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Zhang

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(54) **MATERIALS AND METHODS FOR JOINING METAL SHEETS**

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(22) Filed: **Aug. 27, 2019**

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F16B 35/04 (2006.01)
F16B 5/02 (2006.01)
F16B 5/04 (2006.01)

(52) **U.S. Cl.**
CPC ***F16B 5/0275*** (2013.01); ***F16B 5/04*** (2013.01)

(58) **Field of Classification Search**
CPC F16B 5/04; F16B 5/0275
USPC 411/389
See application file for complete search history.

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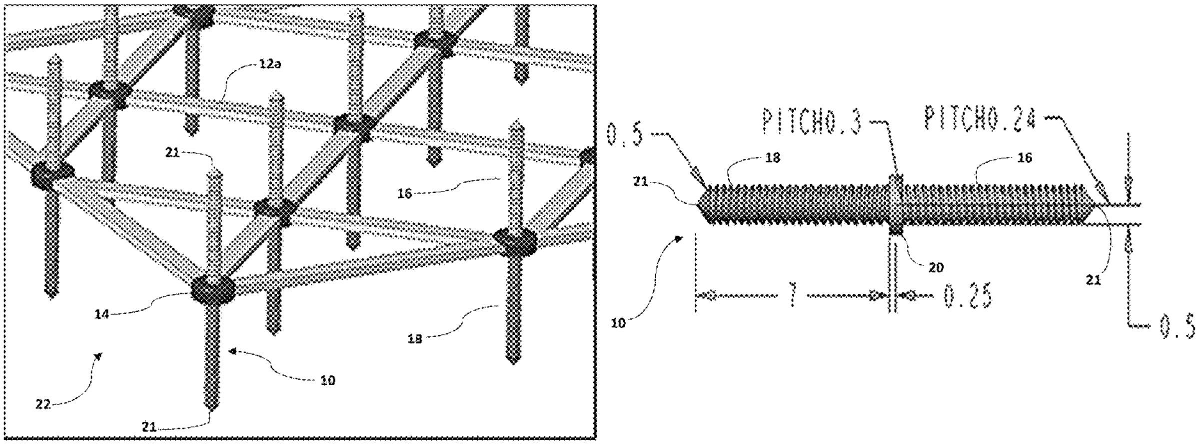
Primary Examiner — Gary W Estremsky
(74) *Attorney, Agent, or Firm* — MacMillan, Sobanski & Todd, LLC

(57) **ABSTRACT**

Embodiments of connectors for joining metal sheets, and methods of using the same, are described.

18 Claims, 20 Drawing Sheets
(10 of 20 Drawing Sheet(s) Filed in Color)



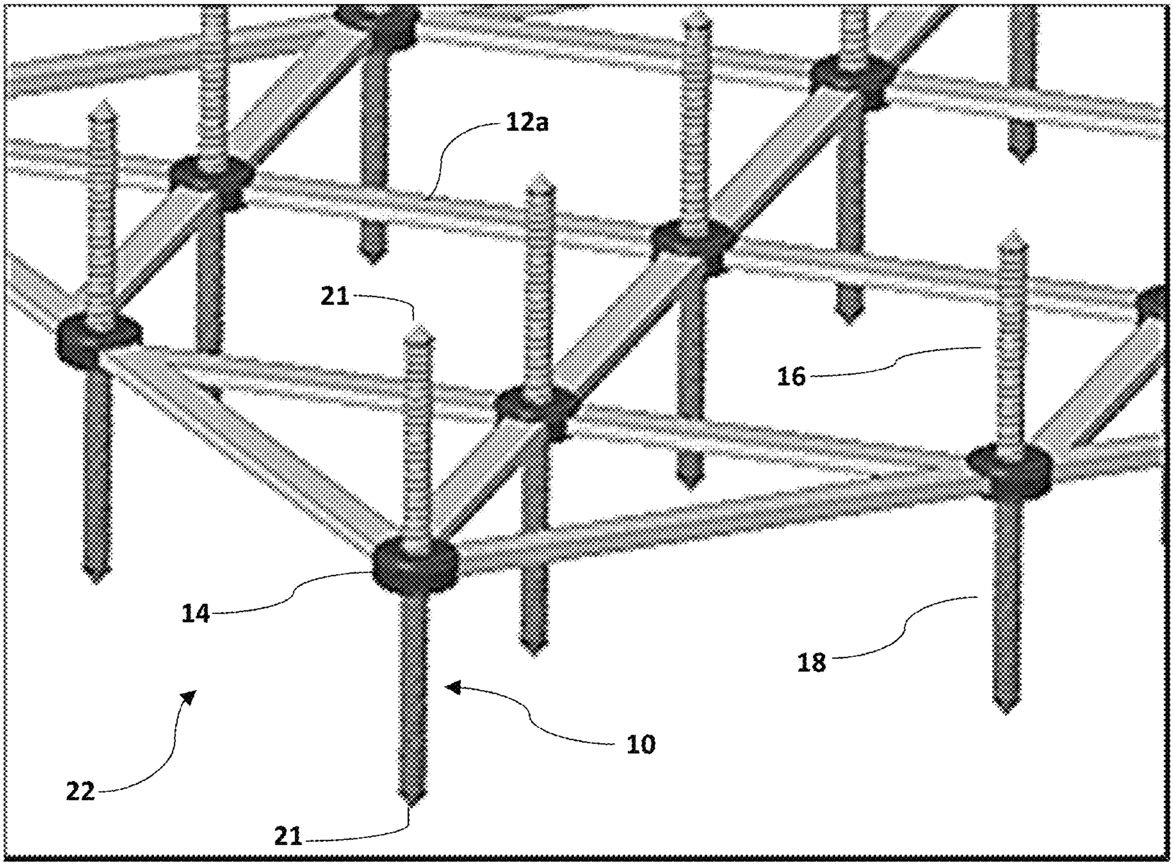


FIG. 1

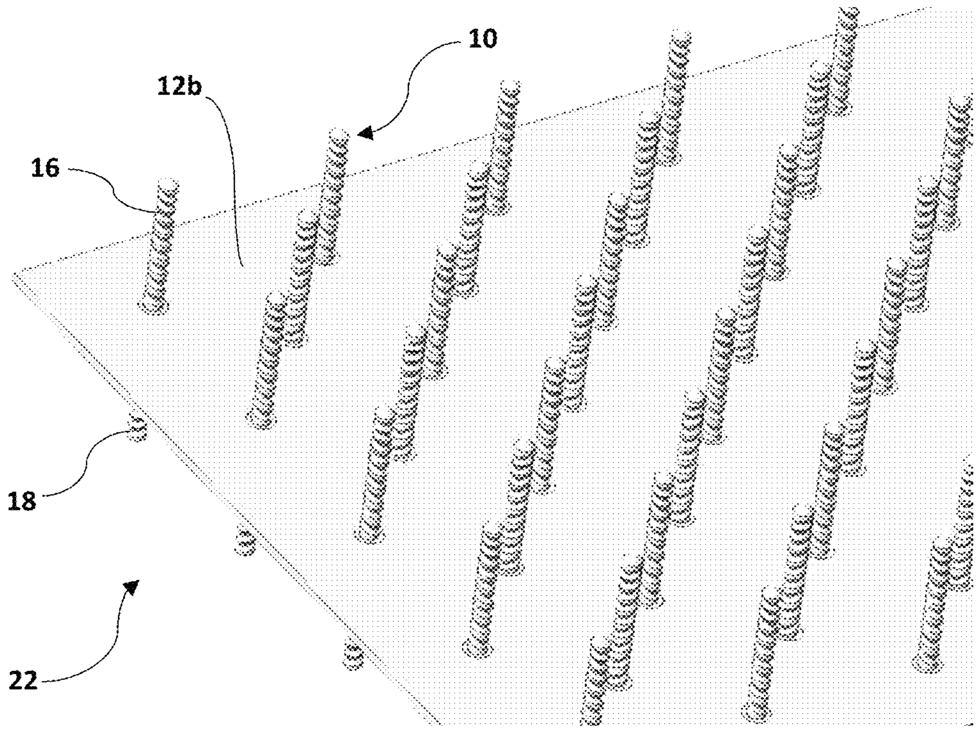


FIG. 2

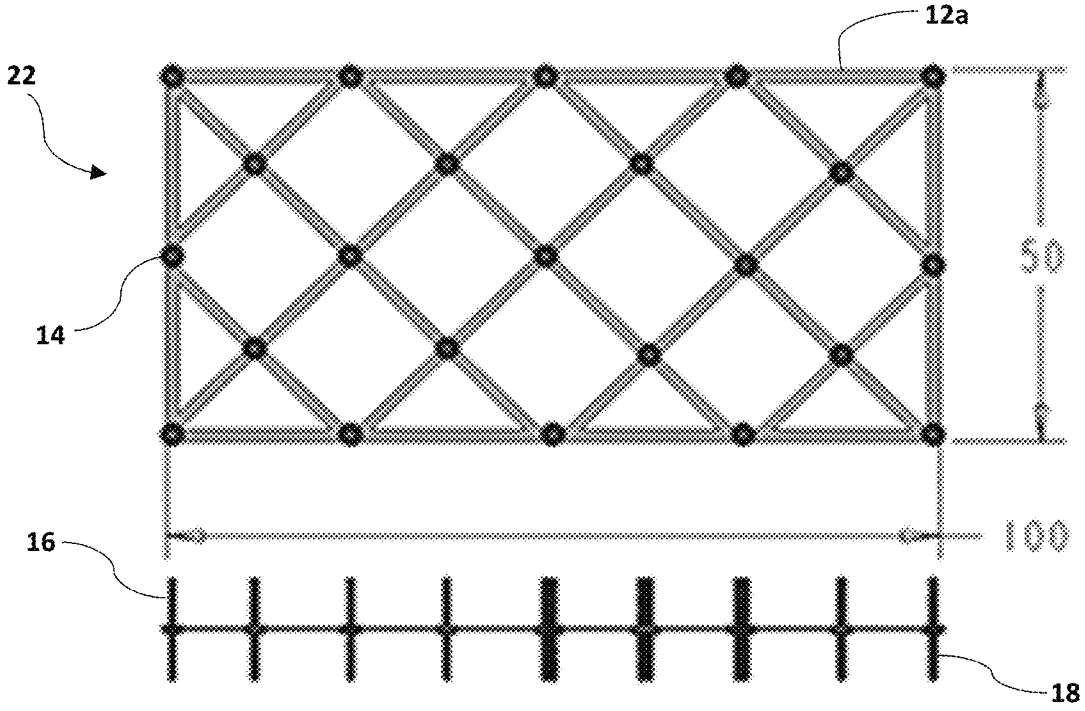


FIG. 3

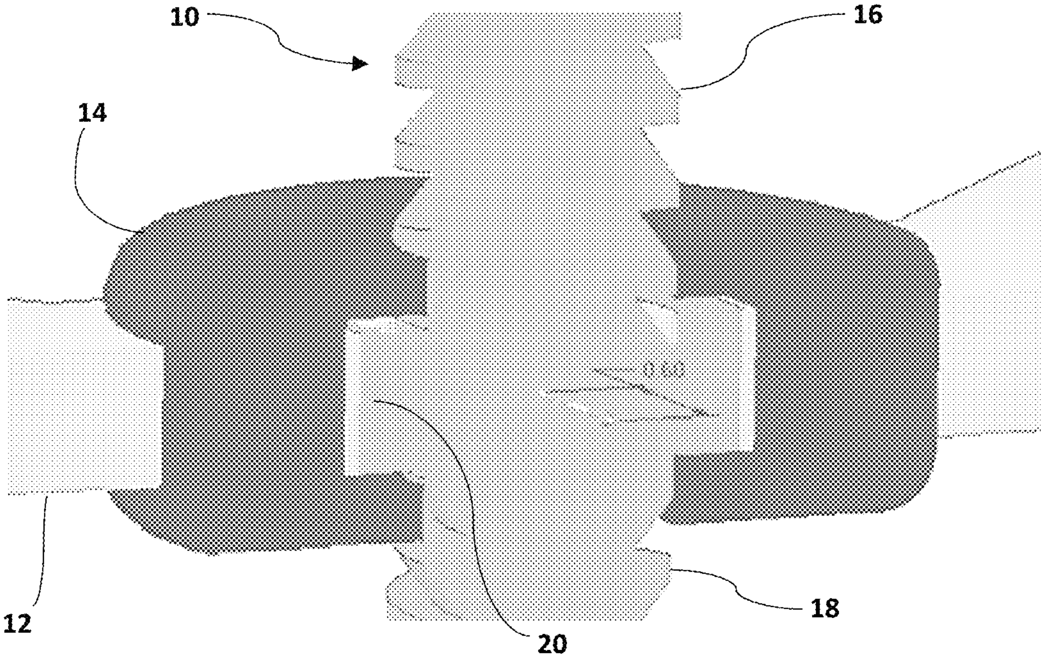


FIG. 4

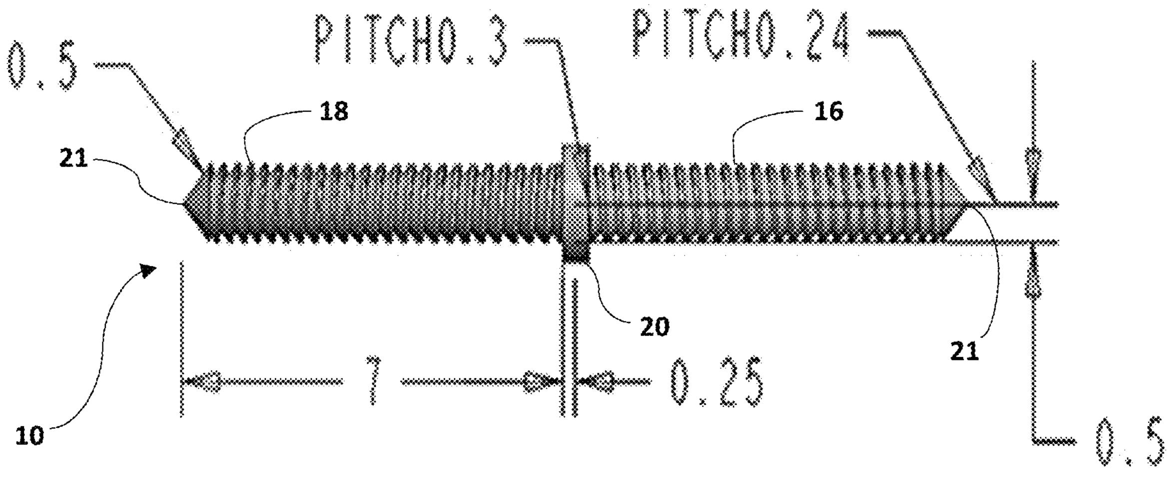


FIG. 5

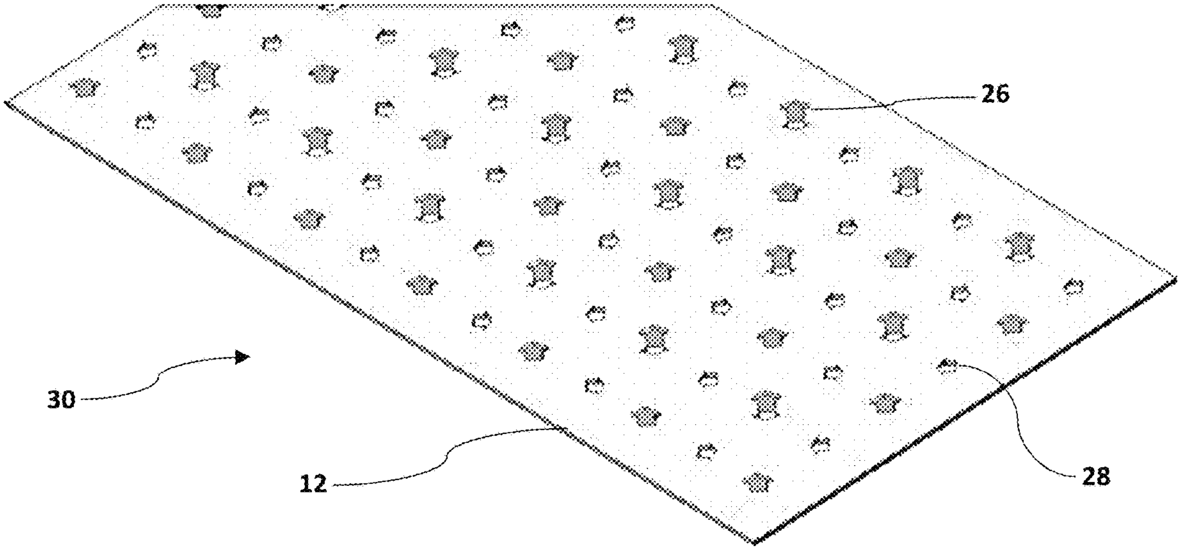

26
30
12
28

FIG. 6

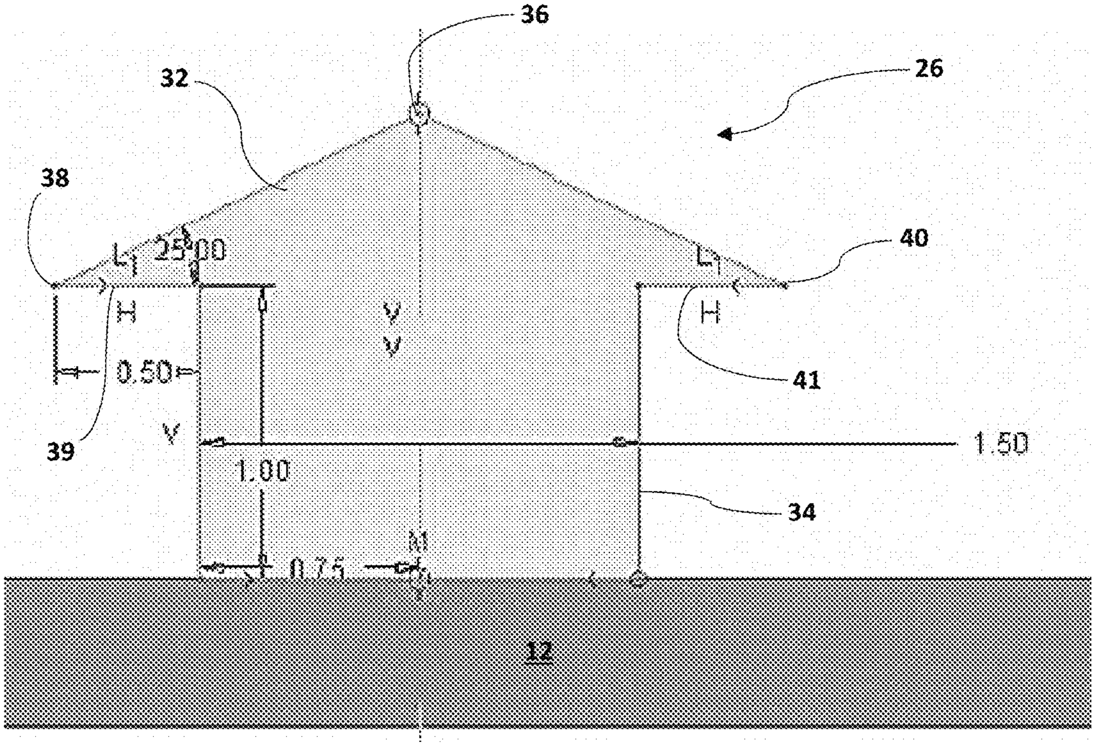

36
32
26
38
L1
25.00
L1
40
H
V
V
H
41
0.50
39
V
1.50
1.00
34
M
0.75
12

FIG. 7

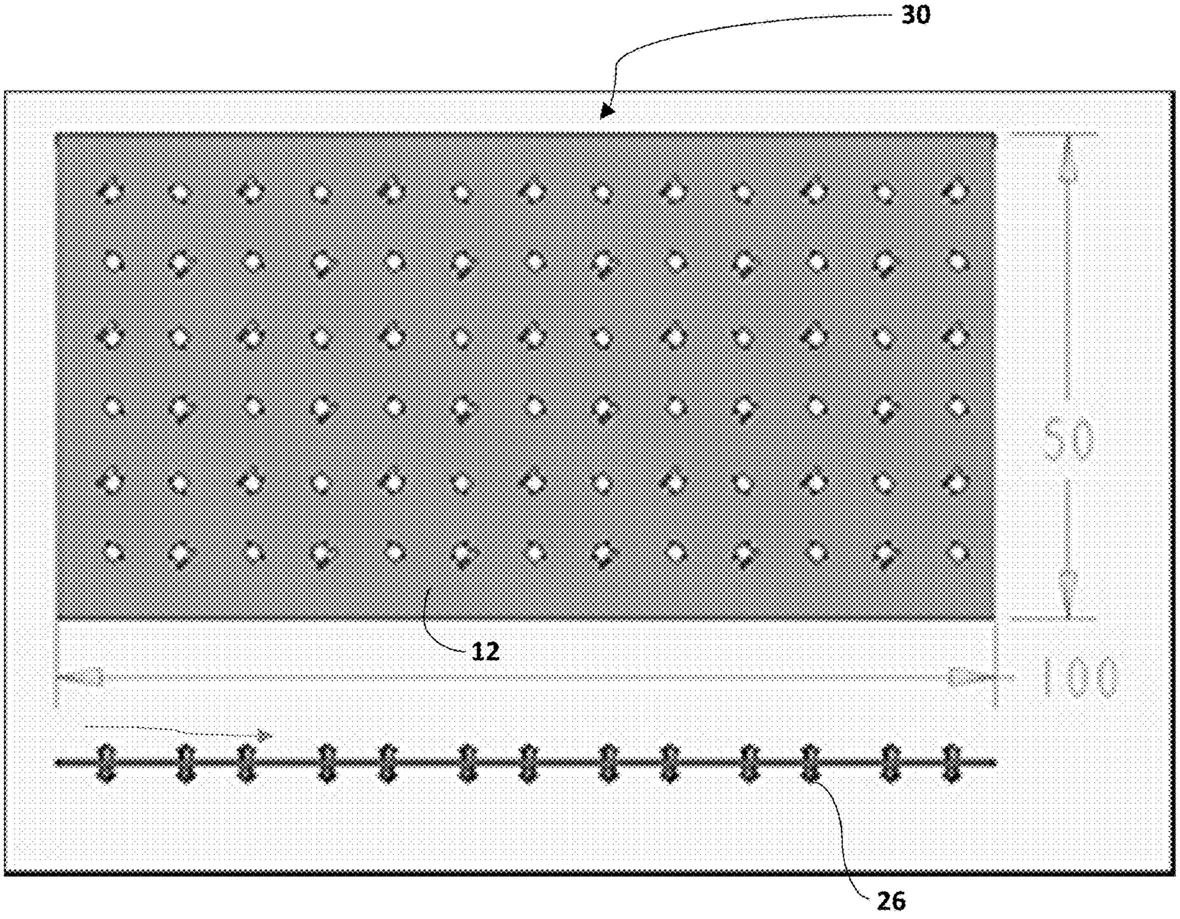


FIG. 8

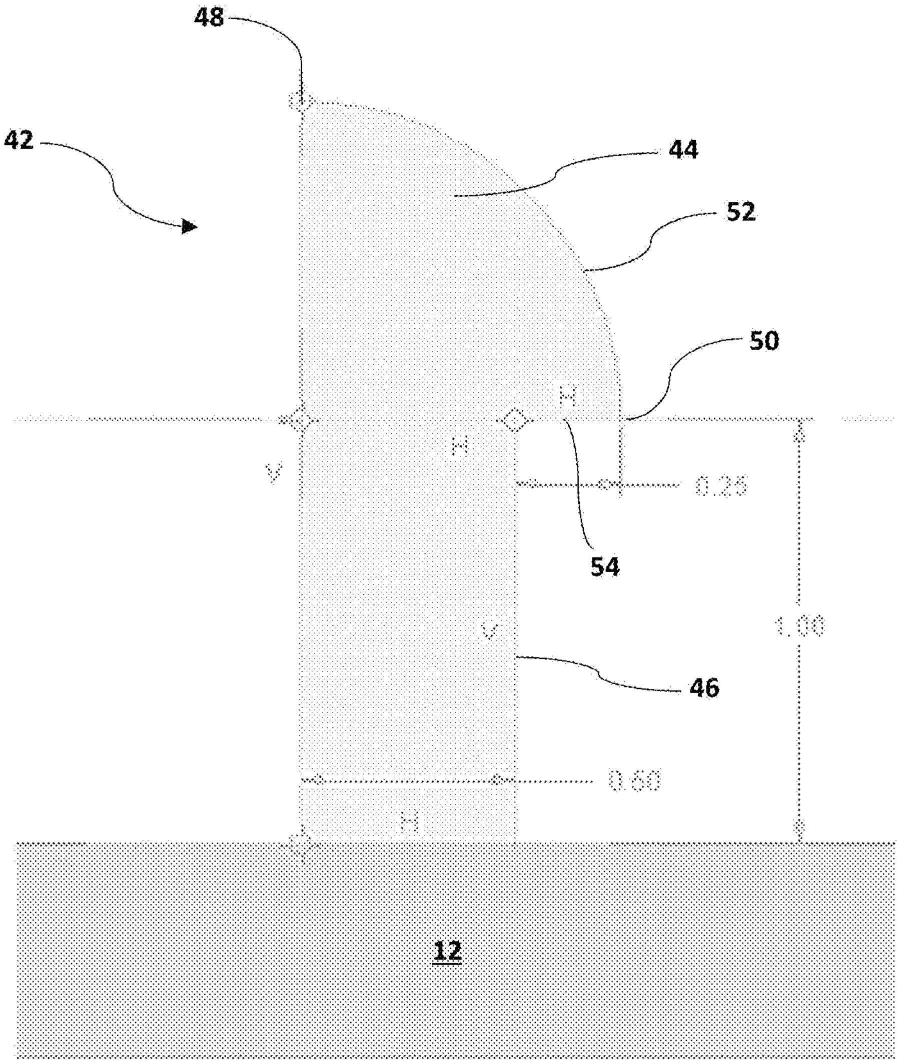


FIG. 9

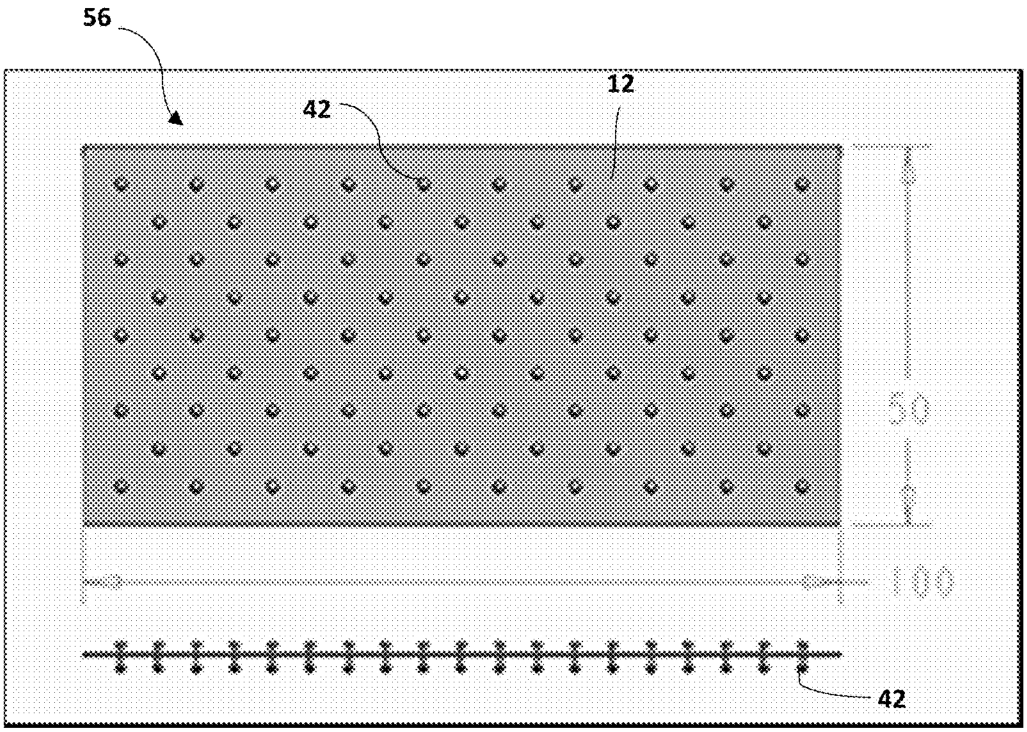


FIG. 10

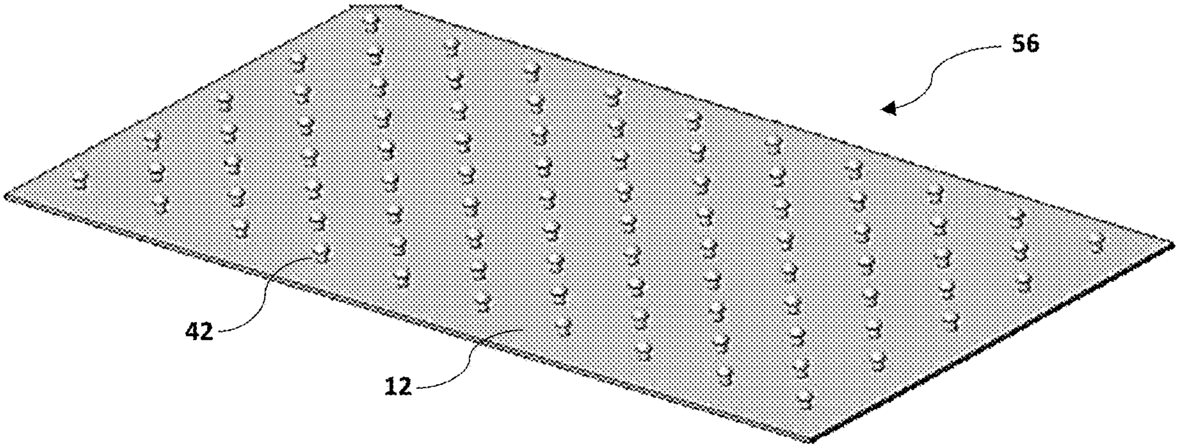


FIG. 11

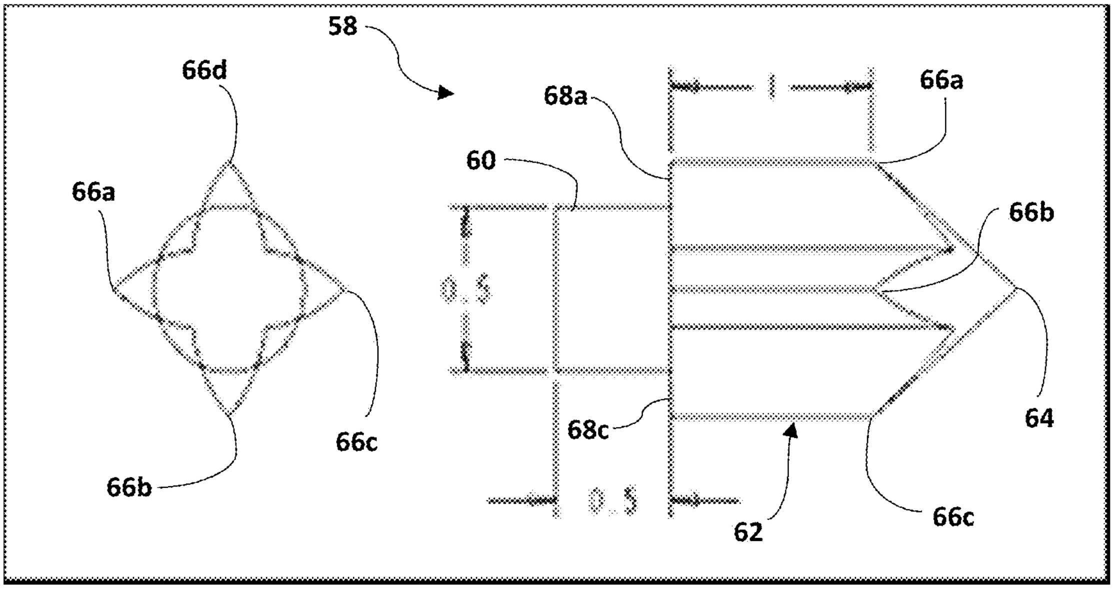

58
66d
66a
66c
66b
68a
60
0.5
1
66a
66b
64
68c
0.5
62
66c

FIG. 12

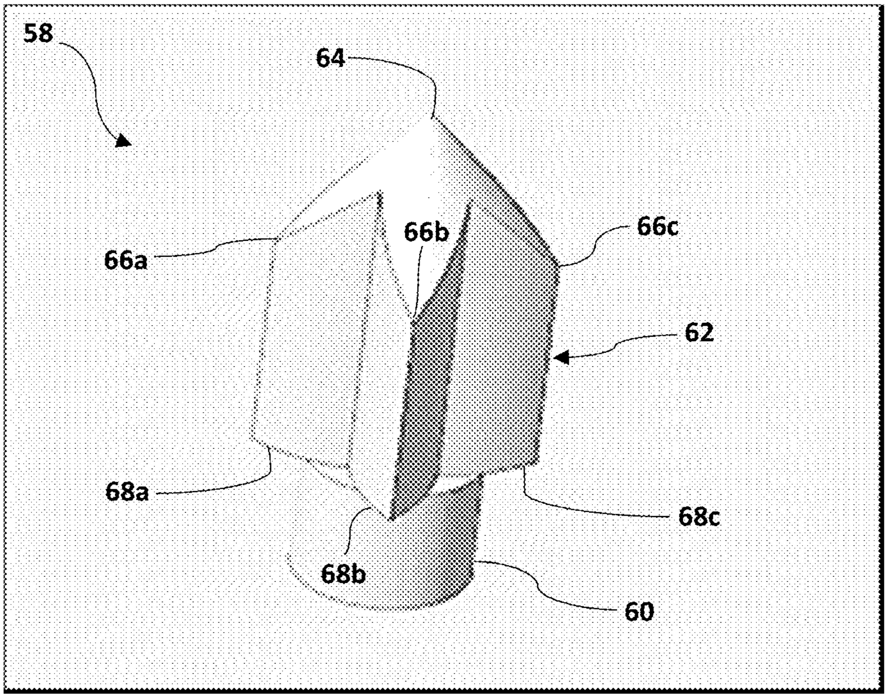

58
64
66a
66b
66c
62
68a
68b
68c
60

FIG. 13

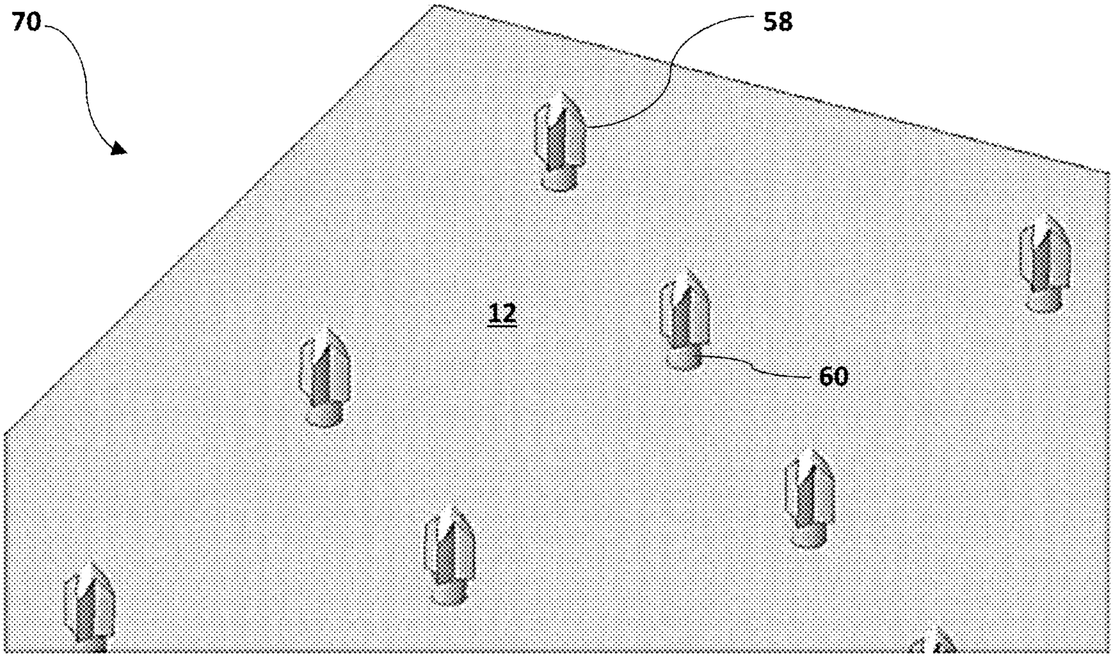


FIG. 14

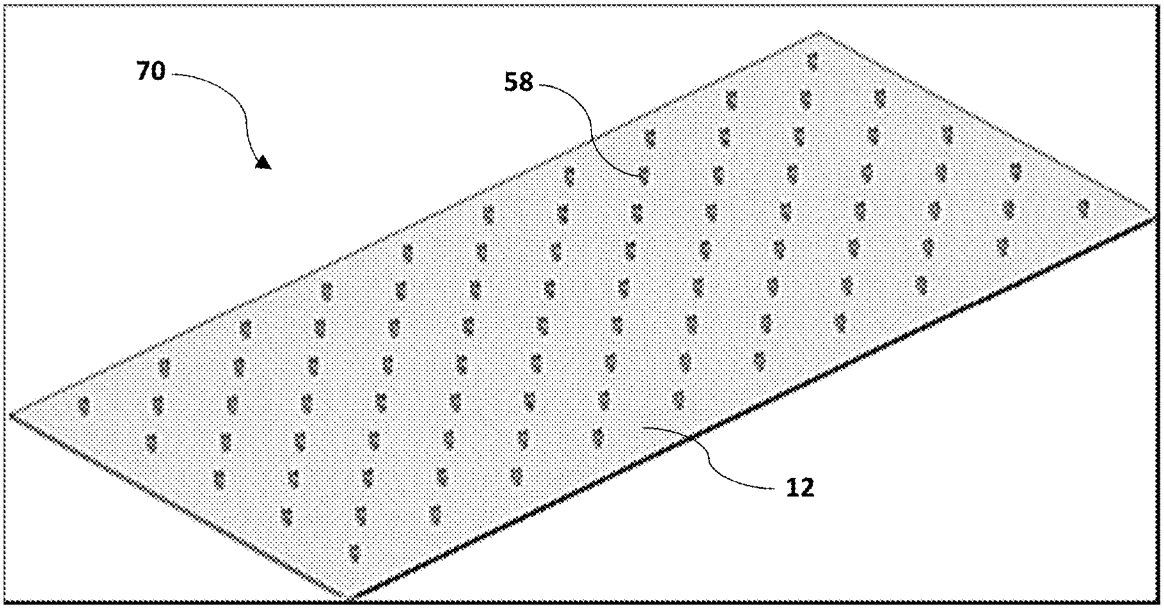


FIG. 15

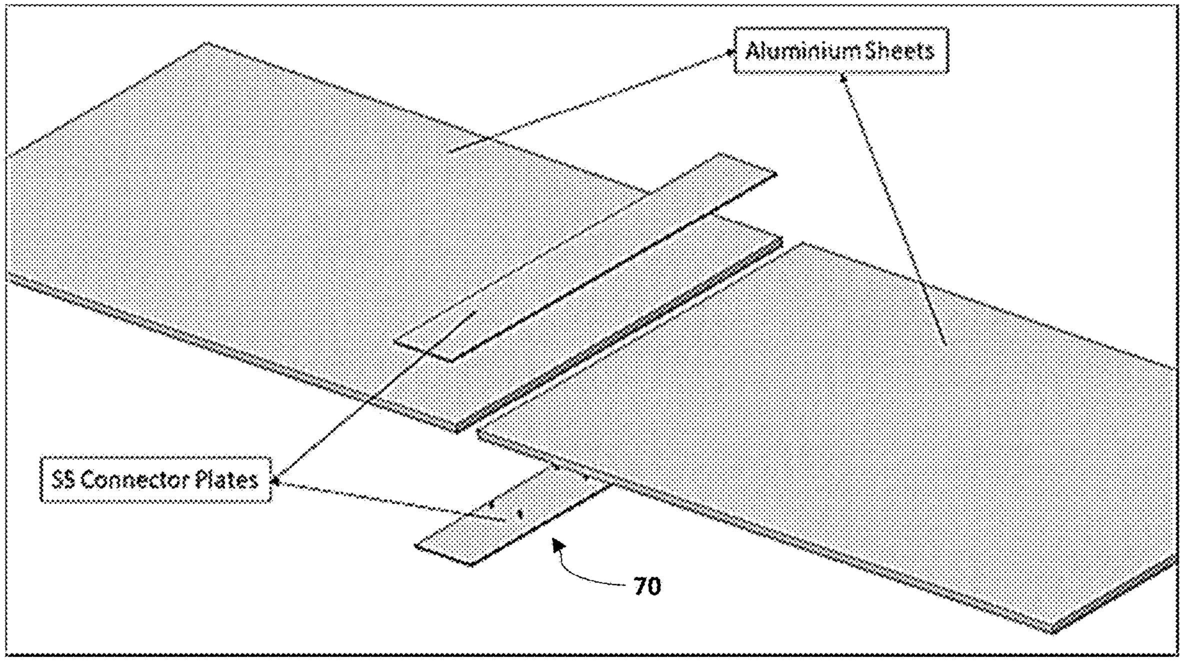


FIG. 16

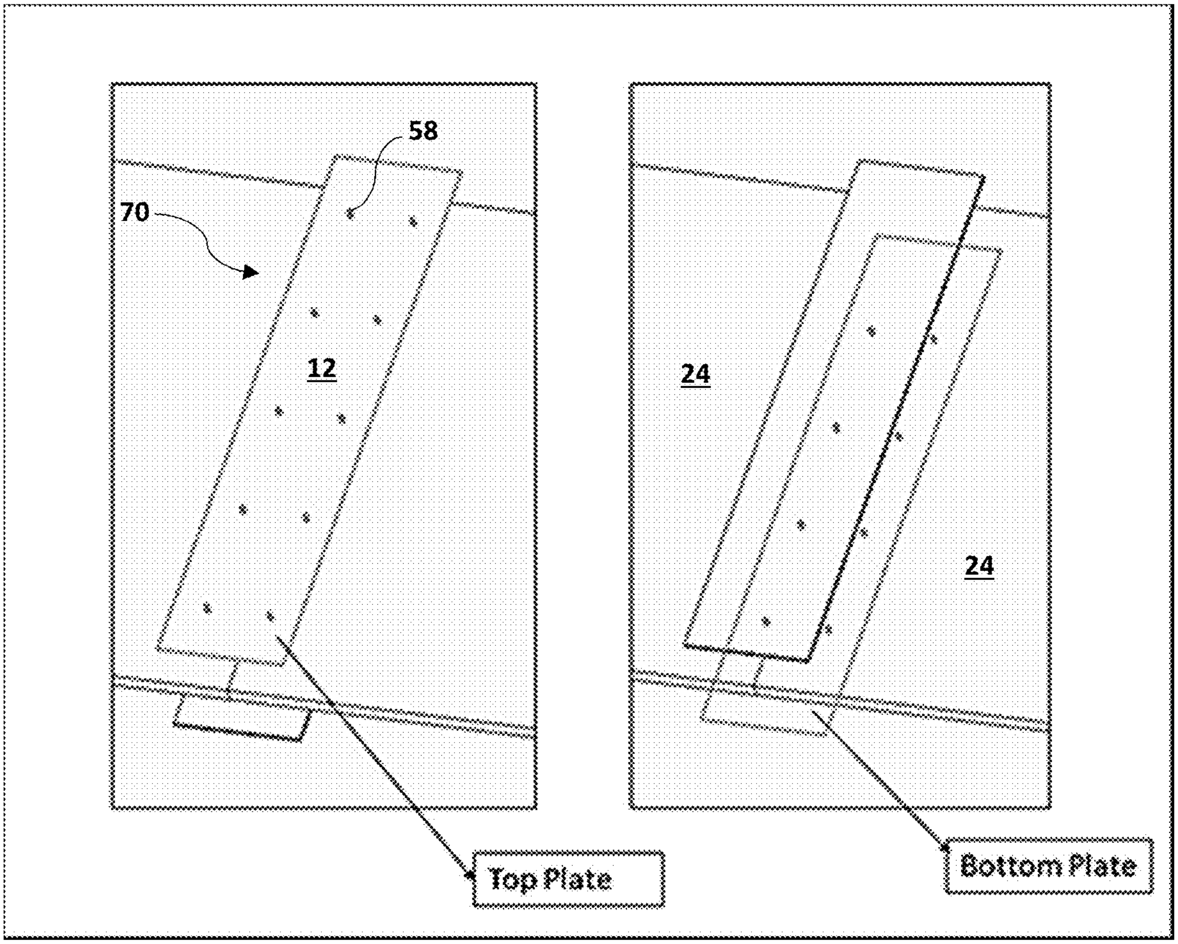


FIG. 17

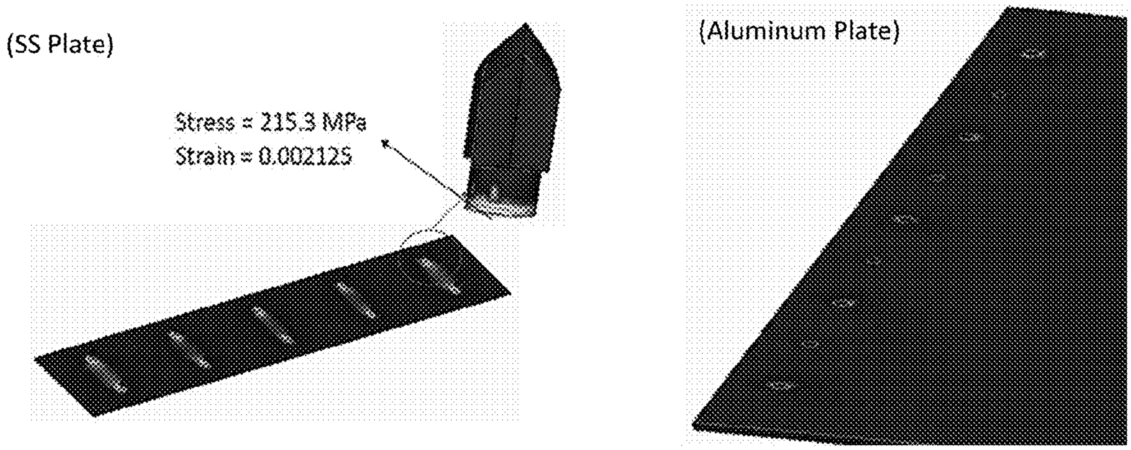


FIG. 18A

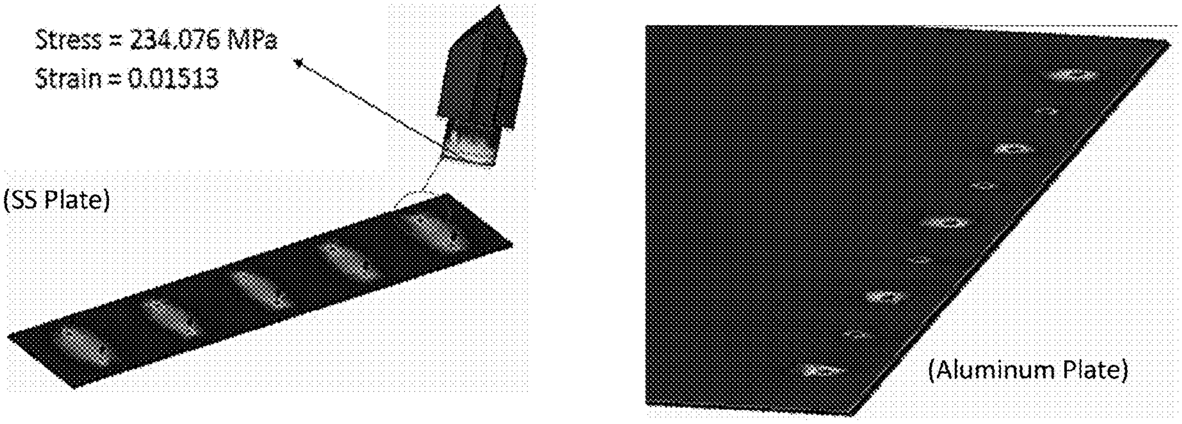


FIG. 18B

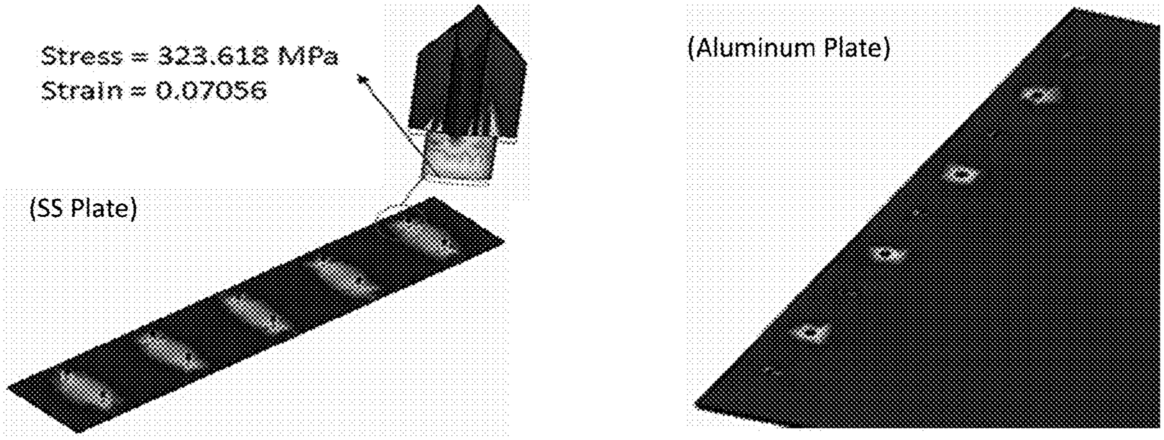


FIG. 18C

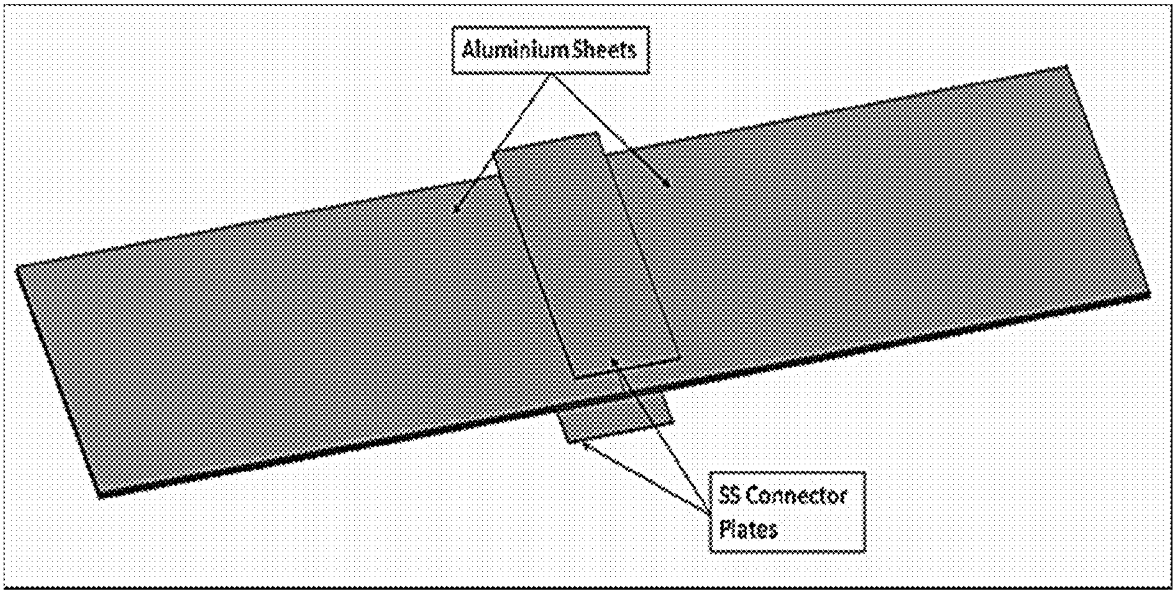


FIG. 19A

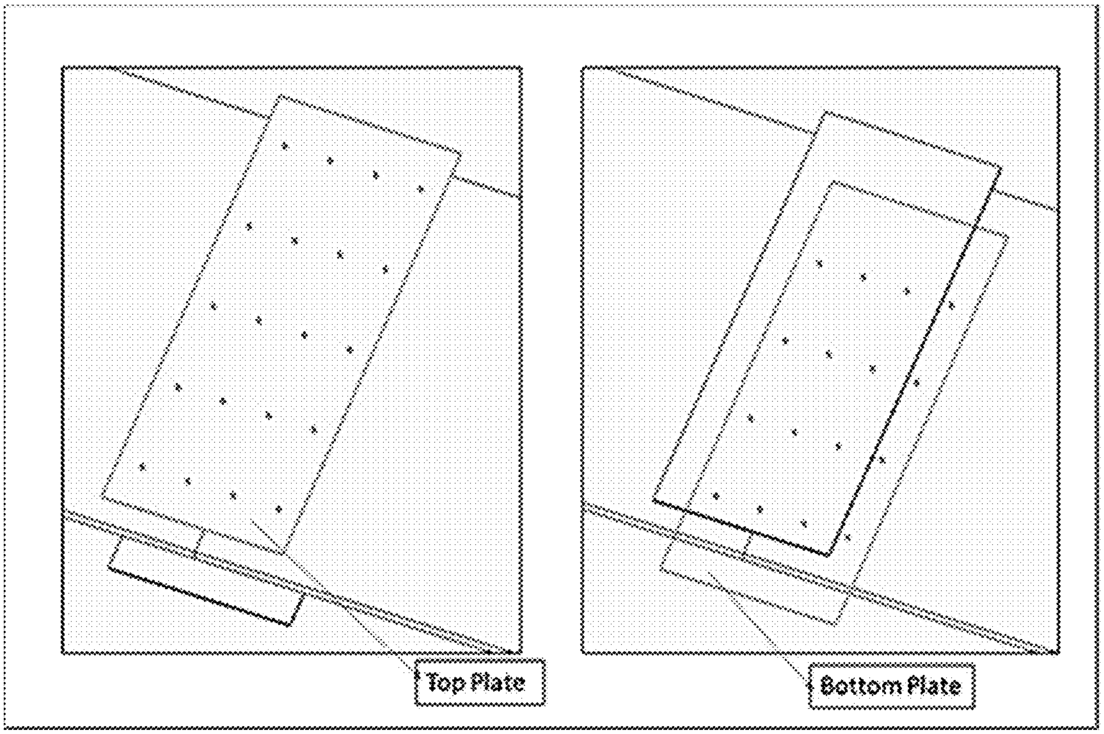


FIG. 19B

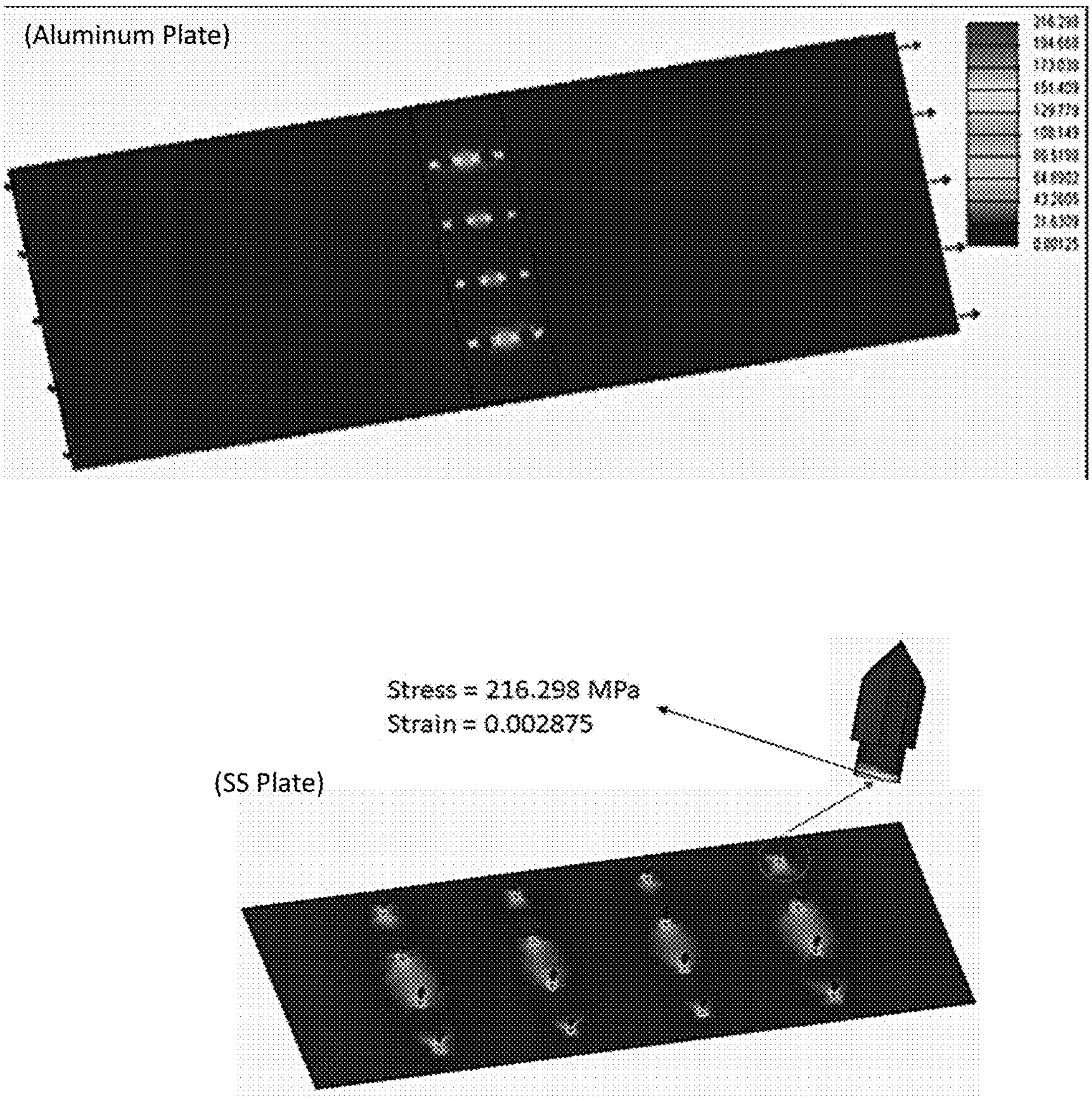

(Aluminum Plate)
216.298
194.668
173.038
151.409
129.779
108.149
86.5198
64.8902
43.2605
21.6309
0.00125
Stress = 216.298 MPa
Strain = 0.002875
(SS Plate)

FIG. 20A

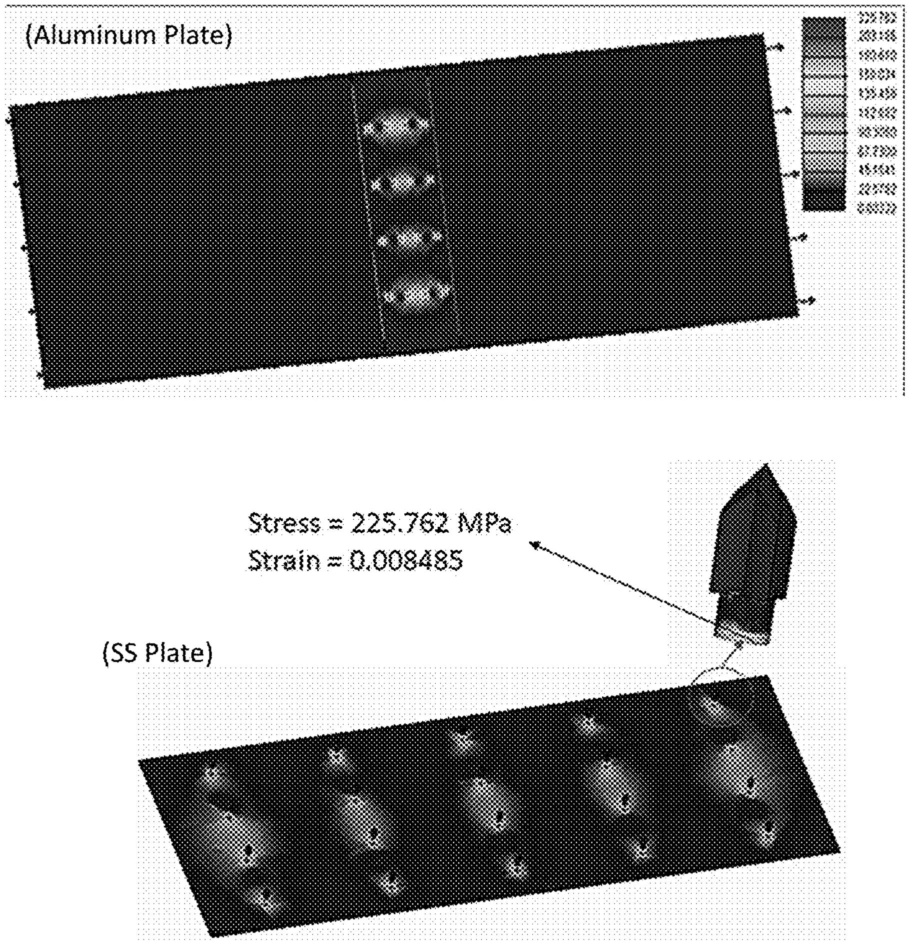


FIG. 20B

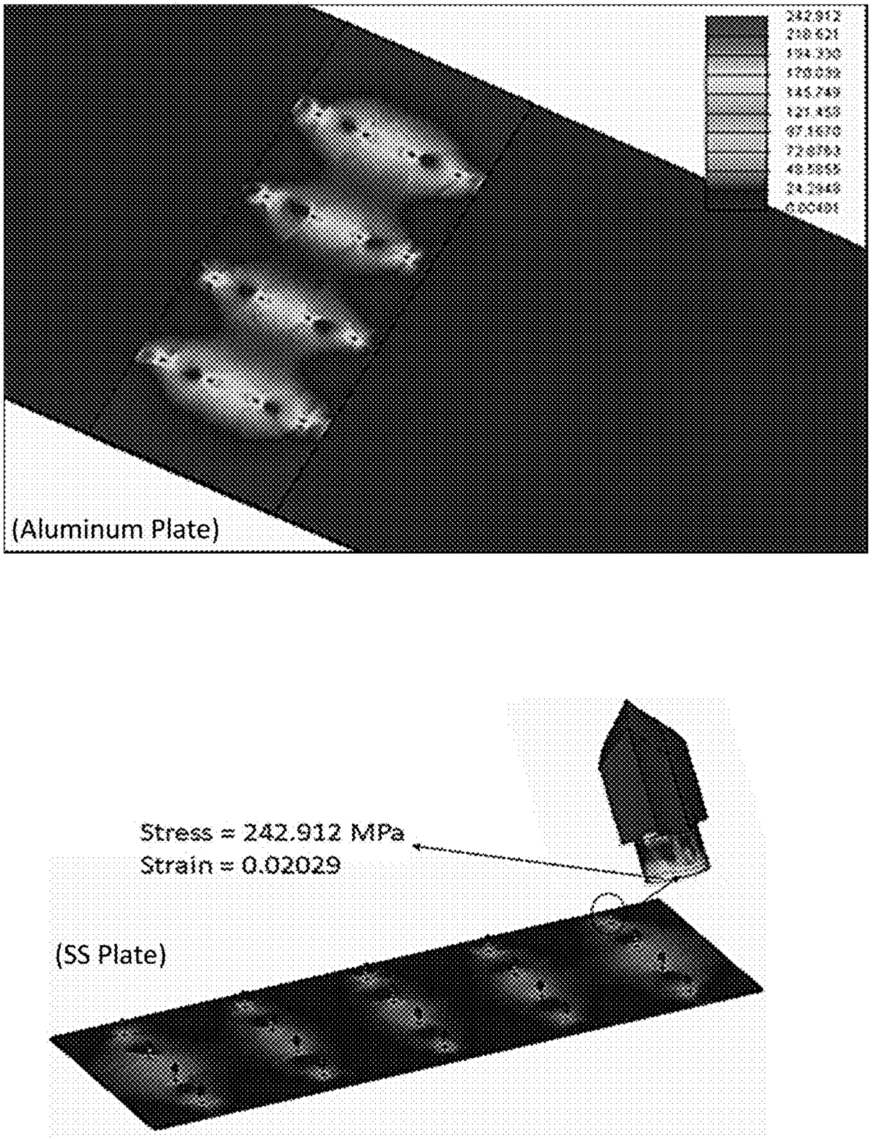

242.912
218.621
194.330
170.039
145.749
121.458
97.1670
72.8763
48.5855
24.2948
0.00401
(Aluminum Plate)
Stress = 242.912 MPa
Strain = 0.02029
(SS Plate)

FIG. 20C

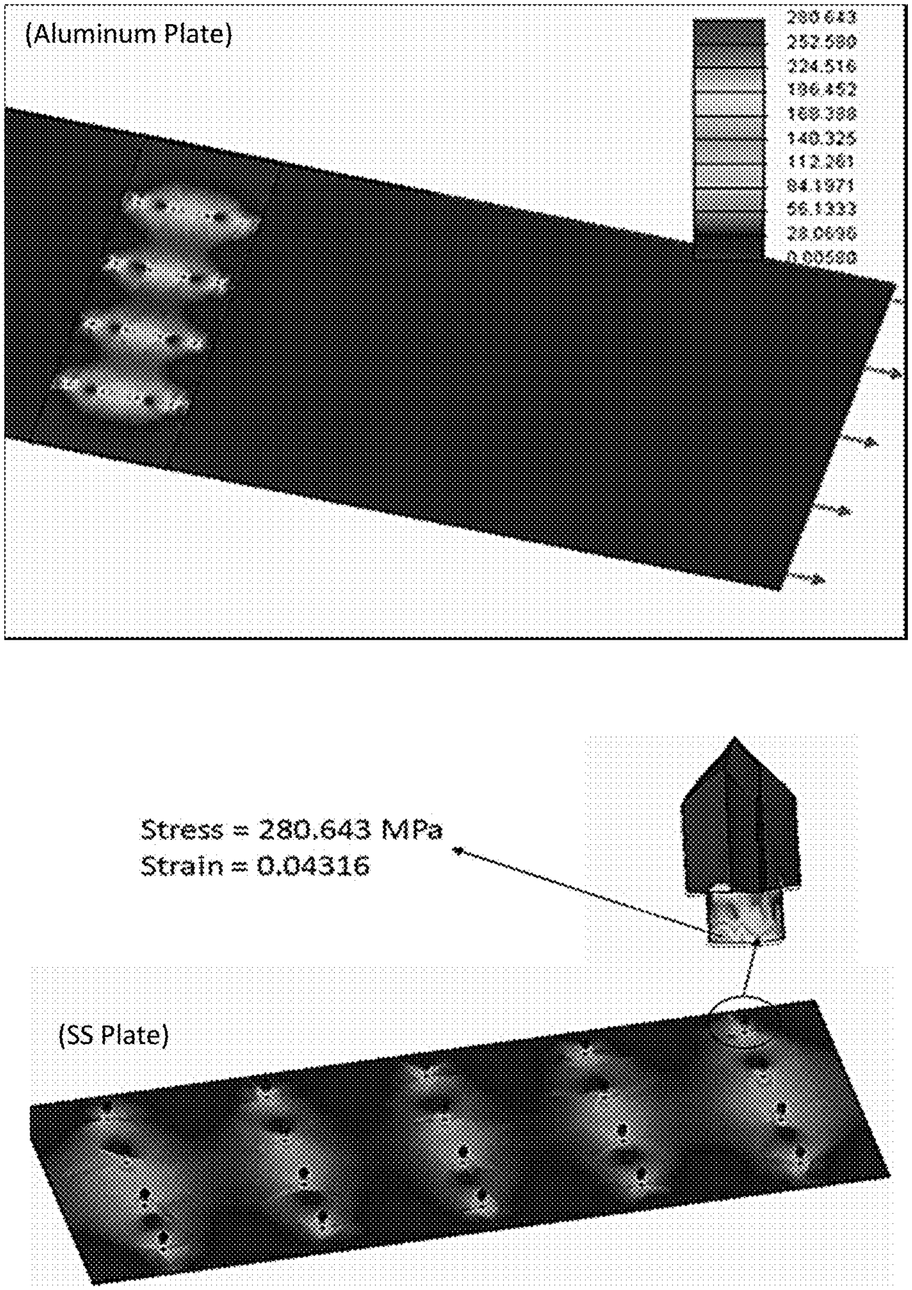

(Aluminum Plate)
280.643
252.580
224.516
196.452
168.388
140.325
112.261
84.1971
56.1333
28.0696
0.00580
Stress = 280.643 MPa
Strain = 0.04316
(SS Plate)

FIG. 20D

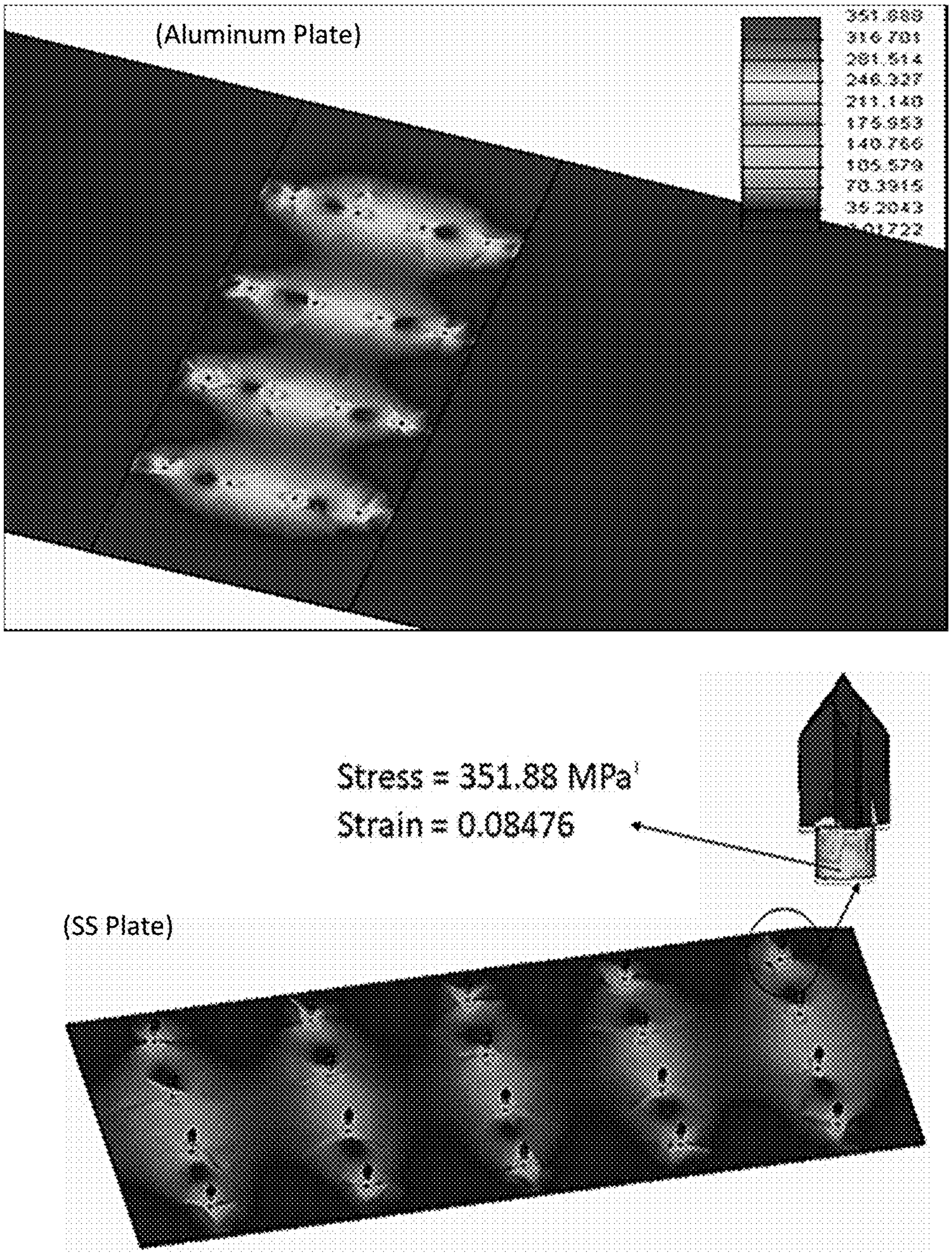

(Aluminum Plate)
351.888
316.701
281.514
246.327
211.140
175.953
140.766
105.579
70.3915
35.2043
.01722
Stress = 351.88 MPa
Strain = 0.08476
(SS Plate)

FIG. 20E

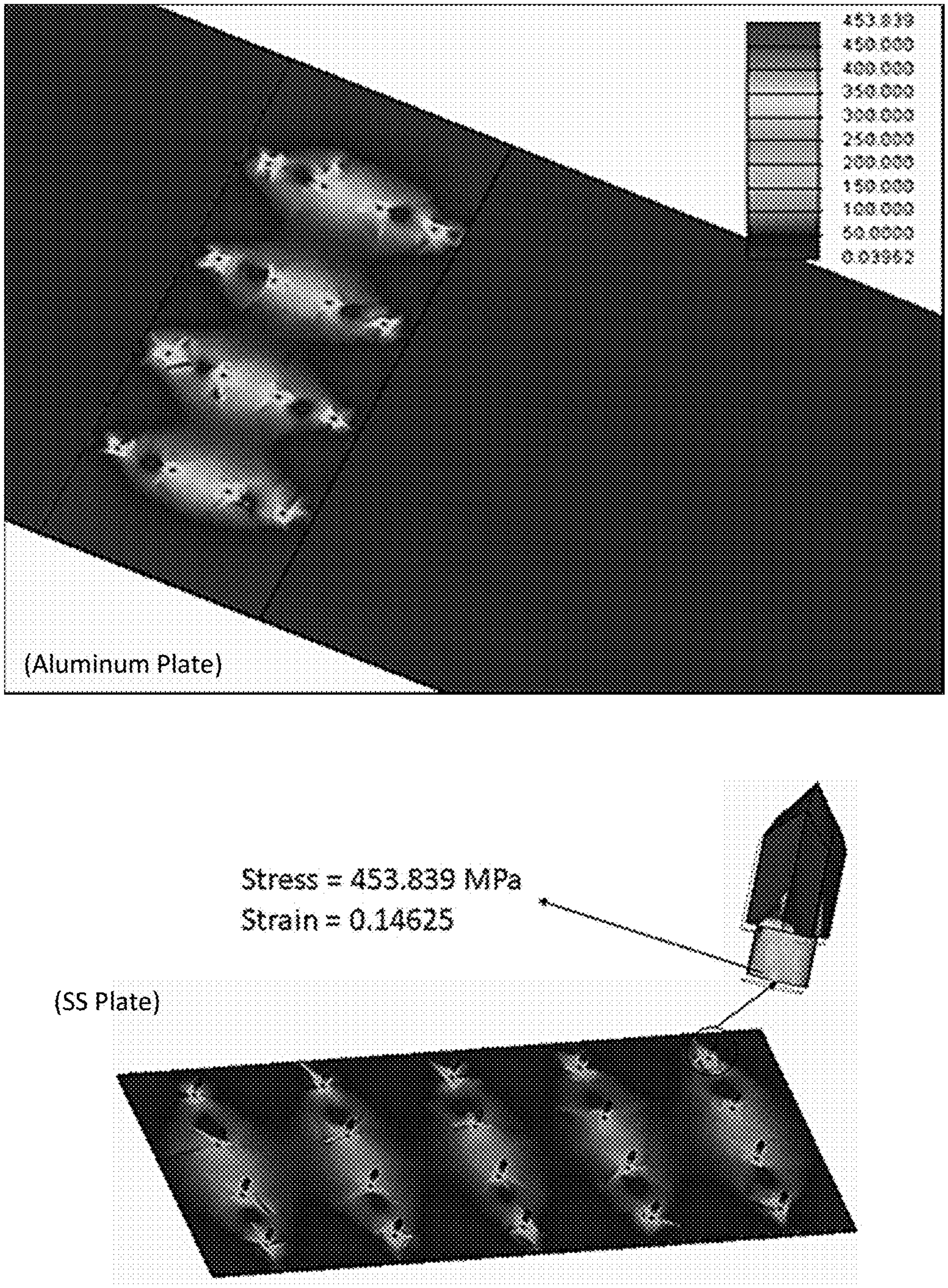

453.839
450.000
400.000
350.000
300.000
250.000
200.000
150.000
100.000
50.0000
0.03952
(Aluminum Plate)
Stress = 453.839 MPa
Strain = 0.14625
(SS Plate)

FIG. 20F

MATERIALS AND METHODS FOR JOINING METAL SHEETS

RELATED APPLICATIONS

This application claims priority to U.S. Provisional Application No. 62,724,238 filed under 35 U.S.C. § 111(b) on Aug. 29, 2018, the disclosure of which is incorporated herein by reference in its entirety.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH

This invention was made with no government support. The government has no rights in this invention.

BACKGROUND

There are several current practices for joining aluminum plates or sheets.

One method for joining aluminum sheets is resistance spot welding (RSW). RSW is a process in which contacting metal surface points are joined by the heat obtained from resistance to electric current. Resistance welding is accomplished when current is caused to flow through electrode tips and the separate pieces of metal to be joined. The resistance of the base metal to electrical current flow causes localized heating in the joint and the weld is made. The process uses two shaped copper alloy electrodes to concentrate welding current into a small 'spot' and to simultaneously clamp the sheets together. Forcing a large current through the spot will melt the metal and form the mold. The amount of heat (energy) delivered to the spot is determined by the resistance between the electrodes and the magnitude and duration of the current. The amount of energy is chosen to match the sheet's material properties, its thickness, and type of electrodes.

However, RSW has its deficiencies. RSW is often subject to expulsion of molten metal from the interface of the joint thereby weakening the weld. There is a danger of developing defects such as voids and cracks and forming gas pockets which affect the appearance and quality of the weld. RSW of alloys is often subject to excessive distortion and residual stresses as well as short electrode life. Spot welding tends to harden the material causing it to warp. This reduces the material's fatigue strength, and may stretch the material as well as anneal it. The physical effects of spot welding include internal cracking, surface cracks, and a bad appearance. The physical/chemical properties affected include the metal's internal resistance and its corrosive properties.

Another method for joining adjacent metal sheets is friction stir welding (FSW). In FSW a rotating tool with a pin and shoulder is pressed into the joint between two pieces of metal and the tool is moved along the line of the joint to form a weld. The metals that are going to be joined must be clamped onto a backing bar so that their joint faces cannot be forced apart by the process. FSW performs two functions. First, it heats the workpiece to raise its temperature sufficiently to the stage at which it is not molten but plastically melted and second it moves along the edges of the workpiece to weld it or to make a joint. Once the process is started, the heating is created by friction between the tool and the workpiece and because of plastic deformation of the workpiece. The tool rotation leads to movement of material from the front of the pin to the back of the pin and this completes the welding.

However, FSW has its deficiencies. FSW leaves an exit hole after withdrawing the tool. Moreover, FSW requires heavy duty clamping to hold the material in place during the welding process because significant downward forces and traversing forces are applied by the tool. FSW lacks the flexibility of other welding processes, such as when metal deposition is required, and FSW is not suitable for joining thin sheets, curved joints, and sheets of dissimilar thickness.

Friction stir spot welding (FSSW) is a variant of friction stir welding. Both FSSW and FSW use a rotating tool with a pin to join metal sheets. However, in FSW the tool traverses along a seam between two metal plates while in FSSW the tool kept to one spot to form a spot weld. FSSW has limitations. For example, FSSW has medium shear load bearing capacity and low peel resistance.

Another method for joining metal sheets is self-piercing riveting. Self-piercing riveting is a high-speed mechanical fastening process for point joining sheet material, typically steels and aluminum alloys. Generally, the technique uses a semi-tubular rivet, or in some cases solid rivets, to clinch the sheets in a mechanical joint. The process starts by clamping the sheets between the die and the blankholder. The semi-tubular rivet is driven into the materials to be joined between a punch and die in a press tool. The rivet pierces the top sheet and the die shape causes the rivet to flare within the lower sheet to form a mechanical interlock. Self-piercing riveting also has drawbacks. For instance, self-piercing riveting requires significant clamping and a die.

There are difficulties in joining or welding aluminum sheets or plates, and known materials and methods for doing so have drawbacks. Thus, it would be advantageous to develop new and improved materials and methods for joining aluminum sheets or plates.

SUMMARY

Provided are improved connectors for joining aluminum sheets. A first embodiment of a connector may include a self-driven, uneven thread screw arrays. A second embodiment of a connector may include an array of punched cross-head protrusions. A third embodiment of a connector may include an array of forged semispherical-head protrusions. A fourth embodiment of a connector may include an array of forged arrow-head protrusions.

Provided herein is a connector comprising a framework having a first side and a second side; and a plurality of projections on at least one of the first side or the second side, wherein at least one of the projections comprises a neck and a head, wherein the neck extends from the framework to the head, and wherein a portion of the head extends outwardly from the neck to form an overhang. In certain embodiments, the at least one projection comprises a semispherical-head. In particular embodiments, the semispherical-head comprises a top point and a side point connected by a dome therebetween. In certain embodiments, the at least one projection comprises a cross-head. In particular embodiments, the cross-head comprises a top point and four side points wherein the side points extend a distance away from the neck to overhang the neck. In certain embodiments, the projections are on both the first side and the second side. In certain embodiments, the framework comprises a metal. In particular embodiments, the framework comprises steel. In certain embodiments, the at least one projection comprises steel.

Further provided is a connector comprising a metal framework having a first side and a second side; and a plurality of arrow-shaped projections extending from at least one of the first side or the second side, wherein at least one of the arrow-shaped projections comprises a neck and a head, wherein the neck extends from the framework to the head, and wherein the head has a first side point that extends outwardly from the neck to define a first overhang and a second side point that extends outwardly from the neck to define a second overhang. In certain embodiments, the metal framework further comprises arrow-shaped openings. In certain embodiments, the first overhang and the second overhang are orthogonal to the neck. In certain embodiments, the plurality of projections extend in different directions relative to the framework.

Further provided is a connector comprising a framework having a first side and a second side; and an array of self-driven screws on the framework, wherein at least one of the self-driven screws comprises a first threaded portion and a second threaded portion, the first threaded portion extending from the first side and the second threaded portion extending from the second side, wherein the first threaded portion and the second threaded portion meet in a bracket and are capable of rotating within the bracket. In certain embodiments, the first threaded portion has a first pitch, and the second threaded portion has a second pitch, wherein the first pitch and the second pitch are different. In particular embodiments, the first pitch changes along a length of the first threaded portion, or the second pitch changes along a length of the second threaded portion. In certain embodiments, the bracket is within a plane defined by the framework. In certain embodiments, the first threaded portion and the second threaded portion are threaded in opposing directions. In certain embodiments, the framework is a solid, continuous sheet. In certain embodiments, the framework is grated.

BRIEF DESCRIPTION OF THE DRAWINGS

The patent or application file may contain one or more drawings executed in color and/or one or more photographs. Copies of this patent or patent application publication with color drawing(s) and/or photograph(s) will be provided by the U.S. Patent and Trademark Office upon request and payment of the necessary fees.

FIG. **1** is a top front perspective view of an array of self-driven screws arranged on a framework.

FIG. **2** is a top front perspective view of an array of self-driven screws arranged on a framework comprising a sheet.

FIG. **3** shows orthogonal top and side views of the array of self-driven screws arranged on a framework. Non-limiting example dimensions are shown.

FIG. **4** is side cutaway view of a section of a self-driven screw.

FIG. **5** is a sectional view of a self-driven screw. Non-limiting example dimensions and pitch sizes are shown.

FIG. **6** is a top front perspective view of a connector plate having an array of punched arrow-head protrusions.

FIG. **7** is a side view of an arrow-head protrusion. Non-limiting example dimensions are shown.

FIG. **8** shows a top and side view of an array of arrow-head protrusions. Non-limiting example dimensions are shown.

FIG. **9** is a side view of a semispherical-head protrusion. Non-limiting example dimensions are shown.

FIG. **10** is an isometric view of an array of a sheet of semispherical-head protrusions. Non-limiting example dimensions are shown.

FIG. **11** is an isometric view of an array of a sheet of semispherical-head protrusions.

FIG. **12** is an illustration of a cross-head projection. Non-limiting example dimensions are shown.

FIG. **13** is an isometric view of a cross-head projection.

FIG. **14** is an isometric view of a connector plate having an array of cross-head projections.

FIG. **15** is an isometric view of a connector plate having an array of cross-head projections.

FIG. **16** is an illustration of a joint assembly having two connector plates each with two rows of projections for connecting aluminum sheets.

FIG. **17** is an illustration of a joint assembly having two connector plates, a top plate and a bottom plate. The image on the left shows the top plate in green, and the image on the right shows the bottom plate in green.

FIGS. **18**A-**18**C show the results of stress testing for a joint assembly with two rows of cross-head projections.

FIGS. **19**A-**19**B show a finite element simulation of joints made using arrays of forged distributed cross-head projections. The connector plates are made of stainless steel (SS) and are composed of four rows of protrusions to secure two aluminum sheets at a joint, as shown in green in FIG. **19**B.

FIGS. **20**A-**20**F show the results of stress testing for a joint assembly with four rows of cross-head projections.

DETAILED DESCRIPTION

Throughout this disclosure, various publications, patents, and published patent specifications are referenced by an identifying citation. The disclosures of these publications, patents, and published patent specifications are hereby incorporated by reference into the present disclosure in their entirety to more fully describe the state of the art to which this invention pertains.

Provided herein are connectors for connecting metal sheets, such as aluminum sheets. Referring now to the drawings, there is illustrated in FIGS. **1**-**5** a first embodiment of a connector **22** in which an array of self-driven screws **10** is arranged on a framework **12**. The self-driven screws **10** can be arranged on a grated framework **12***a*, as depicted in FIG. **1**, or on a solid, continuous sheet **12***b*, as depicted in FIG. **2**. The framework **12** may be composed of steel. The framework **12** can assume a variety of shapes and patterns. For example, the framework **12** may have a rectangular shape, as seen in FIG. **3**, but is not limited to any particular design or shape.

Referring now to FIG. **3**, a top view and a side view are shown of an array of self-driven screws **10** arranged on a rectangular framework **12***a*. The rectangular framework **12***a* may have dimensions comprising a width of 50 and a length of 100 with an internal grated structure comprising a rectangular pattern. However, the framework **12***a* may assume a variety of shapes with a variety of internal grating orientations particularly those most favorable for joining metal sheets. FIG. **3** also shows the self-driven screws **10** arranged at points of intersection on the grated framework **12***a*. However, the self-driven screws **10** may be arranged in any manner suitable to connecting sheets of metal at a joint.

The self-driven screws **10** can be arranged on the framework **12***a* in a variety of patterns. As can be seen in FIG. **3**, for example, the self-driven screws **10** may be arranged on a rectangular shaped framework **12***b* measuring 50×100, and may be evenly spaced apart. However, this is not limited to a particular shape of framework **12** or pattern of self-driven screws **10**. In the side view in FIG. **3**, it can be seen that the self-driven screws **10** extend above and below the framework **12***a*. In other words, the framework **12***a* has a first side and a second side, and defines a plane between the first side and the second side. The self-driven screws **10** may extend away from the plane on the first side and may extend away from the plane on the second side.

Referring to FIG. **4**, a cut away view depicts a self-driven screw **10** attached to the framework **12**. As shown in FIG. **4**, each self-driven screw **10** may be locked in a bracket **14** in which the self-driven screw **10** is free to rotate. The self-driven screw **10** has a top portion **16** composed of a first threaded portion, which extends above the bracket **14** relative to the framework **12**, and a bottom portion **18** composed of a second threaded portion, which extends below the bracket **14** relative to the framework **12**. In some embodiments, the bracket **14** is in a plane defined by the framework **12**.

Non-limiting examples of the threads and pitches of the self-driven screws **10** are illustrated in FIG. **5**. Referring now to FIG. **5**, a side view of an embodiment of the self-driven screw **10** is shown. The self-driven screw **10** has a top portion **16**, a center mount **20**, and a bottom portion **18**. The top portion **16** (i.e, first threaded portion) and the bottom portion **18** (i.e., second threaded portion) may be threaded in opposing directions. In the embodiment illustrated in FIG. **5**, for example, the top portion **16** is threaded in a right-handed direction and the bottom portion **18** is threaded in a left-handed direction. Furthermore, the pitch of the top portion **16** may change along the length of the first threaded portion **16**, and the pitch of the bottom portion **18** may change along the length of the second threaded portion **18**. In the non-limiting example depicted in FIG. **5**, for example, the pitch of the first threaded portion **16** is smaller at the tip **21**, measuring 0.24, and increases in the direction of the center mount **20**, measuring 0.3 adjacent to the center mount **20**. The first threaded portion **16** may have a first pitch, and the second threaded portion **18** may have a second pitch, and the first pitch and the second pitch may be different. In addition, the length and thickness of the top portion **16** of the self-driven screw **10** may be different from the length and thickness of the bottom portion **18** of the self-driven screw **10**.

An assembly of self-driven screws **10**, the framework **12**, and brackets **14** may be called a connector **22**, as seen for example in FIGS. **1**-**3**. A connector **22** can be used to join metal plates **24** together instead of employing a traditional weld. To join metal plates **24** together, such as aluminum sheets, the connector **22** is first placed between the plates **24**. Then, the plates **24** may be compressed. Because the self-driven screws **10** are threaded left-handed on one side and threaded right-handed on the other side, torques from the squeezing metals (aluminum) push the self-driven screws **10** to rotate in the same direction, and penetrate into the plates **24**. The self-driven screws **10** rotate under the torque exerted by squeezing from the plates **24**, and embed themselves into the plates **24**, forming a joint between the plates **24**. The self-driven screw array connectors **22** are especially useful for joining thick plates **24**, and they are loosening-resistant.

Referring now to FIGS. **6**-**8**, there is a perspective view of a second embodiment of a connector **30** in which an array of punched protrusions **26** are arranged on a framework **12**, for example, a metal sheet. The metal sheet may be composed of a metal or metal alloy such as steel. The array of punched protrusions **26** may be placed on only one side of the framework **12** (i.e., one-sided array of punched protrusions) or on both sides of the framework **12** (i.e., two-sided array of punched protrusions) as shown in FIG. **6**. The one-sided array of punched protrusions **26** may be placed at the side of two metal plates **24** to form a joint between the two metal plates **24**, and the two-sided array of punched protrusions **26** may be placed between two metal plates **24** to form a joint between the two metal plates **24**.

The array may be an array of punched arrow projections **26** on a framework **12** such as a metal sheet. These arrow projections **26** may be created by punching a sheet **12** from one side to the other side, creating arrow-shaped projections **26** and arrow-shaped openings **28**. The arrow-shaped projections **26** can be arranged so that half of the projections **26** are pointing to one side relative to the framework **12**, and half of the projections **26** are pointing to another side relative to the framework **12**. However, it is not necessary for the number of projections **26** on one side of the framework **12** to equal the number of projections **26** on the other side of the framework **12**. Example connectors **30** with punched arrow projections **26** on a sheet for joining aluminum plates **24** can be seen in FIGS. **6**, **8**.

Details of a non-limiting example of the punched arrow projections **26** are shown in FIG. **7**. Referring to FIG. **7**, an arrow projection **26** may include a head **32** defining an arrow shape, and an elongated neck **34** extending between the framework **12** and the head **32**. The head **32** may include a tip **36**, a first side point **38**, and a second side point **40**, where the tip **36** is between the first side point **38** and the second side point **40**. The first side point **38** may extend outwardly from the elongated neck **34** to create a first overhang **39**, and the second side point **40** may extend outwardly from the elongated neck **34** to create a second overhang **41**. The first overhang **39** and the second overhang **41** may each be orthogonal to the elongated neck **34**, but the sizes of the first overhang **39** and the second overhang **41** may be different if using an asymmetrically shaped arrow head. A framework **12** having an array of arrow projections **26** may be referred to as a connector **30**.

When placed between two aluminum plates **24** which are compressed against each other, the projections **26** may be pressed into the plates **24**, forming a joint between the plates **24**. A connector **30** having the projections **26** may also be used to join two pieces of metals sheets/plates/bulk **24** from only one side instead of two. When joining two aluminum sheets **24** together, a connector **30** may be placed between the sheets **24** first, and then the two sheets **24** may be pressed together from both sides. The projections **26** may penetrate into the sheets **24**, and the heads **32** of the arrow projections **26** may form interlocks with the sheet material, forming a joint between the sheets **24**.

The arrow projections **26** can be made pointing to the same side, and such a connector **30** can be used to link two pieces of aluminum (not necessarily sheets or plates) from one side. The shape of such connectors **30** may conform to that of the joint, by applying a compressive load through a preformed punch.

FIGS. **9**-**11** show a third embodiment of a connector **56**, in which arrays of forged semispherical-head protrusions **42** are arranged on a framework **12** and placed either on one side of, or between, two sheets or plates **24**. If the semispherical-head protrusions **42** are on both sides of the framework **12**, the semispherical-head protrusions **42** may be aligned, but do not have to be. In some embodiments, an array of solid steel rivet-shaped projections **42** may be provided on a steel sheet **12**. When placed between two metal (aluminum) plates or sheets **24** which are compressed against each other, the projections **42** may be pressed into the plates or sheets **24**, forming a joint between the plates or sheets **24**. The projections **42** may be attached to the sheets **24** from both sides, with pairs of projections **42** aligned.

The details of a non-limiting example semispherical-head projection **42** can be seen in FIG. **9**. Referring to FIG. **9**, a semispherical-head projection **42** may include a semispherical head **44** and an elongated neck **46** extending from the framework **12** to the semispherical head **44**. As seen in FIG. **9**, the cross-section of a semispherical head **44** may include a top point **48** and a side point **50** connected by a dome **52** therebetween. The side point **50** may extend outwardly from the elongated neck **46** to create an overhang **54**. A framework **12** having an array of semispherical-head projections **42** may be referred to as a connector **56**.

When joining two aluminum sheets together, a connector **56** may be placed between the sheets **24** first. Then, the sheets **24** may be pressed from both sides. The projections **42** may penetrate into the sheets **24**, and the heads **44** of the projections **42** may form interlocks with the sheet material, forming a joint between the sheets **24**. In other embodiments, the projections **42** may be arranged on one side of the framework **12** only. The connector **56** may be placed on two (or more) sheets **24** of aluminum or other metal from the same side, and compressed into the metal pieces, forming a joint between the sheets **24** from one side. The shape of such connectors **56** may conform to that of the joint, by applying a compressive load through a preformed punch. The projections **42**, with the support of the plate **24**, may pierce the aluminum sheets **24** and hold them together.

FIGS. **12-15** show a fourth embodiment of a connector **70**, in which an array of cross-head projections **58** on a framework **12** is used for joining aluminum plates or sheets **24**. The projections **58** can be sharp and may be placed either on one side or between two sheets or plates **24**.

FIGS. **12-13** depict details of a non-limiting example of a cross-head projection **58**. Referring to FIGS. **12-13**, a cross-head projection **58** may include a circular neck **60** extending from the framework **12** to a crosshead **62**. The crosshead **62** may include a top point **64** and four side points **66***a*, **66***b*, **66***c*, **66***d*. Each of the side points **66***a*, **66***b*, **66***c*, **66***d* may extend some distance away from the neck **60** so as to create an overhang **68***a*, **68***b*, **68***c*, **68***d*. A framework **12** with an array of cross-head projections **58** on a framework **12** may be referred to as a connector **70**.

An array of solid cross-head projections **58** arranged on a sheet **12** can be seen in FIG. **14**. These projections **58** may be attached to the sheets **12** from both sides, with pairs of projections **58** aligned. When joining two aluminum sheets or plates **24** together, such a connector **70** may be placed between the sheets **24** first. Then, the sheets **24** may be pressed from both sides. The projections **58** may penetrate into the sheets **24**, and the heads of the projections **58** may form interlocks with the sheet material, forming a joint between the sheets **24**. A connector **70** may also be made with projections **58** arranged on only one side of the framework **12**, and may be placed on two (or more) sheets **24** of aluminum from the same side, and compressed into the aluminum sheets **24**, forming a joint from one side. The shape of such connectors **70** may conform to that of the joint, by applying a compressive load through a preformed punch. If a framework **12** is two-sided, the projections **58** may be aligned on both sides. However, it is not necessary for the projections **58** to be aligned on both sides. The projections **58**, with the support of the framework **12**, may pierce the aluminum sheets/plates **24** and hold them together.

In general, the connectors **22**, **30**, **56**, **70** have advantages over known metal joining materials, and the use of connectors **22**, **30**, **56**, **70** to join metals has advantages over known methods for joining metals. First, the connectors **22**, **30**, **56**, **70** can be configured to fit the particular shape/curvature of the joints. Second, the processes for using the connectors **22**, **30**, **56**, **70** may not require complex fixtures, tool alignment, a die, or any sophisticated equipment, and may not produce any harmful gases, fumes, or byproducts. Third, the shape, size of the projections/protrusions **26**, **42**, **58** or screws **10**, and their arrangements, can be altered to meet the joining needs. Fourth, a strong mechanical interlocking may be created by the connectors **22**, **30**, **56**, **70** and maintained in service. Fifth, stress concentration may be lowered and the joint's strength may be raised. Other advantages may be apparent to those skilled in the art.

EXAMPLES

Finite element simulations were conducted to evaluate stress distribution under tensile loading. These simulations demonstrate that the connectors described herein may lower stress concentration.

FIG. **16** shows a finite element simulation of joints made using arrays of forged distributed cross-head projections. The connector plates are made of stainless steel (SS) and are composed of two rows of protrusions to secure two aluminum sheets at a joint, as shown in FIG. **17**.

FIGS. **18**A-**18**C show the von Mises stress distribution under tensile loading. In FIG. **18**A, at 1 kN force, the stress is 215.3 MPa and the strain is 0.002125. In FIG. **18**B, at 2 kN force, the stress is 234.076 MPa and the strain is 0.01513. In FIG. **18**C, at 3 kN force, the stress is 323.618 MPa and the strain is 0.07056.

FIG. **19**A shows a finite element simulation of joints made using arrays of forged distributed cross-head projections. The connector plates are made of stainless steel (SS) and consist of four rows of projections to secure two aluminum sheets at a joint, as shown in FIG. **19**B.

FIGS. **20**A-**20**E show the von Mises stress distribution under tensile loading. In FIG. **20**A, at 2 kN force, the stress is 216.298 MPa and the strain is 0.002875. In FIG. **20**B, at 3 kN force, the stress is 225.762 MPa and the strain is 0.008485. In FIG. **20**C, at 4 kN force, the stress is 242.912 MPa and the strain is 0.02029. In FIG. **20**D, at 5 kN force, the stress is 280.643 MPa and the strain is 0.04316. In FIG. **20**E, at 6 kN force, the stress is 352.88 MPa and the strain is 0.08476. In FIG. **20**F, at 7 kN force, the stress is 453.839 MPa and the strain is 0.14625.

Certain embodiments of the devices and methods disclosed herein are defined in the above examples. It should be understood that these examples, while indicating particular embodiments of the invention, are given by way of illustration only. From the above discussion and these examples, one skilled in the art can ascertain the essential characteristics of this disclosure, and without departing from the spirit and scope thereof, can make various changes and modifications to adapt the compositions and methods described herein to various usages and conditions. Various changes may be made and equivalents may be substituted for elements thereof without departing from the essential scope of the disclosure. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the disclosure without departing from the essential scope thereof.

What is claimed is:

1. A connector comprising:

a framework having a first side and a second side; and

an array of self-driven screws on the framework, wherein at least one of the self-driven screws comprises a first threaded portion and a second threaded portion, the first threaded portion extending from the first side to a first conical tip and the second threaded portion extending from the second side to a second conical tip, wherein the first threaded portion and the second threaded portion meet in a bracket and are capable of rotating within the bracket.

2. The connector of claim **1**, wherein the first threaded portion has a first pitch, and the second threaded portion has a second pitch, wherein the first pitch and the second pitch are different.

3. The connector of claim **2**, wherein the first pitch changes along a length of the first threaded portion, or the second pitch changes along a length of the second threaded portion.

4. The connector of claim **1**, wherein the bracket is within a plane defined by the framework.

5. The connector of claim **1**, wherein the framework is a solid, continuous sheet.

6. The connector of claim **1**, wherein the first threaded portion and the second threaded portion are threaded in opposing directions.

7. The connector of claim **1**, wherein the framework is a grated framework.

8. A connector comprising:

a framework having a first side and a second side; and

an array of self-driven screws on the framework, wherein at least one of the self-driven screws comprises a first threaded portion and a second threaded portion, the first threaded portion extending from the first side and the second threaded portion extending from the second side, wherein the first threaded portion and the second threaded portion meet in a bracket and are capable of rotating within the bracket, and

wherein the first threaded portion and the second threaded portion are threaded in opposing directions.

9. The connector of claim **8**, wherein the first threaded portion has a first pitch, and the second threaded portion has a second pitch, wherein the first pitch and the second pitch are different.

10. The connector of claim **8**, wherein the bracket is within a plane defined by the framework.

11. The connector of claim **8**, wherein the framework is a solid, continuous sheet.

12. A connector comprising:

a framework having a first side and a second side; and

an array of self-driven screws on the framework, wherein at least one of the self-driven screws comprises a first threaded portion and a second threaded portion, the first threaded portion extending from the first side and the second threaded portion extending from the second side, wherein the first threaded portion and the second threaded portion meet in a bracket and are capable of rotating within the bracket, and

wherein the framework is a grated framework.

13. The connector of claim **12**, wherein the first threaded portion has a first pitch, and the second threaded portion has a second pitch, wherein the first pitch and the second pitch are different.

14. The connector of claim **12**, wherein the bracket is within a plane defined by the framework.

15. The connector of claim **12**, wherein the framework is a solid, continuous sheet.

16. A connector comprising:

a framework having a first side and a second side; and

an array of self-driven screws on the framework, wherein at least one of the self-driven screws comprises a first threaded portion and a second threaded portion, the first threaded portion extending from the first side and the second threaded portion extending from the second side, wherein the first threaded portion and the second threaded portion meet in a bracket and are capable of rotating within the bracket,

wherein the first threaded portion has a first pitch, and the second threaded portion has a second pitch, wherein the first pitch and the second pitch are different, and

wherein the first pitch changes along a length of the first threaded portion, or the second pitch changes along a length of the second threaded portion.

17. The connector of claim **16**, wherein the bracket is within a plane defined by the framework.

18. The connector of claim **16**, wherein the framework is a solid, continuous sheet.

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