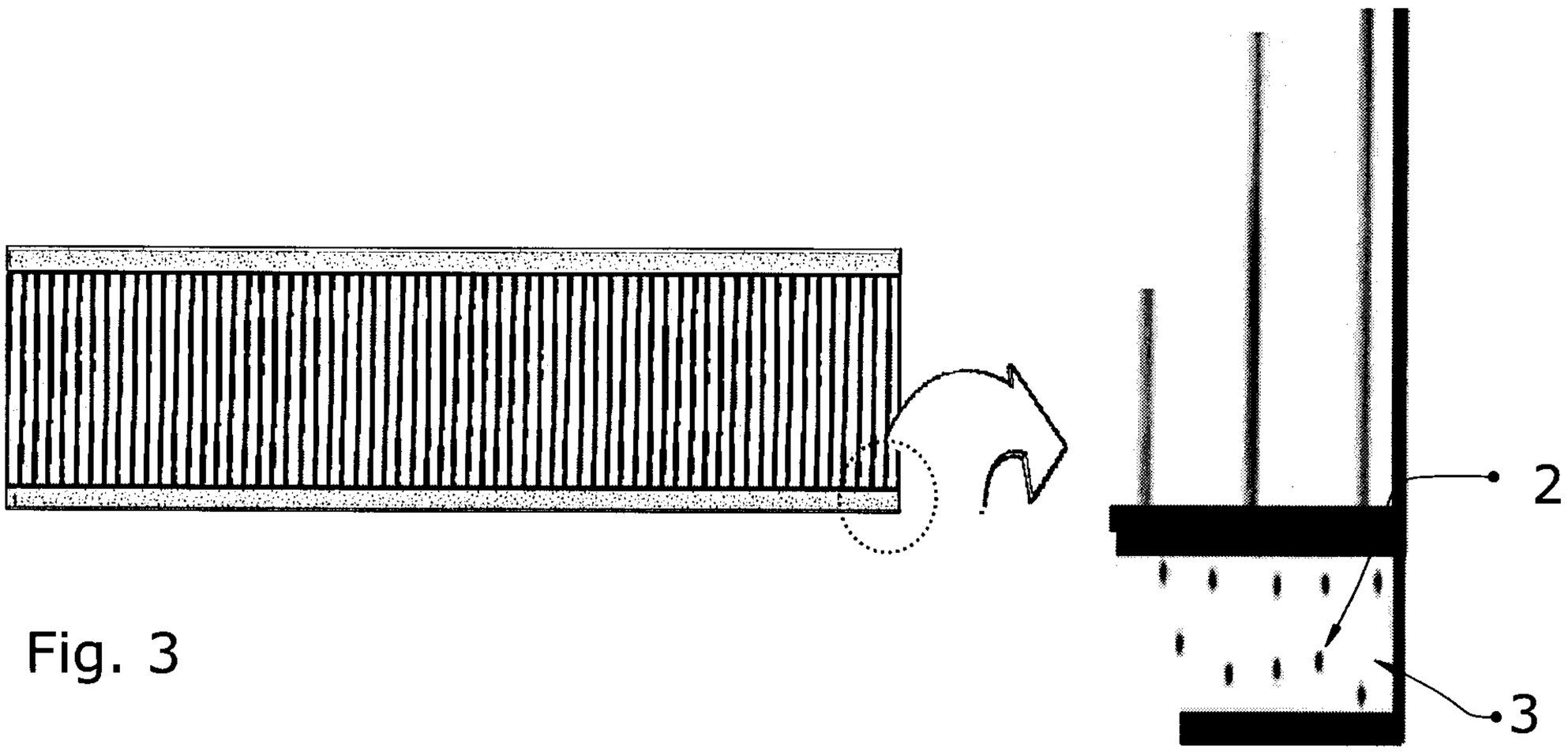

Fig. 3

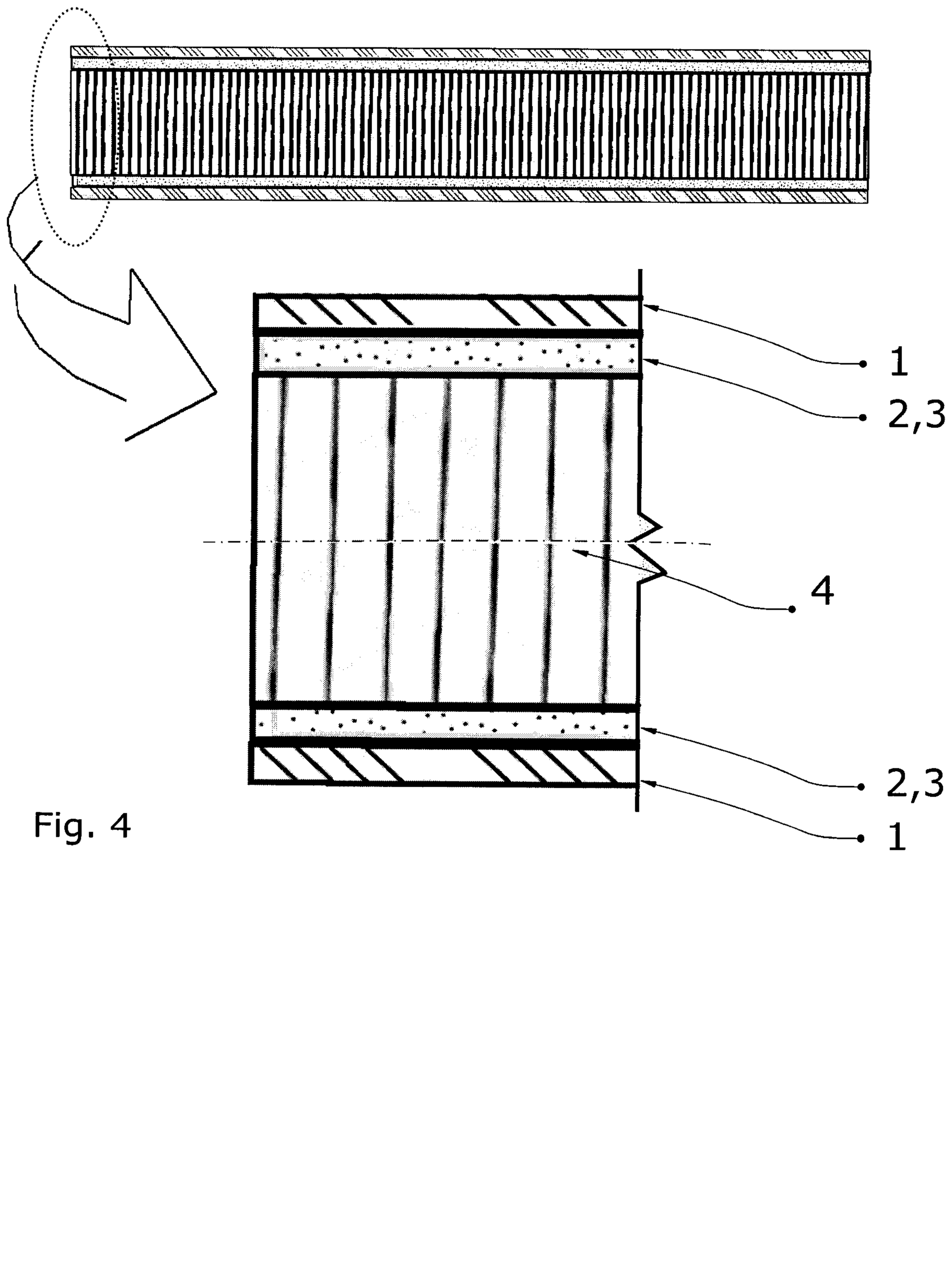

Fig. 4

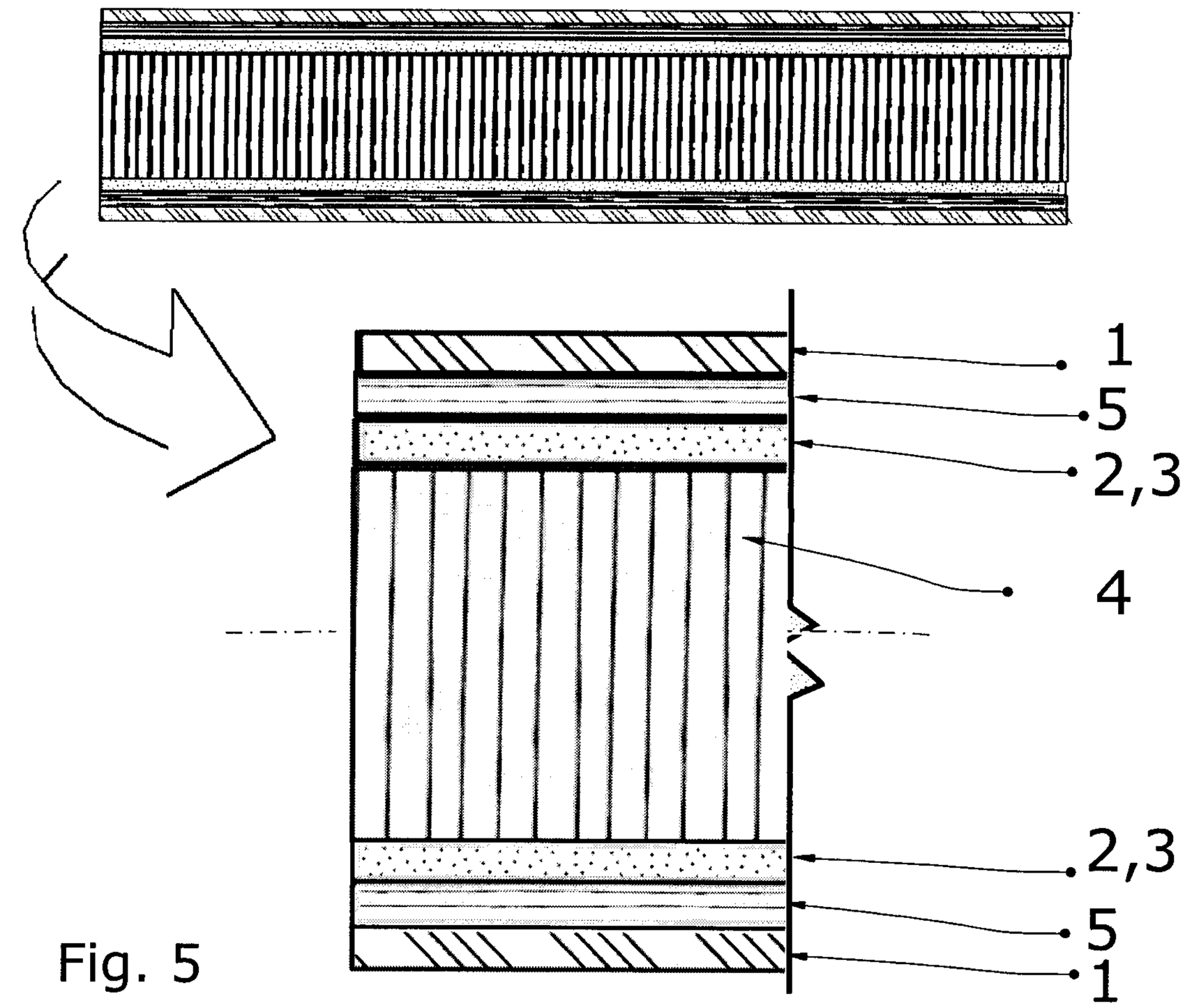

Fig. 5

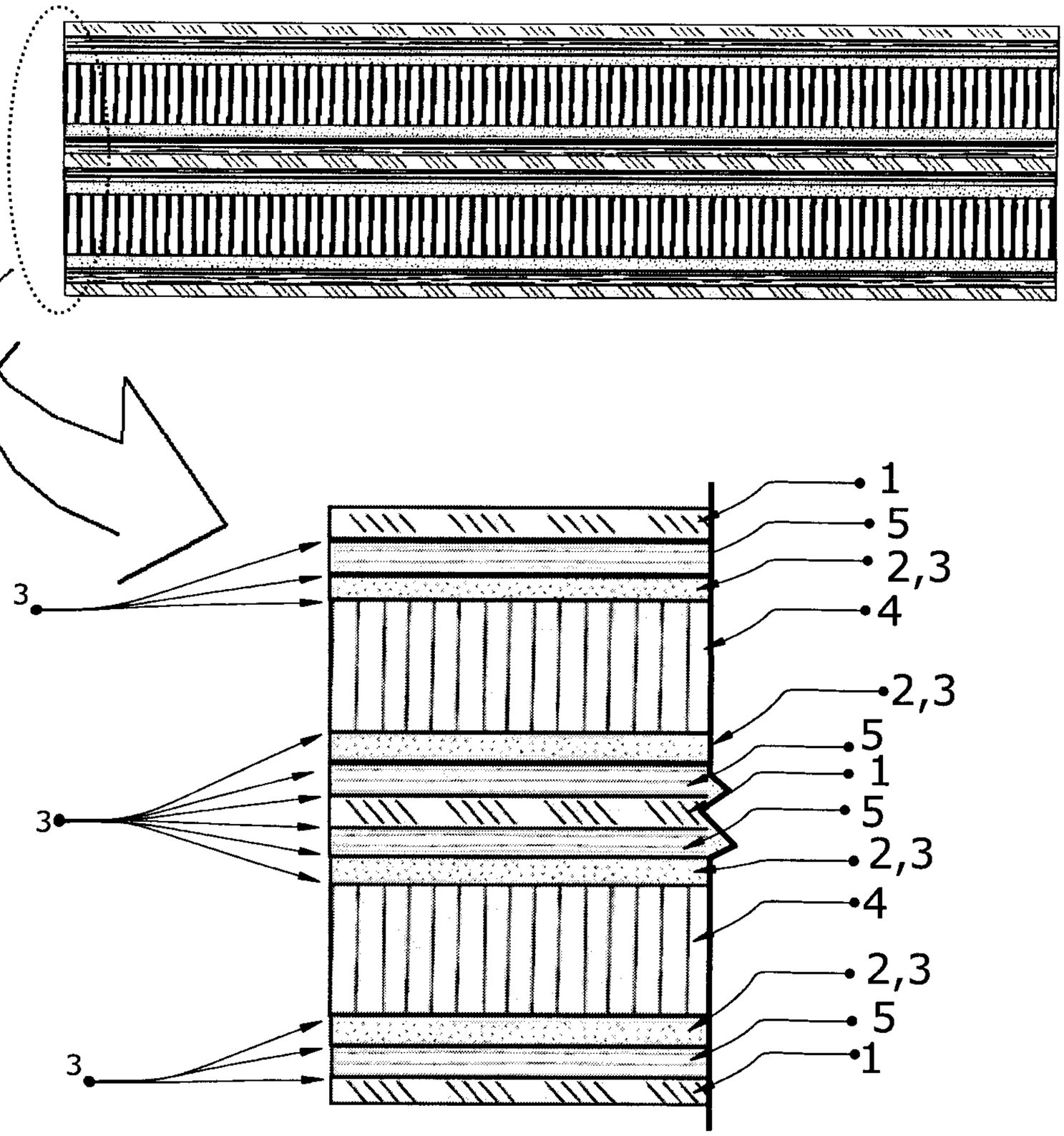

Fig. 6

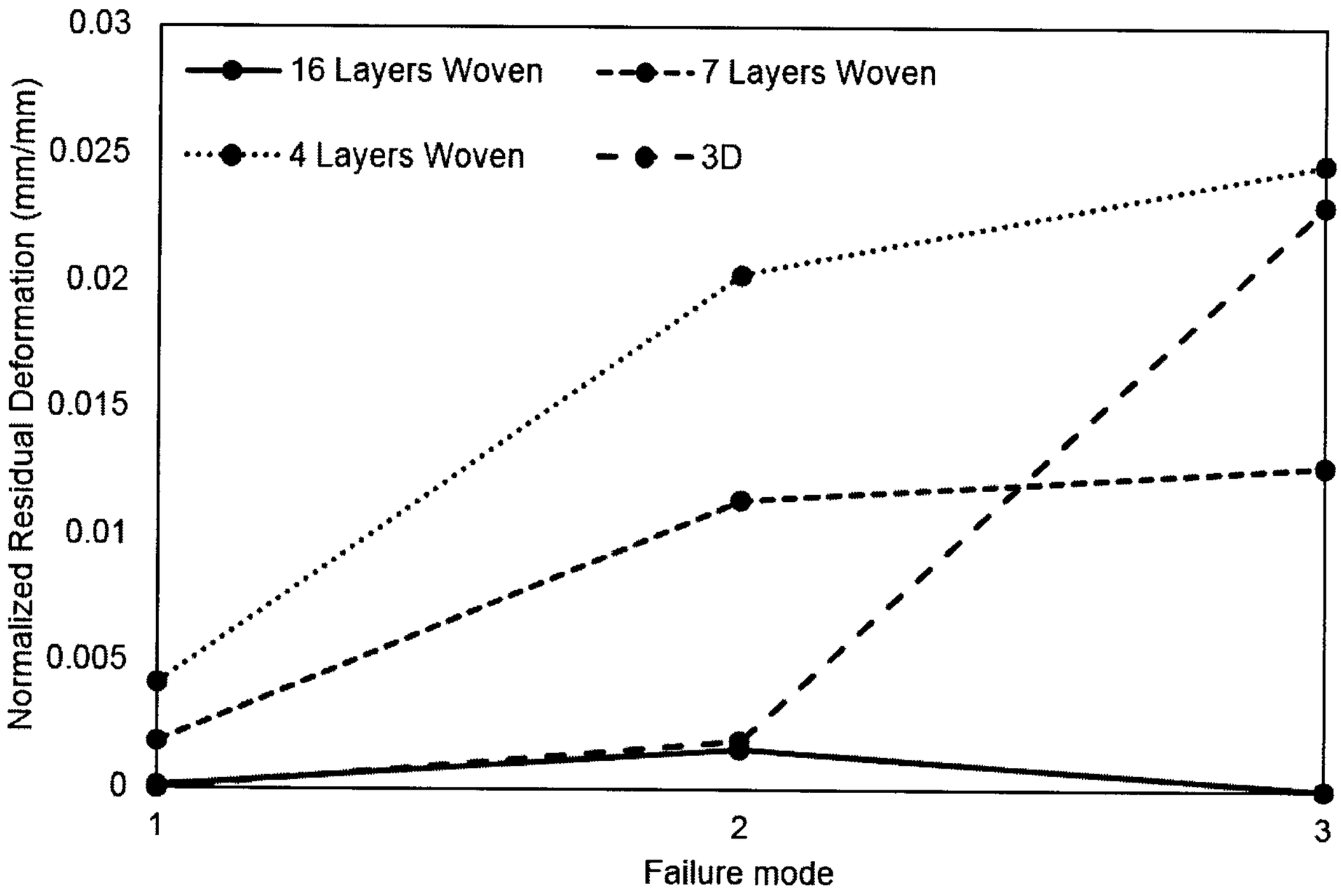
0.03
0.025
0.02
0.015
0.01
0.005
0
Normalized Residual Deformation (mm/mm)
16 Layers Woven
7 Layers Woven
4 Layers Woven
3D
1
2
3
Failure mode

Fig. 7