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(54) Titre : PROCEDE DE FABRICATION D'UNE STRUCTURE SANDWICH
(54) Title: METHOD FOR PRODUCING A SANDWICH STRUCTURE

(57) Abrégé/Abstract:
The invention relates to a method for producing a sandwich structure comprising two steel face sheets separated by a polymer layer, said method comprising the following steps: - the sandwich structure is sized according to an objective to be achieved, by carrying out the following sub-steps: - the objective to be achieved is defined in terms of three target values, that is to say tensile stiffness Tc, expressed in kN/mm, bending stiffness Bc, expressed in kN/mm and mass per unit area Mc, expressed in Kg/m2; - a tolerance margin for achieving the target values is defined; - the sandwich structure is defined in terms of five variables, that is to say the thickness Ea of the steel face sheets, expressed in mm, the thickness Ep of the polymer layer, expressed in mm, the intrinsic Young's modulus Yp of the polymer layer, the intrinsic density dp of the polymer layer and the volume fraction Rp of the polymer layer, expressed as volume percent of the material polymer layer; - the combinations of Ea, Ep, Yp, dp and Rp that make it possible to achieve the target values within the defined tolerance margin are defined; - for every variable a useful range is determined from the above; - the steel and polymer layer are selected for which every variable is situated in the range defined in the previous step; - and the corresponding sandwich structure is produced.

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(54) Title : METHOD FOR PRODUCING A SANDWICH STRUCTURE

(54) Titre : PROCÉDÉ DE FABRICATION D'UNE STRUCTURE SANDWICH

(57) Abstract : The invention relates to a method for producing a sandwich structure comprising two steel face sheets separated by a polymer layer, said method comprising the following steps: - the sandwich structure is sized according to an objective to be achieved, by carrying out the following sub-steps: - the objective to be achieved is defined in terms of three target values, that is to say tensile stiffness Tc, expressed in kN/mm, bending stiffness Bc, expressed in kN/mm and mass per unit area Mc, expressed in Kg/m2; - a tolerance margin for achieving the target values is defined; - the sandwich structure is defined in terms of five variables, that is to say the thickness Ea of the steel face sheets, expressed in mm, the thickness Ep of the polymer layer, expressed in mm, the intrinsic Young's modulus Yp of the polymer layer, the intrinsic density dp of the polymer layer and the volume fraction Rp of the polymer layer, expressed as volume percent of the material polymer layer; - the combinations of Ea, Ep, Yp, dp and Rp that make it possible to achieve the target values within the defined tolerance margin are defined; - for every variable a useful range is determined from the above; - the steel and polymer layer are selected for which every variable is situated in the range defined in the previous step; - and the corresponding sandwich structure is produced.

(57) Abrégé : L'invention porte sur un procédé de fabrication d'une structure sandwich comprenant deux parements en acier séparés par une couche polymérique comprenant les étapes selon lesquelles : - on dimensionne la structure sandwich en fonction d'une cible à atteindre en suivant les sous-étapes selon lesquelles : o on définit la cible à atteindre par trois valeurs-cibles, à savoir sa rigidité en traction T_c exprimée en kN/mm, sa rigidité en flexion B_c exprimée en kN/mm et sa masse surfacique M_c exprimée en Kg/m^2, o on définit une tolérance dans l'atteinte des valeurs-cibles, o on définit la structure sandwich par cinq variables, à savoir l'épaisseur E_a des parements en acier exprimée en mm, l'épaisseur E_p de la couche polymérique exprimée en mm, le module d'Young intrinsèque Y_p de la couche polymérique, la densité intrinsèque d_p de la couche polymérique et le taux volumique R_p de la couche polymérique exprimé en pourcentage volumique de la couche polymérique présentant de la matière, o on identifie les combinaisons E_a, E_p, Y_p, d_p et R_p permettant d'atteindre les valeurs-cibles avec la tolérance définie, o on en déduit, pour chaque variable, un domaine de fonctionnement, - on sélectionne l'acier et la couche polymérique pour lesquels chaque variable se trouve dans le domaine défini à l'étape précédente, - on fabrique la structure sandwich correspondante.

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Method for producing a sandwich structure

The invention relates to sandwich structures including a polymeric layer between two steel skin layers and a process for manufacturing them.

Reducing motor vehicle energy consumption occurs primarily by reducing the weight of these vehicles.

The steel traditionally used for producing both skin parts and structural parts has lighter metal competitors such as aluminum and composites, such as glass fiber-reinforced polymers or carbon fiber-reinforced polymers.

Although sandwich structures can provide an alternative, their complexity makes their dimensioning difficult.

Thus, the purpose of this invention is to propose a method for manufacturing a sandwich structure that facilitates dimensioning of the sandwich structure according to a target to be achieved.

To this end, a first object of the invention is a method for manufacturing a sandwich structure including two steel skin layers separated by a polymeric layer comprising the steps of:

- Dimensioning the sandwich structure according to a target to be attained by following the sub-steps of:
    - o defining the target to be attained by three target values, i.e., tensile strength T_c expressed in kN/mm, bending stiffness B_c expressed in kN/mm, and surface mass M_c expressed in Kg/m²,
    - o defining a tolerance for the attainment of target values,
    - o defining the sandwich structure by five variables, i.e., the thickness E_a of the steel skin layers expressed in mm, the polymeric layer thickness E_p expressed in mm, the intrinsic Young's modulus Y_p of the polymeric layer, the intrinsic density d_p of the polymeric layer, and the volume ratio R_p of the polymeric layer expressed as a volume percentage of the polymeric layer of the material,

- o identifying E_a, E_p, Y_p, d_p, and R_p combinations enabling attainment of target values having the defined tolerance,
- o determining, for each variable, an operating range,

- selecting the steel and the polymeric layer for which each variable is within the range defined in the previous step,
- manufacturing the corresponding sandwich structure.

The method of the invention may also include the following optional features, either individually or in combination:

- the target to be attained is a monolithic metallic material other than steel,
- the target to be attained is aluminum
- the target to be attained is aluminum with a thickness of 0.9 mm,
- the target to be attained is aluminum with a thickness of 0.8 mm,
- the tolerance in attaining target values is 10%,
- the step of identifying the E_a, E_p, Y_p, d_p, and R_p combinations enabling attainment of the target values having the defined tolerance includes a step during which the E_a, E_p, Y_p, d_p, and R_p combinations are generated,
- it includes a graphical analysis step for the E_a, E_p, Y_p, d_p, and R_p combinations generated.

A second object of the invention is a sandwich structure obtainable by the method of the invention implemented for a 0.9 mm aluminum target with T_c=31.5 N/mm, B_c=10.2 N/mm, M_c=2.43 Kg/m² and a tolerance of 10%, the sandwich structure including:

- Two steel skin layers with steel thickness E_a between 0.133mm and 0.165mm,
- A polymeric layer intercalated between the two skin layers and having:
  - o A thickness E_p between (-2.5xEa+0.713) and (-2.5xEa+0.88),
  - o A density d_p between 0.9 and 1.4,
  - o A volume fraction R_p greater than or equal to 0.2 and strictly less than 1,
  - o A Young's modulus Y_p lower than 4000 MPa,
  - o Where the volume fraction R_p and the Young's modulus Y_p satisfy the inequality:

    $Y_p*(0.49*R_p^2+0.23*R_p+1/(Y_p*(1-R_p))) \geq 50$ MPa

This sandwich structure according to the invention may also include the following optional features, either individually or in combination:

- the steel thickness E_a is between 0.141 mm and 0.158 mm and the polymeric layer thickness E_p is between (-2,5xE_a+0,73) and (-2,5xE_a+0,87),
- the polymeric layer includes a mixture of a polyamide and a copolymer of ethylene and unsaturated carboxylic acid and/or its derivative.

A third object of the invention is a sandwich structure obtainable by the process according to any of Claims 1 through 9 implemented for a 0.8 mm aluminum target with T_c=28.0 N/mm, B_c=7.2 N/mm, M_c=2.16 Kg/m^2 and a tolerance of 10%, the sandwich structure including:

- Two steel skin layers with steel thickness E_a between 0.118 mm and 0.146 mm,
- A polymeric layer intercalated between the two skin layers and having:
  - A thickness E_p between (-2,5xE_a+0,632) et (-2,5xE_a+0,75),
  - A density d_p between 0.9 and 1.4,
  - A volume fraction R_p greater than or equal to 0.2 and strictly less than 1,
  - A Young's modulus Y_p lower than 4000 MPa
  - Where the volume fraction R_p and the Young's modulus Y_p satisfy the inequality:

$$Y_p*(0.49*R_p^2+0.23*R_p+1/(Y_p*(1-R_p))) \geq 50 \text{ MPa}$$

This sandwich structure according to the invention may also include the following optional features, either individually or in combination:

- the steel thickness E_a is between 0.126 mm and 0.140 mm and the polymeric layer thickness E_p is between (-2.5xE_a+0.646) and (-2.5xE_a+0.728),
- the mixture of a polyamide and a copolymer of ethylene and unsaturated carboxylic acid and/or its derivative.

Other features and advantages of the invention appear in the description that follows.

The dimensioning of a sandwich structure starts with the selection of a target to be attained. This target can be either a virtual target defined uniquely by target values or a competing product for which replication of the performance is sought. In the latter case, the target values are those of the competing material under consideration.

In particular, the target to be attained is defined by three target values, i.e., tensile strength T_c expressed in kN/mm, bending stiffness B_c expressed in kN/mm, and surface mass M_c expressed in Kg/m².

By way of non-limiting examples, in the case of aluminum as a target, the target values T_c, B_c, and M_c respectively may have the following values:

- 31.5 N/mm, 10.2 N/mm, 2.43 Kg/m² for 0.9 mm aluminum
- 28.0 N/mm, 7.2 N/mm, 2.16 Kg/m² for 0.8 mm aluminum

When dimensioning the sandwich structure, a tolerance margin in the attainment of target values is allowed. This tolerance can be adjusted on a case-by-case basis by a person skilled in the art in accordance with the criticality of the target value in the given context.

For example, a first approach might be to accept that the target values are attained to within plus or minus 10%, or preferentially within plus or minus 5%.

The sandwich structure is then defined by the thickness E_a of the steel skin layers expressed in mm, the thickness E_p of the polymeric layer expressed in mm, the intrinsic Young's modulus Y_p of the polymeric layer, the intrinsic density d_p of the polymeric layer expressed in MPa, and the volume fraction R_p of the polymeric layer expressed as a volume percentage of the polymeric layer of the material.

Intrinsic Young's modulus of the polymeric layer means the Young's modulus of the polymer or polymer mixture constituting the polymeric layer, excluding foaming, if any, of the polymeric layer.

Intrinsic density of the polymer layer means the density of the polymer or polymer mixture constituting the polymer layer, excluding fillers and foaming, if any, in the density calculation.

The volume fraction R_p is a function of the foaming, if any, of the polymeric layer. In the absence of foaming, the volume ratio is therefore 1. The control of the volume fraction is attained by controlling the foaming rate. Preferably, the polymeric layer is foamed, i.e., R_p is strictly less than 1. Foaming provides a better compromise for weight reduction/mechanical performance of the sandwich structure.

The next step is to identify E_a, E_p, Y_p, d_p, and R_p combinations enabling attainment of target values having the defined tolerance.

This step can be implemented according to any method known to a person skilled in the art.

By way of a non-limiting example, a possible method is described below. The first step of this method is to generate E_a, E_p, Y_p, d_p, and R_p combinations as follows:

- The Young's modulus Y_{a1} of the first steel skin layer is set to 210000 MPa,
- The size of the first metal skin layer is set to a width l_{a1} of 50 mm and a length L_{a1} of 100 mm,
- The Poisson coefficient v_{a1} of the first steel skin layer is set to 0.3,
- The size of the polymeric layer is set to a width l_p of 50 mm and a length L_p of 100 mm,
- The Poisson coefficient v_p of the polymeric layer is set to 0.3,
- The thickness E_{a2} of the second steel skin layer is set to that of the first skin layer,
- The Young modulus Y_{a2} of the second steel skin layer is set to 210000 MPa,
- The size of the second steel skin layer is set to a width l_{a2} of 50 mm and a length L_{a2} of 100 mm,
- The Poisson coefficient v_{a2} of the second steel skin layer is set to 0.3,
- The thickness E_{a1} of the first steel skin layer is randomly varied, preferably between 0.1 mm and 0.2 mm to limit the number of iterations,
- The polymeric layer thickness E_p is varied randomly, preferably between 0 and 1 mm to limit the number of iterations,
- The intrinsic Young's modulus Y_p of the polymeric layer is randomly varied,
- The volume fraction R_p of the polymeric layer is randomly varied,
- The intrinsic density d_p of the polymer layer is randomly varied,

- The first steel skin layer quadratic moment of inertia $MM4_{a1}$ is calculated using the equation $MM4_{a1}= I_a*E_{a1}^3/12$,
- The first steel skin layer shear modulus Gc_{a1} is calculated using the equation $Gc_{a1}=Y_{a1}/(2*(1+ v_{a1}))$,
- The first skin layer neutral fiber NF_{a1} is calculated using the equation $Gc_{a1}=E_{a1}/2$,
- The mass M_{a1} of the first steel skin layer is calculated using the equation $M_{a1}= E_{a1}*7.8$,
- The apparent Young's modulus $Yapp_p$ of the polymeric layer is calculated using the equation $Yapp_p =Y_p*(0.7^2*R_p^2+(1-0.77)*R_p+1/(Y_p*(1-R_p)))$
- The quadratic moment of inertia $MM4_p$ of the polymeric layer is calculated using the equation $MM4_p = I_p*E_p^3/12$,
- The shear modulus Gc_p of the polymeric layer is calculated using the equation $Gc_p= Yapp_p/(2*(1+v_p))$,
- The neutral fiber NF_p of the polymeric layer is calculated using the equation $NF_p=E_p/2+E_{a1}$,
- The mass M_p of the polymeric layer is calculated using the equation $M_p=R_p*E_p*d_p$,
- The quadratic moment of inertia $MM4_{a2}$ of the second steel skin layer is calculated using the equation $MM4_{a2}= I_{a2}*E_{a2}^3/12$,
- The shear modulus Gc_{a2} of the second steel skin layer is calculated using the equation $Gc_{a2}= Y_{a2}/(2*(1+v_{a2}))$,
- The second skin layer NF_{a2} neutral fiber is calculated using the equation $NF_{a2}=E_{a2}/2+E_p+E_{a1}$,
- The mass M_{a2} of the second steel skin layer is calculated using the equation $M_{a2}=E_{a2}*7.8$,
- The sandwich structure bending stiffness B_s is calculated using the equation:

  $B_s= 1/(L_{a2}^3/(48*A)+L_{a2}/(4*D))$

  Where:

  $A= (Y_{a1}*MM4_{a1}+E_{a1}*Y_{a1}*I_a*(Gc_{a1}-C)^2) + (Yapp_p*MM4_p+E_p* Yapp_p*I_p*(NF_p-C)^2) + (Y_{a2}*MM4_{a2}+E_{a2}* Y_{a2}*I_{a2}*(NF_{a2}-C)^2)$

  And $D = I_p*Gc_p*((E_{a1}+E_{a2})/2+E_p)^2/E_p$

Where:

$C=(E_{a1}*Y_{a1}*I_a*Gc_{a1}+E_p*Yapp_p*I_p*NF_p+E_{a2}*Y_{a2}*I_{a2}*NF_{a2})/(E_{a1}*Y_{a1}*I_a+E_p*Yapp_p*I_p+E_{a2}*Y_{a2}*I_{a2})$

- The tensile strength T_s of the sandwich structure is calculated using the equation:

  $T_s = 50/100*(Y_{a1}*E_{a1}+Yapp_p*E_p+Y_{a2}*E_{a2})/1000$

- The mass M_s of the sandwich structure is calculated using the equation:

  $M_s = M_{a1} + M_p + M_{a2}$

- T_s, B_s, and M_s are compared to the target values for T_c, B_c, and M_c with the defined tolerance.

The results obtained are analyzed so as to identify E_a, E_p, Y_p, d_p, and R_p combinations allowing the attainment of target values having the defined tolerance. In particular, the results can be analyzed graphically. By way of example, the graph may show a representation of the polymeric layer thickness E_p as a function of the thickness E_a of the steel skin layer and the intrinsic Young's modulus Y_p of the polymeric layer. The graph may also show a representation of the polymeric layer thickness E_p as a function of the thickness E_a of the steel skin layer and the volume fraction Rp of the polymeric layer.

During the process of identifying E_a, E_p, Y_p, d_p, and R_p combinations enabling attainment of target values having the defined tolerance, certain combinations can be excluded because they have been identified as not working.

By way of example, this is the case for sandwich structures with a polymeric layer apparent Young's modulus below 50 Mpa. Below this value, it has been observed that the development of the Young's modulus over time becomes overly sensitive to the environment. In particular, water infiltration or exposure of the sandwich structure to temperatures close to the melting point of the polymeric layer may lead to shearing of the sandwich structure and loss of cohesion.

_ Similarly, it has been found that a volume fraction less than 0.2, i.e., a foaming proportion of more than 80%, does not allow sufficient rigidity of the sandwich structure to be attained and/or maintained.

By way of example, for a 0.9 mm aluminum target with T_c=31.5 N/mm, B_c=10.2 N/mm, M_c=2.43 Kg/m², and a tolerance of 10%, an operating range is determined as defined by:

- A steel thickness E_a between 0.133 mm and 0.165 mm,
- A thickness E_p of the polymeric layer between (-2.5xE_a+0.713) and (-2.5xE_a+0.88),
- A density d_p of the polymeric layer between 0.9 and 1.4,
- A volume ratio R_p of the polymeric layer between 0.2 and 1,
- A Young's modulus Y_p of the polymeric layer lower than 4000 MPa,
- Where the volume fraction R_p and the Young's modulus Y_p satisfy the inequality:
  $Y_p*(0.49*R_p^2+0.23*R_p+1/(Y_p*(1-R_p))) \geq 50$ MPa

Similarly, for a 0.9 mm aluminum target with T_c=31.5 N/mm, B_c=10.2 N/mm, M_c=2.43 Kg/m², and a tolerance of 5%, the operating range is defined by:

- A steel thickness E_a between 0.141 mm and 0.158 mm,
- A thickness E_p of the polymeric layer between (-2.5xEa+0.73) and (-2.5xEa+0.87).
- A density d_p of the polymeric layer between 0.9 and 1.4,
- A volume ratio R_p of the polymeric layer between 0.2 and 1,
- A Young's modulus Y_p of the polymeric layer lower than 4000 MPa,
  Where the volume fraction R_p and the Young's modulus Y_p satisfy the inequality:
  $Y_p*(0.49*R_p^2+0.23*R_p+1/(Y_p*(1-R_p))) \geq 50$ Mpa

Similarly, for a 0.8 mm aluminum target with T_c=28.0 N/mm, B_c=7.2 N/mm, M_c=2.16 Kg/m², and a tolerance of 10%, the operating range is defined by

- A steel thickness E_a between 0.118 mm and 0.146 mm,
- A thickness E_p of the polymeric layer between (-2.5xEa+0.632) and (-2.5xEa+0.75).
- A density d_p between of the polymeric layer between 0.9 and 1.4,
- A volume ratio R_p of the polymeric layer between 0.2 and 1,

- A Young's modulus Y_p of the polymeric layer lower than 4000 MPa,
- Where the volume fraction R_p and the Young's modulus Y_p satisfy the inequality:
  $Y_p*(0.49*R_p^2+0.23*R_p+1/(Y_p*(1-R_p))) \geq 50$ MPa

Similarly, for a 0.8 mm aluminum target with T_c=28.0 N/mm, B_c=7.2 N/mm, C M_c=2.16 Kg/m² and a tolerance of 10%, the operating range is defined by:

- A steel thickness E_a between 0.126 mm and 0.140 mm
- A thickness E_p of the polymeric layer between (-2.5xE_a+0.646) and (-2.5xE_a+0.728).
- A density d_p of the polymeric layer between 0.9 and 1.4,
- A volume ratio R_p of the polymeric layer between 0.2 and 1,
- A Young's modulus Y_p of the polymeric layer lower than 4000 MPa,
- Where the volume fraction R_p and the Young's modulus Y_p satisfy the inequality:
  $Y_p*(0.49*R_p^2+0.23*R_p+1/(Y_p*(1-R_p))) \geq 50$ Mpa

The next step is to select the steel and the polymeric layer for which each variable is within the range defined in the previous step.

A person skilled in the art, who is knowledgeable about the characteristics of steels and polymers, can easily make this selection.

In particular, the selection of the steel is guided by the considerations below.

Preferably, the skin layer is made of sheet steel with thickness E_a between 0.1 mm and 0.2 mm. Below this range, it becomes difficult to achieve sufficient bending stiffness of the sandwich structure. Above this range, the weight of the steel sheets does not allow for a sufficiently light sandwich structure. Preferably, steel sheets have a thickness between 0.118 mm and 0.165 mm. Even more preferably, steel sheets have a thickness between 0.126 mm and 0.158 mm.

The selection of steel grade depends on the intended application. For use in the automotive industry, the grades commonly used are ES grades (EN DC01 to DC06) and HLE grades (EN H240LA to H400LA). Preferably, steels are selected from the IF-Ti grades. These grades have the advantage of being very insensitive to hardening after curing (bake hardening) which allows them to undergo the manufacturing stage of the sandwich structure without damage, a stage during which the sandwich structure is heated to temperatures in the range of 240°C -250°C. These grades also have the advantage of being capable of undergoing deep-drawing.

These steel skin layers can be bare. Alternatively, they can be coated in order to improve their performance, in particular their corrosion resistance. In the case of coated steel, steel thickness E_a means the thickness of the bare steel skin layer, without taking into consideration the thickness of the coating.

The coating may be a metal coating obtained by hot dip galvanizing, electroplating, or vacuum deposition, such as vapor deposition or sonic vapor jet deposition. This coating may include one or more metals such as zinc, aluminum, magnesium, or silicon. By way of non-limiting examples, we can cite zinc coating (GI), alloyed zinc coating (GA), zinc alloy with 0.1 wt-% to 10 wt-% magnesium (ZnMg), zinc alloy with 0.1 wt-% to 10 wt-% magnesium and 5 wt-% to 11 wt-% aluminum (ZnAlMg), zinc alloy with 5 wt-% aluminum (Galfan®), zinc alloy with 55 wt-% aluminum, about 1.5 wt-% silicon, the remainder being zinc and unavoidable impurities due to processing (Aluzinc®, Galvalume®), aluminum alloy having 8 wt-% to 11% wt-% silicon and 2 wt-% to 4 wt-% iron, the remainder being aluminum and unavoidable impurities due to processing (Alusi®), and aluminum coating (Alupur®).

The coating may also include a surface treatment, varnish, or paint or oil coating. These coatings are known to the person skilled in the art, who will know how to use them and how to adjust them on a case-by-case basis.

A person skilled in the art will also be guided in the selection of a polymeric layer by the considerations below.

The polymeric layer can be composed of a single polymer or a mixture of at least two polymers (polymeric mixture below).

The selection of the polymer or the polymeric mixture is mainly guided by the conditions existing for the polymer or the polymer blend during the manufacture and use of the sandwich structure.

For this reason, a polymer or polymer mixture should preferably be selected which:

- has a melting point not exceeding 220°C -240°C so that it can be used on sandwich structure production lines without excessive heating,
- is resistant to the cataphoresis stage, a stage in motor vehicle manufacturing during which paint applied to the vehicle is cured for about 45 minutes at a temperature of up to 210°C.

Preferably, the polymeric layer has sufficient adhesion to the metal to be used as a monolayer directly attached to the steel skin layers during manufacturing of the sandwich structure. Alternatively, the polymeric layer can be attached to steel skin layers by means of a glue or adhesive at the polymeric layer/steel skin layer interface. Alternatively, the polymeric layer may be a multilayer, the outer layers of which have good adhesion to metal.

According to a variant of the invention, the polymeric mixture includes a polyamide such as PA6, PA6-6, PA11, PA12, PA4-6, PA6-10, or PA6-12, for which the densities and the Young's modulus are known. Preferably, the polymer mixture comprises a polyamide and a copolymer of ethylene and unsaturated carboxylic acid and/or its derivative. Details for the characteristics of the components of such a mixture and the process for obtaining this mixture can be found in application WO2005/0142278 incorporated by reference herein. These polyamide-based mixtures have the advantage of being resistant to the cataphoresis stage, having a good surface appearance after shaping, and having good adhesion to metal.

According to a variant of the invention, the polymeric mixture is biphasic and comprises:

- A polyamide having a melting point of not more than 210°C;
- A modified polyolefin having carboxy groups,

whose rheological behavior in the molten state is characterized by the existence of a threshold stress.

Details of the characteristics of the components of such a mixture and the process for obtaining this mixture can be found in application WO2012/076763 incorporated by reference herein.

Such a polymeric mixture has the advantage of resisting the cataphoresis step at 210°C while having a melting point that does not exceed 210°C, which facilitates its implementation and therefore the manufacturing of the sandwich structure.

The polymer layer can be foamed.

The presence of gas bubbles in the mixture may result either from the incorporation of a blowing agent into the polymer mixture or from the physical introduction of gas bubbles into the mixture during processing.

If a blowing agent is used, it should preferably be incorporated during manufacture of the polymer or polymer mixture. During sandwich panel manufacturing, heating of the polymeric layer activates the blowing agent which releases gas into the polymer. The foaming rate, and thus the Rp volume ratio, is then controlled by the amount of blowing agent added to the polymeric layer. Among the blowing agents that can be used, by way of example, Expancel® microspheres can be cited, which are added at a level of a few weight percent to the polymeric layer.

Manufacturing itself, i.e. the assembly of the skin layers and the polymeric layer, can be carried out according to any process known to a person skilled in the art.

CLAIMS

1) Method for manufacturing a sandwich structure comprising two steel skin layers separated by a polymeric layer comprising steps of:
   - Dimensioning the sandwich structure according to a target to be attained by following the sub-steps of:
     - o defining the target to be attained by three target values, i.e., tensile strength T_c expressed in kN/mm, bending stiffness B_c expressed in kN/mm, and surface mass M_c expressed in Kg/m^2,
     - o defining a tolerance for the attainment of target values,
     - o defining the sandwich structure by five variables, i.e., the thickness E_a of the steel skin layers expressed in mm, the polymeric layer thickness E_p expressed in mm, the intrinsic Young's modulus Y_p of the polymeric layer, the intrinsic density d_p of the polymeric layer, and the volume ratio R_p of the polymeric layer expressed as a volume percentage of the polymeric layer of the material,
     - o identifying the E_a, E_p, Y_p, d_p, and R_p combinations enabling attainment of target values having the defined tolerance,
     - o determining, for each variable, an operating range,
   - selecting the steel and the polymeric layer for which each variable is within the range defined in the previous step,
   - manufacturing the corresponding sandwich structure.

2) Manufacturing method according to Claim 1 for which the target to be attained is a monolithic metallic material other than steel.

3) Manufacturing method according to Claim 2 for which the target to be attained is aluminum.

4) Manufacturing method according to Claim 3 for which the target to be attained is aluminum with a thickness of 0.9 mm.

5) Manufacturing method according to Claim 3 for which the target to be attained is aluminum with a thickness of 0.8 mm.

6) Manufacturing method according to any of the preceding claims for which the tolerance in attaining target values is 10%.

7) Manufacturing method according to any of the preceding claims for which the step of identifying the E_a, E_p, Y_p, d_p, and R_p combinations enabling attainment of the target values having the defined tolerance includes a step during which the E_a, E_p, Y_p, d_p, and R_p combinations are generated.

8) Manufacturing method according to Claim 7 including a graphical analysis step for the E_a, E_p, Y_p, d_p, and R_p combinations generated.

9) Sandwich structure obtainable by the process according to any of Claims 1 through 8 implemented for a 0.9 mm aluminum target with T_c=31.5 N/mm, B_c=10.2 N/mm, M_c =2.43 Kg/m² and a tolerance of 10%, for a sandwich structure including:
   - Two steel skin layers with steel thickness E_a between 0.133 mm and 0.165 mm,
   - A polymeric layer intercalated between the two skin layers and having:
     - A thickness E_p between (-2.5xEa+0.713) and (-2.5xEa+0.88),
     - A density d_p between 0.9 and 1.4,
     - A volume fraction R_p greater than or equal to 0.2 and strictly less than 1,
     - A Young's modulus Y_p lower than 4000 MPa,
     - Where the volume fraction R_p and the Young's modulus Y_p satisfy the inequality:

       $Y_p*(0.49*R_p^2+0.23*R_p+1/(Y_p*(1-R_p))) \geq 50$ MPa

10) Sandwich structure according to Claim 9 for which the steel thickness E_a is between 0.141 mm and 0.158 mm and the thickness E_p of polymeric layer is between (-2.5x E_a +0.73) and (-2.5x E_a +0.87).

11) Sandwich structure according to any of Claims 9 through 10 for which the polymeric layer comprises a mixture of a polyamide and a copolymer of ethylene and unsaturated carboxylic acid and/or its derivative.

12) Sandwich structure obtainable by the process according to any of Claims 1 through 8 implemented for a 0.8 mm aluminum target with T_c=28.0 N/mm, B_c=7.2 N/mm, M_c=2.16 Kg/m² and a tolerance of 10%, with the sandwich structure comprising:

- Two steel skin layers with steel thickness E_a between 0.118 mm and 0.146 mm,
- A polymeric layer intercalated between two skin layers and having:
    - A thickness E_p between (-2.5x E_a +0.632) and (-2.5x E_a +0.75),
    - A density d_p between 0.9 and 1.4,
    - A volume fraction R_p greater than or equal to 0.2 and strictly less than 1,
    - A Young's modulus Y_p lower than 4000 MPa,
    - Where the volume fraction R_p and the Young's modulus Y_p satisfy the inequality:

$$Y_p*(0.49*R_p^2+0.23*R_p+1/(Y_p*(1-R_p))) \geq 50 \text{ MPa}$$

13) Sandwich structure according to Claim 12 for which the steel thickness E_a is between 0.126 mm and 0.14 0mm and the polymeric layer thickness Ep is between (-2.5xEa+0.646) and (-2.5xEa+0.728).

14) Sandwich structure according to any of Claims 12 through 13 wherein the polymeric layer comprises a mixture of a polyamide and a copolymer of ethylene and unsaturated carboxylic acid and/or its derivative.