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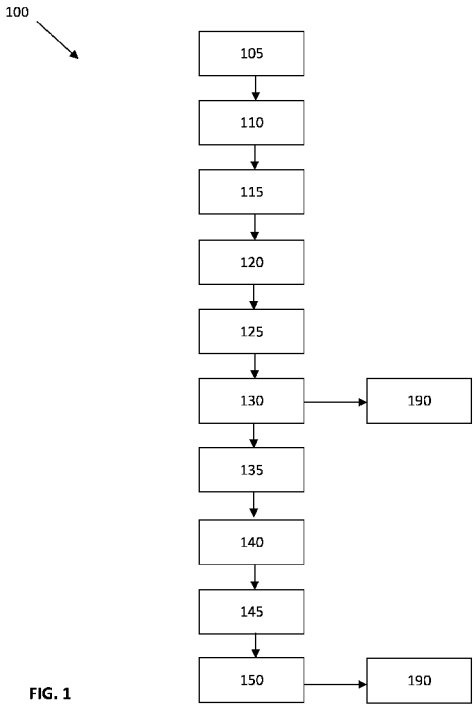


FIG. 1

(57) Abstract: A method of defining a lattice structure for use in an additive manufacturing process having a build direction, the method comprising defining a volume, generating a plurality of nodes within the volume, generating a plurality of struts, wherein each strut extends between a pair of nodes, and wherein each strut extends in a direction relative to a plane normal to the build direction of the additive manufacturing process, identifying struts that form an angle relative to the plane of less than a critical angle of between 0 and 45 degrees, selecting a point on each of the identified struts to define first and second parts of each of the identified struts, displacing the selected point of each of the identified struts such that the angle between each of the first and second parts of each of the identified struts relative to the plane is no less than the critical angle, and outputting control data for use in a device configured to manufacture the structure using an additive manufacturing process.

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A METHOD OF DEFINING A LATTICE STRUCTURE FOR USE IN AN ADDITIVE MANUFACTURING PROCESS AND A LATTICE STRUCTURE

This invention relates to a method of defining a lattice structure for use in an additive manufacturing process and a lattice structure.

BACKGROUND

[0001] Current additive manufacturing processes, such as powder bed fusion or fused deposition modelling, provide a way of generating structures that conventional manufacturing processes are unable to obtain. However, additive manufacturing processes typically deposit material in layers and build up the structure in a vertical build direction and so require support material to be present below the part of the structure being deposited in order to ensure the deposited material does not collapse under its own weight before sufficient material has been deposited to provide the necessary structural integrity. The existing approach to this problem is to ensure material is not deposited in the near-horizontal plane where there would otherwise be a lack of support material beneath the material being deposited. If material is deposited in the near-horizontal plane, the resulting material would either be poorly built, liable to be warped due to residual stresses, or not built at all. This in turn limits the types of structures that can be made using existing additive manufacturing techniques.

[0002] Medical devices, such as orthopaedic implants have benefitted from additive manufacturing techniques, for two reasons, implants can be more easily customised to incorporate patient-specific requirements and implants can include or be comprised of porous structures to allow for bone ingrowth, better fixation and more physiological loading.

[0003] Devices incorporating a synthetic trabecular-like metal lattice are known. However, they are most typically created from periodic structures. These structures are typically not isotropic and consequently will have stiffness peaks in certain directions of loading.

[0004] Additionally, the nodes in periodic structures can be ‘nudged’ such that they appear random such that the resulting struts formed between the pseudo-random nodes will then have the appearance of trabecular bone. There also exists fully stochastic structures as well as triply-periodic structures. However, while these structures may have the appearance of trabecular bone, such lattices fail to control the overall stiffness of the structure in multiple directions, as structures made from additive manufacturing have difficulty incorporating struts that are near the horizontal plane. As such, there will be a

plane in which there will be few or no struts providing any resistance, which compromises the stiffness in that plane, making it considerably more difficult to provide a structure having a pseudo-isotropic stiffness. Furthermore, there are no viable products that incorporate metal lattices available for especially young osteoarthritis patients, such as those between 50 and 60, as this requires tailoring the mechanical characteristics of the metal lattice in a way that has not previously been achieved using existing manufacturing techniques.

[0005] The present invention seeks to alleviate at least some of these issues.

BRIEF SUMMARY OF THE DISCLOSURE

[0006] Viewed from a first aspect, the present invention provides a method of defining a lattice structure for use in an additive manufacturing process having a build direction. The method comprises defining a volume, generating a plurality of nodes within the volume, generating a plurality of struts, wherein each strut extends between a pair of nodes, and wherein each strut extends in a direction relative to a plane normal to the build direction of the additive manufacturing process, identifying struts that form an angle relative to the plane of less than a critical angle of between 0 and 45 degrees, selecting a point on each of the identified struts to define first and second parts of each of the identified struts, displacing the selected point of each of the identified struts such that the angle between each of the first and second parts of each of the identified struts relative to the plane is no less than the critical angle, and outputting control data for use in a device configured to manufacture the structure using an additive manufacturing process.

[0007] Thus, the present invention provides a way of manufacturing near horizontal structures that would otherwise not be possible to build, or would build poorly, due to the limitations of existing metal printing technology. This has the advantage of providing structures that no longer have horizontal planes of weakness that can be built using existing additive manufacturing processes.

[0008] Optionally, the method further comprises the steps of defining a kinking angle as the angle between the first and second parts of each of the identified struts, determining a range of kinking angles of the identified struts, selecting a point on each of the remaining struts to define first and second parts of each of the remaining struts, and displacing the selected point of each of the remaining struts such that the first and second parts of the remaining struts have a kinking angle within the range of kinking angles. This has the advantage of providing a pseudo-isotropic lattice structure that has no hidden peaks of stiffness.

[0009] The method may further comprise calculating an average kinking angle of the identified struts. The selected point of each of the remaining struts may be displaced such that the kinking angle of the remaining struts is equal to the average kinking angle.

[0010] In some cases, struts that form an angle relative to the plane of less than a critical angle of between 0 and 30 degrees are identified.

[0011] The selected point for each of the identified struts or the remaining struts may be between 10 and 90 % of the length of a respective strut. The selected point may be a mid-point of the respective strut. The length of each strut may be between 0.1mm and 4mm.

[0012] The selected point of each of the identified struts may be displaced in the build direction.

[0013] The selected point of each of the identified struts may be displaced in a substantially vertical direction.

[0014] The displacement may be selected such that the angle between the respective first and second parts and the plane is substantially equal to one another.

[0015] The method may further comprise the step of specifying a node connection limit of 2 or more, wherein 2 comprises the maximum number of other nodes to which each node may be connected by respective struts. This advantageously provides a way of controlling the density of the lattice structure, as increasing the node connection limit will increase the density of the lattice structure. In some cases the node connection limit may be 11 or more. Where there are more nodes available for connection relative to the connection node limit, the closest number of nodes equal to the connection node limit are connected to a specific node.

[0016] If there are a greater number of nodes available for connecting to than the node connection limit, the method may include selecting the 2 or more nodes that are closest to the respective node, and generating struts between the closest 2 or more nodes and the respective node.

[0017] The method may further comprise varying a thickness of each of the struts, such that the lattice structure has a stiffness in a first loading direction that is greater by a factor of up to 20 times relative to orthogonal loading directions relative to the first loading direction. In some cases, the stiffness in the first loading direction is greater by a factor of up to 10 times relative to orthogonal loading directions relative to the first loading direction. This advantageously provides a lattice structure that can provide the necessary stiffness in desired directions without also unnecessarily thickening struts that do not contribute to the stiffness in the desired directions.

[0018] The method may further comprise varying a thickness of each of the struts, such that the lattice structure has a stiffness in three mutually orthogonal directions that are within a factor of between 0.8 and 1.2 relative to one another.

[0019] The plurality of nodes may be defined generated in any of: a pseudo-stochastic arrangement, a periodic arrangement or a uniform arrangement. The plurality of nodes may be generated using any of: Poisson-Disc sampling in 3D coordinates, a Mersenne Twister pseudo-random number generator, or a Lagged Fibonacci pseudo-random number generator. The plurality of nodes may be generated in a triply periodic arrangement.

[0020] The additive manufacturing process may be one of: fused deposition modelling, powder bed fusion, laser sintering, electron beam melting or stereolithography printing.

[0021] Viewed from a yet further independent aspect, there is also provided a processor comprising a non-volatile memory having instructions stored therein for executing the method according to any preceding claim. Such a processor may be operatively connected to any device configured to generate the lattice structure and/or manufacture the lattice structure.

[0022] Viewed from a yet further independent aspect, there is also provided a lattice structure comprising a plurality of nodes, and a plurality of struts, wherein each strut extends between a pair of nodes, wherein each strut extends in a direction relative to a plane normal to a first direction, and wherein each strut is arranged to form an angle relative to the plane of no less than a critical angle of between 0 and 45 degrees.

[0023] Each of the struts may be formed of first and second parts that define a kinking angle therebetween, and wherein the kinking angle is no less 70 degrees. Preferably, the kinking angle is between 70 and 160 degrees.

[0024] Each strut may have a length between 0.1mm and 4mm.

[0025] The lattice may comprise a metal. The metal may be any of titanium, steel, tantalum, magnesium, zinc, a titanium alloy, a steel alloy. In some cases, the lattice may comprise any of plastic or ceramic.

[0026] Viewed from a yet further independent aspect, there is also provided a medical device comprising a structure according to any of the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0027] Embodiments of the invention are further described hereinafter with reference to the accompanying drawings, in which:

Figure 1 illustrates an exemplary manufacturing process;

Figures 2A to 2D illustrate a graphical representation of a manufacturing process;

Figures 3A to 3D illustrate graphical representations of exemplary lattice structures;

Figure 4 is a graphical representation of the stiffness profile of exemplary lattice structures in multiple loading directions;

Figure 5 is an illustration of the different loading directions;

Figure 6 is a graphical representation of the standard deviation of the stiffness profile of Figure 4;

Figure 7 is an illustration of an alternative series of loading directions, and

Figure 8 is a graphical representation of the stiffness profile of further exemplary lattice structures.

DETAILED DESCRIPTION

[0028] Figure 1 illustrates an exemplary process 100 for defining a lattice structure 300 for use in an additive manufacturing process, such as metal printing. Reference will be made throughout the description to elements illustrated in Figures 2 and 3. The process 100 begins by defining 105 a volume and generating 110 a pseudo-stochastic arrangement of nodes 305 within the volume using, for example, a Poisson disk algorithm. A plurality of struts 310 are then generated 115 between pairs of nodes 305, where each strut 310 extends at an angle relative to the horizontal plane 215. As illustrated in Figure 3A, node 305 is connected to four adjacent nodes 305A, 305B, 305C, 305D. Each node also has a node connection limit, which defines the maximum number of adjacent nodes a specific node can be connected to. Thus, the lattice structure 300A illustrated in Figure 3A can be considered to have a node connection limit of at least four, as each node 305 is connected to four other nodes. Aside from the node connection limit, other parameters can be used to define the lattice structure. For example, struts 310 may only be formed between nodes 305 that are a specific distance apart from one another, such as between a minimum and a maximum distance. As the nodes 305 are generated 110 in a pseudo-stochastic arrangement, it is possible for there to be more than the number of nodes specified by the connection limit within the maximum and minimum distance from a specific node. By specifying the node connection limit and the distance between each node, it is possible to restrict the number of struts 310 formed between respective pairs of nodes 305. Where there are a greater number of nodes within the specified distance to a specific node compared to the connection limit, nodes that are close to the specific node will be selected preferentially for connection. For example, where the node connection limit is four, such as shown in Figure 3A, but there are five or more adjacent nodes that are

within the minimum and maximum distance from the specific node 305, only the four nodes 305A, 305B, 305C, 305D that are closest to the specific node 305 will be connected to the specific node 305 by respective struts 310. Thus, the initial lattice structure 300A can be generated 115 using only three parameters (as shown in Figure 3A).

[0029] Figure 2A illustrates three exemplary struts 200, 230, 260 that have different orientations. The left illustration of Figure 2A illustrates a strut 200 that is substantially horizontal. In the central illustration of Figure 2A, a strut 230 is illustrated forming an angle Θ relative to the horizontal plane 215. In the right illustration of Figure 2A, a strut 260 is illustrated forming an angle Θ relative to the horizontal plane 215 in the opposite direction to strut 230. It would be apparent that the angle between strut 230 and the horizontal plane 215 need not be the same as the angle between strut 260 and the horizontal plane 215 and that these are both described using an angle Θ for illustrative purposes. While struts 200, 230, 260 are illustrated as having a straight structure, it would be apparent that this was not essential, and that any of struts 200, 230, 260 may have a curved or parabolic structure. The present method is applicable where at least some of the struts 200, 230, 260 forms an angle of less than the critical angle relative to the horizontal plane 215.

[0030] Once the initial lattice structure 300A has been generated 115, struts 310 that are near the horizontal plane 215 (referred to herein as “near horizontal”) are identified 120 for modification. As illustrated, any struts that form an angle of less than a critical angle relative to the horizontal plane of 25 degrees are considered near horizontal. Whilst a critical angle of 25 degrees is described, it would be apparent that this was merely exemplary and that the critical angle may vary depending on the additive manufacturing process used to manufacture the lattice structure, the material used to produce the lattice structure or the strut length. The struts 200, 230 and 260 illustrated in Figure 2A all form an angle of less than the critical angle of 25 degrees, and are thus selected for modification as shown in Figures 2B to 2C.

[0031] As shown in Figures 2B and 2C, a point 205 halfway along the strut 200 is selected 125 in order to define first 200A and second 200B parts of the strut 200. Whilst the mid-point 205 is used to define the first 200A and second 200B parts in the illustrations, it would be apparent this was not essential and that other points along the strut could be selected to define the first 200A and second 200B parts. The selected point 205 is then displaced 130 in the vertical direction 210, which is perpendicular to a longitudinal axis of the strut and results in the first 200A and second 200B parts forming an angle relative to the horizontal plane 215. As shown in the left illustration of Figure 2C, where the strut 200 was horizontal and the mid-point 205 is displaced 130, both the first 200A and second 200B parts will form the same angle relative to the horizontal plane 215.

In this case, the mid-point 205 can be displaced until both the first 200A and second 200B parts form an angle relative to the horizontal plane 215 that is equal to the critical angle of 25 degrees. As shown in the central illustration of Figures 2B and 2C, where strut 230 is not horizontal, but still near horizontal, the displacement of the mid-point 235 in the vertical direction 240 results in the first 230A and second 230B parts forming different angles relative to the horizontal plane 215. In the illustrated example, the first part 230A forms an angle relative to the horizontal plane 215 that is greater than the angle of the second part 230B relative to the horizontal plane 215. Similarly, in the right illustration of Figures 2B and 2C, the second part 260B may form an angle relative to the horizontal plane 215 that is greater than the angle of the first part 260A relative to the horizontal plane 215. Accordingly, in order for the smaller of the respective displaced angles to equal the critical angle, the larger of the displaced angles must exceed the critical angle. While the mid-point 205 is illustrated as being displaced in the vertical direction, which is also the build direction 302 in the illustrated process, it would be apparent this was not essential and that the mid-point 205 could be displaced in other directions relative to the build direction 302 and that the build direction need not be vertical.

[0032] By displacing selected points for all struts that are near horizontal, a modified lattice structure 300B is obtained, where none of the struts or strut parts of the lattice structure 300B form an angle with the horizontal plane 215 that is less than the critical angle 315 (see Figures 3A and 3B). This ensures that none of the struts 310 or strut parts 310A, 310B are near horizontal and would therefore build poorly or fail during manufacturing. At this stage, it is possible to output 190 the lattice structure 300B for manufacturing, for example using powder bed fusion or similar metal printing technology. This enables structures that incorporate near horizontal struts or overhanging features that would otherwise have been built poorly, if at all, and would have therefore incorporated horizontal planes of weakness to be reliably manufactured using existing additive manufacturing techniques.

[0033] Where a pseudo-isotropic structure is desired, the lattice structure 300B can be modified further, using a similar displacement process 130 applied to near horizontal struts, but applied to the remaining struts 320 in the lattice structure 300B.

[0034] As shown in Figure 2D, following displacement 130 of the mid-point 205, 235, 265 of the near horizontal struts 200, 230, 260, each of these struts 200, 230, 260 will have a “kink” in their structure due to the angled connection between their respective first 200A, 230A, 260A and second 200B, 230B, 260B parts. As illustrated in Figure 2D, the first 200A and second 200B parts of strut 200 define 135 a kinking angle 220, while the first 230A, 260A and second 230B, 260B parts of struts 230 and 260 define kinking angles 245 and

275 respectively. Due to the stochastic arrangement of the nodes 305, which results in struts that extend in different directions, after all of the near horizontal struts have been kinked, the resulting lattice 300B will contain struts having a range of kinking angles. By taking a mean average 140 of all of the kinking angles of the struts that were originally near the horizontal plane 215, the remaining struts can be modified in a similar manner to the near horizontal struts such that they also have a "kink" in their structure. This process is described below.

[0035] As shown in Figures 3B and 3C, a mid-point of the remaining struts 320 is selected 145 to define first 320A and second 320B parts of the remaining struts 320. The mid-point is then displaced 150 in a lateral direction to kink the remaining struts 320 such that all of the remaining struts 320 have a kinking angle 325 substantially equal to the average kinking angle of the struts 310 that were originally near horizontal. Whilst the mid-point of the remaining struts has been selected in the illustrated example, it would be apparent that this was not essential and that other points along the strut could be selected to kink the remaining struts. Similarly, while the remaining struts are kinked at an angle equal to the average kinking angle from the near horizontal struts 310, this is not essential, as the kinking angle of the remaining struts may be equal to a similar range of kinking angles produced by the initial displacement process 130 for the near horizontal struts 310. As a result of this further displacement process 150, lattice structure 300C is formed which has a wavy structure that was not originally present in either the illustrated lattice structure 300A or 300B. By modifying the structure 300B in this manner, the resulting lattice structure 300C will have similar mechanical properties in all directions and provide a pseudo-isotropic lattice structure 300C. The pseudo-isotropic lattice 300C can then be outputted 190 for manufacturing via an additive manufacturing process in the known manner. Thus the present method provides a method of producing isotropic lattice structures using known additive manufacturing techniques that were previously not possible to produce due to the limitations of the manufacturing process. By using a random arrangement of nodes 305 and kinked struts throughout the lattice structure 300C, the lattice structure 300C does not have any hidden peaks of stiffness that would otherwise be found in lattice structures formed of multiple BCC units joined together, even where the nodes have been displaced to give the appearance of a random structure.

[0036] The isotropic lattice structure 300C can be incorporated within medical devices such as orthopaedic implants. For example, the lattice structure 300C can fill any voids within such implants to provide the necessary stiffness properties without significantly increasing the weight of the component due the porous nature of the lattice structure 300C.

[0037] An important aspect of the present lattice structure 300C is the ability to reliably manufacture a lattice structure 300C that has isotropic stiffness characteristics, as this provides the starting point from which the mechanical properties of the lattice structure 300C, and therefore any component containing the lattice structure 300C, can be tuned or customised. For example, the lattice structure 300C can be easily scaled for different patients using the same three parameters described above. One advantage of this is a method of providing customised implants that have mechanical properties that have been tuned for specific patients, such as paediatric patients.

[0038] Where it is desirable to have a higher stiffness in a first loading direction (e.g. a vertical direction) compared to the remaining orthogonal directions relative to the first loading direction (e.g. perpendicular horizontal axes), this can be achieved by first generating the isotropic lattice structure 300C, and then increasing the thickness of selected struts so as to provide the desired stiffness characteristics of the lattice structure 300C. By way of example, the thickness of specific struts can be increased by changing the parameters of the laser (e.g. laser exposure time) or by altering the path of the laser such that the contour of the strut is increased to produce larger diameter struts. As shown in Figure 3D, such an approach can produce struts 320 that have a larger diameter in the vertical direction compared to the remaining struts 310 in the horizontal direction. Specifying which individual struts need to be thickened in order to provide tuned stiffness characteristics also takes advantage of the specificity of additive manufacturing processes.

[0039] In some cases it is also desirable to have regions of different mechanical stiffness characteristics within the same implant. For example, an implant may require some regions that can provide higher isotropic stiffness, while other regions may require greater stiffness in particular directions. By starting with an isotropic lattice structure 300, these different regions can be incorporated within the same implant by modifying the original isotropic lattice 300 as required and blending these regions together in combination with the main body of the implant. By way of example, the lattice structure can be incorporated within a tibial tray. However, it would be apparent that the lattice structure could be applied to any implant.

[0040] Figure 4 is a graphical representation of the stiffness profile of exemplary lattice structures in multiple loading directions (see also Figure 5). Table 1 below details each of the loading directions.

Direction	θ	φ
0	0.00	90.00
1	45.00	35.26
2	0.00	0.00

3	90.00	45.00
4	20.10	18.97
5	90.00	0.00
6	0.00	45.00
7	69.90	18.97
8	45.00	0.00
9	45.00	62.63

Table 1

[0041] In Figure 4, lattice structure "A" comprises a plurality of nodes arranged in a pseudo-stochastic arrangement, without any kinking of the struts, such as illustrated in Figure 3A. As shown in Figure 4, the Elastic modulus of lattice structure A varies considerably in the different loading directions. Taking directions 2, 5 and 8 as a horizontal plane, it can be seen that the stiffness in these directions is significantly lower than the stiffness in vertical directions 0, 3, 6 and 9. As such, lattice structures that do not incorporate any kinking will be less stiff in the horizontal plane and have an inherent plane of weakness, which is undesirable.

[0042] Lattice structure "B" of Figure 4 comprises a plurality of nodes in a stochastic arrangement where the horizontal struts 310 have been kinked according to the present method, such as illustrated in Figure 3B. As can be seen from Figure 4, the Elastic modulus of lattice structure B in the horizontal plane (directions 2, 5 and 8) is significantly increased compared to that of lattice structure A. This illustrates the desirable effect kinking the struts in the described manner has on the mechanical properties of the lattice structure, Struts that were previously near-horizontal can now be made in a reliable manner and can also produce a lattice structure having increased overall stiffness in all directions.

[0043] Lattice structure "C" comprises a plurality of nodes in a stochastic arrangement where the vertical 320 and horizontal 310 struts have been kinked according to the present method, such as illustrated in Figure 3C. As can be seen from Figure 4, the Elastic modulus of lattice structure C is significantly more consistent across all loading directions compared to lattice structures A and B, with a reduced range of stiffness values for lattice structure C compared to those of lattice structures A and B. Furthermore, lattice structure C does not have any peaks of stiffness in particular directions, which is highly desirable. In addition to having a smaller range of stiffness values across all directions, the variability of the stiffness profile of lattice structure C is also reduced compared to that of lattice structures A and B (see Figure 6), indicating greater isotropy of the resulting lattice structure. In some cases the lattice structure has a stiffness in three mutually orthogonal

directions that are within 20% of a mean stiffness across the three mutually orthogonal directions.

[0044] Figure 7 is an illustration of an alternative series of loading directions, and Figure 8 is a graphical representation of the stiffness profile of further exemplary lattice structures. Figure 8 shows the Elastic modulus of different exemplary lattice structures “D”, E” and “F”, in different directions “0”, “1”, “2” and “3”. Lattice structure D comprises a plurality of nodes arranged in a pseudo-stochastic arrangement, without any kinking of the struts and may be similar to that illustrated in Figure 3A. As can be seen from Figure 8, the Elastic modulus of lattice structure D varies in each of the loading directions, with a stiffness peak in the vertical direction 0 and decreased stiffness in the horizontal direction 3 and in intermediary directions 1 and 2.

[0045] Lattice structure E comprises a plurality of nodes in a stochastic arrangement where the vertical 320 and horizontal 310 struts have been kinked according to the present method, such as illustrated in Figure 3C. As can be seen from Figure 8, the Elastic modulus of lattice structure E is significantly more uniform compared to lattice structure D, in the horizontal, vertical and intermediary directions and provides a lattice structure having isotropic loading characteristics.

[0046] Lattice structure F comprises a plurality of nodes in a stochastic arrangement where the vertical 320 and horizontal 310 struts have been kinked according to the present method, and the vertical struts 320 are thicker than the horizontal struts to provide a tuned stiffness profile, such as illustrated in Figure 3D. As can be seen from Figure 8, the Elastic modulus of lattice structure F has been tuned to provide the greatest stiffness in direction “0”, and decreasing stiffness in directions “1, “2” and “3”. It should be noted that the tuned lattice structure F is based on the isotropic lattice structure E, further highlighting the advantage of being able to reliably produce an isotropic lattice structure that can be easily scaled according to the specific end-use, and tuned by simply increasing the thickness of specific struts. This is considerably more convenient than defining bespoke lattice structures for a specific application that have loading characteristics tuned for specific applications that can also be manufactured reliably using existing additive manufacturing techniques.

[0047] Throughout the description and claims of this specification, the words “comprise” and “contain” and variations of them mean “including but not limited to”, and they are not intended to (and do not) exclude other moieties, additives, components, integers or steps. Throughout the description and claims of this specification, the singular encompasses the plural unless the context otherwise requires. In particular, where the indefinite article is

used, the specification is to be understood as contemplating plurality as well as singularity, unless the context requires otherwise.

[0048] Features, integers, characteristics, or groups described in conjunction with a particular aspect, embodiment or example of the invention are to be understood to be applicable to any other aspect, embodiment or example described herein unless incompatible therewith. All of the features disclosed in this specification (including any accompanying claims, abstract and drawings), and/or all of the steps of any method or process so disclosed, may be combined in any combination, except combinations where at least some of such features and/or steps are mutually exclusive. The invention is not restricted to the details of any foregoing embodiments. The invention extends to any novel one, or any novel combination, of the features disclosed in this specification (including any accompanying claims, abstract and drawings), or to any novel one, or any novel combination, of the steps of any method or process so disclosed.

CLAIMS

1. A method of defining a lattice structure for use in an additive manufacturing process having a build direction perpendicular to a build plane, the method comprising:

defining a volume,

generating a plurality of nodes within the volume,

generating a plurality of struts, wherein each strut extends between a pair of nodes, and wherein each strut extends in a direction relative to the build plane,

identifying struts that form an angle relative to the build plane of less than a critical angle of between 0 and 45 degrees,

selecting a point on each of the identified struts to define first and second parts of each of the identified struts,

displacing the selected point of each of the identified struts such that the angle between each of the first and second parts of each of the identified struts relative to the build plane is no less than the critical angle, and

outputting control data for use in a device configured to manufacture the structure using an additive manufacturing process.

2. A method according to claim 1 further comprising the steps of:

defining a kinking angle as the angle between the first and second parts of each of the identified struts,

determining a range of kinking angles of the identified struts,

selecting a point on each of the remaining struts to define first and second parts of each of the remaining struts, and

displacing the selected point of each of the remaining struts such that the first and second parts of the remaining struts have a kinking angle within the range of kinking angles.

3. A method according to claim 2 comprising calculating an average kinking angle of the identified struts, wherein the selected point of each of the remaining struts is displaced such that the kinking angle of the remaining struts is equal to the average kinking angle.

4. A method according to any preceding claim, wherein the selected point for each of the identified struts or the remaining struts is between 10 and 90 % of the length of a respective strut, preferably a mid-point of the respective strut.

5. A method according to claim 4, wherein the length of each strut is between 0.1mm and 4mm.

6. A method according to any preceding claim, wherein the selected point of each of the identified struts is displaced in the build direction.

7. A method according to any preceding claim, wherein the selected point of each of the identified struts is displaced in a vertical direction.

8. A method according to any preceding claim, wherein the displacement is selected such that the angle between the respective first and second parts and the plane is substantially equal to one another.

9. A method according to any preceding claim further comprising specifying a node connection limit of 2 or more, wherein 2 or more comprises the maximum number of other nodes to which each node may be connected by respective struts.

10. A method according to claim 9, wherein, if there are a greater number of nodes available for connecting to than the node connection limit, selecting the 2 or more nodes that are closest to the respective node, and generating struts between the closest 2 or more nodes and the respective node.

11. A method according to any preceding claim, wherein the method further comprises varying a thickness of each of the struts, such that the lattice structure has a stiffness in a first loading direction that is greater by a factor of up to 20 times relative to orthogonal loading directions relative to the first loading direction.

12. A method according to claim 2 or any claim dependent thereon, wherein the method further comprises varying a thickness of each of the struts, such that the lattice structure has a stiffness in three mutually orthogonal directions that are within a factor of between 0.8 and 1.2 relative to one another.

13. A method according to any preceding claim, wherein the plurality of nodes are generated in any of: a pseudo-stochastic arrangement, a periodic arrangement or a uniform arrangement.

14. A method according to any preceding claim, wherein the additive manufacturing process is one of: fused deposition modelling, powder bed fusion, laser sintering, electron beam melting or stereolithography printing.

15. A processor comprising a non-volatile memory having instructions stored therein for executing the method according to any preceding claim.

16. A lattice structure comprising:

a plurality of nodes, and

a plurality of struts, wherein each strut extends between a pair of nodes,

wherein each strut extends in a direction relative to a plane normal to a first direction, and

wherein each strut is arranged to form an angle relative to the plane of no less than a critical angle of between 0 and 45 degrees.

17. A structure according to claim 16, wherein each of the struts are formed of first and second parts that define a kinking angle therebetween, and wherein the kinking angle is no less 70 degrees.

18. A structure according to claim 16 or claim 17, wherein each strut has a length between 0.1mm and 4mm.

19. A structure according to any of claims 16 to 18, wherein the lattice comprises a metal.

20. A structure according to any of claims 16 to 19, wherein the plurality of nodes are arranged in any of: a pseudo-stochastic arrangement, a periodic arrangement or a uniform arrangement.

21. A medical device comprising a structure according to any of claims 16 to 20.

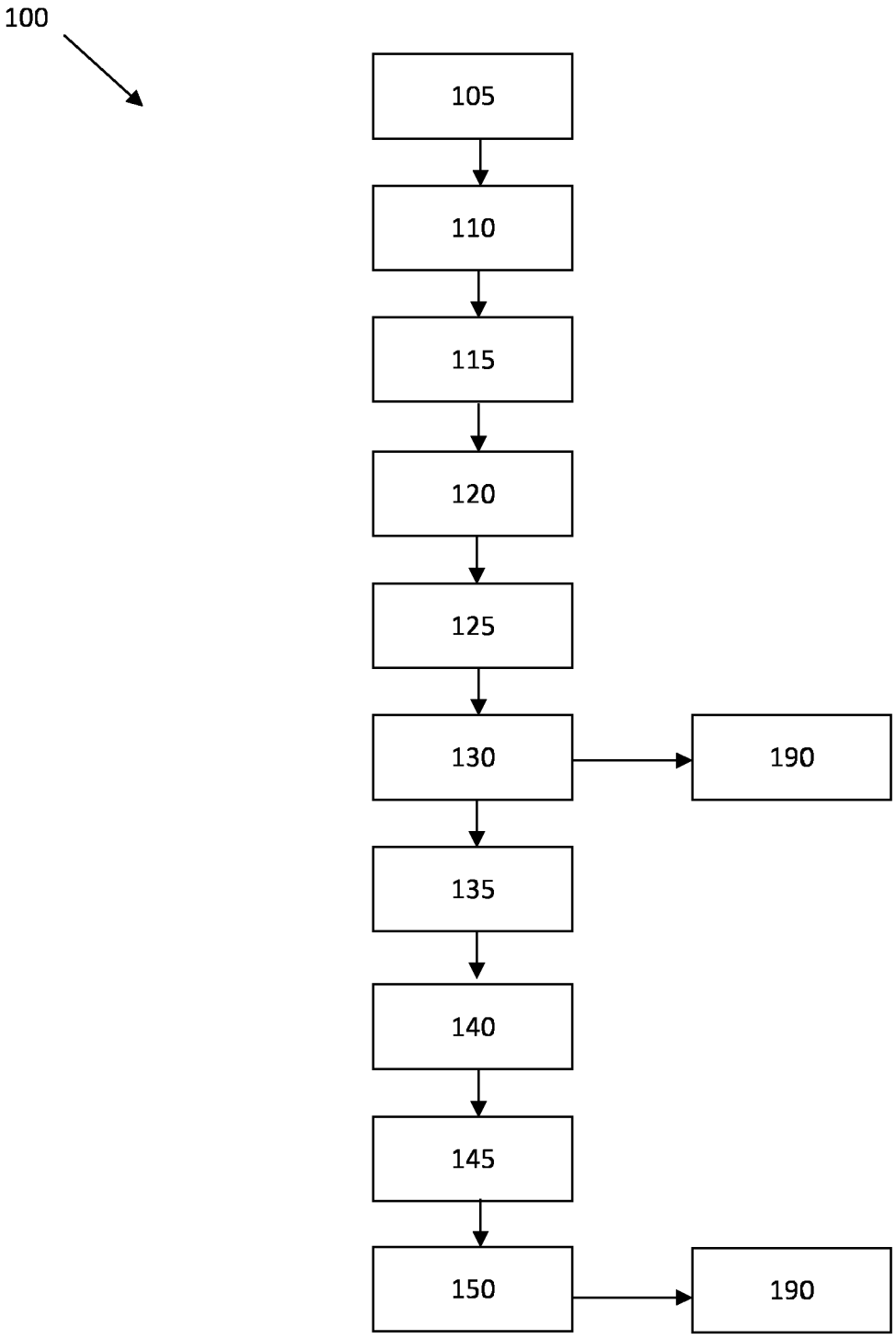


FIG. 1

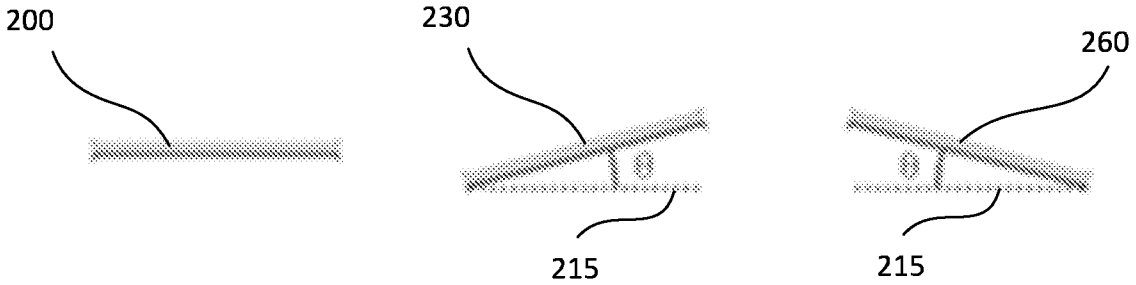


FIG. 2A

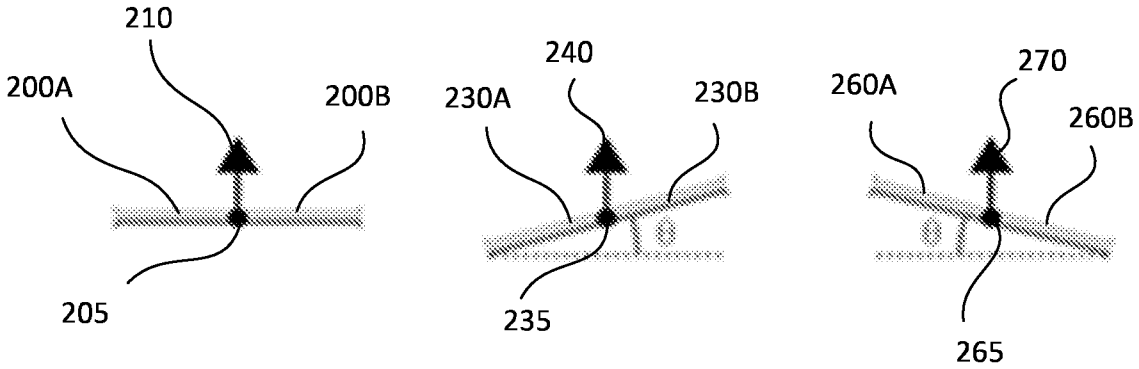


FIG. 2B

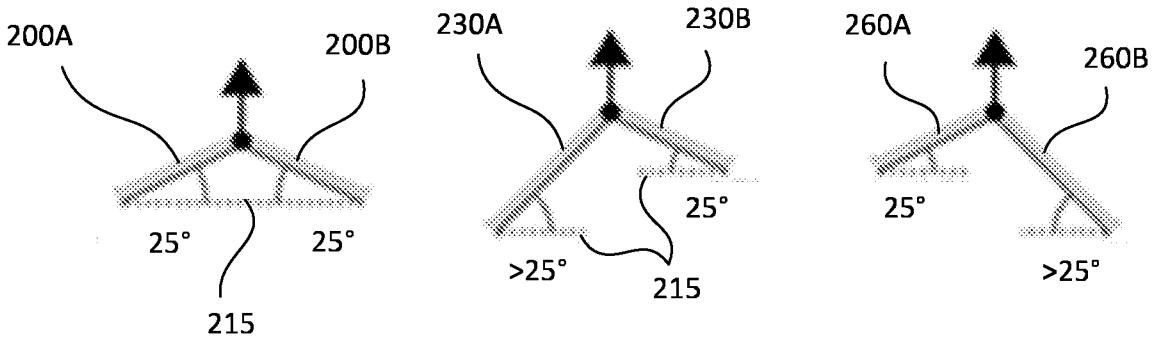


FIG. 2C

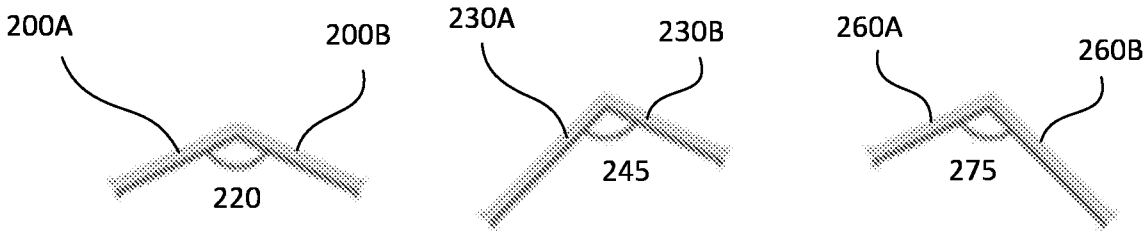


FIG. 2D

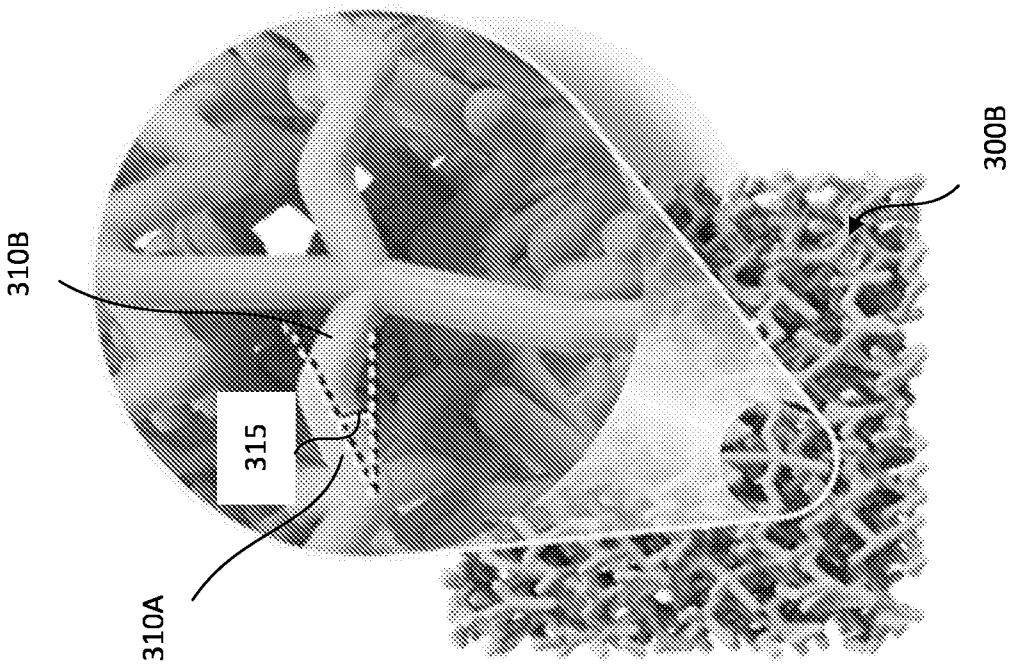


FIG. 3B

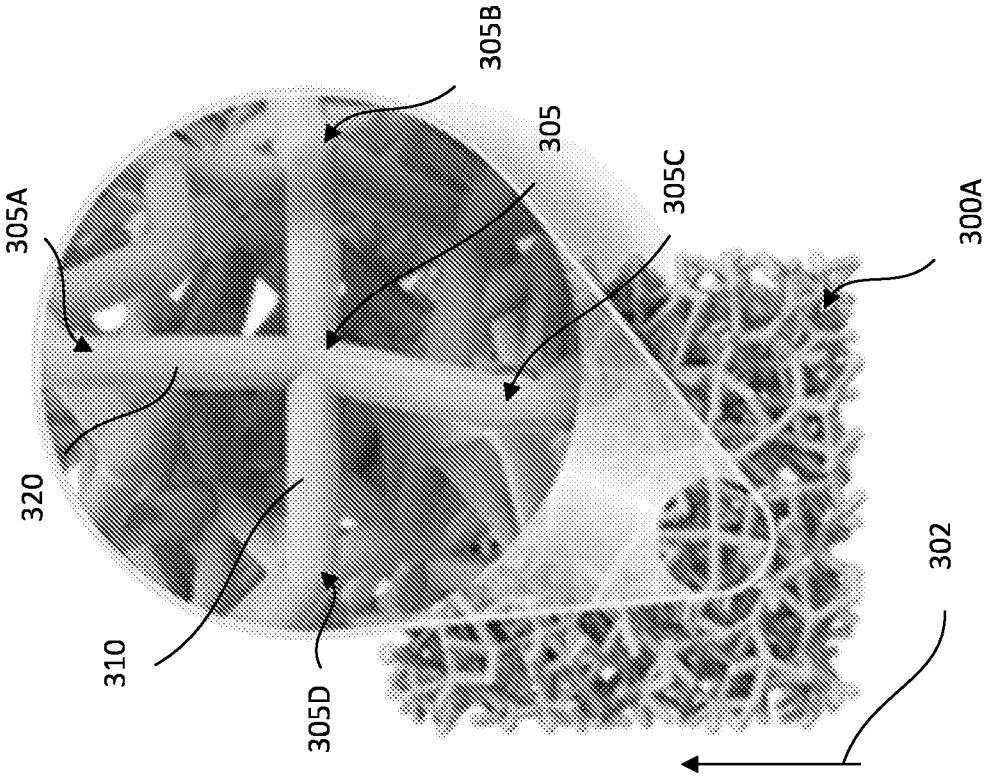


FIG. 3A

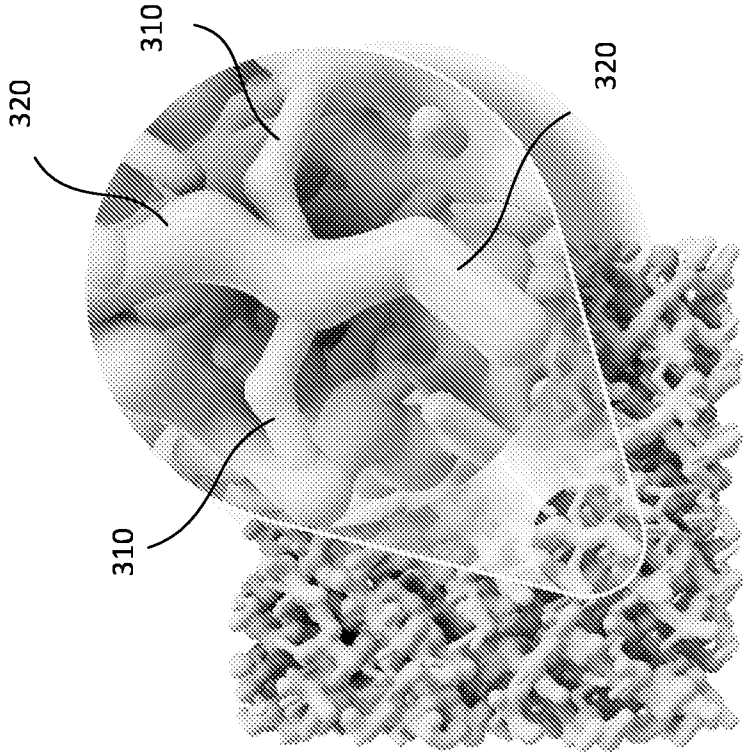


FIG. 3D

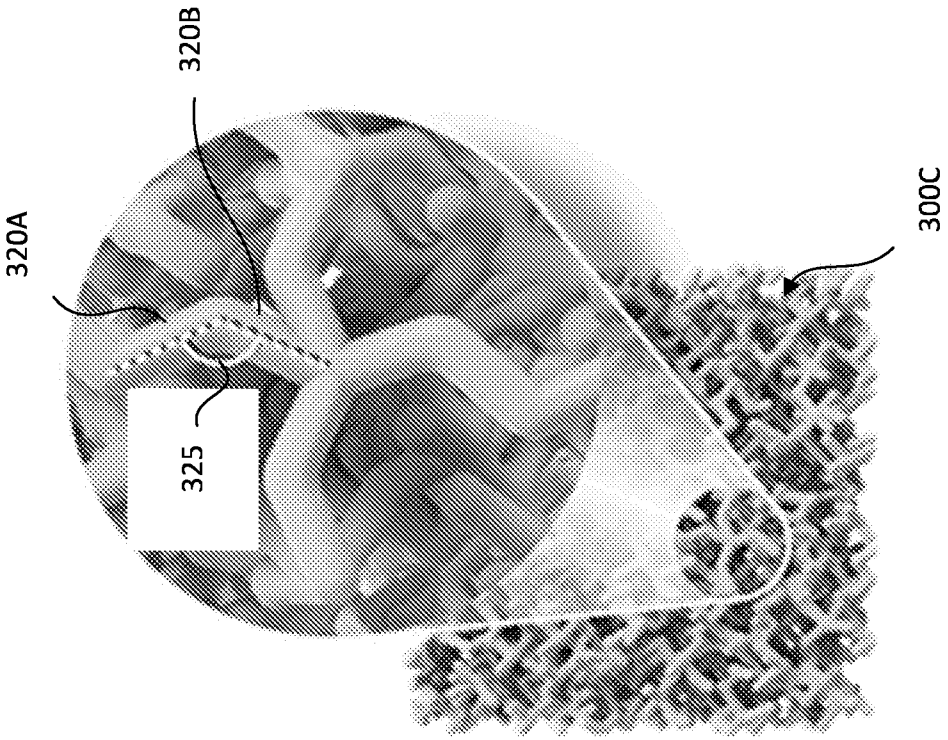


FIG. 3C

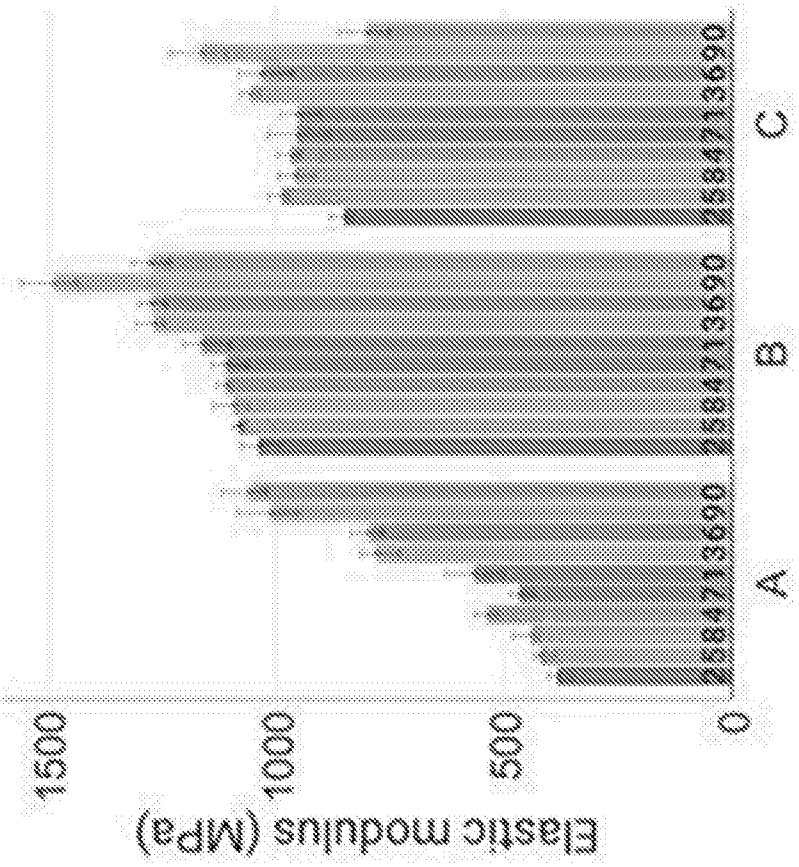


FIG. 4

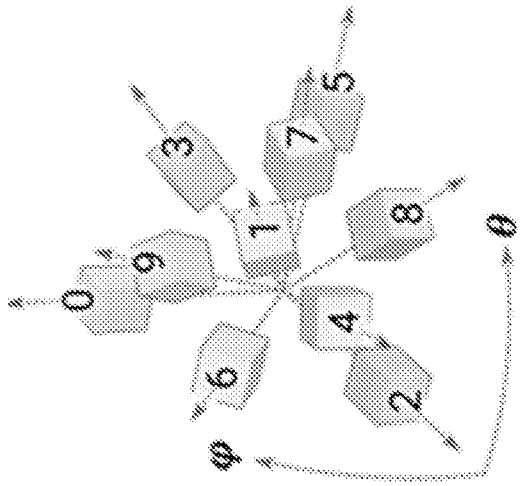


FIG. 5

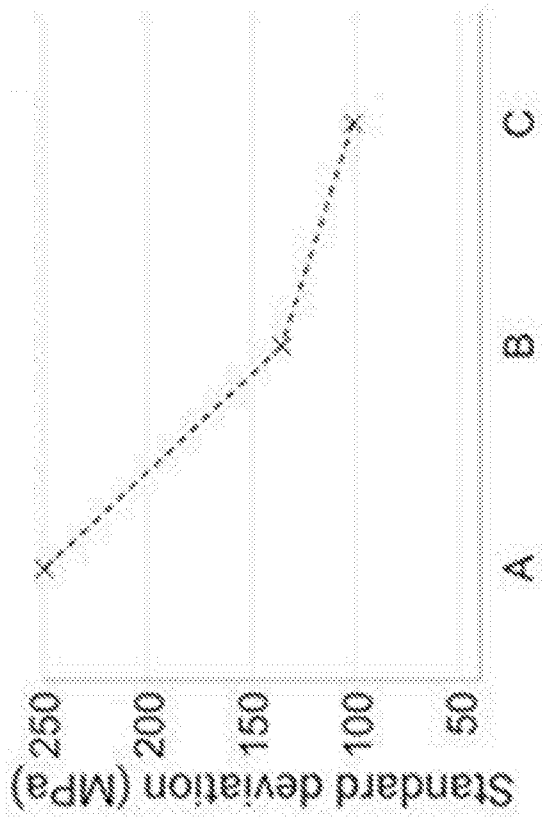


FIG. 6

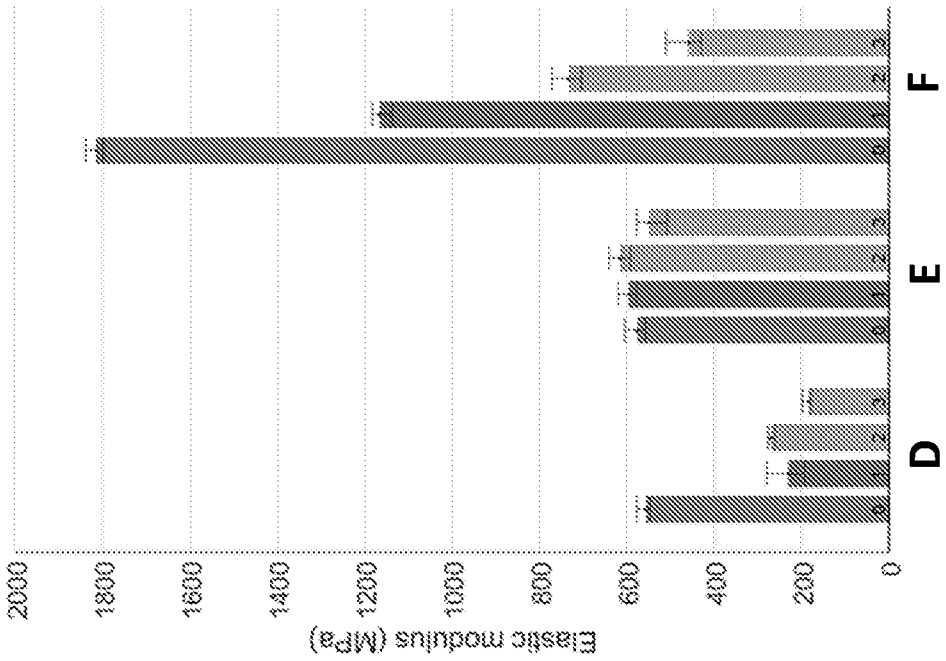

Elastic modulus (MPa)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
D
E
F

FIG. 8

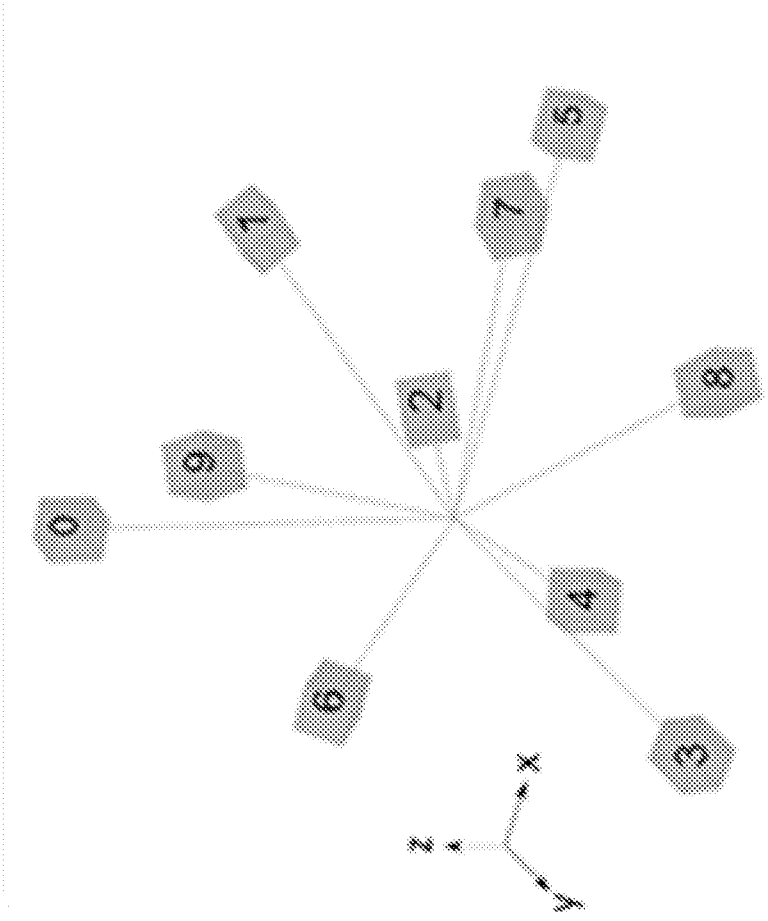

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FIG. 7

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2021/050795

A. CLASSIFICATION OF SUBJECT MATTER
INV. B22F10/20 A61F2/30 B22F10/28 B22F10/38 B22F10/80
B33Y80/00 B33Y50/02
ADD.
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B22F A61F B33Y C22C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
1 June 2021	10/06/2021

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Reich, Claus

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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X	EP 1 683 593 A2 (HOWMEDICA OSTEONICS CORP [US]) 26 July 2006 (2006-07-26) figures 1-9 paragraphs [0088], [0089], [0096]	16,18-21
A	EP 2 647 453 A2 (HOWMEDICA OSTEONICS CORP [US]; UNIV LIVERPOOL [GB]) 9 October 2013 (2013-10-09) figures 1-36 paragraphs [0106], [0121]	1-21
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International application No
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