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(54) **Gripping device for transmission of tensile load to an elastic strip**

(57) A gripping device (10,40) for transmitting a tensile load to an elastic strip (22,48) comprising: a first part, having a through slit (20,46) adapted to accommodate the elastic strip (22,48), wherein the slit (20,46) constitutes, in its longitudinal section, a wavy curve such that a curvature of the wavy curve has a zero value at an entry point (24,74) into the through slit (20,46) , and a maximum value of the curvature in each subsequent wave is greater than in the previous one; wherein the load is transmitted to the elastic strip (22,48) due to friction forces arising from the elastic strip (22,48) tensioning into the through slit (20,46) and microslipping over curved surfaces of the through slit (20,46); and a second part adapted to fasten, in relation to the first part, an end of the elastic strip (22,48) emerging from an exit point (26,76) of the through slit (20,46). A method of transmitting a tensile load to an elastic strip (22,48) by means of the device is also provided.

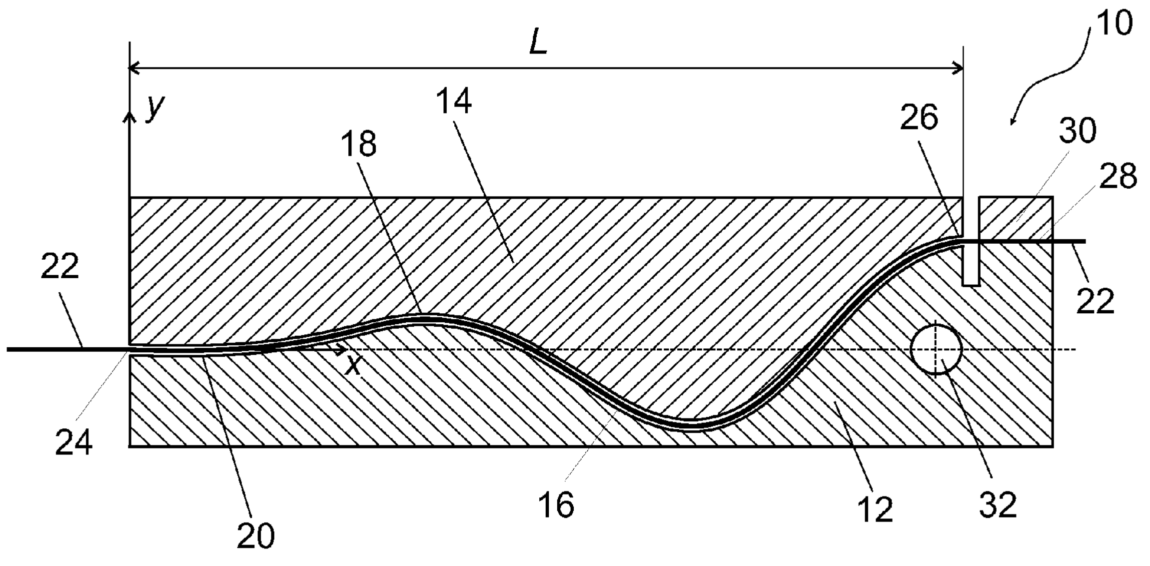

FIG. 1

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Description

TECHNICAL FIELD

[0001] The invention relates to gripping devices for transmitting a tensile load to an elastic strip and in particular to devices for transmitting a tensile load to elastic strips made of composite materials.

BACKGROUND ART

[0002] The advantages of tensioned elements made of composite materials, for example, from fibre reinforced plastic (FRP), can be summarized as follows: availability in any length, corrosion resistance, very high tensile strength, extremely low weight, low installation costs, flexibility.

[0003] The transmission of an outer load to tensioned composite strips is the key problem for their use and testing. The load transmission is realized by use of the anchorages also called grips or gripping devices. A tensile load is transmitted to a tensioned strip through shear stresses induced on its surface. These stresses can be frictional by their nature and generated during the microslipping of the strip in the gripping device.

[0004] The flat shape of the strip seems to be very appropriate for friction anchors where the strip is clamped between wedges or bolted plates.

[0005] Shear stresses may also have an adhesive nature, when the load is transmitted through the adhesive layer at the surface of the tensioned strip. In both cases shear stresses at the load transmission area are not uniformly distributed - there is a stress peak at the point of entry into anchorage or gripping device.

[0006] As is shown in G. PORTNOV and E. BAKIS Analysis of stress concentration during tension of round pultruded composite rods. Composite Structures. 2008, vol.83, p.100-109, this peak produces the normal stress concentration into near-surface layers considerably exceeding the mean stress in the tensioned strip. Such a situation causes the premature failure of a tensioned strip near the entry in anchorage and does not allow to achieve or determine the real maximum load carrying capacity corresponding to attainment of tensile strength by a uniformly distributed stress in the working area of the strip.

[0007] One way to decrease the shear stress peak at the entry into gripping device is the reduction of stiffness of the parts which are in direct contact with the surface of the tensioned strip. Such an idea was used in the patent application US 2007221894 A (BURTSCHER STEFAN L), entitled Anchoring for pre-tensioned and/or stressed tensile elements. It has been suggested to insert interlayers between the steel wedges and tensioned strip. Material of the interlayers must be more compliant than materials of strip and wedges. This allows to decrease the normal pressure near the entry into the gripping device and correspondingly to lower frictional shear stresses acting on the strip.

[0008] However, it is not an easy task to select a suitable material for the interlayers, a material combining such properties as compliance and sufficiently high bearing resistance and shear strength. Moreover, such interlayers, which are difficult to manufacture, could not be re-used. Finally, a peak of shear stress at the entry in such grips still remains.

[0009] Another way to reduce the stress concentration at the entry in the anchor is the use of wedge-shaped grips made of materials with variable stiffness, which is increasing in the direction away from the entry point. This way was described in the patent US 5713169 B (MEIER URS ET AL.), entitled Anchorage device for high-performance fiber composite cables. A cone element made of material with a minimum stiffness is located at the entry in the anchor, followed by another cone element of material with a higher stiffness and so on. This results in flattening of the shear stress peak.

[0010] However, selection of materials, manufacture of the cone elements, and assembling of the anchorage is labour consuming. Moreover, the reliability of the compliant materials under the high stress remains problematic. Finally, by applying this method, the shear stress peak at the entry in the anchor may be reduced but could not be avoided.

[0011] A gripping device of variable rigidity is proposed in the patent application US 2004216403 A (ANDRA HANS-PETER ET AL.), entitled The anchor for a strip-type tension member. The main idea is to divide clamping plates into segments connected by bridges of varying rigidity, the farther is the segment from the entry point the higher is the rigidity of the bridge.

[0012] However, the construction as a whole is difficult to manufacture and assemble, whereas it only reduces the shear stress peak, but does not permit to eliminate it completely.

[0013] Thus, the existing solutions of the problem of load transmission on a tensioned high-strength FRP strip solve this problem only partially. They lead to a certain decrease of shear stress concentration but the shear stress peak on the surface of tensioned strip does not disappear completely. The character of shear stresses distribution along a tensioned strip remains essentially the same - with maximum stress at the entry point in the gripping device followed by their decrease farther away from the entry. Hence the stress concentration at the entry in anchorage, while decreased, remains. Moreover, the application of adhesive or compliant interlayers in the gripping devices practically excludes a possibility to re-use the anchorage parts which are in an immediate contact with the surface of the tensioned element.

[0014] Therefore, there is a need in a simple gripping device which has not a shear stress peak at the entry point.

SUMMARY OF INVENTION

[0015] This objective is achieved by a gripping device for transmitting a tensile load to an elastic strip which comprises:

a first part, having a slit adapted to accommodate the elastic strip, wherein the through slit constitutes, in its longitudinal section, a wavy curve, such that a curvature of the wavy curve has a zero value at an entry point into the through slit, and a maximum value of the curvature in each subsequent wave is greater than in the previous one; wherein the load is transmitted to the elastic strip due to friction forces arising from the elastic strip tensioning into the through slit and microslipping over curved surfaces of the slit; and
a second part adapted to fasten, in relation to the first part, an end of the elastic strip emerging from an exit point of the through slit.

[0016] In such a gripping device the stresses in the elastic strip are smoothly changing along the slit in the first part. The absence of stress peaks in the elastic strip allows increasing the load transmitted to the strip.

[0017] The longitudinal wavy through slit for strip placement permits to load this strip by frictional shear and transversal stresses on its surfaces, generated by the tension of the strip lying on the curved surface of the slit. These stresses are applied alternately from the direction of upper or lower clamp depending upon the sign of curvature of the wavy slit.

[0018] Transmission of a tensile load to the elastic strip by tensioning the strip inside the wavy slit prevents from stress concentration on the surface of the strip at the entry point. The stress peaks that usually cause premature rupture of the strip in traditional grips being excluded, the load transmittable to the strip by the new gripping device may be substantially increased. The gripping device of invention permits to avoid peaks of the both types of stresses, the shear and transversal normal stresses, on the surface of the strip as well as longitudinal tensile stress concentrating in the near-surface layers of the strip.

[0019] Advantageously, the gripping device to be used for the elastic strip is made of fiber reinforced plastic (FRP), or carbon fiber reinforced plastic (CFRP). The device advantageously may be used with strips made of these or other composite materials obtained by pultrusion.

[0020] The gripping device is especially effective for loading strips made of composite materials, and in particular of FRP and CFRP materials because these materials, particularly CFRP, have essentially anisotropic mechanical properties - their shear and transversal strengths are dozens of times lower than their longitudinal tensile strength. Preferably, a tangent to the through slit at the exit point is parallel to the direction in which the tensile load is applied to the elastic strip at the entry point. This simplifies design and manufacture of the device.

[0021] Preferably, the first part contains two clamps having complementary wavy surfaces and the through slit is formed between the clamps by these complementary surfaces. This simplifies design and manufacture of the device.

[0022] It may be advantageous for some application to make the clamps of wood or plywood. Because the load is distributed along the length of the slit, the hardness of wood is high enough to make a reliable gripping device, while wood is a cheap and easily workable material. Use of these materials essentially simplifies making profiled surfaces of the clamps of the first part of the gripping device.

[0023] It may be advantageous in some embodiments to make the first part and the second part separate from each other. Preferably the first part and the second part are installed on a common base. That may simplify designing and manufacture of the device.

[0024] Preferably the wavy curve of the slit longitudinal section is defined by the equation

$$y_m(x_m) = A \cdot x_m^b \cdot \exp(-k(1-x_m)) \cdot \sin(\omega(1-x_m)+a),$$

where $x_m = \frac{x}{L}, y_m = \frac{y}{L}$ - dimensionless rectangular coordinates of the wavy curve with an origin at the entry point, L - a longitudinal distance between the entry and exit points, A, b, k, ω, a - dimensionless parameters.

[0025] The given equation permits to carry out analytical calculations of the load on the strip inside the first part of the gripping device and determine the stresses in it at the given properties of the strip. Availability of five parameters permits to control the shape of clamps profile in a wide range and optimize it to get the highest drop of strip tension (the lowest strip tension) at the exit from the first part of gripping device provided that the stresses in the strip nowhere exceed limit values. This will permit to decrease the length of the gripping device and simplify the design of its second part.

[0026] Preferably, the parameter b is greater than 2. At b higher than 2 the curvature of the strip at the entry point is always equal to zero, i.e. flexure and friction at this point are absent.

[0027] In another aspect of the invention there is proposed a method of transmitting a tensile load to an elastic strip comprising the following steps:

a) providing a gripping device according to the present invention as described above;
b) inserting the elastic strip into the through slit in the first part of the gripping device;
c) fastening the end of the elastic strip emerging from the exit point of the slit into the second part;
d) tensioning the elastic strip;
wherein the step d is performed after steps a, b, and c.

[0028] The method provides for absence of stress peaks in the elastic strip and allows increasing the load transmitted to the strip.

[0029] Preferably, the first part of the gripping device contains two clamps, further comprising a step of tightening of the elastic strip in the through slit. This simplifies the process of accommodation of the strip in the gripping device.

[0030] Still more preferably, the elastic strip is accommodated in the through slit with the possibility of its slipping inside the through slit. As there is no need to tightly jam the strip between claims, the danger of damaging the strip when pressing clamps together is eliminated.

[0031] Preferably, the second part may be attached only to the elastic strip and will abut against the first part when the strip is tensioned. This may simplify the construction of the device.

BRIEF DESCRIPTION OF DRAWINGS

[0032]

FIG. 1 is a schematic longitudinal section of a first embodiment;
FIG. 2 is a schematic side view of the preferred embodiment;
FIG. 3A shows a slit profiles calculated with different parameters;
FIG. 3B shows initial parts of the profiles shown in FIG. 3A;
FIG. 4 shows the curvature of the slit;
FIG. 5 shows a transversal force in the strip along with slit profile;
FIG. 6 shows the longitudinal tensile forces in the strip along the slit;
FIG. 7 shows the frictional forces acting on the strip along the slit together with the slit curvature;
FIG. 8A shows the frictional stresses acting on the surfaces of the strip;
FIG. 8B shows the initial part of the graph in FIG. 8A;
FIG 9 shows the distribution of stresses on the surface of the strip loaded by means of traditional wedged grips.

DESCRIPTION OF EMBODIMENTS

[0033] In the first embodiment of the invention the gripping device 10, schematically represented in FIG. 1, consists of one clamp 12 and another clamp 14 which have complementary wavy surfaces, shown on the figure as an upper surface 16 of clamp 12 and lower surface 18 of clamp 14. When clamps 12 and 14 are put together, a slit 20 is formed between them. The strip 22 made of a composite material is inserted into this slit 20 and the clamps 12 and 14 are slightly pressed together either by tightening screws (not shown) or by an external case (not shown) or by any other suitable means. That initial clamping force applied to clamps 12 and 14 is needed to provide the initial bending of the strip 22 before its tensioning. It is not important by what means the clamps 12 and 14 are pressed together as far as this means are strong enough to keep both clamp 12 and 14 together when the strip 22 is tensioned and tends to push the clamps 12 and 14 apart.

[0034] The strip 22 entering into the slit 20 at the entry point 24, follows the curvature of the slit 20 and emerges from the slit 20 at the exit point 26. Here, after emerging from the exit point 26, the outer end 28 of the strip 22 is fastened or fixed to the clamp 12 by a clamping device or a terminal clamp 30 which serves as an end fixing_mean to prevent the strip 22 from sliding out of the slit 20.

[0035] Thus, the gripping device 10 consists of two distinctive parts, one of them being frictional, in which the load is transferred to the strip 22 by frictional forces arising when the strip 22 is tensioned in the wavy slit 20, and the other being just the end fixing mean, in which the end of the strip 22 is fixed to provide an initial resistance that will keep the strip 22 from sliding out of the slit 20 and provide balance of forces acting on the strip during its loading.

[0036] The outer end 28 of the strip 22 may be fixed by any known in the art method, it can be clamped, wedged, glued, etc. At this point the tensile force produced by the load applied to the strip 22 is substantially reduced by the frictional forces applied to the strip 22 in the slit 20.

[0037] The gripping device 10 further has an opening 32 for application of an external tensile force to the gripping device 10. The opening is located in such a way that the direction of external tensile force coincides with direction of the strip 22 at the entry point 24.

[0038] A schematic representation of the preferred embodiment of the gripping device 40 is shown in FIG. 2. Such gripping device 40 may be used for tensioning of strip type tension elements that are used for strengthening of building structure. The device 40 may also be used for mechanical testing such strip type elements. The gripping device 40 consists of two main parts.

[0039] It contents first frictional part with longitudinal curved through slit 46. Surfaces of the slit are complementary, orthogonal to the plane of gripping device and are snug against the surfaces of the strip 48 without significant pressure.

[0040] Presence of the gap between surfaces of strip 48 and slit 46 is allowed and do not affect significantly on the behavior of the first part of the gripping device 40.

[0041] A longitudinal cross-section of the mentioned slit 46 represents a wavy curve with zero curvature at the tip of the slit, i.e. the strip 48 enters into the slit 46 without flexure and with zero frictional stresses.

[0042] Then the curvature of the slit 46 increases gradually along the slit 46 up to a maximum value, next drops to zero, again increases, changing its sign, up to another maximum value and so on.

[0043] At the same time, maximum values of the curvature increase as they move away from the entry point further into the slit 46. In line with this change of the curvature of the slit 46, shear stresses on the surface of the strip 48 in its tension state are changed and the bending moments, created in the strip 48 during its installing into the slit 46 in preparation of device for operation, are changed also.

[0044] The longitudinal profile of the slit 46 and change of its curvature are calculated for a specified strip in such a way that total tension stresses in the strip 48 into the slit 46 arising from the bending during its installing into the slit 46 and from the tension created under loading of gripping device do not exceed the tensile strength of the strip 48.

[0045] Since the tension in the strip 48 is decreasing in the direction away from the entry point 74 into the slit 46 then the curvature can increase correspondingly. When designing the slit 46 it is appropriate to seek to maximize an allowable increase of its curvature since at that the frictional stresses at the surface of the strip 48 increase and therefore the effectiveness of the gripping device 40 as a whole grows too. This, in particular, permits to shorten the length of the device.

[0046] Parameters of the curve describing the profile of the slit are chosen so that the direction of the strip 48 at the entry into the slit 46 coincides with the direction of the external tensile force, but at the exit point 76 from the slit it might be parallel to this direction.

[0047] A slit profile in the first frictional part of gripping device 40 is defined by the flexural stiffness and strength of the loaded strip 48. Use of the same gripping device 40 for strips with different flexural stiffnesses may be ineffective.

[0048] An increase of the friction coefficient between the surfaces of the slit 46 and strip 48 increases the load transferred to the strip 48 by frictional part of gripping device 40.

[0049] To provide a normal behavior of the gripping device 40 the end of the strip 48 that exits from the rear end (exit point 76) of the through slit 46 must be fastened to prevent its displacement under tension which is equal to the difference between the full external load and part of the load transmitted by the frictional part of gripping device 40.

[0050] This fastening is carried out by the second part of the gripping device 40. A design of this part is not of fundamental importance for the serviceability of gripping device 40 as the tension at the entrance into the second part of device 40 is much lower than a maximum tension applied to the strip 48 at the entry in the first part. This task may be done by means of any traditional clamp, bond, bond-clamp or wedge type anchor.

[0051] The first part - frictional - is made by two complimentary clamps 42 and 44 that are forming a curvilinear through slit 46 where a strip type element or strip 48 is placed.

[0052] The clamps are inserted into a fixture made by two bars - a fixed bar 50 and a movable bar 52 that are pressed to the clamp 44 with adjusting screws 54 penetrating the fastened bar 56.

[0053] Bars 56 and 50 are fastened to the device base 58 by screws 64. Stepped thrust blocks 60 and 62 for the clamps 44 and 42 face planes are fastened also to the base 58 by screws 64.

[0054] The second part of the gripping device 40 is a wedge anchor 66,68 that can move along the guiding grooves (not shown) in the base 58. A cover plate 70 with a hole or opening 72 for the thrust axis is placed behind the anchor 66, 68.

[0055] During preparation of the gripping device 40 the adjusting screws 54 are unscrewed and bar 52 is extended. This allows pulling apart the clamps 42 and 44, widening the slit 46 and placing the strip 48 into it.

[0056] After the strip 48 is placed in the slit 46 the bar 52 is put back in place and the clamps 42 and 44 are slightly pressed with adjusting screws 54 to take out the clearance between clamps 42, 44 and strip 48. After that the end of the strip 48 is clamped in the anchor 66,68 (second part of the gripping device 40) that is installed in the level with the rear end of the slit 46.

[0057] After applying an external force through the cover plate 70, the strip 48 slides inside the slit of the first part of gripping device up to appearance of a longitudinal force in the anchor 66,68. After that the strip 48 is loaded with the friction forces and pressure appearing during its turning round under tension of the curved surfaces of the clamps 42 and 44.

[0058] These forces going with microsliding of the strip 48 due to its deformation increase with the rise of tension of strip 48.

[0059] The adjusting screws 54 prevent the separation of the clamps 42 and 44 under the action of transversal forces generated by tension of the strip 48 on the curved surfaces of the clamps 42, 44.

[0060] The longitudinal components of the forces acting on the clamps 42 and 44 are taken up by the stepped thrust blocks 62 and 60. While significantly decreased tensions in the strip-type element 48 after its exit from the first (frictional) part of the gripping device 40 are taken up in the second part of gripping device by the wedge anchor 66,68 or another traditional anchor.

AN EXAMPLE OF DESIGNING AND ANALYSIS OF THE GRIPPING DEVICE

Description of the contact surfaces of the clamps

[0061] For the purpose of this example we consider a gripping device schematically shown in Fig.1, wherein the first part of the gripping device consist of two clamps that form a slit between their contact surfaces.

[0062] The equation governed the shape of the clamps contact surfaces is chosen in line with a conception that a tensioned strip is loaded into the clamps with gradually increasing shear forces. This is achieved by a gradual increase of friction on its surface, generated mainly by the contact pressure of the tensioned strip on the convex curved surfaces of the clamps that define the slit and elastic line of the strip. This pressure and, therefore, friction is proportional to the curvature of the surface.

[0063] Deformation of the strip, along the curvature of the slit, is accompanied with the emergence of the bending moment and bending stresses in it. It is evident that these stresses must increase gradually, in accordance with the decrease of the tension in the strip as the distance of the entrance into the clamps to avoid the failure under the action of both these stresses. Total stresses induced by bending and tension must not exceed the tensional strength of the strip. So both requirements lead to conclusion that the shape of the slit profile must have a variable curvature increasing along the slit starting from the zero value at the entrance into the gripping device.

[0064] Taking into account the limitation of the clamps thicknesses, the profile must be defined as a periodic curve. A curve described by the equation according to claim 10 can meet these requirements:

$$y_m(x_m) = A \cdot x_m^b \cdot \exp(-k(1-x_m)) \cdot \sin(\omega(1-x_m)+a) \qquad (1)$$

where $x_m = \frac{x}{L}, y_m = \frac{y}{L}$, L - distance between entry and exit points of the slit,

A, b, k, ω, a - dimensionless parameters .

[0065] Presence of multiplier x_m^b *at* $b > 2$ ensures the zero values of the first and second derivatives at the initial point of the slit ($x_m = 0$). This means that at the entrance into the slit the strip will be directed along the axle x (see FIG. 1) and not be loaded with bending. One can obtain the zero value of the first derivative also at the exit point $x_m = 1$ ($x=L$) by the corresponding choice of the parameter *a,* i.e. at the exit point the strip will be parallel to the axle x too. These properties provide a substantially simpler design of the gripping device. Corresponding value of parameter $a = a_o$ is as following:

$$a_0 = \arctan\left(\frac{\omega}{b-k}\right) + n \cdot \pi \qquad (2)$$

$n = 0,2,4...$
$n = 1,3,5...$

[0066] Substitution of $a = a_o$ into Eq. (1) gives at n equal to even and odd numbers specularly reflected curves which shape does not depend on n . Curves described with Eq.(1) at $a = a_0$ ($n = 1$) and different values of other parameters are shown in FIG. 3 A, B. For all curves $A = 0.5, \omega = 3 \cdot \pi, n = 1$. For $y1_m(x_m)$ (thick curve) - $k = 1$, $b = 3$, *for* $y2_m(x_m)$ (dashed curve) - $k = 2$, $b = 3$, and for $y3_m(x_m)$ (thin curve) - $k = 1.5$, $b = 2.1$. An initial part of profile is shown in FIG. 3B. As may be seen, changing the values of parameters one can change the shape of the slit profile within wide limits.

[0067] Let us define the first and second derivative of the slit profile, described by Eq. (1) at $a = a_0$

$$\frac{dy}{dx}=\frac{dy_m}{dx_m}=-A\cdot x_m^{b-1}\cdot e^{-k\cdot x_m}\left(\left(b-k\cdot x_m\right)\sin\left(\omega\left(1-x_m\right)+a_0\right)-\omega\cdot x_m\cos\left(\omega\left(1-x_m\right)+a_0\right)\right)$$

(3)

$$\frac{d^2y}{dx^2}=\frac{1}{L}\cdot\frac{d^2y_m}{dx_m^2}=-A\cdot x_m^{b-2}e^{-k\cdot x_m}\begin{bmatrix}2x_m\omega\left(k\cdot x_m-b\right)\cos\left(\omega\left(1-x_m\right)+a_0\right)+\\+\left(\left(b-k\cdot x_m\right)^2-b-\omega^2x_m{}^2\right)\cdot\sin\left(\omega\left(1-x_m\right)+a_0\right)\end{bmatrix}\quad(4)$$

[0068] In what follows the value of profile curvature K must be defined exactly because the amplitude of strip bending into the slit may be much more than its thickness:

$$K=\frac{\dfrac{d^2y}{dx^2}}{\left[1+\left(\dfrac{dy}{dx}\right)^2\right]^{\frac{3}{2}}}=\frac{\dfrac{1}{L}\cdot\dfrac{d^2y_m}{dx_m^2}}{\left[1+\left(\dfrac{dy_m}{dx_m}\right)^2\right]^{\frac{3}{2}}}\qquad(5)$$

[0069] Full expression for K is not cited due to its awkwardness. Variation of reduced (dimensionless) curvature $K_m = K \cdot L$ along the profile of the slit with A = 0.5,k =1,ω = 3·π,b = 3,n =1 and reduced profile itself (multiplied by 3 0) are shown in FIG. 4.

[0070] As may be seen, the exact value of the strip curvature between the closed clamps (thick line) differs significantly in the second part of considered slit profile (thin line) from its approximation - second derivative (dashed line) - usually used in the theory of bending. The force factors acting on the strip during its loading into the gripping device

[0071] A set of equations descriptive of the stress-state of elastic flexible strip is used to determine force factors in the strip placed between closed profiled clamps and loaded with tensile force at the entrance into the slit. These equations take a form (USIUKIN, V.I. Structural mechanics of space structures. Moscow, Mashinostroenie, 1988, 390p (in Russian)) in the strip:

$$\frac{dQ}{dx}-T\frac{d^2y}{dx^2}\left[1+\left(\frac{dy}{dx}\right)^2\right]^{-1}=-q_3\left[1+\left(\frac{dy}{dx}\right)^2\right]^{\frac{1}{2}};\qquad(A)$$

$$\frac{dT}{dx}+Q\frac{d^2y}{dx^2}\left[1+\left(\frac{dy}{dx}\right)^2\right]^{-1}=-q_1\left[1+\left(\frac{dy}{dx}\right)^2\right]^{\frac{1}{2}};\qquad(B)$$

$$\frac{dM}{dx}-Q\left[1+\left(\frac{dy}{dx}\right)^2\right]^{\frac{1}{2}}=0;\qquad(C)$$

$$M = EJ\frac{d^2y}{dx^2}\left[1+\left(\frac{dy}{dx}\right)^2\right]^{-\frac{3}{2}}. \qquad \text{(D)}$$

where Q,T,M - transverse, tensile forces and bending moment in the strip correspondingly, q_1,q_3 - distributed longitudinal and compressive surface loads per unit length, $y(x)$ - elastic line of loaded strip, EJ - bending stiffness of the strip (E- longitudinal modulus of the strip, J - moment of inertia of the strip cross-section)

[0072] To solve the inverse problem - calculate the force factors Q,T,M and external loads q_1, q_3 in the strip placed into the slit and flexed to a predetermined curve y(x) (corresponding to the profile of the slit) - it is necessary to establish analytically the shape of curve and the relation between q_1 and q_3.

[0073] The shape of curve and its first and second derivatives were defined in previous section.

[0074] Using the fourth equation (D) of the system (A) ÷ (D) one can calculate the current value of the reduced bending moment

$$M_m = \frac{M \cdot L}{EJ} = K_m, \qquad (6)$$

[0075] Thus the reduced (dimensionless) bending moment in the section of strip flexed to the predetermined shape of the slit profile is equal to the reduced curvature of profile at the x_m - coordinate corresponding to considered section of the strip and may be illustrated with the same FIG. 4.

[0076] Substituting (6) into equation (C) one can obtain the expression for reduced transversal force:

$$Q_m = \frac{Q \cdot L^2}{EJ} = \frac{1}{\sqrt{1+\left(\frac{dy_m}{dx_m}\right)^2}} \cdot \frac{dM_m}{dx_m} = \frac{1}{\sqrt{1+\left(\frac{dy_m}{dx_m}\right)^2}} \cdot \frac{dK_m}{dx_m}, \qquad (7)$$

[0077] Variation of Q_m along the axle of profile is shown in FIG. 5. Differentiation $\frac{dK_m}{dx_m}$ required for calculation of Q_m was performed numerically using MAPLE software. Values of profile parameters corresponded to used as before. The shape of the curved strip increased in 300 times is also shown in FIG. 5 (thin line).

[0078] Let us go to estimation of longitudinal force T in the strip under the tension with the force To, applied at the entrance into the gripping device. Tension of the strip into the slit formed by profiled clamps, which are snug against to a strip, is accompanied with the microslipping of the tensioned strip over the entire curved surfaces of the clamps. This causes the appearance of a contact pressure per unit length q_3, normal to enveloped surface and frictional force per unit length $q_1 = f_r \cdot q_3$, backward to the direction of microslipping (f_r - coefficient of sliding friction). Thus, it is assumed that pressure on the strip is unilateral and is generated only by tension of the strip. Contact pressure due to the external compression of the clamps is absent. Bolted connection of the clamps is required only for preconnecting the clamps and avoidance of their further separation under the action of strip tension.

[0079] Using the accepted relation between q_1 and q_3 and eliminating them from the equations (A) and (B) we obtain the following differential equation with respect to the longitudinal force in the strip T :

$$\frac{dT}{dx}+\frac{\left|\frac{d^2y}{dx^2}\right|}{1+\left(\frac{dy}{dx}\right)^2}\cdot f_r\cdot T+\frac{dQ(x)}{dx}\cdot f_r+\frac{\left|\frac{d^2y}{dx^2}\right|}{1+\left(\frac{dy}{dx}\right)^2}\cdot Q(x)=0\ . \qquad (8)$$

with initial condition

$$T(0)=T_0 \qquad (9)$$

[0080] The solution of Eq. (8) must not depend on the sign of curvature and direction of normal pressure q_3. Regardless of the side of strip where pressure is applied, corresponding frictional force per unit length $q_1 = f_r \cdot q_3$ always will be directed backward to the direction of the strip tension, i.e. in the direction of increasing *x* and has a positive value. This leads to the need to use absolute values of the second derivative of the profile - $\left|\frac{d^2y}{dx^2}\right|$. The transversal force Q(x) is defined from equations (C) and (D), as was shown before. Multiplying every term in (8) by $\frac{L^3}{EJ}$ we can pass to dimensionless values:

$$\frac{dT_m}{dx_m}+\frac{\frac{d^2y_m}{dx_m{}^2}}{1+\left(\frac{dy_m}{dx_m}\right)^2}\cdot f_r\cdot T_m+\frac{dQ_m(x_m)}{dx_v}\cdot f_r+\frac{\frac{d^2y_m}{dx_m{}^2}}{1+\left(\frac{dy_m}{dx_m}\right)^2}\cdot Q_m(x_m)=0 \qquad (10)$$

$$T_m(0)=T_{m0} \qquad (11)$$

where

$$T_m=\frac{T\cdot L^2}{EJ},\ \ Q_m=\frac{Q\cdot L^2}{EJ},\ \ y_m=\frac{y}{L}, x_m=\frac{x}{L}.$$

[0081] It is interesting to compare the future solution of (10), describing the distribution of the longitudinal force in the flexible strip having little but finitesimal bending stiffness with a similar solution obtained ignoring of resisting to bending, i.e. assuming that *M* = 0 and, hence, Q = 0 in Eq. (A) - (D). With these assumptions Eq. (10) takes a form:

$$\frac{dT_m}{dx_m}+\frac{\left|\frac{d^2y_m}{dx_m^{\;2}}\right|}{1+\left(\frac{dy_m}{dx_m}\right)^2}\cdot f_r\cdot T_m=0 \qquad (12)$$

[0082] Eq. (12) coincides in shape with equation for limit balance of absolutely flexible thread on the curved surface with consideration of friction between thread and surface. (MINAKOV, A.P. The foundations of thread winding and reeling. Tekstiljnaja promishlennostj. 1944 , 10, pp. 11-16, 11-12, pp.10-18). Eq. (12) with initial condition (11) allows the analytical decision:

$$T2_m(x_m)=T_{m0}\cdot\exp\left(-f_r\int_0^{x_m}\frac{\left|\frac{d^2y_m}{dx_m^2}\right|}{1+\left(\frac{dy_m}{dx_m}\right)^2}dx_m\right); \qquad (13)$$

[0083] The solution of Eq. (10) - $T1_m(x_m)$ may be obtained with numerical methods after substitution of $Q_m(x_m)$ from (7).

[0084] For comparison of the solutions and analysis of the stress-state of the loaded strip it is expediently to assign the numerical values of geometrical and physical parameters described the properties of CFRP strip.

<u>The properties of considered CFRP strip</u>

[0085] Mechanical properties: Strength in tension $\sigma_T^{\lim}=2700MPa$, elastic modulus in tension E =148.3GPa.

[0086] Geometry: width b = $15\cdot10^{-3}\,m$, thickness $h=0.5\cdot10^{-3}m$.

[0087] Cross-section characteristics: area $S=bh=0.75\cdot10^{-5}m^2$, moment of inertia

$J=\dfrac{bh^3}{12}=0.1562500\cdot10^{-12}m^4$, moment of resistance $W=\dfrac{bh^2}{6}=0.625\cdot10^{-9}m^3$,

stiffness in bending $EJ=0.023172\cdot N\cdot m^2$.

<u>Limiting characteristics of the strip</u>

[0088] Limiting radius of curvature lim R = 0.015m (was defined experimentally and correspond to the failure in pure bending).

[0089] Limiting curvature $\lim K=\dfrac{1}{\lim R}=66.67(1/m)$

[0090] Limiting tensile force in the stripe $T_{\lim}=\sigma_T^{\lim}\cdot S=20250N$

[0091] Let suppose that the tensile force at the entrance in the gripping device is equal to limiting value: $T(0)=T_0=T_{\lim}=20250N$. Then the reduced initial value of longitudinal force at $x_m=0$ will be equal to $T_{m0}=\dfrac{T_{\lim}\cdot L^2}{E\cdot J}=78650$.

This value is considered as the initial condition (11) in solution of equations (10), (12).

[0092] Outcomes of solving equations (10) and (12) are shown in FIG. 6 for the same geometry of the slit profile as before and at $f_r=0.2$ and $T_{m0}=78650$. As may be seen the results of the numerical solution of exact Eq. (10) (solid line) and analytical solution of simplified Eq. (12) (points) practically coincide at the given value of the applied external force.

[0093] Thus, the interaction of considered strip of low rigidity in bending with the surfaces of profiled clamps during its microslipping coincide with the interaction of a flexible thread. Calculations showed that difference is noticeable only at very low values of T_{m0} - on the order of 1 % of the limiting tension. Over the range of loads of practical interest the analytical solution (13) may be used where the impact of the initial bending of the strip, generated by the closing of profiled clamps, on the distribution of tensile force is neglected.

[0094] As one can see, the longitudinal tensile force in the strip at the exit point is about two times less than at the entrance. Fixation of the strip's end in the second part of gripping device can be made with traditional methods: bond, clamp or wedged anchors. Stress concentration at such level of tensile load cannot be dangerous.

[0095] Let us consider frictional forces acting on the surface of the strip under application of the limit tensile load To = $T_{\lim}$ at the entrance into the gripping device. Frictional force per unit length q_1 may be defined from Eq. (B) neglecting the value of transversal force Q:

$$q_1 = -\frac{\frac{dT}{dx}}{\sqrt{1+\left(\frac{dy}{dx}\right)^2}}; \qquad (14)$$

[0096] Transferring to the dimensionless force $T_m = \frac{T}{E \cdot J / L^2}$ and coordinates $x_m = \frac{x}{L}, y_m = \frac{y}{L}$ one obtains that dimensionless frictional force per unit length has a form

$$q_{1m} = \frac{q_1}{E \cdot J / L^3}. \qquad (15)$$

[0097] Its distribution along the profile of grips at friction coefficient equal to 0.2 is shown in FIG. 7 together with variation of curvature (thin line). As would be expected, frictional force achieves its maximums at locations of slit profile curvature maximums. Positive values of the curvature correspond to the frictional forces applied to the lower side of strip, negative - to the upper side.

[0098] Dimensional values of shear stresses τ_{fr} acting on the surfaces of the stripe may be calculated through the values of reduced frictional force per unit length (15) and characteristics of the stripe, which were defined earlier:

$$\tau_{fr} = \frac{q_{1m} \cdot EJ}{L^3 b} \qquad (16)$$

where the assumed longitudinal length of the slit L = 0.3m

[0099] Frictional stresses acting on the surfaces of the strip are presented in FIG. 8A, B.

[0100] The peak of shear stress at the entrance into the gripping device typical for traditional force transfer - through bonding or wedge grips - is absent. Interaction of the strip with grips increases gradually- frictional forces on the surface of the strip increase wavy with gradually increasing height of each wave. Elimination of shear stress peak leads to elimination of other stress concentration at the entrance into the gripping device.

[0101] For comparison, stress distribution on the surface of the strip loaded by means of traditional wedged grips is shown in FIG. 9. As may be seen the distributions of shear stress in FIG. 8 and FIG. 9 differ fundamentally from each other.

[0102] Stresses in the strip may be calculated and compared with their limit values using the above mentioned formulae and characteristics of considered CFRP strip.

REFERENCE SIGNS LIST

[0103]

10 gripping device

12 clamp

14 clamp

16 wavy surface of clamp 12

18 wavy surface of clamp 14

20 slit

22 strip

24 entry point

26 exit point

28 outer end of strip

30 end clamp

32 opening

40 gripping device

42 clamp

44 clamp

46 slit

48 strip

50 fixed bar

52 movable bar

54 adjustment screws

56 fastened bar

58 device base

60 stepped thrust block

62 stepped thrust block

64 fastening screws

66 wedge casing

68 wedges

70 cover plate

72 opening

74 entry point 76 exit poit

CITATION LIST

[0104]

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Claims

1. A gripping device (10, 40) for transmitting a tensile load to an elastic strip (22, 48) comprising:

a first part, having a through slit (20, 46) adapted to accommodate the elastic strip (22, 48), wherein
the slit (20, 46) constitutes, in its longitudinal section, a wavy curve such that
a curvature of the wavy curve has a zero value at an entry point (24, 74) into the through slit (20, 46), and
a maximum value of the curvature in each subsequent wave is greater than in the previous one; wherein
the load is transmitted to the elastic strip (22, 48) due to friction forces arising from the elastic strip (22, 48) tensioning into the through slit (20, 46) and microslipping over curved surfaces of the through slit (20, 46); and
a second part adapted to fasten, in relation to the first part, an end of the elastic strip (22, 48) emerging from an exit point (26, 76)of the through slit (20, 46).

2. The device according to claim 1, wherein the elastic strip (22, 48) is made of a fiber reinforced plastic (FRP).

3. The device according to claim 1, wherein the elastic strip (22, 48) is made of a carbon fiber reinforced plastic (CFRP).

4. The device according to any of claims, wherein the elastic strip (22, 48) is made of a composite material by pultrusion.

5. The device according to claim 1, wherein a tangent to the through slit (20, 46) at the exit point (26, 76) is parallel to the direction in which the tensile load is applied to the elastic strip (20, 46) at the entry point (24, 74).

6. The device according to claim 1 wherein the first part comprises two clamps (12, 14, 42, 44) having complementary wavy surfaces and the through slit (20, 46) is formed between the clamps (12, 14, 42, 44) by these complementary surfaces.

7. The device according to claim 6, wherein the clamps (12, 14, 42, 44) are made of wood or plywood.

8. The device according to claim 1 wherein the first part and the second part are separate from each other.

9. The device according to claim 8 wherein the first part and the second part are installed on a common base (58).

10. The device according to any of preceding claims wherein the wavy curve is defined by the equation

$$y_m(x_m) = A \cdot x_m^b \cdot \exp(-k(1-x_m)) \cdot \sin(\omega(1-x_m)+a),$$

where $x_m = \frac{x}{L}, y_m = \frac{y}{L}$ - dimensionless rectangular coordinates of the wavy curve with an origin at the entry point, *L* - a longitudinal distance between the entry and exit points, *A, b, k,* ω*, a* - dimensionless parameters.

11. The device according to claim 10, wherein the parameter *b* is greater than 2.

12. A method of transmitting a tensile load to an elastic strip (22, 48) comprising the following steps:

a) providing a gripping device (10, 40) according to any of the claims 1-11;
b) inserting the elastic strip (22, 48) into the through slit (20, 46) in the first part of the gripping device (10, 40);
c) fastening the end of the elastic strip emerging from the exit point (26, 76) of the slit (20, 46) into the second part;
d) tensioning the elastic strip (22, 48);
wherein the step d is performed after the steps a, b, and c.

13. The method according to claim 12, wherein the first part of the gripping device (10, 40) comprises two clamps (12, 14, 42, 44), further comprising a step of tightening of the elastic strip (22, 48) in the through slit (20, 46).

14. The method according to claim 12 or 13, wherein the elastic strip (22, 48) is accommodated in the through slit (20, 46) with the possibility of its slipping inside the through slit (20, 46).

15. The method according to any of claims 12-14, wherein the second part with attached elastic strip (22, 48) abuts against the first part when the strip (22, 48) is tensioned.

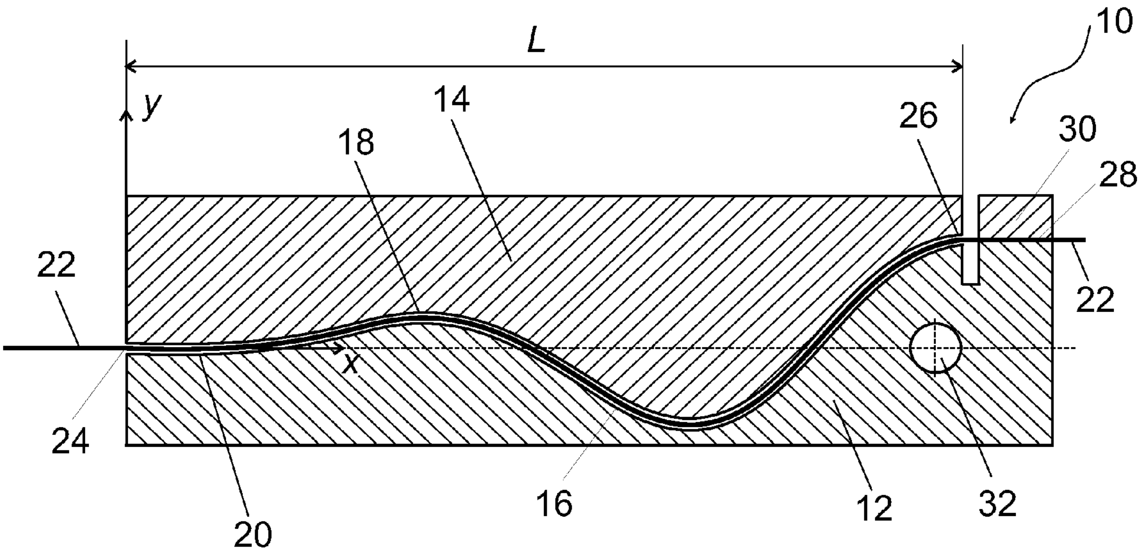


FIG. 1

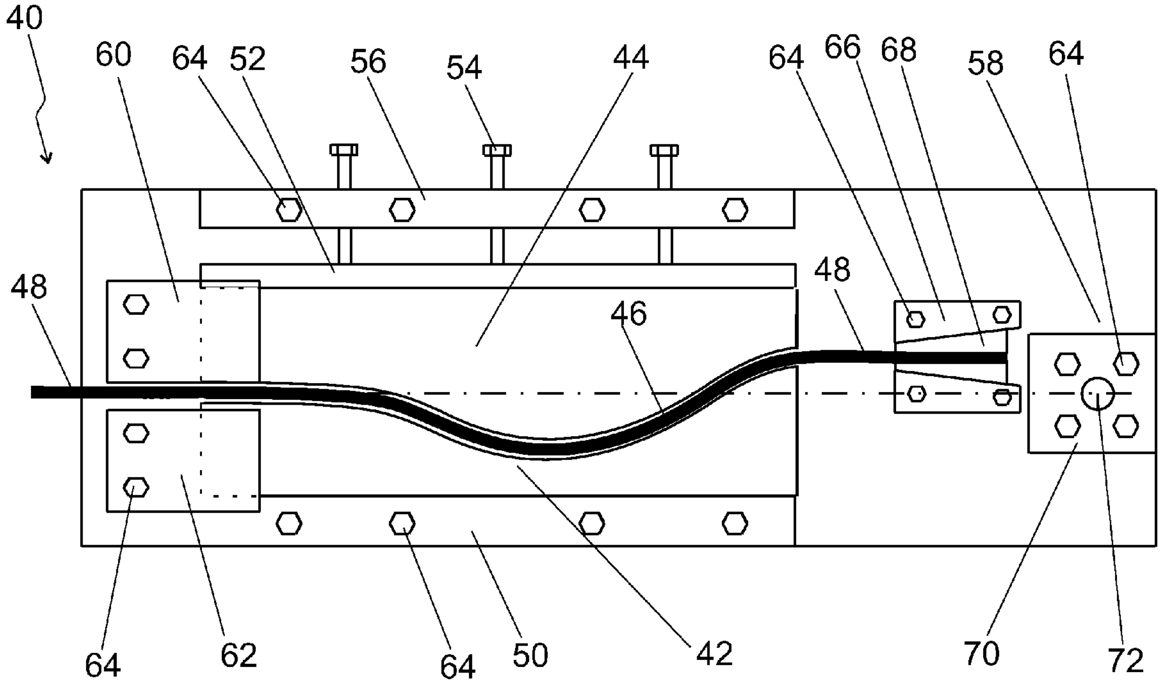


FIG. 2

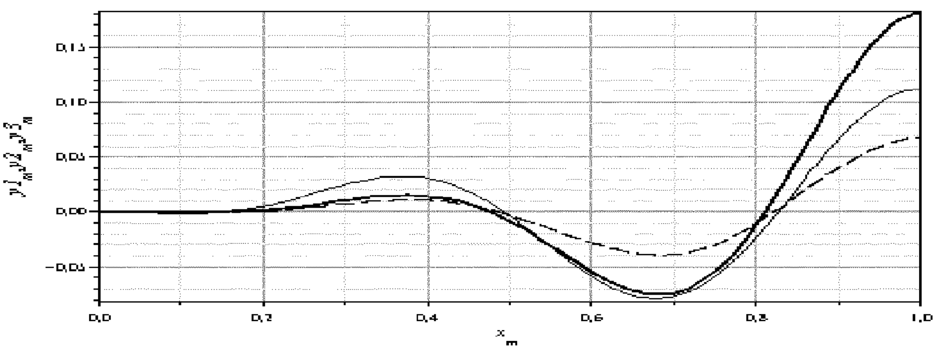


FIG. 3A

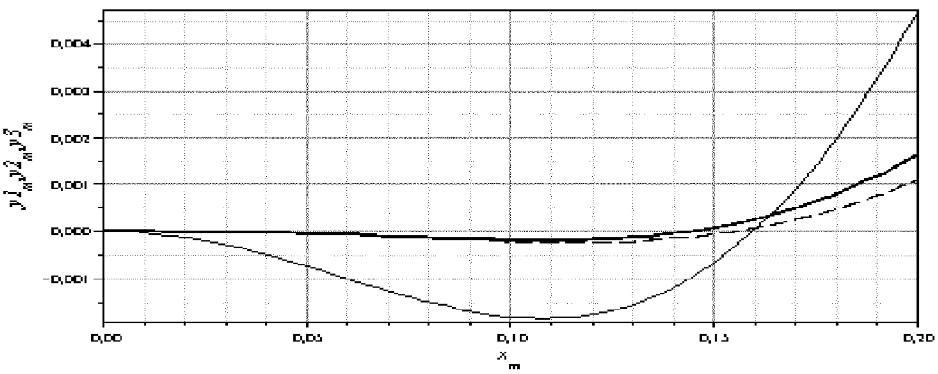


FIG. 3B

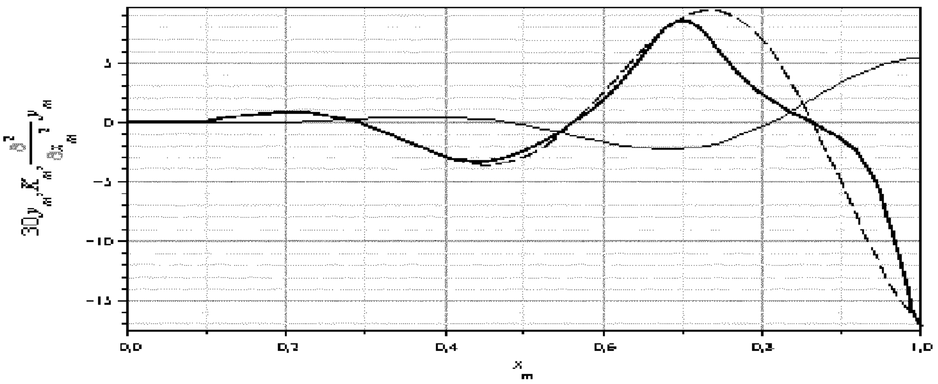


FIG. 4

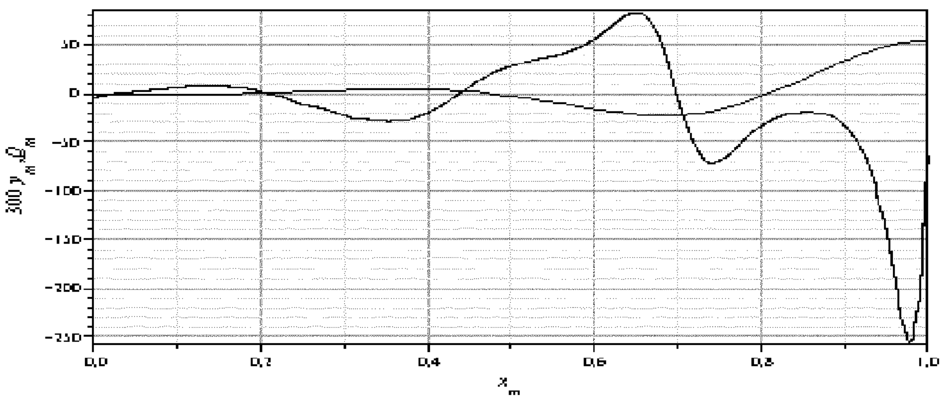


FIG. 5

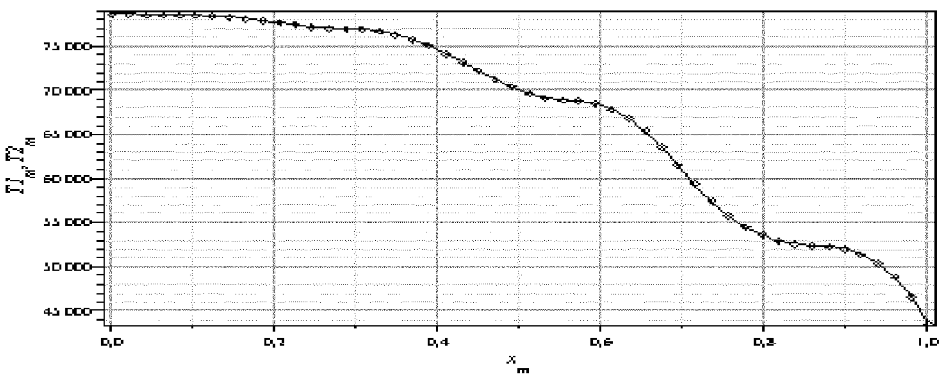


FIG. 6

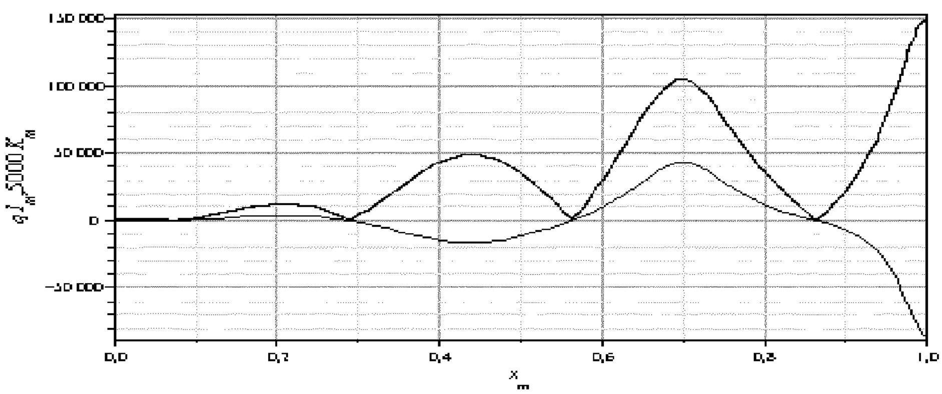


FIG. 7

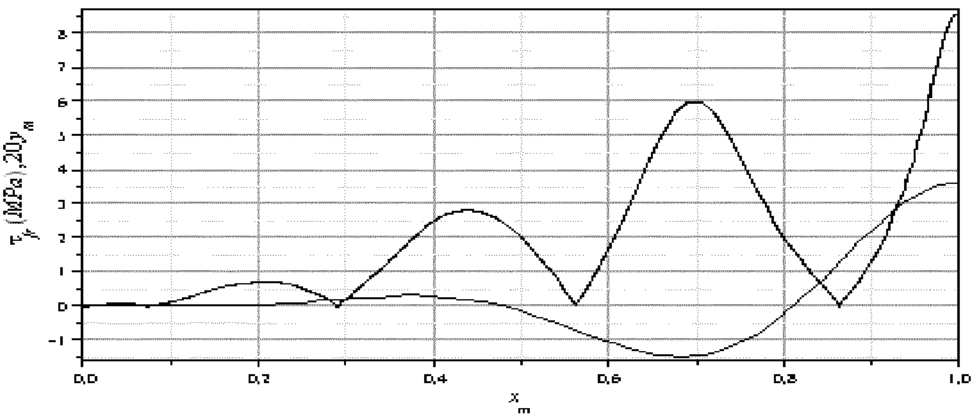

τ_{yr} (MPa), 20 y_m
8
7
6
5
4
3
2
1
0
-1
0,0
0,2
0,4
0,6
0,8
1,0
x_m

FIG. 8A

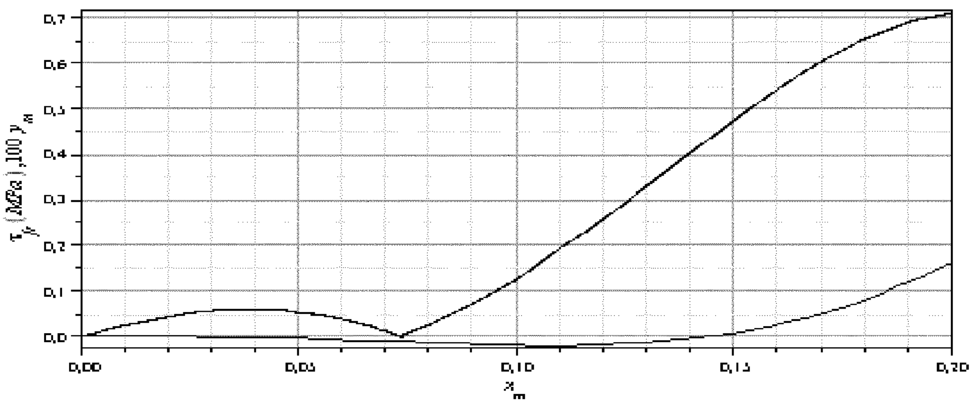
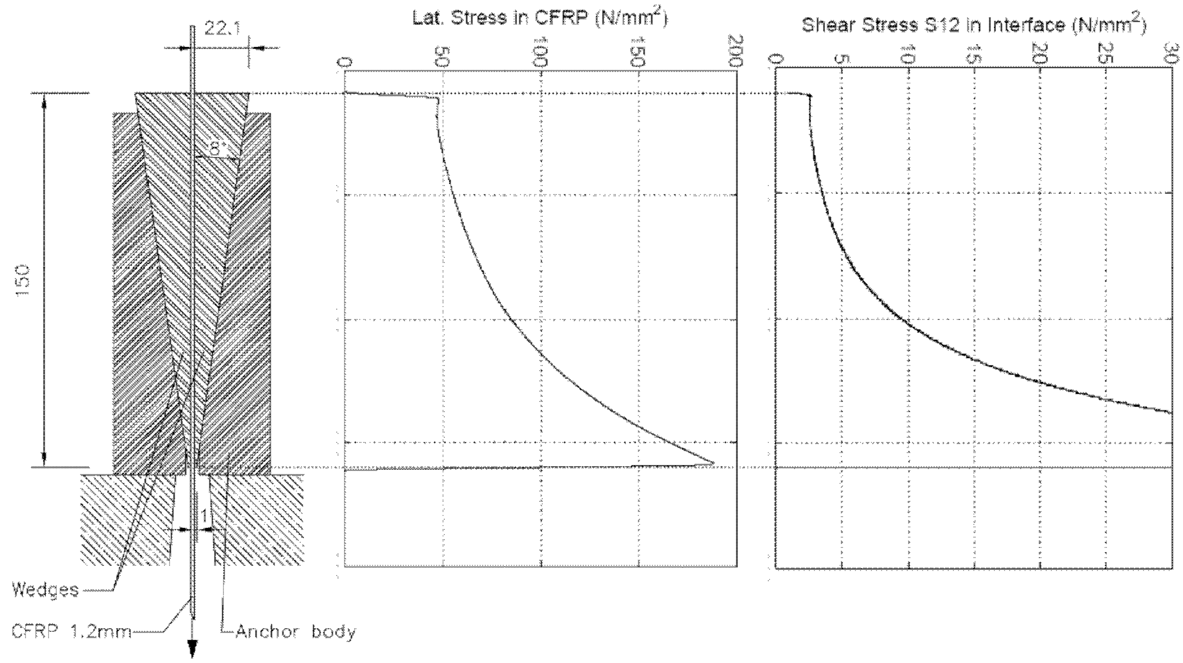

τ_{yr} (MPa), 100 y_m
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0,0
0,00
0,05
0,10
0,15
0,20
x_m

FIG. 8B



(PRIOR ART)

FIG. 9

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EUROPEAN SEARCH REPORT

Application Number
EP 11 19 1880

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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1

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	21 May 2012	Giannakou, Evangelia

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