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(58) Field of Search:
Other: **ONLINE: INTERNET, EPODOC, WPI**

(54) Title of the Invention: **Truss structure node joint**
Abstract Title: **Truss structure node with clevis collar for hollow strut**

(57) A truss structure, e.g. a bicycle frame, is formed with a truss structure node 4 having inner and outer collar walls 8 and 10. This provides a clevis 12 to receive a strut wall of a hollow strut 6, creating a double lap joint. Additive manufacturing may be used to create a deep clevis 12 with a thin inner 8 and outer collar 10 wall. An adhesive injection port 16 may be used to insert adhesive 14 into the base of the clevis 12, or a syringe may be used, following degreasing and roughening of the joint. Adhesive 14 may be squeezed and flow between the strut wall 6 and inner 8 and outer 10 collar wall during assembly. The inner 8 and/or outer collar wall 10 may be tapered to reduce peeling of the double lap joint. Structure 6 may have a circular or non-circular cross-section (e.g. elliptical or square, figs 5 & 6). The strut wall 6 and clevis 12 may have a matching non-uniform shape.

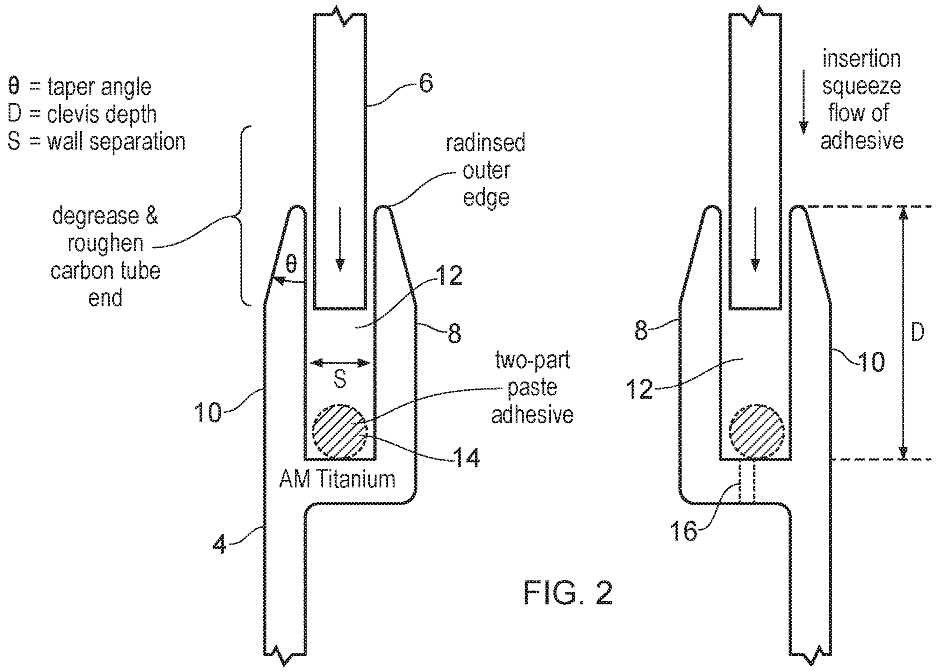

FIG. 2

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

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04 08 16

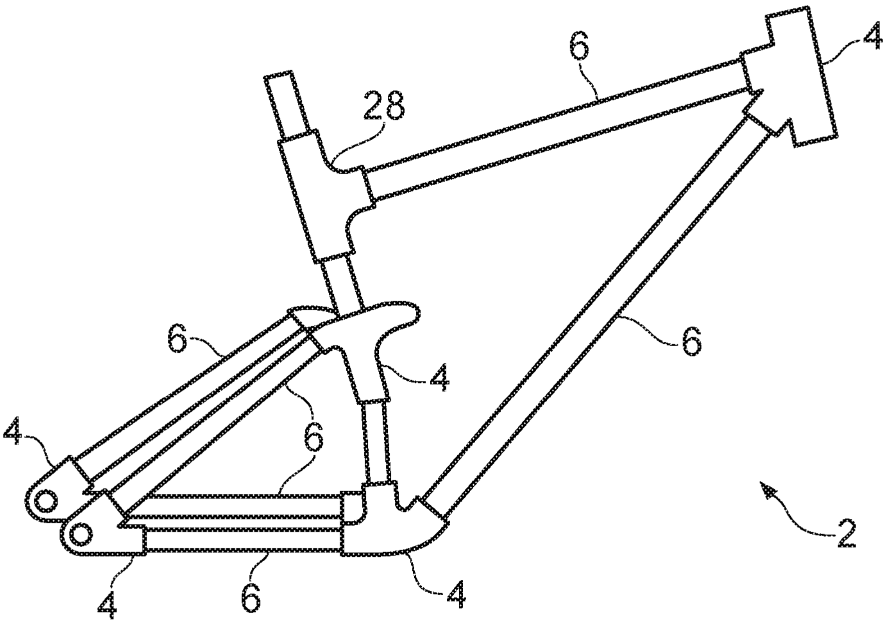

FIG. 1

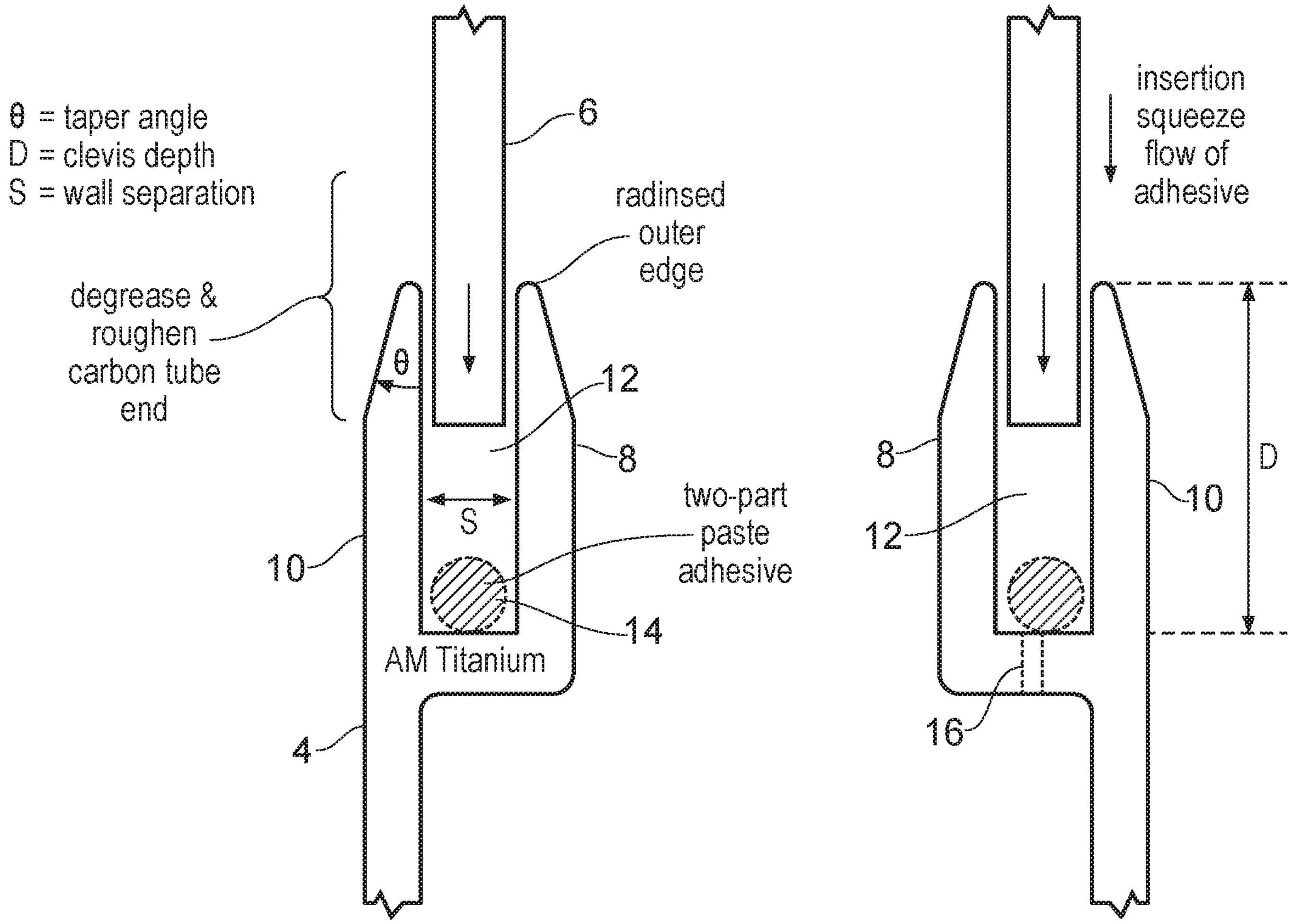
θ = taper angle
D = clevis depth
S = wall separation
degrease & roughen carbon tube end
6
radinsed outer edge
θ
12
8
S
two-part paste adhesive
10
14
AM Titanium
4
insertion squeeze flow of adhesive
8
12
10
D
16

FIG. 2

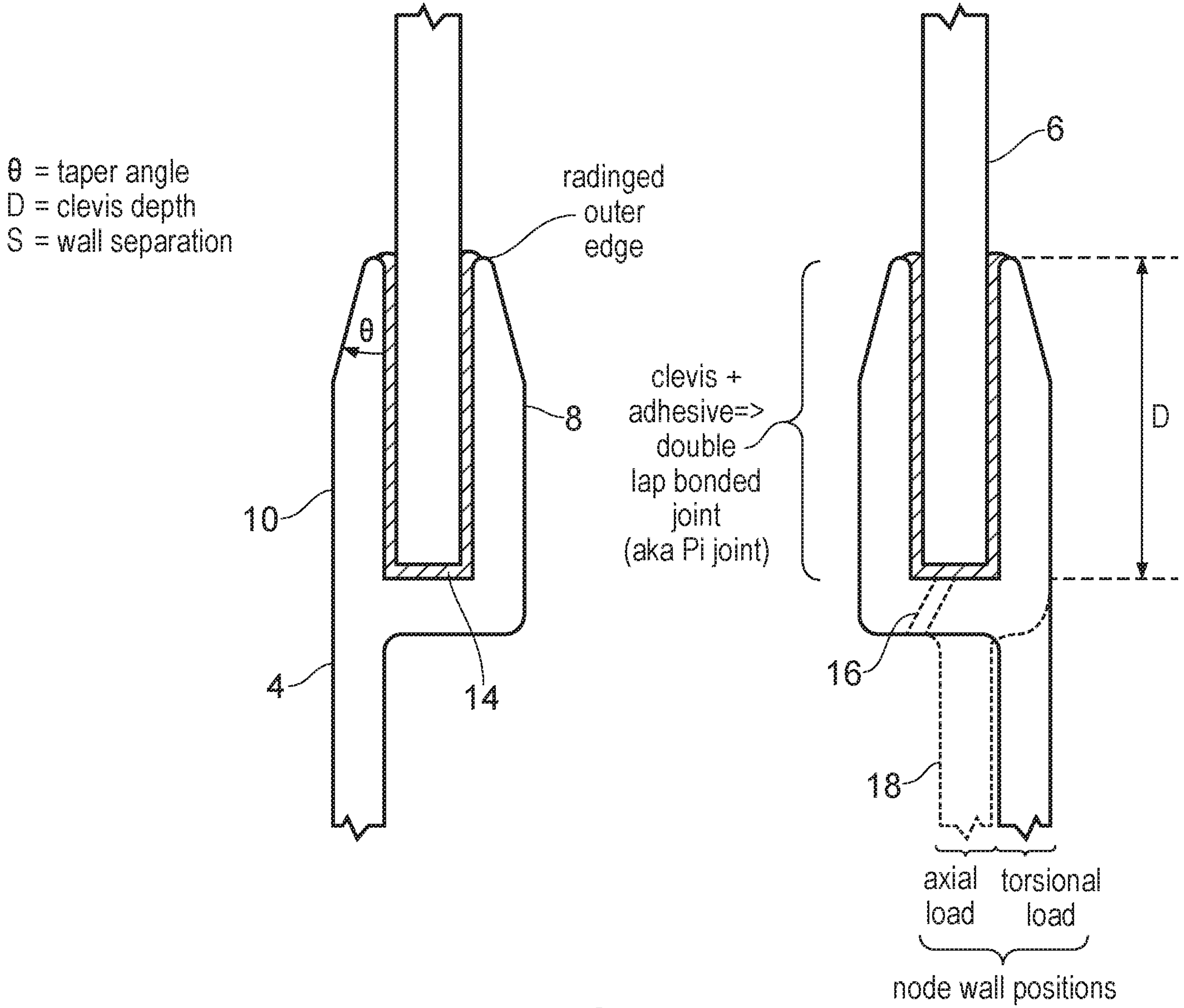
θ = taper angle
D = clevis depth
S = wall separation
radinged outer edge
θ
6
8
10
4
14
clevis + adhesive=> double lap bonded joint (aka Pi joint)
D
16
18
axial load
torsional load
node wall positions

FIG. 3

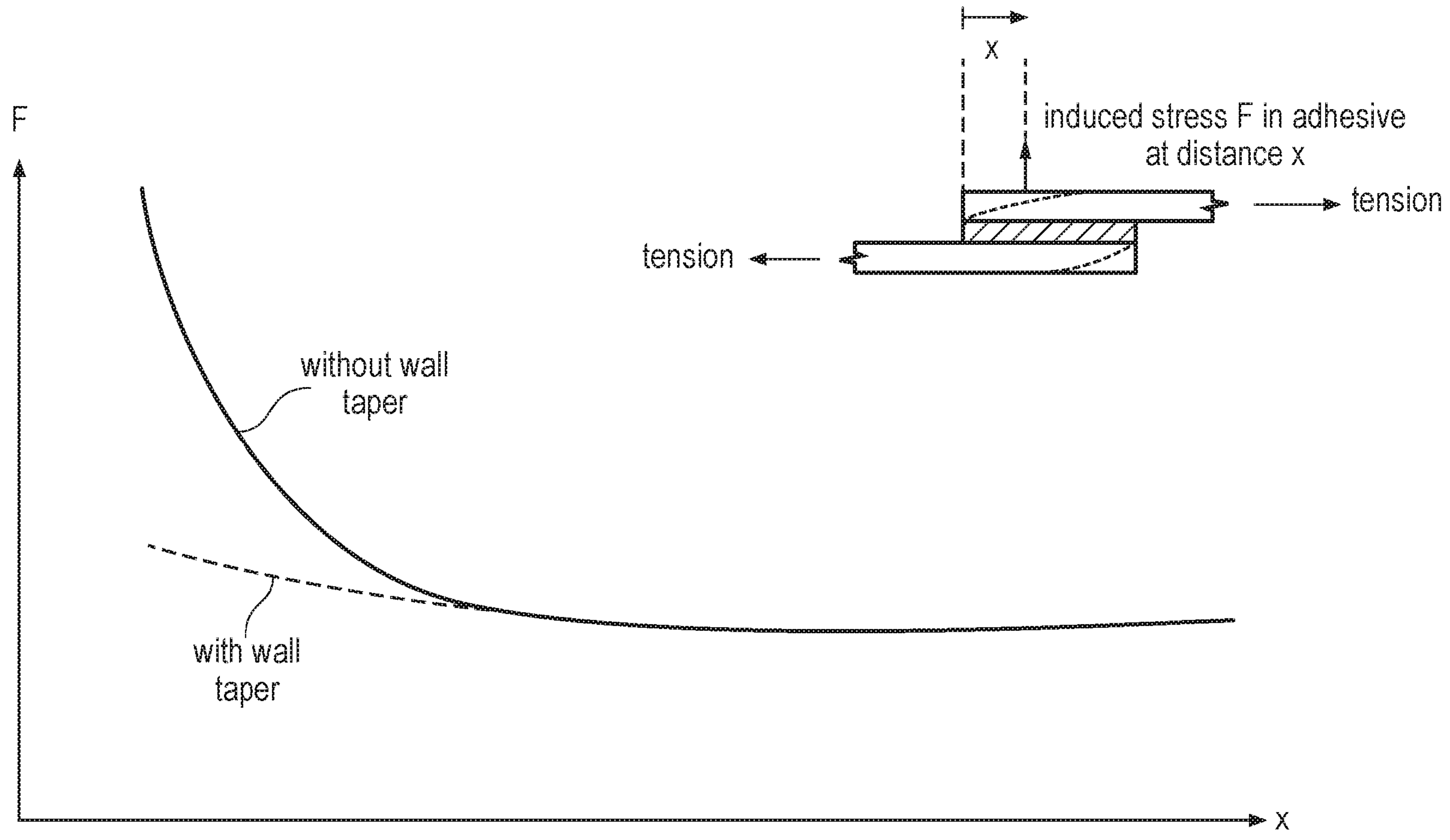
x
induced stress F in adhesive at distance x
tension
tension
F
without wall taper
with wall taper
x

FIG. 4

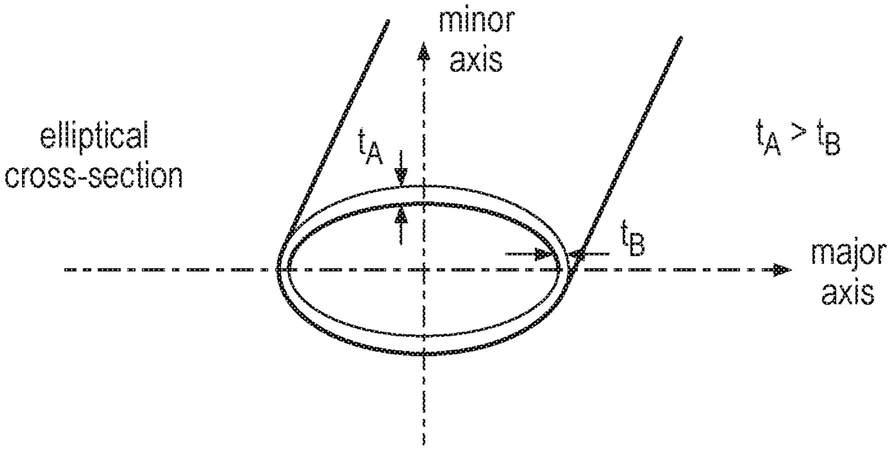

FIG. 5

04 08 16

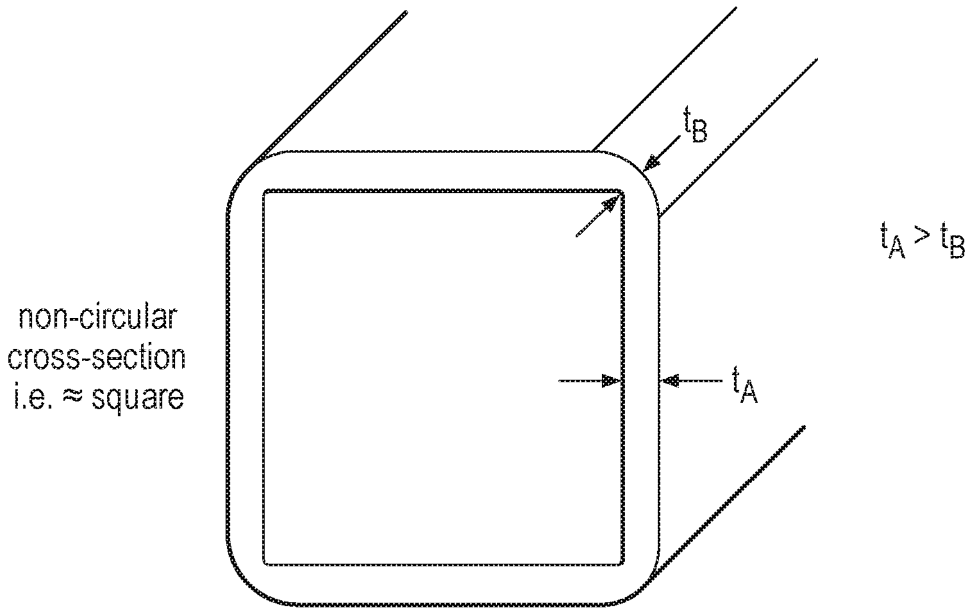

FIG. 6

04 08 16

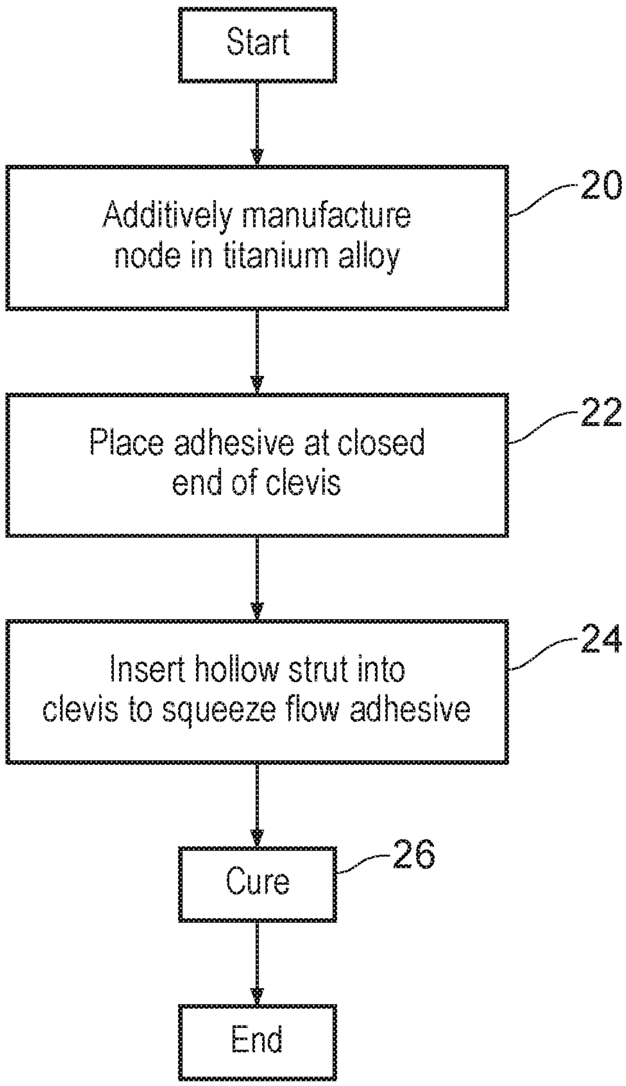
Start
Additively manufacture node in titanium alloy
20
Place adhesive at closed end of clevis
22
Insert hollow strut into clevis to squeeze flow adhesive
24
Cure
26
End

FIG. 7

TRUSS STRUCTURE NODE JOINT

This disclosure relates to truss structures. More particularly, this disclosure relates to joints for joining truss structure nodes to hollow struts to form a truss structure.

It is known to provide truss structures formed from a combination of truss structure nodes joined together by hollow struts. The truss structure nodes are typically formed of high strength isotropic materials and join together hollow struts formed to have a high strength in tension and compression. It is desirable that a strong joint should be provided between the truss structure nodes and the hollow struts within such a truss structure.

At least some embodiments of the present disclosure provide a truss structure node comprising:

a collar having an inner collar wall and an outer collar wall to provide a clevis to receive a strut wall of a hollow strut to form a double lap joint.

Providing a collar in a truss structure node within which a clevis (groove) is formed allows a high strength double lap joint (Pi joint) to be formed whilst keeping the weight and material volume of the truss structure node.

Providing a clevis deep enough to receive a sufficient length of a hollow strut to form a strong double lap joint whilst maintaining a thin inner collar wall and a thin outer collar wall is a difficult manufacturing challenge. One way of meeting this challenge is to use a collar comprising consolidated material formed by additive manufacture, such as, for example, energy beam fusing of a metal powder laid down in successive layers in a powder bed.

The strength of the joint between the truss structure node and the hollow strut may be increased within embodiments in which one or both of the inner collar wall and the outer collar wall tapers in wall thickness towards an open end of the clevis. This geometry reduces the force seeking to peel to collar walls away from the hollow strut causing a failure of an adhesive bonding therebetween as a consequence of forces between the truss structure node and the hollow strut which arise in use of the truss structure.

In some embodiments the tapering of the wall thickness toward the open end of the clevis may be substantially uniform, such as tapering the wall thickness at a taper angle of greater than 0.025 degrees and preferably between 0.05 and 30 degrees.

In other embodiments, the taper rate may be controlled such that the stress induced by forces between the truss structure node and the hollow strut in an adhesive bonding the strut wall to the collar and normal to the longitudinal axis of the collar is substantially constant at least for a majority of the longitudinal extent of the tapering portion. The taper rate which achieves this may be uniform or non-uniform depending upon the particular geometry of the joint. The taper may also vary at different angular positions around the collar depending, for example, on the cross sectional shape of the hollow strut and/or the loads to be carried by the truss structure.

As previously mentioned, it can be difficult to provide a deep and narrow clevis within the collar whilst keeping the inner and outer collar walls thin. This difficulty may be addressed by forming the collar of consolidated material via an additive manufacturing process. Such an approach can allow a clevis to be formed with a relatively high aspect ratio such that, for example, when the inner collar wall and the outer collar wall are separated by a distance S and, the clevis has a depth D, D/S is between 0.02 and 400 and more preferably between 20 and 40.

When using embodiments in which the inner collar wall and the outer collar wall taper so as to reduce the forces seeking to peel the collar walls away from the strut wall, a logical extension of this design goal would be to taper the inner collar wall and the outer collar wall towards a sharp outer edge at the opening of the clevis. However, such an approach can give rise to stress risers within the trust structure node and accordingly, in at least some embodiments of the present disclosure, at least one of the inner collar wall and the outer collar wall tapers towards a radiused outer edge where this radius may have, for example, a value of between greater than 0.05mm and preferably less than half the wall thickness.

While it will be appreciated that the truss structure node may be formed of a variety of different materials, depending upon the particular strength, environmental, cost constraints and other parameters associated with the desired truss structure, at least some embodiments of the disclosure are ones in which the truss structure node is formed of metal. Metal typically has a high isotropic strength making it well suited to carrying the loads associated with a truss structure node. Particular types of metal well suited to this use, and also suited to being formed as consolidated material via additive manufacture, are a titanium alloy or an aluminium alloy.

The bonding between the strut wall and the inner collar wall and the outer collar wall which forms the double lap joint may be enhanced in some example embodiments of the disclosure when at least the surfaces of the inner collar wall and the outer collar wall which bound the clevis have a mean surface roughness of between 0μm and 500μm and preferably between 1μm and 100μm. Such a surface roughness may serve to increase the effective bonding achieved (e.g. increase the strength with which the adhesive bonds to the collar walls) while not unduly increasing the susceptibility of the collar walls to failure through fatigue.

In some embodiments, the strut wall of the hollow strut may have a uniform thickness, at least for the portion inserted within the clevis. This may be the case, for example, when the hollow strut has a uniform circular cross-section. However, in some situations, the loads to be carried by the hollow strut or other dimensional constraints associated with the truss structure, may mean that the strut wall has a non-uniform thickness. In such cases, the clevis may be formed to have a matching non-uniform spacing between the inner collar wall and the outer collar wall such that when the strut wall with a non-uniform thickness is inserted into the clevis, then the gap between the strut wall and the inner collar wall and the outer collar wall into which adhesive may be introduced to bond the joint is kept substantially constant, or at least does not fall outside of a desired range that consistently produces an appropriate bond strength.

While it will be appreciated that the strut wall may have a non-uniform thickness for a variety of reasons, and the hollow strut may have a variety of cross-sectional shapes differing from that of a circle, one particular form of hollow strut which may have a non-uniform cross-section is a hollow strut with an elliptical cross-section in which the strut wall has a lower thickness proximal to a major axis of the elliptical cross-section than proximal to a minor axis of the elliptical cross-section. Such a non-uniform thickness in hollow struts with a non-circular cross-section may arise, for example, as a consequence of the manufacturing processes used for those hollow struts, such as forming the struts using a fibre layup wound around a mandrel of non-circular cross section with the result that the fibres tend to be more tightly packed together around regions of lower radius of curvature of the cross-section.

As will be appreciated from the above, truss structure nodes in accordance with the present disclosure may be supplied and provided separately from the hollow struts with the hollow struts, these being relatively conventional items which may be more widely sourced. When the truss structure nodes and the hollow struts are assembled together, then a truss structure may be formed, the strut walls may be bonded via an adhesive to the inner collar wall and the outer collar wall during the assembly of the truss structure.

Whilst it will be appreciated that the adhesive used between the truss structure node and the strut wall within the clevis may be applied in a variety of different ways, depending upon the clearances involved and the nature of the adhesive (e.g. the viscosity of the adhesive), in at least some embodiments of the disclosure the adhesive is distributed between the strut wall, the inner collar wall and the outer collar wall by insertion squeeze flow upon insertion of the strut wall into the clevis. The distribution of adhesive at the joint which results from such insertion squeeze flow is sufficiently uniform and consistent to achieve a high strength of the double lap joint formed.

Within some example embodiments of the disclosure the adhesive may be, for example, inserted into the clevis via a needle reaching down to the closed end of the clevis. The narrow clevis desirable for the reasons previously discussed may require the use of a needle that is also narrow and consequently introduce difficulties in the process of inserting a viscous adhesive at the closed end of the clevis so as to achieve the desired insertion squeeze flow. This problem may be addressed, in some example embodiments of the disclosure, by the provision of an adhesive injection port providing a path for injecting the adhesive into the closed end of the clevis.

Whilst it will be appreciated that the hollow struts used may be formed of a variety of different materials selected so as to carry the compression and tension loads associated with the hollow struts, particularly suitable forms of material are a composite material or an aluminium alloy. A particularly suitable form of composite material is a carbon fibre reinforced polymer tube.

At least some embodiments of the present disclosure further provide a method of forming a truss structure comprising:

additively manufacturing a truss structure node as claimed in any one of claims 1 to 15;

placing an adhesive at a closed end of said clevis; and

assembling said hollow strut and said truss structure node such that as said strut wall is inserted into said clevis, said adhesive is squeezed and flows between said strut wall, said inner collar wall and said outer collar wall.

Example embodiments will now be described, by way of example only, with reference to the accompanying drawings in which:

Figure 1 schematically illustrates a truss structure in the form of bicycle frame;

Figure 2 schematically illustrate the joint between a truss structure node and a hollow strut prior to assembly;

Figure 3 schematically illustrates the joint of Figure 2 after assembly;

Figure 4 is a graph schematically illustrating peeling stress forces induced in an adhesive of a lap joint due to tension applying a shear force to the joint;

Figures 5 and 6 schematically illustrate example non-circular hollow strut cross-sections with non-uniform strut wall thickness; and

Figure 7 is a flow diagram schematically illustrating the forming of a truss structure.

Figure 1 schematically illustrates a truss structure 2 in the form of a bicycle frame. The truss structure 2 is formed of a plurality of truss structure nodes 4 connected by a plurality of hollow struts 6. The truss structure nodes 4 may be formed, for example, of metal. Metals giving a high isotropic strength with a relatively low weight which may be used in some example embodiments are a titanium alloy or an aluminium alloy. The truss structure nodes 4 may be formed of consolidated material formed by additive manufacture, such as laser beam melting of metal powder of a powder bed additive manufacturing technique. It will be seen from Figure 1 that the truss structure nodes 4 have a wide variety of different shapes adapted to receive the hollow struts 6 from different directions to carry a variety of different loads. The use of additive manufacture for such truss structure nodes enables a wide variety of different shapes of node to be employed without each having to use a dedicated set of manufacturing tooling, such as moulds for casting. It is also possible that the truss structure 2 may be individually customised for a particular use or user whereby the geometry of the truss structure 2 varies between individual instances requiring a variation in the form of the truss structure nodes, e.g. the hollow strut lengths may be adjusted to suit the body size of a particular rider of a bicycle with a consequent requirement to adjust the angles of the joints providing by the truss structure nodes.

The hollow struts 6 may themselves be formed of a variety of different materials, such as, for example, composite materials or an aluminium alloy. Hollow struts well suited to carrying the compression, tension, torsion and bending loads associated with a truss structure and providing a high strength and low mass are ones made of a carbon fibre reinforced polymer tube. The fibre orientations of the fibre layers within such tubes may be selected so as to improve the ability of the hollow strut concerned to carry the particular loads associated with that hollow strut within the overall truss structure 2.

An important characteristic of the truss structure 2 is the strength of the joints between the hollow struts 6 and the truss structure nodes 4. These joints may be provided in the form of double lap joints (Pi joints) as described below. Such double lap joints having a clevis (groove) sufficiently deep and narrow to receive the strut wall of a hollow strut with a length desired to provide sufficient joint strength are difficult to achieve with conventional manufacturing. For example, it is difficult to machine a deep and narrow groove within a collar leaving only relatively thin collar walls.

It would also be difficult to arrange for such a groove to be machined with a non-uniform thickness to match the non-uniform thickness of the strut wall should such be required.

Figure 2 schematically illustrates the joint between a truss structure node 4 and a hollow strut 6 prior to the assembly of the joint by insertion of the hollow strut 6 into the truss structure node 4. As illustrated, the trust node 4 has a collar at its open end comprising an inner collar wall 8 and an outer collar wall 10.

The inner collar wall 8 and the outer collar wall 10 together provide a clevis 12 to receive a strut wall of the hollow strut 6. As illustrated the inner collar wall 8 and the outer collar wall 10 are separated by a distance S (which may vary around the joint to accommodate a structure wall of non-uniform thickness) and the clevis 12 has a depth D. The aspect ratio of the clevis 12 may desirably fall within a range such that D/S is between 0.02 and 400 (e.g. S in a range 0.5 to 1mm and D in a range up to 400mm) and more preferably in the range 20 to 40. Additive manufacture techniques used in forming the truss structure node 4 are suited to providing a clevis with such a high aspect ratio and thin collar walls 8, 10 compared to what may conventionally be achieved with other manufacturing techniques such as machining or casting.

The hollow strut 6 when inserted into the clevis 12 presses against an adhesive 14, (such as a two-part paste adhesive) at the closed end of the clevis 12. As the hollow strut 6 is inserted, it squeezes against the adhesive 14 and results in insertion squeeze flow of the adhesive in the gap between the strut wall and the inner and outer collar walls 8, 10. The adhesive 14 may be inserted into the base of the clevis 12 via an adhesive injection port 16. Alternatively, the adhesive 14 may be introduced via a syringe. If the adhesive port 16 is used, then it would also be possible for the hollow strut 6 to be inserted into the clevis 12 to the base of the clevis 12 and then the adhesive injected via the adhesive injection port 16 and forced to flow through the gap between the strut wall and the inner and outer collar walls 8, 10, e.g. injection and flow of the adhesive after the hollow strut 6 has been fully inserted into the clevis 12. The adhesive joint between the inner and outer collar walls 8, 10 and the strut wall of the hollow strut 6 may be improved if at least the portion of the hollow strut 6 which is to be bonded is degreased and roughened prior to the joint being assembled.

As illustrated in Figure 2 the inner collar wall 8 and the outer collar wall 10 may individually or both have a tapered wall thickness towards the open end of the clevis. As illustrated in this example embodiment, this taper is substantially uniform at a taper angle of greater than 0.025 degrees and preferably in the range 0.05 to 30 degrees. Such tapering reduces the tendency for the double lap joint formed by the adhesive 14 to fail due to peel of the inner collar wall 8 and the outer collar wall 10 away from the strut wall of the hollow strut 6 due to forces carried by the joint (e.g. tension along the longitudinal access of the joint). It is also possible that the tapering of the thickness of the inner collar wall 8 and the outer collar wall 10 may be non-uniform. More particularly, the wall thickness may be tapered at a rate such that the stress induced by forces between the truss structure node 4 and the hollow strut 6 in the adhesive 14 bonding the strut wall to the collar (formed of the inner collar wall 8 and the outer collar wall 10) and normal to the longitudinal axis of the joint is substantially constant as will be illustrated below in relation to Figure 4.

In order to reduce stress risers at the outer edge of the open end of the inner collar wall 8 and the outer collar wall 10, these outer edges may be radiused. For example, these outer edges may have a radius of curvature greater than 0.05mm and preferably less than half the collar wall thickness.

The truss structure node 4 may be formed by the additive manufacturing techniques discussed above. Such techniques typically produce a surface finish with a degree of surface roughness. This surface roughness may normally be regarded as a disadvantage as it can increase susceptibility to fatigue failure. However, in the context of the present techniques, such surface roughness at least on the surfaces of the inner collar wall 8 and the outer collar wall 10 which bound the clevis 12 may be advantageous in increasing the adhesive bond strength. Accordingly, such surfaces may be provided with a mean surface roughness of between 0μm (a mirror finish) and 500μm and preferably between 1μm and 100μm. Other surfaces of the truss structure node 4 may be left with their original surface roughness as manufactured, or, if desired, polished or otherwise treated to reduce that surface roughness and reduce the susceptibility to fatigue failure.

Figure 3 schematically illustrates the double lap joint of Figure 2 after insertion of the hollow strut 6 into the clevis 12. As shown, the adhesive 14 has flowed through the gap between the strut wall of the hollow strut 6 and the inner collar wall 8 and the outer collar wall 10 to form the double lap joint. Excess adhesive 14 may be wiped away. Such joints provide a high degree of strength along the longitudinal axis of the hollow strut 6 which is the major loading direction of the struts within a truss structure.

As illustrated in Figures 2 and 3, the outer collar wall 10 continues with its outer surface un-deviated beyond the depth of the clevis 12. This provides a visually attractive joint and if strength against torsional loads in the joint is required then this arrangement provides a greater ability to carry such loads for a given mass of material. Alternatively, an improved axial strength of the joint may be achieved if the wall of the truss structure node 14 is formed longitudinally aligned with the strut wall of the hollow strut 6 beneath the clevis as shown in dashed line form in Figure 3.

Figure 4 is a graph schematically illustrating how the induced stress F in an adhesive between two sheets of material and forming a lap joint therebetween varies with distance x from the end of the lap joint under tension applied so as to load the lap joint in shear. As illustrated, the induced stress F increases as the distance x from the end of the lap joint decreases. This induced stress F serves to induce a peeling failure of the lap joint which can limit its strength. If the thickness of the material which is forming the sheets bonded together by the lap joint is tapered to be lower as the distance x from the end of the lap joint is reduced, then the induced stress F in the peel direction is also reduced. This is illustrated by the dashed line in Figure 4. The induced stresses may be modelled, for different variable taper rates and the rate of tapering of the material may be controlled so as to result in an induced stress which is substantially constant in the longitudinal direction (at least at some finite distance away from the final end point of the lap joint). The inner collar wall 8 and the outer collar wall 10 of Figures 2 and 3 may be tapered at a non-uniform rate to take account of such behaviour and thereby increase the resistance to failure of the joint due to adhesive peeling.

As previously mentioned, the hollow struts 6 may have a variety of different cross-sections. In some example embodiments, a circular uniform cross-section may be desirable. However, for particular portions of an overall truss structure 6 given the loads associated with those portions, or other constraints, such as packaging space constraints, a non-circular cross-section of hollow strut may be used. Figure 5 illustrates one example of such a non-circular cross-section hollow strut which may be employed in some situations. This example uses an elliptical cross-section. In the example of the bicycle frame of Figure 1 such a tube may be used for the chain stays. The elliptical cross-section has a major axis and a minor axis. Typically if hollow struts 6 with such a non-uniform cross-section are formed via a fibre layup wrapping process around a mandrel, then the resulting strut walls will have a non-uniform thickness and will be thinner proximal to the major axis than they are proximal to the minor axis. Higher rates of curvature proximal to the major axis of the elliptical cross-section tend to more tightly pack the fibres when forming, for example, carbon reinforced polymer tubing. The clevis 12 to accept such struts may be made to have a corresponding non-uniform wall spacing such that an appropriated clearance is provided at positions around the joint.

Figure 6 schematically illustrates another possible non-circular cross-section, in this case an approximately square cross-section. As illustrated, proximal to the corners of this approximately square cross-section, the strut thickness is less than it is in the portions of the strut wall relatively far from the corners.

In order to accommodate the use of hollow struts 6 with such non-uniform strut wall thicknesses, the clevis 12 formed between the inner collar 8 and the outer collar 10 may be arranged to have a matching non-uniform thickness. Such a matching non-uniform thickness may then provide a substantially constant gap between the strut wall of the hollow strut 6 and the inner surfaces of the inner collar wall 8 and the outer collar wall 10 into which the adhesive 14 may flow and serve to provide a strong joint. The strength of the bond achieved by the adhesive 14 may be reduced if the thickness of the adhesive 14 is either too thin or too thick at a particular point. Accordingly, matching the wall separation S within the clevis 12 to the strut wall thickness t_A or t_B at different points (and smoothly and appropriately varying therebetween) has the advantage of increasing the joint strength. Additive manufacture of the truss structure nodes 4 is a way of achieving such a non-uniform wall separation S within a clevis 12 with a high aspect ratio in a manner which would otherwise be difficult.

As previously mentioned, the hollow strut 6 may be formed of a variety of materials, such as composite materials or aluminium alloy. Such materials may also show non-uniform wall thicknesses as a consequence of their manufacture and accordingly the advantage of being able to provide a clevis 12 with a non-uniform thickness matched to the strut wall thickness is also applicable to such embodiments.

Figure 7 is a flow diagram schematically illustrating the manufacture of the truss structure 2 of Figure 1. At step 20 the truss structure nodes for a particular geometry of the truss structure are additively manufactured in titanium alloy (other metal alloys, such as aluminium alloy, may alternatively be used). At step 22 the adhesive 14 is introduced to the closed ends of the clevis 12 of the various double lap joints to be formed. At step 24 the hollow strut 16 is inserted into the clevis 12 of each joint so as to squeeze flow the adhesive 14 into the gap between the strut wall of the hollow strut 6 and the inner and outer collar walls 8, 10. At step 26 the truss structure 2 is left for the adhesive to cure and the joints to reach their full strength.

It will be appreciated that depending upon the geometry of the truss structure 2 to be assembled, it may be necessary that one of the joints is not a double lap joint of the type illustrated in Figures 2 and 3. This is because the final joint within an overall truss structure may not be capable of being assembled due to the restrictions in movement imposed by previously assembly of other portions of the truss structure 2. In this case, the final joint may be made in another way, such as sliding a tube through a hollow collar to provide a single lap joint. The truss structure 2 of Figure 1 may employ such a joint 28 at the base of the seat post.

CLAIMS

1. A truss structure node comprising:

a collar having an inner collar wall and an outer collar wall to provide a clevis to receive a strut wall of a hollow strut to form a double lap joint.

2. A truss structure node as claimed in claim 1, wherein at least said collar comprises consolidated material formed by additive manufacture.

3. A truss structure node as claimed in any one of claims 1 and 2, wherein at least one of said inner collar wall and said outer collar wall tapers in wall thickness towards an open end of said clevis.

4. A truss structure node as claimed in claim 3, wherein both said inner collar wall and said outer collar wall taper in wall thickness towards an open end of said clevis.

5. A truss structure node as claimed in any one of claim 3 and 4, wherein said wall thickness tapers at a rate such that stress induced by forces between said truss structure node and said hollow strut in an adhesive bonding said strut wall to said collar and normal to said longitudinal axis is substantially constant.

6. A truss structure node as claimed in any one of claims 3 and 4, wherein said wall thickness tapers substantially uniformly.

7. A truss structure node as claimed in claim 6, wherein said wall thickness tapers at a taper angle of between AAA degrees and BBB degrees.

8. A truss structure node as claimed in any one of the preceding claims, wherein said inner collar wall and said outer collar wall are separated by a distance S, said clevis has a depth D and D/S is between one or more of:

0.2 and 400; and

20 and 40.

9. A truss structure node as claimed in any one of claims 3 to 8, wherein at least one of said inner collar wall and said outer collar wall tapers toward a radiused outer edge.

10. A truss structure node as claimed in claim 9, wherein said radiused outer edge has a radius of greater than 0.05mm.

11. A truss structure node as claimed in any one of the preceding claims, wherein said truss structure node is formed of metal.

12. A truss structure node as claimed in claim 11, wherein said metal is one of a titanium alloy and an aluminium alloy.

13. A truss structure node as claimed in any one of the preceding claims, wherein at least surfaces of said inner collar wall and said outer collar wall bounding said clevis have a mean surface roughness of between one or more of:

0µm and 500µm; and

1µm and 100µm.

14. A truss structure node as claimed in any one of the preceding claims, wherein said strut wall has an non-uniform thickness and said clevis has a matching non-uniform spacing between said inner collar wall and said outer collar wall.

15. A truss structure as claimed in any one of the preceding claims, wherein said hollow strut has an elliptical cross-section and said strut wall has a lower thickness proximal to a major axis of said elliptical cross-section than proximal to a minor axis of said elliptical cross-section.

16. A truss structure comprising a truss structure node as claimed in any one of the preceding claims and said hollow strut, wherein said strut wall is bonded with an adhesive to said inner collar wall and said outer collar wall.

17. A truss structure as claimed in claim, 16, wherein said adhesive is distributed between said

strut wall, said inner collar wall and said she outer collar wall by insertion squeeze flow upon insertion of said structure wall into said clevis.

18. A truss structure as claimed in any one of the preceding claims, comprising an adhesive injection port providing a path for injecting said adhesive into a closed end of said clevis.

19. A truss structure as claimed in any one of claims 16, 17 and 18, wherein said hollow strut is formed of one of a composite material and an aluminium alloy.

20. A truss structure as claimed in claim 19, wherein said hollow strut is a carbon fibre reinforced polymer tube.

21. A method of forming a truss structure comprising:

additively manufacturing a truss structure node as claimed in any one of claims 1 to 15;

placing an adhesive at a closed end of said clevis; and

assembling said hollow strut and said truss structure node such that as said strut wall is inserted into said clevis, said adhesive is squeezed and flows between said strut wall, said inner collar wall and said outer collar wall.

22. A truss structure node substantially as hereinbefore described with reference to the accompanying drawings.

23. A truss structure substantially as hereinbefore described with reference to the accompanying drawings.

24. A method of forming a truss structure substantially as hereinbefore described with reference to the accompanying drawings.

Intellectual Property Office

Application No:	GB1605177.3	**Examiner:**	John Hewet
Claims searched:	1-24	**Date of search:**	14 November 2016

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1-21	JP H0891271 A (YASUHARA) see especially figure 6; and WPI abstract, accession number: JP-17266295-A
X	1-21	US5842711 A (LEGEROT) see especially figure 4
X	1-21	CN102619830 A (BINQUAN) see especially figure 1; and WPI abstract, accession number: CN-201210095237-A
X	1-21	CN200960971 Y (LIN) see especially clevis 26 of figure 3; and WPI abstract, accession number: CN-200620007598-U
X	1-21	US5211415 A (GASIOROWSKI) see especially clevis 16 of fig 12
X	1-21	US6308937 B1 (PETTIT) see especially figure 2

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC[X] :

Worldwide search of patent documents classified in the following areas of the IPC

The following online and other databases have been used in the preparation of this search report

ONLINE: INTERNET, EPODOC, WPI

Intellectual Property Office

International Classification:

Subclass	Subgroup	Valid From
F16B	0007/04	01/01/2006
B62K	0019/04	01/01/2006
B62K	0019/22	01/01/2006