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Ir. H.Th. van den Heuvel c.s.**te 'S-HERTOGENBOSCH.**(54) **Improved Fiber-Metal Laminate.**

(57) The invention relates to a fiber-metal laminate of mutually bonded fiber-reinforced composite layers and metal sheets, the laminate comprising a combination of a fiber-reinforced composite layer and an adjacent metal sheet, in which combination the properties satisfy the following relations:

$$E_{\text{lam}} * E_{\text{comp}} / (E_{\text{metal}} * t_{\text{metal}}^2) = a * (V_f - c) / (V_f - c)^{(b/(V_f - c))}$$

$$c \leq V_f \leq 0.57$$

$$0 < E_{\text{lam}} * E_{\text{comp}} / (E_{\text{metal}} * t_{\text{metal}}^2) \leq 500 \text{ kN/mm}^4$$

wherein $a = 1200 \text{ kN/mm}^4$, $0.36 \leq b \leq 0.88$; $0 \leq c \leq 0.3$; and

E_{lam} = tensile Young's modulus of the total fiber-metal laminate in kN/mm^2

E_{comp} = tensile Young's modulus of the fiber-reinforced composite layer in kN/mm^2 in the combination

E_{metal} = tensile Young's modulus of the metal sheet in kN/mm^2 in the combination

t_{metal} = thickness of the metal sheet in mm in the combination

V_f = fiber volume fraction of the fiber-reinforced composite layer in the combination,

The invention further relates to a method for obtaining such laminate. The fiber-metal laminate according to the invention shows a high crack growth resistance and stiffness. The invention further relates to an assembly of the fiber-metal laminate and a further element, bonded to the fiber-metal laminate by a bonding layer, comprising an adhesive and/or a fiber-reinforced composite, or bonded by mechanical fastening means.

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Dit octrooi is verleend ongeacht het bijgevoegde resultaat van het onderzoek naar de stand van de techniek en schriftelijke opinie. Het octrooischrift komt overeen met de oorspronkelijk ingediende stukken.

Improved Fiber-Metal Laminate

FIELD OF THE INVENTION

The present invention relates to a fiber-metal laminate comprising mutually bonded
5 fiber-reinforced composite layers and metal sheets. More particularly, the invention
relates to a fiber-metal laminate comprising mutually bonded fiber-reinforced composite
layers and metal sheets having an optimal configuration.

BACKGROUND OF THE INVENTION

10 The behavior of engineering structures under load is determined by many design
parameters, and defining the optimum material for a specific application is often a
tedious task and moreover has to deal with conflicting requirements. Among the
commonly used engineering materials are metals, like steel alloys, titanium alloys,
aluminum alloys; fiber-reinforced composites, like glass fiber composites, carbon fiber
15 composites, and aramid composites; and hybrid materials, further defined below.

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

Fiber-metal laminates (also referred to as FML), such as those described in US
25 4,500,589 for instance are obtained by stacking alternating sheets of metal (most
preferably aluminum) and fiber-reinforced prepregs, and curing the stack under heat and
pressure. These materials are increasingly used in industries such as the transportation
industry, for example in ships, cars, trains, aircraft and spacecraft. They can be used as
sheets and/or a reinforcing element and/or as a stiffener for (body) structures of these
30 transports, like for aircraft for wings, fuselage and tail panels and/or other skin panels
and structural elements of aircraft.

Although fiber-metal laminates may provide improved resistance to fatigue (in
particular crack propagation) over metal alloys, in particular aluminum alloys, their

behavior in a structure is still open for improvement, in particular in structures that are subject to dynamic loadings. An important characteristic in this respect is resistance to crack growth. It would be highly desirable if the right metal sheets and fiber-reinforced composite layers could be identified in terms of their properties in view of achieving the lowest crack growth rate of the corresponding fiber-metal laminate.

It is an object of the invention to provide a fiber-metal laminate comprising mutually bonded fiber-reinforced composite layers and metal sheets with an optimal structural response in dynamic loading, in particular with the lowest crack growth rate.

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SUMMARY OF THE INVENTION

According to one aspect of the present invention there is provided a fiber-metal laminate comprising mutually bonded fiber-reinforced composite layers and metal sheets having a range of fiber and metal properties that yield an optimal structural response.

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In accordance with the present invention, a fiber-metal laminate of mutually bonded fiber-reinforced composite layers and metal sheets is provided, the laminate comprising a combination of a fiber-reinforced composite layer and an adjacent metal sheet, for which combination the following relations are satisfied:

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$$E_{\text{lam}} * E_{\text{comp}} / (E_{\text{metal}} * t_{\text{metal}}^2) = a * (V_f - c)^{b / (V_f - c)} \quad (1)$$

$$c \leq V_f \leq 0.57 \quad (2)$$

$$0 < E_{\text{lam}} * E_{\text{comp}} / (E_{\text{metal}} * t_{\text{metal}}^2) \leq 500 \text{ kN/mm}^4 \quad (3)$$

25

wherein $a = 1200 \text{ kN/mm}^4$; $0.36 \leq b \leq 0.88$; and $0 \leq c \leq 0.3$; and

E_{lam} = tensile Young's modulus of the total fiber-metal laminate in kN/mm^2

E_{comp} = tensile Young's modulus of the fiber-reinforced composite layer in kN/mm^2 in the combination

E_{metal} = tensile Young's modulus of the metal sheet in kN/mm^2 in the combination

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t_{metal} = thickness of the metal sheet in mm in the combination

V_f = fiber volume fraction of the fiber-reinforced composite layer in the combination

The relations (1) to (3) define the optimum properties of a fiber-reinforced composite layer (these properties depend on the fiber-volume fraction of the layer) and the properties of a metal sheet adjacent to said fiber-reinforced composite layer in terms of fatigue resistance of the fiber-metal laminate. Combinations of V_f and t_{metal} that satisfy relations (1) to (3) yield a maximum number of fatigue life cycles in a fatigue test.

It is sufficient when in a fiber-metal laminate only one fiber-composite layer and one metal sheet adjacent to it satisfy the relations (1) to (3). There is no need therefore that all metal sheets have a thickness that satisfies relation (1) nor that all fiber-reinforced composite layers satisfy relations (1) to (3). In an embodiment of a fiber-metal laminate according to the invention however, the properties in any combination of a fiber-reinforced composite layer and an adjacent metal sheet satisfy the relations (1) to (3).

Another embodiment of the fiber-metal laminate according to the invention is characterized in that the properties in a combination of a fiber-reinforced composite layer and two adjacent metal sheets of different thickness, the thickest of the two adjacent metal sheets satisfy the relations (1) to (3).

Another preferred embodiment of the fiber-metal laminate is one that satisfies $0 < E_{\text{lam}} * E_{\text{comp}} / (E_{\text{metal}} * t_{\text{metal}}^2) \leq 400 \text{ kN/mm}^4$, and more preferred satisfies $0 < E_{\text{lam}} * E_{\text{comp}} / (E_{\text{metal}} * t_{\text{metal}}^2) \leq 300 \text{ kN/mm}^4$.

A fiber-reinforced composite layer in the laminate of the invention is defined to be a layer that extends from one metal sheet to another (or to an end surface of the laminate). Such a layer may comprise one or more composite lamina, in which latter case the laminae are stacked to form the layer. The fiber-reinforced composite layers or laminae preferably comprise fibers in substantially one direction (so-called unidirectional or UD composites) although layers or laminae may also be used that comprise oriented woven fabrics, i.e. fabrics with fibers oriented predominantly in one direction, cross-pplies, having reinforcing fibers running in mutually perpendicular directions, angle plies, having fibers running in directions that differ from the main loading direction, and any combination thereof. The use of standard woven fabrics in the fiber-reinforced layers is also possible but less preferred.

The invention further relates to a method for obtaining the metal sheet thickness and fiber volume fraction of the fiber-reinforced composite layers in a fiber-metal laminate comprising mutually bonded fiber-reinforced composite layers and metal sheets in order to obtain optimum fatigue properties of the fiber-metal laminate, the method comprising selecting a combination of a fiber-reinforced composite layer and an adjacent metal sheet, selecting one of the metal sheet thickness or fiber volume fraction, and calculating the corresponding fiber volume fraction or metal sheet thickness that satisfies the above described relations (1) to (3). Laminates according to the invention use a fiber composite-metal combination that satisfies the relations (1) to (3), and such configurations may be obtained by first selecting a metal and a fiber reinforced composite and determining the tensile Young's modulus at room temperature of both, assuming a starting value for the fiber volume fraction V_f of the fiber reinforced composite, taking into account relation (2). A starting value for the thickness of the metal sheets t_{metal} or for the fiber volume fraction V_f is then selected and checked against Eq. (1) and (3). Please note that the thickness of the metal sheets t_{metal} and the fiber volume fraction V_f of the composite layer are both needed to calculate the tensile Young's modulus E_{lam} of the fiber-metal laminate. The selection of starting values for t_{metal} and V_f is aided by the notion that as metal sheet thickness increases V_f should generally decrease and vice versa to simultaneously satisfy the Eq. (1) to (3).

Preferred embodiments of the method are given in the appended claims.

A fiber-metal laminate satisfying the relations (1) to (3) shows optimal properties, by which is meant a lower crack growth rate than fiber reinforced laminates that do not satisfy the relations (1) to (3). This teaching has not been disclosed before and the combination of metal sheet thickness and composite fiber volume fraction that offers the lowest crack growth rate can now be determined.

To obtain a robust fiber-metal laminate according to the invention, a fiber-metal laminate according to the invention wherein $a = 1200 \text{ kN/mm}^4$; $0.36 \leq b \leq 0.88$; $0 \leq c \leq 0.3$ is preferred. A fiber-metal laminate in accordance with this embodiment not only exhibits a high resistance against crack growth but also achieves high stiffness, which is for instance important for performance in compression and for aero-elastic performance.

- Compared to engineered composites, laminates according to the invention are, hardly sensitive to compression after impact degradation (quite often even better than its metal ingredient) and therefore can be designed with a substantial higher strain to failure than for fiber composite structures. Furthermore, combining the fibrous composite layers and the metal sheets with properties that satisfy equations (1) to (3) results in general in a fiber-metal laminate with a higher stiffness than the corresponding metal sheets above their proportionality limit, and consequently will have increased yield strength.
- 5 In another embodiment of the invention a fiber-metal laminate is provided wherein the fiber volume fraction of the fiber-reinforced composite layers satisfies $V_f < 0.54$. This is quite in contrast with the general teaching that fiber-composite properties improve with increasing fiber volume fraction and therefore V_f should be as high as possible.
- 10 An embodiment of the fiber-metal laminate according to the invention wherein the fiber volume fraction of the fiber-reinforced composite layers satisfies $0.25 < V_f < 0.54$ is particularly preferred. Even more preferred is a fiber-metal laminate wherein the fiber volume fraction of the fiber-reinforced composite layers satisfies $0.30 \leq V_f \leq 0.50$.
- 15 According to a further aspect of the invention a fiber-metal laminate is provided comprising a number of n mutually bonded and alternating fiber-reinforced composite layers and metal sheets. Preferred laminates comprise one or both outer layers of metal, or one or both outer layers of a fiber-reinforced composite. Particularly preferred is a three-layer fiber-metal laminate comprising two metal sheets and one fiber-reinforced composite layer, or, alternatively, one metal sheet and two fiber-reinforced composite layers.
- 20
- 25

- Although the thickness of the metal sheets in the fiber-metal laminate of the invention may all be the same, according to an embodiment of the invention, a fiber-metal laminate is provided comprising metal sheets of different thicknesses whereby one or more of the metal sheets satisfies the relationships (1) to (3). A further embodiment of the invention provides a fiber-metal laminate, comprising metal sheets of different metal alloys. In accordance with another embodiment however, a fiber-metal laminate may be provided that comprises metal sheets of the same metal alloy.
- 30

In another aspect of the invention, a fiber-metal laminate is provided comprising fiber-reinforced composite layers of different thicknesses whereby one or more of the fiber-reinforced composite layers satisfies the relations (1) to (3). A preferred embodiment is
 5 one in which at least one of the fiber reinforced composite layers adjacent to the thickest metal layer fulfills the requirements of relations (1) to (3) together with said thickest metal layer. A fiber-metal laminate, comprising fiber-reinforced composite layers of different thicknesses between metal layers provides another useful embodiment.

10 The thickness of the metal sheet or sheets may be chosen within a large range as long as relations (1) to (3) are satisfied. A preferred embodiment of the fiber-metal laminates according to the invention comprises metal sheets having a thickness of below 4 mm, since the effects of the invention are most apparent below this threshold value. Even more preferred is an embodiment of the fiber-metal laminate wherein the thickness of
 15 the metal sheets is below 2 mm.

In another aspect of the invention, a fiber-metal laminate is provided wherein the fibers in the fiber-reinforced composite layers extend in at least two mutually different directions and the thickness of the metal sheets is below 1.5 mm.

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In another aspect of the invention, a fiber-metal laminate is provided wherein the thickness of the metal sheets ranges between 0.3 and 4 mm, more preferably between 0.5 and 2 mm, and most preferably between 0.6 and 1.5 mm.

25 Still another embodiment in accordance with the invention provides a fiber-metal laminate wherein the fiber volume fraction of the fiber-reinforced composite layers satisfies $0.25 \leq V_f < 0.54$ and the thickness of the metal sheets is below 2 mm. Even more preferred is a fiber-metal laminate wherein the fiber volume fraction of the fiber-reinforced composite layers satisfies $0.35 \leq V_f < 0.54$ and the thickness of the metal
 30 sheets is below 1.2 mm.

Although the metal of the metal sheets in the fiber-metal laminate may be chosen at will, in still another aspect of the invention, a fiber-metal laminate is provided wherein

the metal of the metal sheets is selected from steel alloys, aluminum alloys, and titanium alloys, whereby titanium alloys are particularly useful.

5 In a further preferred embodiment of the invention, a fiber-metal laminate is provided wherein the fiber-reinforced composite layers comprise glass, aramid, PBO, copolymer or carbon fibers, or combinations thereof. The fiber reinforced composite layers may comprise substantially continuous fibers that extend mainly in one direction and/or may comprise substantially continuous fibers that extend mainly in two perpendicular directions, such as in a woven fabric or a cross ply in either $0^0/90^0$ and/or under angles
10 with respect the 0^0 direction, like for instance $+45^0/-45^0$ form.

A particularly preferred fiber-metal laminate according to the invention comprises a flat or curved doubler and an aluminum-lithium skin for a fuselage, wing or tailplane.

15 In yet another aspect of the invention, an assembly of a fiber-metal laminate according to anyone of the preceding claims and a further element, the further element being connected to the fiber-metal laminate by a bonding layer, comprising an adhesive and/or a fiber-reinforced composite, or being connected by mechanical fastening means. The further element preferably comprises a structural element and/or combinations of structural elements selected from a stiffener, such as an angle section, Z-stringer, hat
20 stringer, C-stringer, Y-stringer; a spar(section), rib(section), shear-cleat and/or frame(section) of an aircraft structure.

In another aspect of the invention, the further element comprises a flat or tapered plate made from a metal, such as an aluminum alloy, titanium alloy and/or steel alloy and/or a
25 combination of metal sheets and composite layers.

In still another aspect of the invention, an assembly of a fiber-metal laminate and a further element connected thereto is provided wherein the further element comprises at least one structural element selected from a stiffener, such as an angle section, Z-
30 stringer, hat stringer, C-stringer, Y-stringer; a spar (section), rib (section), shear-cleat and/or frame (section) of an aircraft structure, or a combination thereof.

Still another aspect of the invention provides the use of such an assembly in providing a fatigue resistant structure.

BRIEF DESCRIPTION OF THE FIGURES

- Figure 1 – is a view in perspective of a fiber-metal laminate according to an
5 embodiment of the present invention;
Figure 2 - is a view in perspective of a fiber-metal laminate according to another
embodiment of the present invention;
Figures 3-7 – illustrate the relationship between fatigue life and fiber volume fraction of
the fiber-reinforced composite layers in several embodiments of the fiber-reinforced
10 laminate according to the invention;
Figure 8 - illustrates the relationship between the parameters of claim 1 and fiber
volume fraction of the fiber-reinforced composite layers for several embodiments of the
fiber-reinforced laminate according to the invention; and
Figure 9 - illustrates the relationship between the parameters of claim 2 and fiber
15 volume fraction of the fiber-reinforced composite layers for several other embodiments
of the fiber-reinforced laminate according to the invention.

DETAILED DESCRIPTION OF THE INVENTION

- In the following description, reference is made to the accompanying drawings, which
20 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.
- 25 The basis of the present invention is a unique arrangement of fiber-reinforced composite
layers and at least one metal sheet. In accordance with the invention a fiber-metal
laminate is provided comprising fiber-reinforced composite layers and metal sheets,
wherein the fiber properties relate to the metal sheet properties in a specific manner, as
given by equations (1) to (3). The fiber-reinforced composite layers preferably comprise
30 fibers pre-impregnated with a composite matrix system, preferably a metal adhesive
(prepreg). The system of composite layers and metal sheets is preferably processed
under heat and pressure to cure the adhesive and form a solid panel or component.

It has been discovered by the inventors that fiber-metal laminates with fiber properties according to equations (1) to (3) have better structural properties in fatigue, in particular a higher resistance against crack growth than fiber-metal laminates of which the relevant properties are not in accordance with relations (1) to (3). The parameters used
 5 in equations (1) to (3) are well known to the person skilled in the art and this person will have no difficulty in determining the properties mentioned. The invention is based on the insight that metal sheet thickness and fiber volume fraction of the fiber-reinforced composite layers are related in view of obtaining a high crack growth resistance.

10 The relation between the fiber volume fraction of the fiber-metal laminate and the stiffness and thickness of the metal sheets (equation (1)) in accordance with the invention is graphically shown in figure 8 for values of $a = 1200 \text{ kN/mm}^4$; $0.36 \leq b \leq 0.88$; $0 \leq c \leq 0.3$. Fiber-metal laminates according to several embodiments of the invention use fiber reinforced layers with a fiber volume fraction at and below 0.57, i.e.
 15 at and below the line 19 and between the lines 51 and 50.

Figure 9 graphically shows the relation between the fiber volume fraction of the fiber-metal laminate and the stiffness and thickness of the metal sheets (equation (1)) in accordance with another embodiment wherein $a = 1200 \text{ kN/mm}^4$; $0.41 \leq b \leq 0.85$; 0.02
 20 $\leq c \leq 0.26$. Fiber-metal laminates according to several embodiments of the invention use fiber reinforced layers with a fiber volume fraction at and below 0.57, i.e. at and below the line 19 and between the lines 53 and 52.

The fiber-reinforced composite layers in the fiber-metal laminates according to the
 25 invention are light and strong and comprise reinforcing fibers embedded in a polymer. The polymer may also act as a bonding means between the various layers. Reinforcing fibers that are suitable for use in the fiber-reinforced composite layers depend on the choice of metal in the metal sheets (see equations (1) to (3)) but may include glass fibers, aramid fibers, PBO fibers, carbon fibers, copolymer fibres and metal fibers
 30 and/or combinations of the above fibers. Preferred fibers include reinforcing fibers with a relatively high tensile strength and/or stiffness, of which class high modulus fibers, such as carbon fibers, are particularly preferred. Preferred reinforcing fibers include copolymer fibers, such as those known as Copol® fibers and available from Tejin.

Examples of suitable matrix materials for the reinforcing fibers include but are not limited to thermoplastic polymers such as polyamides, polyimides, polyethersulphones, polyetheretherketone, polyurethanes, polyphenylene sulphides (PPS), polyamide-imides, polycarbonate, polyphenylene oxide blend (PPO), as well as mixtures and
5 copolymers of one or more of the above polymers. Suitable matrix materials also comprise thermosetting polymers such as epoxies, unsaturated polyester resins, melamine/formaldehyde resins, phenol/formaldehyde resins, polyurethanes, of which thermosetting polymers epoxies are most preferred. In accordance with the invention, the fibrous composites comprise equal or less than 57% by volume of fibers.

10

In the laminate according to the invention, the fiber-reinforced composite layer preferably comprises substantially continuous fibers that extend in multiple direction (like 0^0 , 90^0 and angles with respect to 0^0) and more preferable in two almost orthogonal directions (for instance isotropic woven fabrics or cross plies). However it is even more
15 preferable for the fiber-reinforced composite layer to comprise substantially continuous fibers that mainly extend in one direction (so called UD material). It is advantageous to use the fiber-reinforced composite layer in the form of a pre-impregnated semi-finished product. Such a "prepreg" shows generally good mechanical properties after curing thereof, among other reasons because the fibers have already been wetted in advance by
20 the matrix polymer.

Fiber-metal laminates may be obtained by connecting a number of metal sheets and fiber-reinforced composite layers to each other by means of heating under pressure and subsequent cooling. The fiber-metal laminates of the invention have good specific
25 mechanical properties (properties per unit of density). Metals that are particularly appropriate to use include steel (alloys) and light metals, such as aluminum alloys and in particular titanium alloys. Suitable aluminum alloys are based on alloying elements such as copper, zinc, magnesium, silicon, manganese, and lithium. Small quantities of chromium, titanium, scandium, zirconium, lead, bismuth and nickel may also be added,
30 as well as iron. Suitable aluminum alloys include aluminum copper alloys (2xxx series), aluminum magnesium alloys (5xxx series), aluminum silicon magnesium alloys (6xxx series), aluminum zinc magnesium alloys (7xxx series), aluminum lithium alloys (8xxx series), as well as aluminum magnesium scandium alloys. Suitable titanium alloys include but are not limited to alloys comprising Ti-15V-3Cr-3Al-3Sn, Ti-15Mo-3Al-

3Nb, Ti-3Al-8V-6Cr-4Zr-4Mo, Ti-13V-11Cr-3Al, Ti-6Al-4V and Ti-6Al-4V-2Sn. In other respects, the invention is not restricted to laminates using these metals, so that if desired other metals, for example steel or another suitable structural metal can be used. The laminate of the invention may also comprise metal sheets of different alloys.

5

A fiber-metal laminate according to the invention will generally be formed by a number of metal sheets and a number of fiber-reinforced composite layers, with the proviso that the properties of the fiber-reinforced composite layers and of the metal sheets satisfy equations (1) to (3).

10

The outer layers of the fiber-metal laminate may comprise metal sheets and/or fiber-reinforced composite layers. The number of metal layers may be varied over a large range and is at least one. In a particularly preferred fiber-metal laminate, the number of metal layers is two, three or four, between each of which fiber-reinforced composite layers have preferably been applied. Depending on the intended use and requirements set, the optimum number of metal sheets can easily be determined by the person skilled in the art. The total number of metal sheets will generally not exceed 40, although the invention is not restricted to laminates with a maximum number of metal layers such as this. According to the invention, the number of metal sheets is preferably between 1 and 30, and more preferably between 1 and 10, with the metal sheets preferably having a tensile ultimate strength of at least 0.25 GPa.

20

To prevent the laminate from warping as a result of internal tensions, the laminate according to the invention can be structured symmetrically with respect to a plane through the center of the thickness of the laminate.

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Fiber-metal laminate configurations according to the invention are readily obtained by arranging (alternating) layers of fiber-reinforced composite, preferably in the form of prepregs, and at least one metal sheet. The fiber-metal laminates can be designed in many different arrangements.

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With reference to figure 1, a fiber-metal laminate according to one embodiment is shown, wherein the total number of layers is 3, and wherein layer 1 and layer 3 comprise a metal layer and layer 2 a fibrous composite layer. Alternatively, layer 1 and

layer 3 comprise a fibrous composite layer and layer 2 is a metal layer. Layer 1 and layer 3 can comprise the same metal or may be a different kind of metal. The fibrous composite layer(s) may contain fibers in multiple directions as well as different kind of fibers for which at least one of the fiber types in at least one of the fibrous composite layer(s) fulfills the requirements set in equations (1) to (3).

With reference to figure 2, a fiber-metal laminate according to another embodiment is shown, wherein the total number of layers is n , and wherein layer 1 is a metal layer and layer 2 is a fibrous composite layer, which will be alternating until layer $n-1$ and layer n .

Alternatively, layer 1 is a fibrous composite layer and layer 2 is a metal layer, which will be alternating until layer $n-1$ and layer n . The alternating metal layers can be of the same metal or be a different kind of metal, and can have different thicknesses. Also, at least one of the alternating fibrous composite layers may contain fibers in multiple directions as well as different kind of fibers, for which at least one of the fiber types in at least one of the fibrous composite layer fulfills the requirements set in equations (1) to (3) with respect to the adjacent metal layer, preferably with the largest metal thickness. According to the invention, at least one combination of a fiber-reinforced composite layer (for instance layer 2) and an adjacent metal sheet (for instance layer 1 or 3) needs to satisfy relations (1) to (3) in which E_{lam} corresponds to the tensile Young's modulus in kN/mm^2 of the total fiber-metal laminate comprising all layers 1, 2, ..., $n-1$, n . In case metal layers (1) and (3) differ in thickness, the thickest metal layer is preferably selected in the combination. In case the outer layer of the laminate is a fibrous composite layer, this layer preferably needs to fulfill the requirements set in equations (1) to (3) with respect to its adjacent metal layer, unless another metal layer with its adjacent fibers composite layer already fulfills the requirements. If the outer layer is metal, it preferably needs to fulfill the requirements set in equations (1) to (3) with respect to its adjacent fibrous composite layer, unless another metal layer with its adjacent fibrous composite layer already fulfills the requirements.

The laminates are produced by preparing a stack of fibrous composite and metal sheets in the sequence as exemplified in figures 1 and 2, for example on a flat or single, double or multiple curved mold. After lamination, the overall structure is cured at a temperature suitable for the matrix resin, preferably an epoxy resin, for instance in an autoclave, and preferably under vacuum in order to expel entrapped air from the laminate. For most

applications, an epoxy resin with a high glass transition temperature will be most suitable. Any epoxy resin may be used however. Epoxy resins are generally cured at or slightly above room temperature, at a temperature of approximately 125°C or at a temperature of approximately 175°C. After curing under pressure a consolidated laminate is obtained. As mentioned above, it is also possible to use a thermoplastic resin.

EXAMPLES AND COMPARATIVE EXAMPLES

The invention will be illustrated by several Examples. The Examples are if appropriate compared to known laminates, i.e. laminates falling outside the area bound by lines “Upper band” and “Lower band” in figures 8 or figure 9.

The investigated laminates are referred to as:

FML-G-A-UD-4/3: a S2 glass fiber reinforced FML having unidirectional fibers in the fiber-reinforced composite layers oriented in the load direction and an aluminum 2024-T3 alloy as metal in the metal sheets;

FML-C-A-UD-4/3: a high strength carbon fiber reinforced FML having unidirectional fibers in the fiber-reinforced composite layers oriented in the load direction and an aluminum 2024-T3 alloy as metal in the metal sheets;

FML-C-T-UD-4/3: a high strength (HS) carbon fiber reinforced FML having unidirectional fibers in the fiber-reinforced composite layers oriented in the load direction and a titanium Ti-6Al-4V alloy as metal in the metal sheets;

FML-I-T-UD-4/3: an intermediate modulus (IM) fiber (with stiffness in between high performance glass fibers and high modulus carbon fibers) reinforced FML having unidirectional fibers in the fiber-reinforced composite layers oriented in the load direction and a titanium Ti-6Al-4V alloy as metal in the metal sheets; and

FML-G-A-CP-4/3: a S2 glass fiber reinforced FML having cross plies in the fiber-reinforced composite layers mainly oriented in the metal rolling direction and an aluminum 2024-T3 alloy as metal in the metal sheets.

All analyzed laminates comprise 4 metal sheets and 3 fiber-reinforced composite layers interspersed with the metal sheets. To be able to compare correctly, each grade of laminate (i.e. having the same metal and fibers) with the same metal thickness has the

same weight and a running load corresponding with a stress of 100 MPa taken at $V_f = 0.57$.

5 An analysis method was developed based on numerous fatigue tests for specimens with a starter notch of 5 mm whereby fatigue life was defined as the number of cycles needed to obtain a metal crack length of 20 mm.

Results are provided in figures 3-7 for all laminates at different metal sheet thicknesses and fiber volume fraction in the fiber-reinforced layers.

10

Figure 3 shows the notched fatigue life 10 in terms of the number of dynamic loading cycles against the fiber volume fraction 20 for a FML-G-A-UD-4/3 FML with different metal sheet thicknesses. The curves 11, 12, 13, 14, 15, 16, 17 and 18 are for metal sheet thicknesses of 0.4 mm, 0.5 mm, 0.6 mm, 0.8 mm, 1.0 mm, 1.5 mm, 2.0 mm and 4.0 mm 15 respectively. Line 19 corresponds to $V_f = 0.57$.

Figure 4 shows the notched fatigue life 10 in terms of the number of dynamic loading cycles against the fiber volume fraction 20 for a FML-C-A-UD-4/3 FML with different metal sheet thicknesses. The curves 21, 22, 23, 24, 25 and 26 are for metal sheet 20 thicknesses of 0.6 mm, 0.8 mm, 1.0 mm, 1.5 mm, 2.0 mm and 4.0 mm respectively. Line 19 corresponds to $V_f = 0.57$.

Figure 5 shows the notched fatigue life 10 in terms of the number of dynamic loading cycles against the fiber volume fraction 20 for a FML-C-T-UD-4/3 FML with different 25 metal sheet thicknesses. The curves 31, 32, 33, 34 and 35 are for metal sheet thicknesses of 0.8 mm, 0.9 mm, 1.0 mm, 2.0 mm and 2.0 mm respectively. Line 19 corresponds to $V_f = 0.57$.

Figure 6 shows the notched fatigue life 10 in terms of the number of dynamic loading 30 cycles against the fiber volume fraction 20 for a FML-I-T-UD-4/3 FML with different metal sheet thicknesses. The curves 41, 42, 43, 44, 45 and 46 are for metal sheet thicknesses of 0.6 mm, 0.7 mm, 0.8 mm, 1.0 mm, 1.5 mm and 2.0 mm respectively. Line 19 corresponds to $V_f = 0.57$.

Figure 7 finally shows the notched fatigue life 10 in terms of the number of dynamic loading cycles against the fiber volume fraction 20 for a FML-G-A-CP-4/3 FML with different metal sheet thicknesses. The curves 51, 52, 53 and 54 are for metal sheet thicknesses of 0.3 mm, 0.5 mm, 0.8 mm and 1.5 mm respectively. Line 19 corresponds to $V_f = 0.57$.

All results show an optimum V_f for each metal sheet thickness, whereby the optimum shifts to lower V_f for FML with thicker metal sheets. The optimum corresponds to the maximum value of the number of fatigue life (cycles) 10.

10

The FML showing a maximum value of fatigue life (the maxima in figures 3-7) were selected and grouped in figures 8 and 9. These figures show the parameter $60 = E_{\text{lam}} * E_{\text{comp}} / (E_{\text{metal}} * t_{\text{metal}}^2)$ in kN/mm^4 against the fiber volume fraction 20. These figures also graphically represent relations (1) to (3) whereby dotted line 50 and 51 in figure 8 represents resp. the upper and lower band of relation (1), corresponding to 90% of the maximum fatigue performances of the laminates. Dotted lines 50 and 51 represent the boundaries defined by claim 1. Figure 9 represents a tighter upper and lower band of relation (1) i.e. resp. dotted line 52 and 53, corresponding to 95% of the maximum fatigue performances of laminates Dotted lines 52 and 53 represent the boundaries defined by claim 2.

20

Optimum fiber-metal laminates, i.e. FML having the highest crack resistance under dynamic loading are all situated within the boundaries defines by dotted lines 50, 51 and line 19, which represents relation (2). Preferred embodiments as defined in claim 2 are all situated within the boundaries defines by dotted lines 52, 53 and line 19. Non-optimum fiber-metal laminates which are outside the scope of the present invention fall outside the area bound by dotted lines 50, 51 (or 52, 53) and line 19.

25

Conclusies

1. Een vezelmetaallaminaat van onderling verbonden vezelversterkte composietlagen en metaalplaten, het laminaat omvattende een samenstel van een vezelversterkte composietlaag en een aangrenzende metaalplaat, waarbij de eigenschappen in het samenstel voldoen aan de volgende relaties:

$$E_{\text{lam}} * E_{\text{comp}} / (E_{\text{metaal}} * t_{\text{metaal}}^2) = a * (V_f - c)^{(b / (V_f - c))} \quad (1)$$

$$c \leq V_f \leq 0.57 \quad (2)$$

$$0 < E_{\text{lam}} * E_{\text{comp}} / (E_{\text{metaal}} * t_{\text{metaal}}^2) \leq 500 \text{ kN/mm}^4 \quad (3)$$

waarin $a = 1200 \text{ kN/mm}^4$; $0.36 \leq b \leq 0.88$; $0 \leq c \leq 0.3$; en

E_{lam} = elasticiteitsmodulus in trek van het totale vezelmetaallaminaat in kN/mm^2

E_{comp} = elasticiteitsmodulus in trek van de vezelversterkte composietlaag in kN/mm^2

in het samenstel

E_{metaal} = elasticiteitsmodulus in trek van de metaalplaat in kN/mm^2 in het samenstel

t_{metaal} = dikte van de metaalplaat in mm in het samenstel

V_f = vezelvolumefractie van de vezelversterkte composietlaag in het samenstel

2. Vezelmetaallaminaat volgens conclusie 1, waarin $a = 1200 \text{ kN/mm}^4$; $0.41 \leq b \leq 0.85$; $0.02 \leq c \leq 0.26$.

3. Vezelmetaallaminaat volgens conclusie 1 of 2, waarbij de eigenschappen in elk samenstel van een vezelversterkte composietlaag en een aangrenzende metaalplaat voldoen aan relaties (1) tot (3).

4. Vezelmetaallaminaat volgens één van de voorgaande conclusies, waarbij de eigenschappen in een samenstel van een vezelversterkte composietlaag en de dikste van twee aangrenzende metalen platen voldoen aan relaties (1) tot (3).

5. Vezelmetaallaminaat volgens één van de voorgaande conclusies, waarbij de vezelvolumefractie van de vezelversterkte composietlaag voldoet aan $V_f < 0.54$.

6. Vezelmetaallaminaat volgens één van de voorgaande conclusies, waarbij de
vezelvolumefractie van de vezelversterkte composietlaag voldoet aan $0.25 \leq V_f < 0.54$,
en met meer voorkeur aan $0.30 \leq V_f < 0.50$.
- 5 7. Vezelmetaallaminaat volgens één van de voorgaande conclusies, omvattende
metaalplaten van verschillende diktes.
8. Vezelmetaallaminaat volgens één van de voorgaande conclusies, omvattende
metaalplaten van verschillende metaallegeringen.
- 10 9. Vezelmetaallaminaat volgens één van de voorgaande conclusies, omvattende
metaalplaten van dezelfde metaallegering.
10. Vezelmetaallaminaat volgens één van de voorgaande conclusies, omvattende
15 vezelversterkte composietlagen van verschillende diktes, en/of omvattende een
vezelversterkte composietlaag met ten minste twee verschillende vezels, en/of
omvattende vezelversterkte composietlagen die verschillen in vezel.
11. Vezelmetaallaminaat volgens één van de voorgaande conclusies, waarbij de
20 dikte van de metaalplaten lager is dan 4 mm.
12. Vezelmetaallaminaat volgens conclusie 11, waarbij de dikte van de metaalplaten
lager is dan 2 mm, bij voorkeur begrepen is tussen 0.6 en 1.5 mm.
13. Vezelmetaallaminaat volgens één van de voorgaande conclusies, waarbij de
25 vezels in de vezelversterkte composietlagen zich uitstrekken in meerdere verschillende
richtingen.
14. Vezelmetaallaminaat volgens conclusie 13, waarbij de vezels in de
30 vezelversterkte composietlagen zich uitstrekken in ten minste twee onderling
verschillende richtingen.

15. Vezelmetaallaminaat volgens één van de voorgaande conclusies, waarbij de vezelversterkte composietlagen in hoofdzaak continue vezels omvatten die zich hoofdzakelijk in één richting uitstrekken.
- 5 16. Vezelmetaallaminaat volgens één van de voorgaande conclusies, waarbij de vezelvolumefractie van de vezelversterkte composietlagen voldoet aan $0.30 \leq V_f < 0.54$ en de dikte van de metaalplaten lager is dan 2 mm.
- 10 17. Vezelmetaallaminaat volgens conclusie 16, waarbij de vezelvolumefractie van de vezelversterkte composietlagen voldoet aan $0.35 \leq V_f < 0.54$ en de dikte van de metaalplaten lager is dan 1.2 mm.
- 15 18. Vezelmetaallaminaat volgens één van de voorgaande conclusies, waarbij het metaal is gekozen uit staallegeringen, aluminiumlegeringen en titaniumlegeringen.
19. Vezelmetaallaminaat volgens één van de voorgaande conclusies, waarbij de vezelversterkte composietlagen glas-, aramide-, PBO-, copolymeer- of koolstofvezels omvatten, of combinaties daarvan.
- 20 20. Vezelmetaallaminaat volgens één van de voorgaande conclusies, waarbij het laminaat een vlakke of gebogen doubler omvat.
21. Vezelmetaallaminaat volgens één van de voorgaande conclusies, waarbij het laminaat een aluminiumlithium huid voor een romp, vleugel of staartstuk omvat.
- 25 22. Samenstel van een vezelmetaallaminaat volgens één van de voorgaande conclusies en een verder element, waarbij het verdere element verbonden is met het vezelmetaallaminaat door een verbindingslaag, die een hechtmiddel en/of een vezelversterkt composiet omvat, of door middel van een mechanisch verankermiddel.
- 30 23. Samenstel volgens conclusie 22 waarbij het verdere element ten minste één structurelement omvat gekozen uit een verstijver, zoals een hoeksectie, Z-spant, hoedspant, C-spant, Y-spant; een rondhout(deel), ribbe(deel), afschuifsteun en/of geraamte(deel) van een vliegtuigconstructie, of een combinatie daarvan.

24. Samenstel volgens conclusie 22, waarbij het verdere element een vlak of taps toelopende metaalplaat omvat uit bijvoorbeeld een aluminiumlegering, titaniumlegering, staallegering, en/of een samenstel van metaalplaten en
5 vezelcomposietlagen.
25. Samenstel volgens conclusie 24, waarbij de vlakke of taps toelopende metaalplaat is verbonden met een verder element, omvattende ten minste één structurelement gekozen uit een verstijving, zoals een hoekdeel, Z-spant, hoedspant,
10 C-spant, Y-spant; een rondhout (deel), ribbe(deel), afschuifsteun en/of geraamte(deel) van een vliegtuigconstructie, of een combinatie daarvan.
26. Gebruik van een samenstel volgens één van de conclusies 20-25 voor het verschaffen van een vermoeiingresistente structuur.
15
27. Werkwijze voor het verkrijgen van de metaalplaatdikte en vezelvolumefractie van de vezelversterkte composietlagen in een vezelmetaallaminaat omvattende onderling verbonden vezelversterkte composietlagen en metaalplaten ten einde optimale vermoeiingseigenschappen van het vezelmetaallaminaat te verkrijgen, de werkwijze
20 omvattende het selecteren van een samenstel van een vezelversterkte composietlaag en een aangrenzende metaalplaat, het selecteren van één uit de metaalplaatdikte of de vezelvolumefractie, en het berekenen van de bijbehorende vezelvolumefractie of metaalplaatdikte die voldoet aan de volgende relaties:
- 25
$$E_{\text{lam}} * E_{\text{comp}} / (E_{\text{metaal}} * t_{\text{metaal}}^2) = a * (V_f - c)^{(b / (V_f - c))} \quad (1)$$
- $$c \leq V_f \leq 0.57 \quad (2)$$
- $$0 < E_{\text{lam}} * E_{\text{comp}} / (E_{\text{metaal}} * t_{\text{metaal}}^2) \leq 500 \text{ kN/mm}^4 \quad (3)$$
- waarin $a = 1200 \text{ kN/mm}^4$; $0.36 \leq b \leq 0.88$; $0 \leq c \leq 0.3$; en
- 30 E_{lam} = elasticiteitsmodulus in trek van het totale vezelmetaallaminaat in kN/mm^2
 E_{comp} = elasticiteitsmodulus in trek van de vezelversterkte composietlaag in kN/mm^2 in het samenstel
 E_{metaal} = elasticiteitsmodulus in trek van de metaalplaat in kN/mm^2 in het samenstel

t_{metaal} = dikte van de metaalplaat in mm in het samenstel

V_f = vezelvolumefractie van de vezelversterkte composietlaag in het samenstel

28. Werkwijze volgens conclusie 27, waarbij $a = 1200 \text{ kN/mm}^4$; $0.41 \leq b \leq 0.85$;
5 $0.02 \leq c \leq 0.26$.

29. Werkwijze volgens conclusies 27 en 28, waarbij de vezelvolumefractie van de vezelversterkte composietlaag voldoet aan $V_f < 0.54$.

- 10 30. Werkwijze volgens één van de conclusies 27-29, waarbij de vezelvolumefractie van de vezelversterkte composietlaag voldoet aan $0.25 \leq V_f < 0.54$.

31. Werkwijze volgens één van de conclusies 27-30, omvattende metaalplaten van verschillende diktes.

15

32. Werkwijze volgens één van de conclusies 27-31, omvattende metaalplaten van verschillende metaallegeringen.

- 20 33. Werkwijze volgens één van de conclusies 27-31, omvattende metaalplaten van dezelfde metaallegering.

34. Werkwijze volgens één van de conclusies 27-33, omvattende vezelversterkte composietlagen van verschillende diktes tussen metaallagen.

- 25 35. Werkwijze volgens één van de conclusies 27-34, waarbij de dikte van de metaalplaten lager is dan 4 mm.

36. Werkwijze volgens conclusie 35, waarbij de dikte van de metaalplaten lager is dan 2 mm.

30

37. Werkwijze volgens conclusie 35, waarbij de vezels in de vezelversterkte composietlagen zich uitstrekken in ten minste twee onderling verschillende richtingen en de dikte van de metaalplaten lager is dan 1.5 mm, bij voorkeur is begrepen tussen 0.6 en 1.5 mm.

38. Werkwijze volgens één van de conclusies 27-37, waarbij de vezels in de vezelversterkte composietlaag zich uitstrekken in meerdere verschillende richtingen.
- 5 39. Werkwijze volgens conclusie 38, waarbij de vezels in de vezelversterkte composietlaag zich uitstrekken in ten minste twee onderling verschillende richtingen.
40. Werkwijze volgens één van de conclusies 27-37, waarbij de vezelversterkte composietlagen voornamelijk continue vezels omvatten die zich hoofdzakelijk in één
10 richting uitstrekken.
41. Werkwijze volgens één van de conclusies 27-40, waarbij de vezelvolumefractie van de vezelversterkte composietlagen voldoet aan $0.30 \leq V_f < 0.54$ en de dikte van de metaalplaten lager is dan 2 mm.
15
42. Werkwijze volgens conclusie 41, waarbij de vezelvolumefractie van de vezelversterkte composietlagen voldoet aan $0.35 \leq V_f < 0.54$ en dat de dikte van de metaalplaten lager is dan 1.2 mm.
- 20 43. Werkwijze volgens één van de conclusies 27-42, waarbij het metaal is gekozen uit metaallegeringen, aluminiumlegeringen en titaniumlegeringen.
44. Werkwijze volgens één van de conclusies 27-43, waarbij de vezelversterkte composietlagen glas-, aramide-, PBO-, copolymeer- of koolstofvezels omvatten, of een
25 combinatie daarvan.

1/8

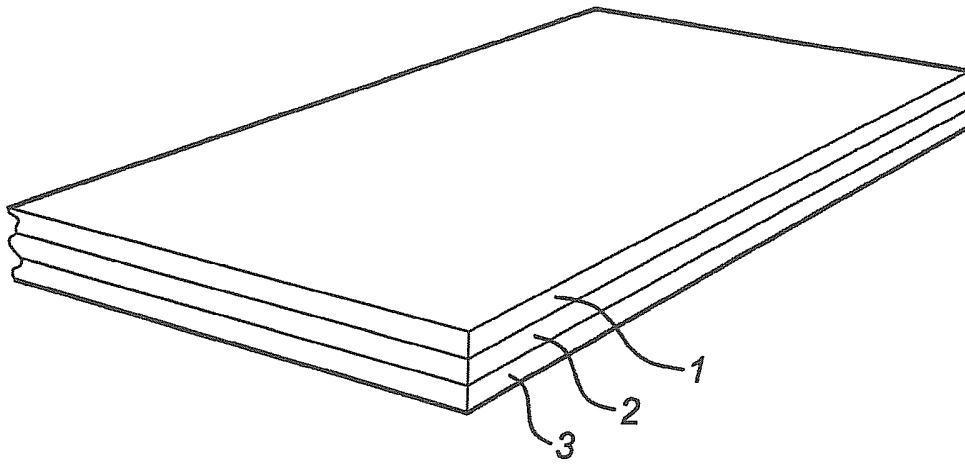


Fig. 1

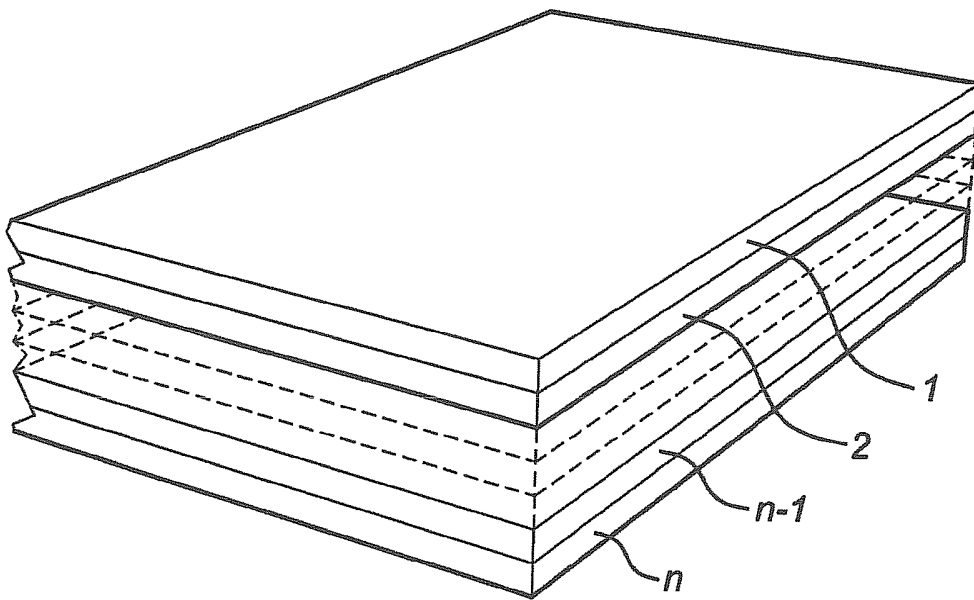


Fig. 2

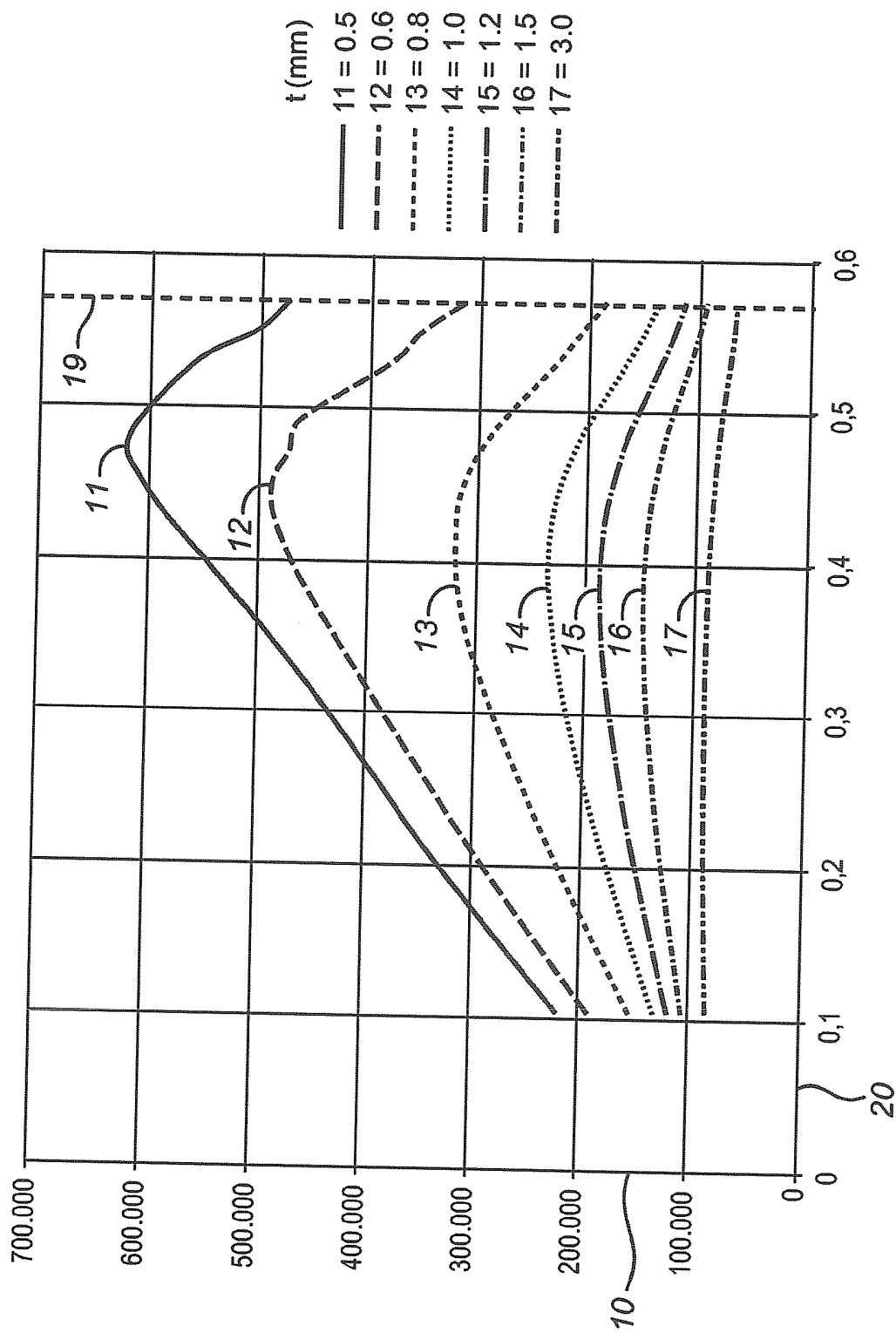


Fig. 3

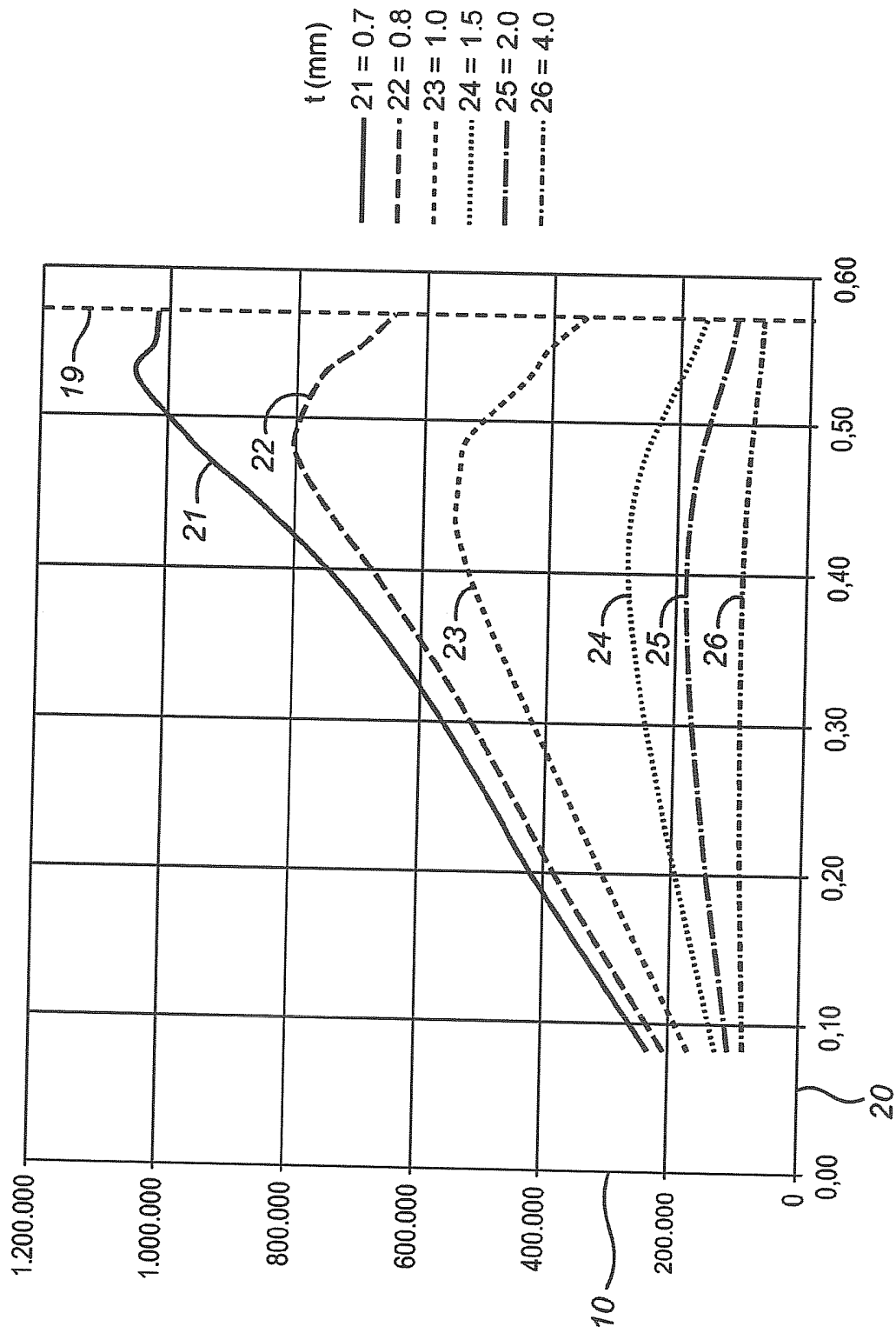


Fig. 4

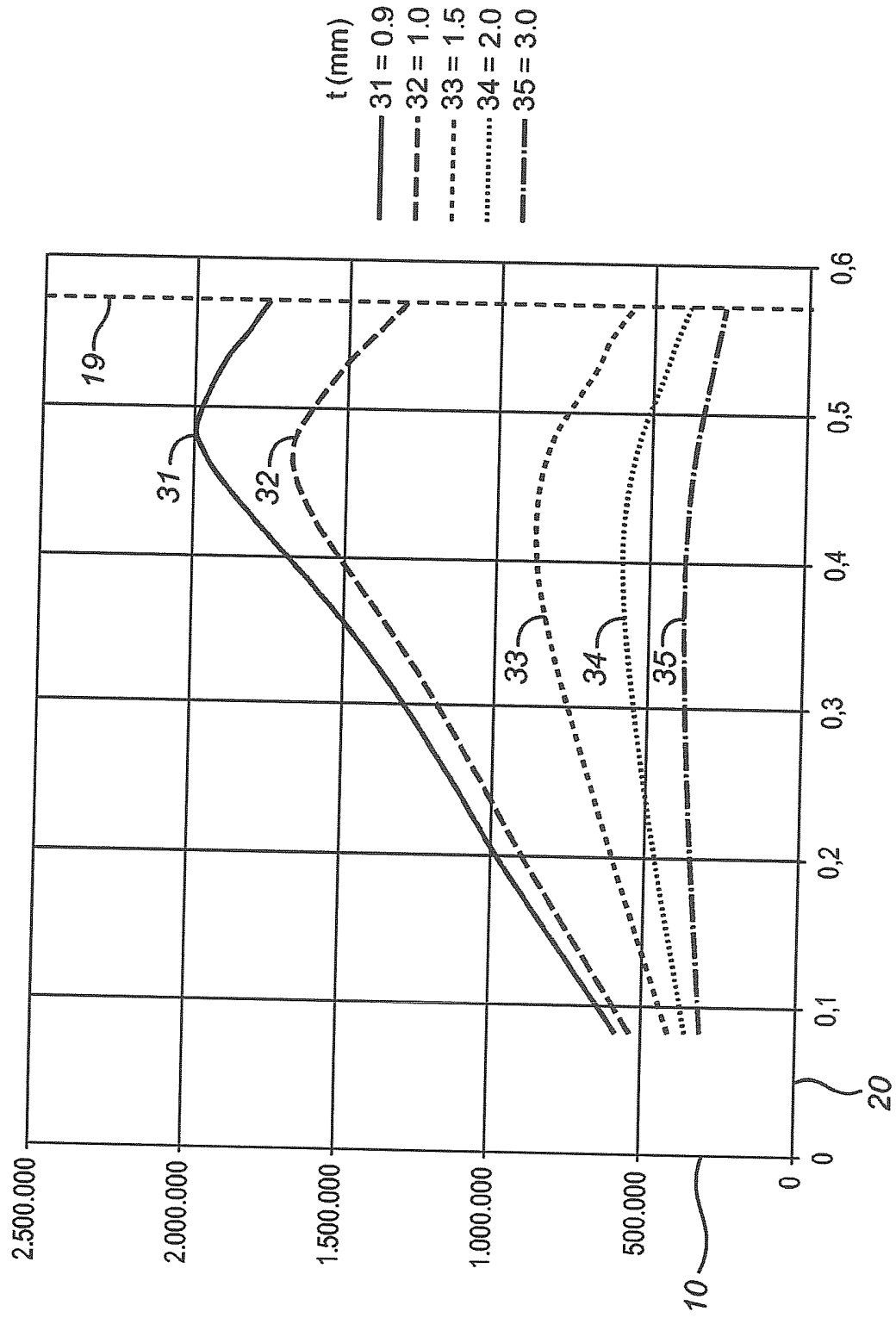


Fig. 5

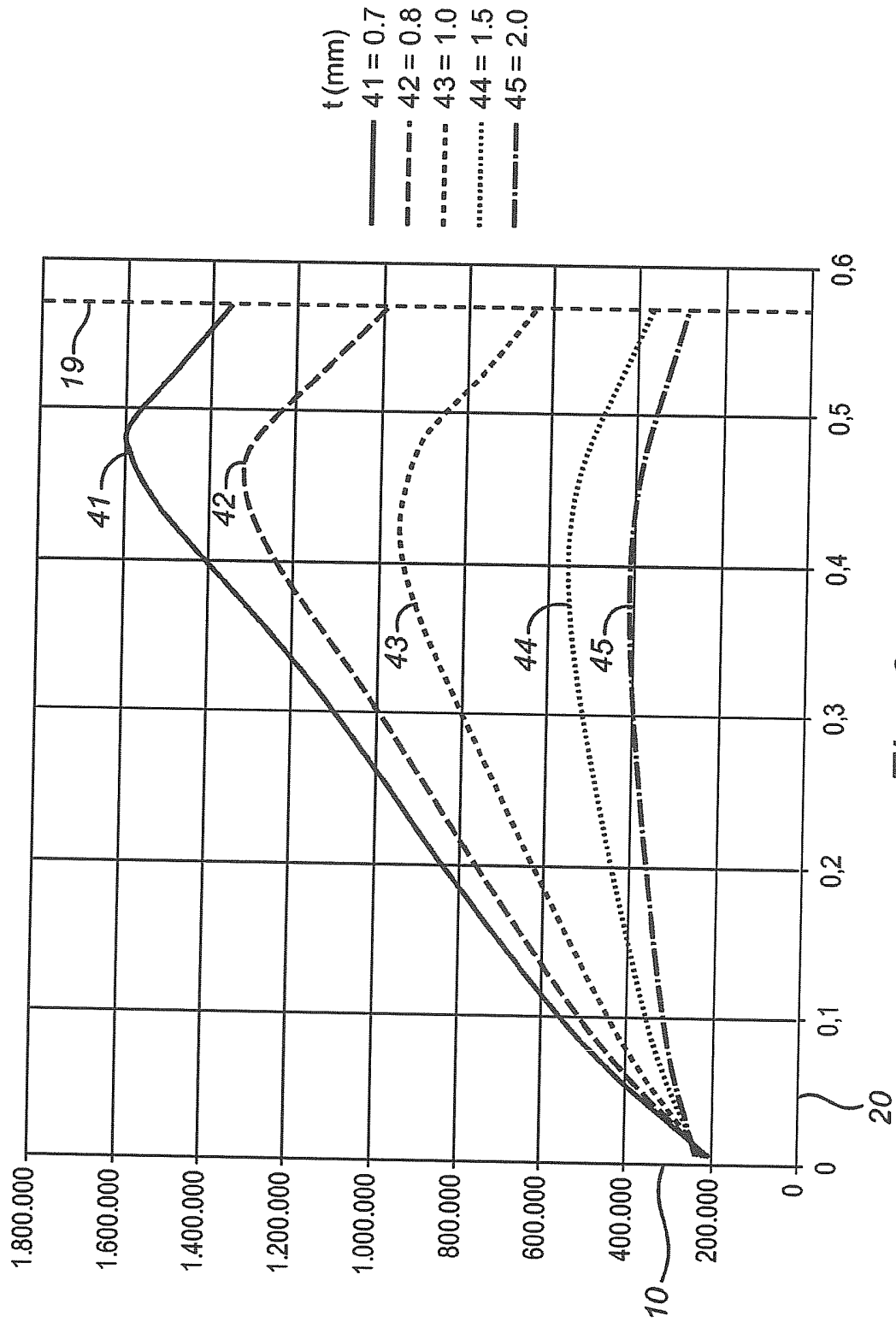


Fig. 6

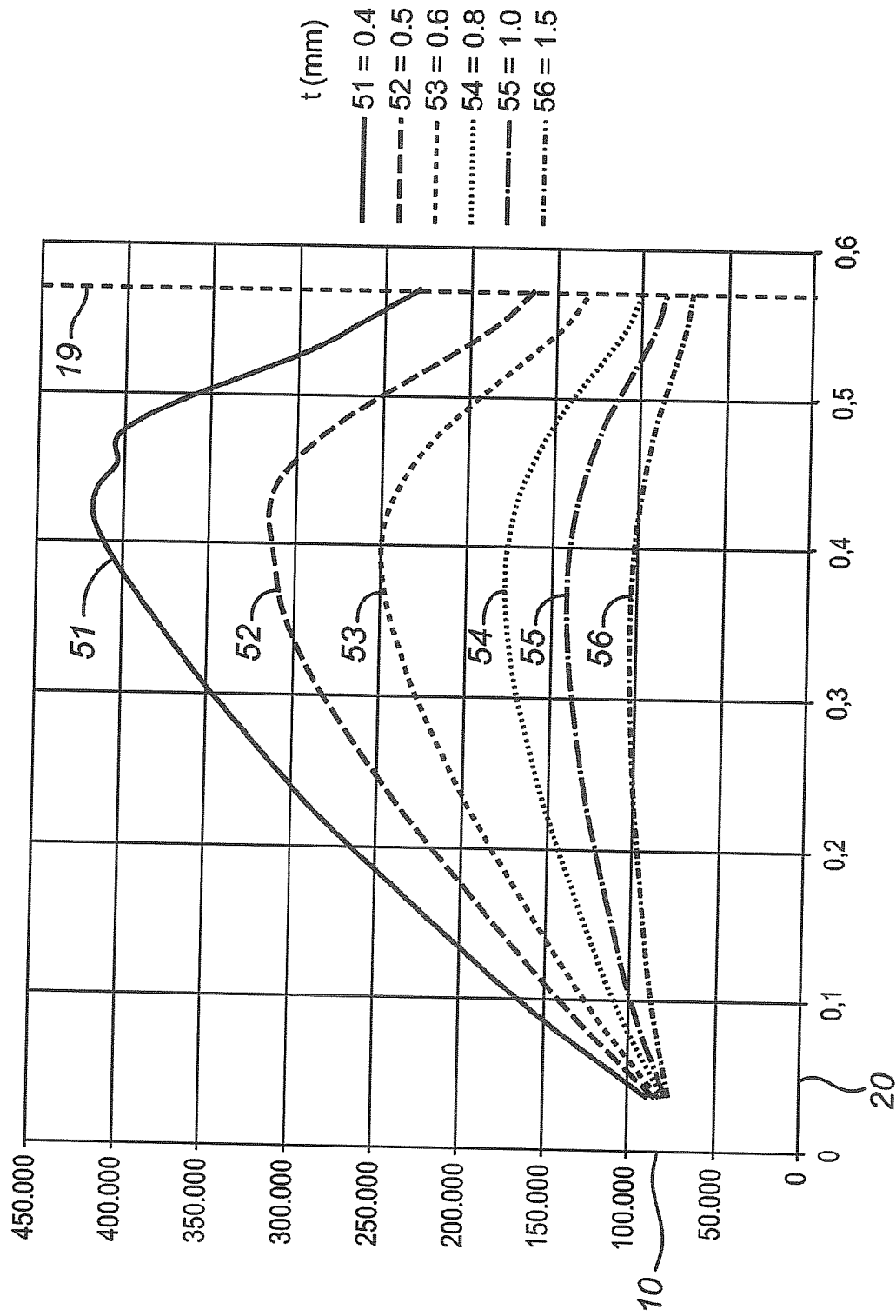


Fig. 7

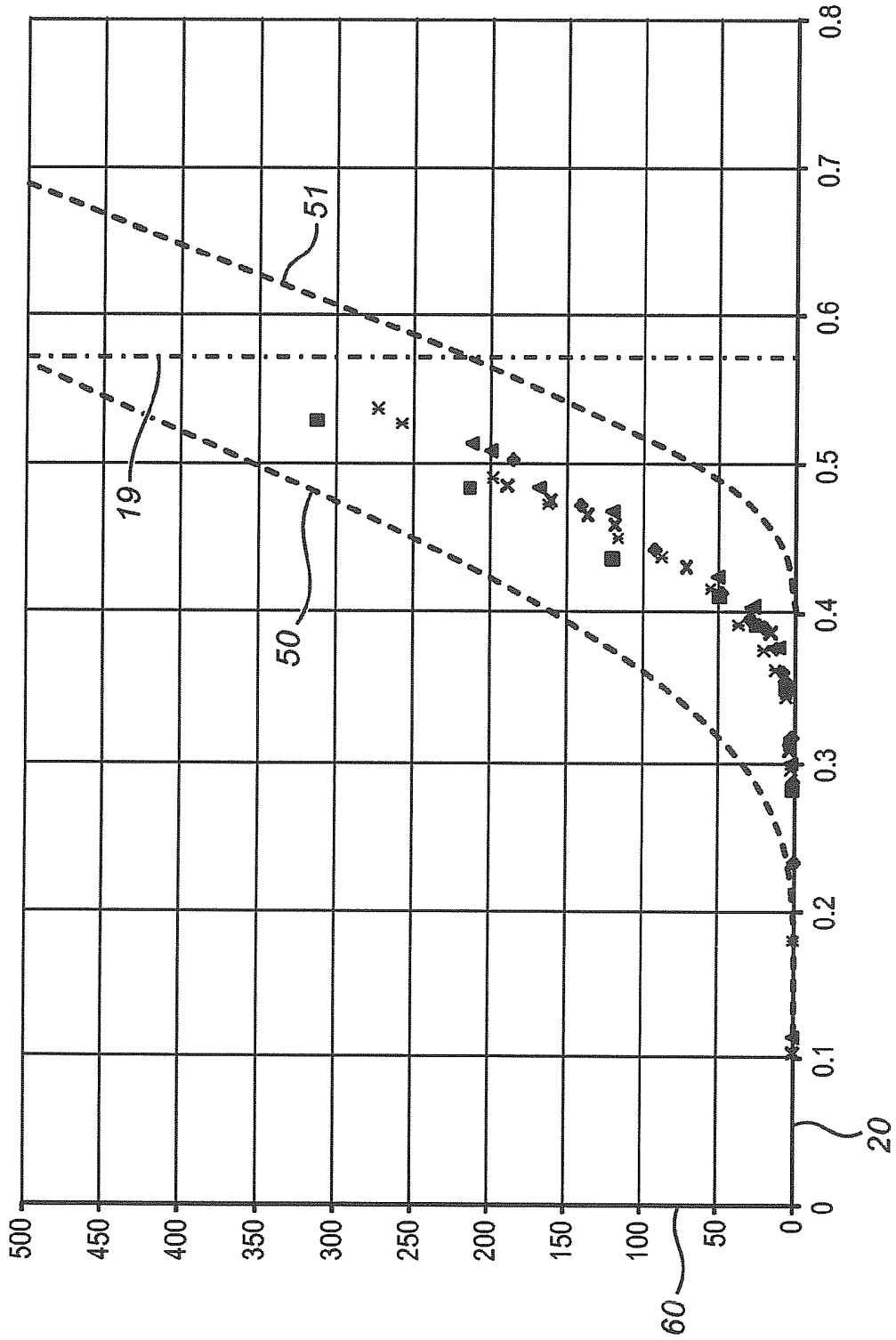


Fig. 8

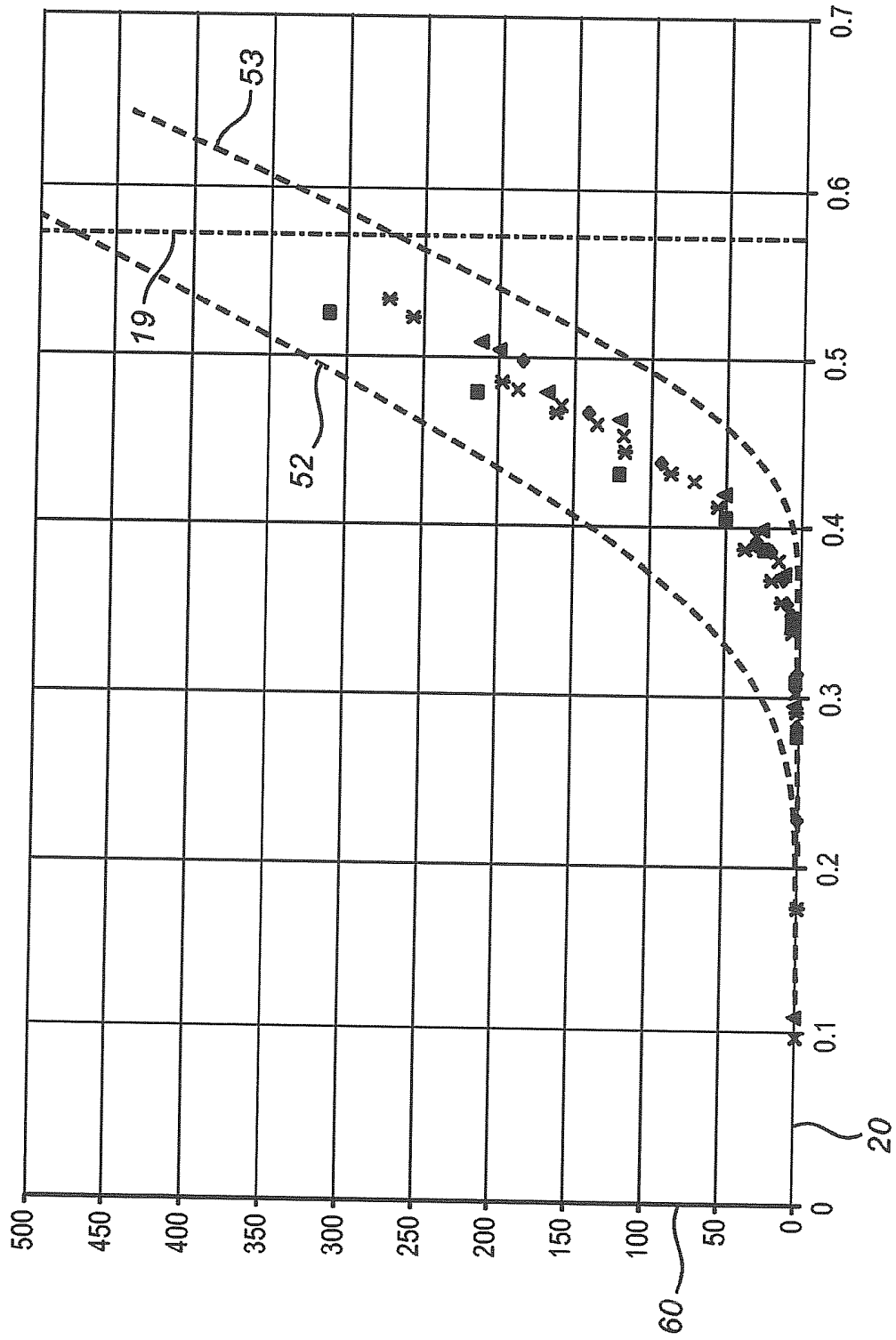


Fig. 9

SAMENWERKINGSVERDRAG (PCT)

RAPPORT BETREFFENDE NIEUWHEIDSONDERZOEK VAN INTERNATIONAAL TYPE

IDENTIFICATIE VAN DE NATIONALE AANVRAGE	KENMERK VAN DE AANVRAGER OF VAN DE GEMACHTIGDE 1.352.011 NL
Nederlands aanvraag nr. 2007683	Indieningsdatum 31-10-2011
	Ingeroepen voorrangsdatum
Aanvrager (Naam) GTM-Advanced Products B.V.	
Datum van het verzoek voor een onderzoek van internationaal type 24-12-2011	Door de Instantie voor Internationaal Onderzoek aan het verzoek voor een onderzoek van internationaal type toegekend nr. SN 57412
I. CLASSIFICATIE VAN HET ONDERWERP (bij toepassing van verschillende classificaties, alle classificatiesymbolen opgeven)	
Volgens de internationale classificatie (IPC) B32B15/08 B64C1/12 B64C3/26	
II. ONDERZOCHE GEBIEDEN VAN DE TECHNIEK	
Onderzochte minimumdocumentatie	
Classificatiesysteem	Classificatiesymbolen
IPC8	B32B B64C
Onderzochte andere documentatie dan de minimum documentatie, voor zover dergelijke documenten in de onderzochte gebieden zijn opgenomen	
III. ☐	GEEN ONDERZOEK MOGELIJK VOOR BEPAALDE CONCLUSIES (opmerkingen op aanvullingsblad)
IV. ☐	GEBREK AAN EENHEID VAN UITVINDING (opmerkingen op aanvullingsblad)

**ONDERZOEKSRAPPORT BETREFFENDE HET
RESULTAAT VAN HET ONDERZOEK NAAR DE STAND
VAN DE TECHNIEK VAN HET INTERNATIONALE TYPE**

Nummer van het verzoek om een onderzoek naar
de stand van de techniek

NL 2007683

A. CLASSIFICATIE VAN HET ONDERWERP

INV. B32B15/08 B64C1/12 B64C3/26
ADD.

Volgens de Internationale Classificatie van octrooien (IPC) of zowel volgens de nationale classificatie als volgens de IPC.

B. ONDERZOCHE GEBIEDEN VAN DE TECHNIEK

Onderzochte minimum documentatie (classificatie gevolgd door classificatiesymbolen)
B32B B64C

Onderzochte andere documentatie dan de minimum documentatie, voor dergelijke documenten, voor zover dergelijke documenten in de onderzochte gebieden zijn opgenomen

Tijdens het onderzoek geraadpleegde elektronische gegevensbestanden (naam van de gegevensbestanden en, waar uitvoerbaar, gebruikte trefwoorden)

EPO-Internal, WPI Data

C. VAN BELANG GEACHTE DOCUMENTEN

Categorie °	Geciteerde documenten, eventueel met aanduiding van speciaal van belang zijnde passages	Van belang voor conclusie nr.
X	WO 2009/095381 A1 (GTM HOLDING B V [NL]; WERCO MFG INC [US]; GUNNINK JAN WILLEM [NL]; EVA) 6 augustus 2009 (2009-08-06) * het gehele document * * bladzijde 13, regels 10-25; figuur 12 *	1-44
X	WO 2007/145512 A1 (ALCOA INC [US]; ROEBROEKS GEERARDUS HUBERTUS J [NL]; GUNNINK JAN WILLE) 21 december 2007 (2007-12-21) * het gehele document * * bladzijde 2, regel 19 - bladzijde 4, regel 4; conclusies *	1-44
X	EP 0 312 150 A1 (AKZO NV [NL]) 19 april 1989 (1989-04-19) * het gehele document *	1-44
	----- -/-	

☒ Verdere documenten worden vermeld in het vervolg van vak C.

☒ Leden van dezelfde octrooifamilie zijn vermeld in een bijlage

° Speciale categorieën van aangehaalde documenten

"A" niet tot de categorie X of Y behorende literatuur die de stand van de techniek beschrijft

"D" in de octrooiaanvraag vermeld

"E" eerdere octrooi(aanvraag), gepubliceerd op of na de indieningsdatum, waarin dezelfde uitvinding wordt beschreven

"L" om andere redenen vermelde literatuur

"O" niet-schriftelijke stand van de techniek

"P" tussen de voorrangsdatum en de indieningsdatum gepubliceerde literatuur

"T" na de indieningsdatum of de voorrangsdatum gepubliceerde literatuur die niet bezwarend is voor de octrooiaanvraag, maar wordt vermeld ter verheldering van de theorie of het principe dat ten grondslag ligt aan de uitvinding

"X" de conclusie wordt als niet nieuw of niet inventief beschouwd ten opzichte van deze literatuur

"Y" de conclusie wordt als niet inventief beschouwd ten opzichte van de combinatie van deze literatuur met andere geciteerde literatuur van dezelfde categorie, waarbij de combinatie voor de vakman voor de hand liggend wordt geacht

"&" lid van dezelfde octrooifamilie of overeenkomstige octrooipublicatie

Datum waarop het onderzoek naar de stand van de techniek van internationaal type werd voltooid

17 februari 2012

Verzenddatum van het rapport van het onderzoek naar de stand van de techniek van internationaal type

Naam en adres van de instantie

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
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De bevoegde ambtenaar

Hutton, David

**ONDERZOEKSRAPPORT BETREFFENDE HET
RESULTAAT VAN HET ONDERZOEK NAAR DE STAND
VAN DE TECHNIEK VAN HET INTERNATIONALE TYPE**

Nummer van het verzoek om een onderzoek naar
de stand van de techniek
NL 2007683

C.(Vervolg). VAN BELANG GEACHTE DOCUMENTEN		
Categorie °	Geciteerde documenten, eventueel met aanduiding van speciaal van belang zijnde passages	Van belang voor conclusie nr.
X	EP 0 312 151 A1 (AKZO NV [NL]) 19 april 1989 (1989-04-19) * het gehele document *	1-44
A	----- US 4 500 589 A (SCHIJVE JACOBUS [NL] ET AL) 19 februari 1985 (1985-02-19) * het gehele document *	1-44
A	----- R. VAN ROOIJEN ET AL: "Property Optimisation in Fibre Metal Laminates", APPLIED COMPOSITE MATERIALS, deel 11, nr. 2, 1 maart 2004 (2004-03-01), bladzijden 63-76, XP55019056, ISSN: 0929-189X, DOI: 10.1023/B:ACMA.0000012880.01669.c0 * het gehele document *	1-44

**ONDERZOEKSRAPPORT BETREFFENDE HET
RESULTAAT VAN HET ONDERZOEK NAAR DE STAND
VAN DE TECHNIEK VAN HET INTERNATIONALE TYPE**

Informatie over leden van dezelfde octrooifamilie

Nummer van het verzoek om een onderzoek naar
de stand van de techniek

NL 2007683

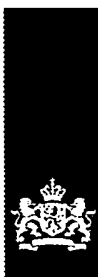
In het rapport genoemd octrooigeschrift	Datum van publicatie	Overeenkomend(e) geschrift(en)	Datum van publicatie
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			JP 57137148 A 24-08-1982
			NL 8100087 A 02-08-1982
			US 4500589 A 19-02-1985



Agentschap NL
Ministerie van Economische Zaken,
Landbouw en Innovatie

WRITTEN OPINION

File No. SN57412	Filing date (day/month/year) 31.10.2011	Priority date (day/month/year)	Application No. NL2007683
International Patent Classification (IPC) INV. B32B15/08 B64C1/12 B64C3/26			
Applicant GTM-Advanced Products B.V.			

This opinion contains indications relating to the following items:

- ☒ Box No. I Basis of the opinion
- ☐ Box No. II Priority
- ☐ Box No. III Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
- ☐ Box No. IV Lack of unity of invention
- ☒ Box No. V Reasoned statement with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
- ☐ Box No. VI Certain documents cited
- ☐ Box No. VII Certain defects in the application
- ☐ Box No. VIII Certain observations on the application

	Examiner Hutton, David
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WRITTEN OPINION

Application number
NL2007683

Box No. I Basis of this opinion

1. This opinion has been established on the basis of the latest set of claims filed before the start of the search.
2. With regard to any **nucleotide and/or amino acid sequence** disclosed in the application and necessary to the claimed invention, this opinion has been established on the basis of:
 - a. type of material:
 - ☐ a sequence listing
 - ☐ table(s) related to the sequence listing
 - b. format of material:
 - ☐ on paper
 - ☐ in electronic form
 - c. time of filing/furnishing:
 - ☐ contained in the application as filed.
 - ☐ filed together with the application in electronic form.
 - ☐ furnished subsequently for the purposes of search.
3. ☐ In addition, in the case that more than one version or copy of a sequence listing and/or table relating thereto has been filed or furnished, the required statements that the information in the subsequent or additional copies is identical to that in the application as filed or does not go beyond the application as filed, as appropriate, were furnished.
4. Additional comments:

Box No. V Reasoned statement with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty	Yes: Claims	1-44
	No: Claims	
Inventive step	Yes: Claims	
	No: Claims	1-44
Industrial applicability	Yes: Claims	1-44
	No: Claims	

2. Citations and explanations

see separate sheet

1 Reference is made to the following documents:

- D1 WO 2009/095381 A1 (GTM HOLDING B V [NL]; WERCO MFG INC [US]; GUNNINK JAN WILLEM [NL]; EVA) 6 augustus 2009 (2009-08-06)
- D2 WO 2007/145512 A1 (ALCOA INC [US]; ROEBROEKS GEERARDUS HUBERTUS J [NL]; GUNNINK JAN WILLE) 21 december 2007 (2007-12-21)
- D3 EP 0 312 150 A1 (AKZO NV [NL]) 19 april 1989 (1989-04-19)
- D4 EP 0 312 151 A1 (AKZO NV [NL]) 19 april 1989 (1989-04-19)
- D5 US 4 500 589 A (SCHIJVE JACOBUS [NL] ET AL) 19 februari 1985 (1985-02-19)
- D6 R. VAN ROOIJEN ET AL: "Property Optimisation in Fibre Metal Laminates",
APPLIED COMPOSITE MATERIALS,
deel 11, nr. 2, 1 maart 2004 (2004-03-01), bladzijden 63-76,
XP55019056,
ISSN: 0929-189X, DOI: 10.1023/B:ACMA.0000012880.01669.c0

2 **Novelty and Inventive Step.**

- 2.1 The present application relates to fibre metal laminates of mutually bonded fiber-reinforced composite layers and metal sheets, the laminate comprising a combination of a a fiber-reinforced composite layer and an adjacent metal sheet, in which the combination of the properties satisfy the following empirical relationships:-

$$E_{\text{lam}} * E_{\text{comp}} / (E_{\text{metal}} * t_{\text{metal}}^2) = a * (V_f - c)^{b / (V_f - c)} \quad (1)$$

$$c \leq V_f \leq 0.57 \quad (2)$$

$$10 \quad 0 < E_{\text{lam}} * E_{\text{comp}} / (E_{\text{metal}} * t_{\text{metal}}^2) \leq 500 \text{ kN/mm}^4 \quad (3)$$

wherein $a = 1200 \text{ kN/mm}^4$; $0.36 \leq b \leq 0.88$; $0 \leq c \leq 0.3$; and

E_{lam} = tensile Young's modulus of the total fiber-metal laminate in kN/mm^2

E_{comp} = tensile Young's modulus of the fiber-reinforced composite layer in kN/mm^2 in

15 the combination

E_{metal} = tensile Young's modulus of the metal sheet in kN/mm^2 in the combination

t_{metal} = thickness of the metal sheet in mm in the combination

V_f = fiber volume fraction of the fiber-reinforced composite layer in the combination

- 2.2 Such laminates are available commercially under the GLARE and ARALL designations and have also been heavily researched by the University of Delft (NL) and ALCOA. These materials commonly have a fibre volume fraction in excess of the 0.57 (or 57 vol. %) specified in the above equation. Comparison with the prior art (where available for lower fibre loadings is difficult) in that not all of the parameters (although inter related) are available, the E_{lam} depending on the make up of the laminate and the E_{comp} (which is normally lower than the E_{metal} , and the E_{comp} in itself depending to a large extent on the volume fraction of fibres.
- 2.3 Document D1 discloses (cf. Fig.12 and p.13, ll.10-25) laminates with an S2 glass layer and Al 2024-T3 layers with a 50% fibre volume content. It is unclear as to whether this laminate falls within the scope of the present claims.
- 2.4 Document D2 (as EP 2026962 B1 currently the subject of opposition proceedings) discloses laminates with lower ($< 45\%$) fibre volume fractions and the influence of such fibre loadings on (cf., p.2, l.19 - p.4, l.4) on mechanical and fatigue properties. Again it is unclear as to whether the disclosures of D2 fall within the scope of the present claims, however D2 teaches the reduction in fibre volume fraction to improve fatigue performance. Thus it is unclear as to whether, even if demonstrated to be novel, the subject-matter of the present claims can be considered to involve the presence of an Inventive Step.
- 2.5 In the earlier patents D3(p.3, ll.3-21) and D4 (p.2, ll.34-53), laminates with FRP layers with fibre loadings of from 35-75 vol. % are disclosed.

2.6 Thus whilst not wishing to detract from the insight provided by the claimed relationship, it is felt that the novelty of the claimed subject matter may be open to attack on grounds of lack of novelty from isolated experiments employing lower fibre volume fractions in the FRP layer or as indicated in D2, that the influence of the fibre fraction on fatigue properties is known in the art.

3 Clarity.

3.1 The claims do not meet the requirement of clarity because the matter for which protection is sought is not clearly defined. The claims attempt to define the subject-matter in terms of the result to be achieved, which merely amounts to a statement of the underlying problem, without providing the technical features necessary for achieving this result. The application cites much experimental data without indicating which compositions/laminates lie within the scope of the claims, nor the crucial moduli necessary to evaluate the claimed relationships. Such a deficiency could also be construed as an insufficiency of disclosure. The parameters b and c can take a variety of values in satisfying the claimed relationships.