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Improved Self-Piercing Rivet Die and Associated Methods

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IMPROVED SELF-PIERCING RIVET DIE AND ASSOCIATED METHODS

FIELD OF THE INVENTION

[0001] This application relates to self-piercing riveting systems and methods, and, more specifically, to improved self-piercing riveting dies and methods of using the improved dies during a self-piercing riveting process.

BACKGROUND

[0002] Various joining techniques may be used to join components such as one or more metal workpieces or metal alloy workpieces together to form various parts or components of a final product. Such joining techniques may include various types of welding (resistance spot welding, friction stir welding, laser beam welding, ultrasonic welding, etc.), adhesives, and mechanical fastening, among others.

[0003] Self-piercing riveting is a type of mechanical fastening technique that uses a rivet. The rivet typically includes a head and a base, and during the self-piercing riveting process, the rivet is driven by a punch into one or more sheets such that the base pierces through at least the upper sheet and flares outwardly while being supported by a die. The deformed base forms a mechanical interlock in the lower sheet and thereby joins the sheets together. A problem with the self-piercing riveting process is that in high strength materials, such as high-strength aluminum alloy workpieces, cracking generally occurs in the portion of the lower sheet interlocked with the rivet (also known as the "button region" of the resulting joint). Such cracking may result in premature failing of the self-piercing riveting joint, and may be entirely unacceptable in certain industries such as the automotive industry.

SUMMARY

[0004] According to certain embodiments of the present disclosure, a die for a self-piercing rivet system includes an upper surface and a cavity. The cavity includes a sidewall surface and a bottom surface. In some examples, the sidewall surface includes a rib extending along the sidewall surface within the cavity, the bottom surface includes a rib extending along the bottom surface within the cavity, and/or the upper surface defines a groove that at least partially surrounds the cavity.

[0005] According to various embodiments of the present disclosure, a self-piercing rivet system includes a punch and a die. The die includes an upper surface and a cavity, and the cavity includes a sidewall surface and a bottom surface. In certain examples, the sidewall surface includes a rib extending along the sidewall surface within the cavity, the bottom surface includes a rib extending along the bottom surface within the cavity, and/or the upper surface defines a groove that at least partially surrounds the cavity.

[0006] According to certain embodiments of the present disclosure, a method of joining a first metal workpiece with a second metal workpiece includes positioning the first metal workpiece relative to the second metal workpiece such that at least a portion of the first metal workpiece overlaps a portion of the second metal workpiece. The method includes punching a rivet through the first metal workpiece and at least partially into the second metal workpiece such that the second metal workpiece is at least partially displaced into a cavity of a die. The die includes an upper surface, and the cavity includes a sidewall surface and a bottom surface. In some examples, the sidewall surface includes a rib extending along the sidewall surface within the cavity, the bottom surface includes a rib extending along the bottom surface within the cavity, and/or the upper surface defines a groove that at least partially surrounds the cavity.

[0007] According to various embodiments of the current disclosure, a rivet for a self-piercing rivet joint includes a rivet head defining a first end of the rivet and a rivet base defining a second end of the rivet. The rivet includes at least one mechanical property. The rivet includes a first region between the first end and the second end and a second region between the first region and the second end, and a value of the at least one mechanical property in the first region is different from a value of the at least one mechanical property in the second region.

[0008] According to some embodiments of the present disclosure, a rivet for a self-piercing rivet joint includes a rivet head defining a first end of the rivet and a rivet base defining a second end of the rivet. The rivet includes at least one mechanical property, and a value of the at least one mechanical property is non-uniform along a length of the rivet between the first end and the second end.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] The features and components of the following figures are illustrated to emphasize the general principles of the present disclosure. Corresponding features and components throughout the figures can be designated by matching reference characters for the sake of consistency and clarity.

[0010] FIG. 1A is a schematic of a traditional self-piercing riveting system.

[0011] FIG. 1B is another schematic of the system of FIG. 1A.

[0012] FIG. 1C is a schematic of a joint formed with the system of FIG. 1A.

[0013] FIG. 2 is a scanning electron microscope (SEM) photograph of a self-piercing riveting joint formed with the traditional self-piercing riveting process.

[0014] FIG. 3A is a photograph of a self-piercing riveting joint formed with the traditional self-piercing riveting process without natural aging.

[0015] FIG. 3B is a photograph of a self-piercing riveting joint formed with the traditional self-piercing riveting process without natural aging.

[0016] FIG. 3C is a photograph of a self-piercing riveting joint formed with the traditional self-piercing riveting process with one day natural aging.

[0017] FIG. 3D is a photograph of a self-piercing riveting joint formed with the traditional self-piercing riveting process with one day natural aging.

[0018] FIG. 4 is a schematic top view of a die for a self-piercing riveting system according to aspects of the current disclosure.

[0019] FIG. 5 is a schematic sectional view of the die of FIG. 4 taken along line 5 – 5 in FIG. 4.

[0020] FIG. 6 is a schematic sectional view of a self-piercing riveting joint formed with the die of FIG. 4.

[0021] FIG. 7 is a schematic top view of a die for a self-piercing riveting system according to aspects of the current disclosure.

[0022] FIG. 8 is a schematic sectional view of the die of FIG. 7 taken along line 8 – 8 in FIG. 7.

[0023] FIG. 9 is a schematic sectional view of a self-piercing riveting joint formed with the die of FIG. 7.

[0024] FIG. 10 is a schematic top view of a die for a self-piercing riveting system according to aspects of the current disclosure.

[0025] FIG. 11 is a schematic sectional view of the die of FIG. 10 taken along line 11 – 11 in FIG. 10.

[0026] FIG. 12 is a schematic sectional view of a self-piercing riveting joint formed with the die of FIG. 10.

[0027] FIG. 13 illustrates a schematic of a self-piercing riveting process using a die according to aspects of the current disclosure.

[0028] FIG. 14 illustrates an example of an improved rivet for a self-piercing riveting joint according to aspects of the current disclosure.

DETAILED DESCRIPTION

[0029] Aspects and features of the present disclosure can be used with any suitable metal workpiece including, but not limited to, aluminum, aluminum alloys, steel, steel-based materials, nickel, nickel-based materials, copper, copper-based materials, cast iron, titanium, titanium-based materials, aluminum cladded alloys, a monolithic alloy, a roll bonded alloy, and/or various other metals or combinations of metals. Aspects and features of the present disclosure may be especially useful for bonding aluminum and/or aluminum alloys. In this description, reference is made to alloys identified by aluminum industry designations, such as “series” or “7xxx.” For an understanding of the number designation system most commonly used in naming and identifying aluminum and its alloys, see “International Alloy Designations and Chemical Composition Limits for Wrought Aluminum and Wrought Aluminum Alloys” or “Registration Record of Aluminum Association Alloy Designations and Chemical Compositions Limits for Aluminum Alloys in the Form of Castings and Ingot,” both published by The Aluminum Association.

[0030] FIGs. 1A and 1B illustrate an example of a traditional system 100 for self-piercing riveting (“SPR”) of a first workpiece 102 to a second workpiece 104. FIG. 1C illustrates an SPR joint 116 joining the first workpiece 102 and the second workpiece 104 using the system 100. In various examples, the workpieces may be metals sheets, metal shates, or other suitable types of workpieces to form various parts or components of a final product. As used herein, a sheet generally refers to a metal (e.g., aluminum) product having a thickness of less than about 4 mm. For example, a sheet may have a thickness of less than 4 mm, less than 3 mm, less than 2 mm, less than 1 mm, less than 0.5 mm, less than 0.3 mm, or less than 0.1 mm. A shate (also referred to as a sheet plate) generally has a thickness of from about 4 mm to about 15 mm. For example, a shate may have a thickness of 4 mm, 5 mm, 6 mm, 7 mm, 8 mm, 9 mm, 10 mm, 11 mm, 12 mm, 13 mm, 14 mm, or 15 mm.

[0031] The system 100 generally includes a die 106, a punch 108, and a holder 110. During an SPR process, the workpieces 102 and 104 are clamped together between the die 106 and the holder 110. A rivet 112 having a head 118 and a base 120 is positioned between the punch 108 and the first workpiece 102. The base 120 of the rivet 112 includes a cavity 122. During the SPR process, the punch 108 drives the rivet 112 such that the rivet 112 pierces the first workpiece 102 and at least partially engages the second workpiece 104. As illustrated in FIG. 1B, the die 106 causes the rivet base 120 to flare or otherwise deform within the second workpiece 104 to form a mechanical interlock, thereby forming an SPR joint 116. In some cases, the die 106 also forms a button region 114 in the workpieces 102 and 104. In various aspects, the rivet base 120 does not pierce the button region 114. As illustrated in FIG. 1C, the rivet head 118 may optionally be set flush with a top surface of the first workpiece 102 in the resulting SPR joint 116, although it need not be in other examples.

[0032] In the traditional SPR process and depending on the material used in the workpieces 102 and 104, cracking or other defects may occur in the SPR joint 116 due to the high tensile stress levels (among others) experienced during the process. As one non-limiting example, workpieces with high-strength aluminum alloys, such as 2xxx, 5xxx, 6xxx, and 7xxx aluminum alloys, among others, may experience cracking in various regions of the SPR joint 116. As illustrated in FIG. 1C, in some cases, workpieces with high-strength aluminum alloys may experience cracking at an edge region 121 of the button region 114 (among other locations).

[0033] FIG. 2 is an SEM photograph of an SPR joint 216 formed in a workpiece with a 7xxx aluminum alloy using the traditional SPR process. As illustrated in FIG. 2, cracking has occurred in various regions of the SPR joint 216.

[0034] FIGs. 3A and 3B are photographs of SPR joints 316A-B without natural aging. FIGs. 3C and 3D are photographs of SPR joints 316C-D with one day of natural aging compared to the SPR joints 316A-B. As illustrated in FIGs. 3C and 3D, cracking occurs on the SPR joints 316C-D, making them unsuitable for various applications.

[0035] In view of the problems associated with traditional SPR systems, disclosed is an SPR system with an improved die. The improved die may include one or more ribs within a die cavity and/or one or more grooves in an upper surface of the die. Without being bound by any theory, it is believed that the ribs in the die cavity of the improved die (when included) minimize or reduce tensile stresses in the lower workpiece by increasing hydrostatic compression of the material while maintaining the necessary mechanical interlock for a satisfactory SPR joint. Without being bound by any theory, it is also believed that the grooves in the upper surface of the improved die (when included) may minimize or reduce the friction between the lower workpiece and the die to promote lower workpiece forming.

[0036] FIGs. 4 and 5 illustrate an example of an improved die 406 according to aspects of the present disclosure. FIG. 6 illustrates an example of an SPR joint 616 formed in a first workpiece 602 and a second workpiece 604 using the die 406.

[0037] The die 406 includes an upper surface 424 and a die cavity 426 formed in the upper surface 424. During the SPR process, the upper surface 424 supports portions of the workpieces being joined. The die cavity 426 includes a sidewall surface 428 and a bottom surface 430. In some cases, the bottom surface 430 is substantially parallel to the upper surface 424, although it need not be in other examples. For example, in other embodiments, the bottom surface 430 may be curved, angled, or have various other profiles as desired.

[0038] As illustrated in FIGs. 4 and 5, in various examples, the die 406 includes a rib 432 on the bottom surface 430 within the die cavity 426. In FIG. 5, only a profile of the rib 432 is shown for clarity; however, as illustrated in FIG. 4, the rib 432 extends along the bottom surface 430. While a single rib 432 is illustrated, the number of ribs should not be considered limiting on the current disclosure as in other examples, two or more ribs may be provided on the bottom surface 430. In some examples, and as illustrated in FIG. 4, the rib 432 extends in a generally annular pattern along the bottom surface 430 such that the rib 432 separates the bottom surface 430 into an inner portion 434 and an outer portion 436. However, in other examples, the rib 432 may extend along the bottom surface 430 in various other patterns as desired such that the rib 432 separates the bottom surface 430 into the inner portion 434 and the outer portion 436. Moreover, in other examples, the rib 432 need not be axisymmetric on the bottom surface 430, and the rib 432 may be any shape such as a square, higher order polygon, ellipse, or various other suitable shapes that help increase hydrostatic pressure on the deforming sheet material. In some examples, and as best illustrated in FIG. 5, a sectional profile of the rib 432 may be triangular. However, in other examples, the sectional profile of the rib 432 may have various shapes or profiles as desired, including, but not limited to, arcuate-shaped, curved, rectangular, angled, or various other profiles as desired.

[0039] The rib 432 has a height and profile (as described above) such that during the SPR process, a score is formed in the lower workpiece without penetrating or cutting completely through the lower workpiece. FIG. 6 illustrates the SPR joint 616 formed in the first workpiece 602 and the second workpiece 604. In some examples, the second workpiece 604 includes a high-strength material such as a 2xxx, 5xxx, 6xxx or 7xxx aluminum alloy, although it need not in other examples. While two workpieces are illustrated, the number of workpieces joined together through the SPR joint should not be considered limiting on the current disclosure. As illustrated in FIG. 6, the score 638 is formed in the button region 614 of the second workpiece 604 (which is the lower workpiece).

[0040] FIGs. 7 and 8 illustrate another example of a die 706 according to aspects of the current disclosure. The die 706 is substantially similar to the die 406 except that the die 706 additionally includes a rib 740 on the sidewall surface 428. In FIG. 8, only a profile of the rib 432 and only a profile of the rib 740 are shown for clarity; however, as illustrated in FIG. 7, the rib 432 extends along the bottom surface 430 and the rib 740 extends along the sidewall surface 428. Similar to the rib 432, the number of ribs and the profiles the rib 740 on the sidewall surface 428 should not be considered limiting on the current disclosure. As best illustrated in FIG. 7, in various examples, the sidewall surface 428 defines a perimeter of the die cavity 426. In some cases, the rib 740 extends along the entire perimeter of the die cavity 426, although it need not in other examples (i.e., the rib 740 may not extend fully along the perimeter). Similar to the rib 432, the rib 740 has a height and profile such that during the SPR process, a score is formed in the lower workpiece without penetrating or cutting completely through the lower workpiece. In other examples, the rib 432 may be omitted from the bottom surface 430, and the die 706 may only include the rib(s) 740 on the sidewall surface 428.

[0041] FIG. 9 illustrates an example of an SPR joint 916 formed in the first workpiece 602 and the second workpiece 604. As illustrated in FIG. 6, in addition to the score 638 formed by the rib 432, the SPR joint 916 includes a score 942 formed by the rib 740 in the button region 614 of the second workpiece 604 (which is the lower workpiece).

[0042] FIGs. 10 and 11 illustrate another example of a die 1006 according to aspects of the current disclosure. In FIG. 11, only a profile of the rib 432 and only a profile of the rib 740 are shown for clarity; however, as illustrated in FIG. 10, the rib 432 extends along the bottom surface 430 and the rib 740 extends along the sidewall surface 428. The die 1006 is substantially similar to the die 706 except that the upper surface 424 of the die 1006 includes grooves 1044. While two grooves 1044 are illustrated, the number of grooves should not be considered limiting on the current disclosure as the die 1006 may include one groove 1044 or more than two grooves 1044.

[0043] As illustrated in FIG. 10, the grooves 1044 at least partially surround the die cavity 426. In some examples, the grooves 1044 completely surround the die cavity 426, although they need not in other examples (i.e., the grooves 1044 may not extend fully around the die cavity 426). In various examples, the grooves 1044 may have an angled profile as illustrated in FIG. 11; however, in other examples, the grooves 1044 may have various profile shapes as desired. During the SPR process, the lower workpiece is supported on the upper surface 424. The grooves 1044 in the upper surface 424 may minimize or reduce the friction between the lower workpiece and the die during the SPR process by reducing the contact between the lower workpiece and the die, thereby promoting lower workpiece formation. It will be appreciated that in other examples, the rib 432 and/or the rib 740 may be omitted. Stated differently, in other examples, an improved die may include any combination of ribs 432 on the bottom surface 430, ribs 740 on the sidewall surface 428, and/or grooves 1044 on the upper surface 424.

[0044] FIG. 12 illustrates an SPR joint 1216 formed using the die 1006.

[0045] FIG. 13 illustrates an SPR system 1300 according to aspects of the current disclosure. The SPR system 1300 includes the die 1006, the punch 108, and the holder 110. While the die 1006 is illustrated, in other examples, the die 406, the die 706, or other improved dies including any combination of ribs 432 on the bottom surface 430, ribs 740 on the sidewall surface 428, and/or grooves 1044 on the upper surface 424 may be utilized.

[0046] Referring to FIG. 13, a method of joining the first workpiece 402 with the second workpiece 404 using the SPR system 1300 is also disclosed. In various examples, the method includes holding the workpieces 402, 403 using the holder 110. In steps 1-3, the method includes driving the rivet 112 with the punch 108 such that the rivet 112 pierces through the first workpiece 402. In steps 1-3, the workpieces 402, 404 may begin to plastically deform. The pressure on the rivet 112 against the die 1006 may cause at least a portion of the second workpiece 404 to start to deform into the die cavity 426. In step 4, the method includes driving the rivet 112 with the punch 108 such that the rivet 112 at least partially pierces the second workpiece 404. As illustrated, in steps 4-6, the pressure on the rivet 112 against the die 1006 further deforms the workpieces 402, 404 at least partially into the die cavity 426 and deforms the base 120 of the rivet such that the base 120 flares or otherwise deforms within the second workpiece 404 to form a mechanical interlock. As illustrated, the pressure on the rivet 112 against the die 1006 may deform the second workpiece 404 against the rib 432 and the rib 740 such that the score 638 and the score 942 are formed in the second workpiece 404. The grooves 1044 on the upper surface 424 of the die 1006 may minimize friction between the die 1006 and the second workpiece 404, thereby promoting formation of the second workpiece 404 into the SPR joint 1216.

[0047] FIG. 14 illustrates an example of an SPR joint 1416 joining a first workpiece 1402 and a second workpiece 1404. The SPR joint 1416 includes a rivet 1412. Similar to the rivet 112, the rivet 1412 includes the head 118 and the base 120. The head 118 defines a first end 1446 of the rivet 1412 and the base 120 defines a second end 1448 of the rivet 1412, and a length of the rivet 1412 is a distance from the first end 1446 to the second end 1448.

[0048] As illustrated in FIG. 14, the rivet 1412 includes a first region 1450 (labeled Zone 1 in FIG. 14) between the first end 1446 and the second end 1448 and a second region 1452 (labeled Zone 2 in FIG. 14) between the first region 1450 and the first end 1446. Optionally, the rivet 1412 includes a third region 1454 (labeled Zone 3 in FIG. 14) between the second region 1452 and the first end 1446. While three regions are illustrated, in other examples, the rivet 1412 may include two regions or more than three regions between the first end 1446 and the second end 1448.

[0049] The rivet 1412 includes at least one adjustable mechanical property. The adjustable mechanical property may include, but is not limited to, strength, hardness, ductility, elasticity, stiffness, etc. In some examples, the rivet 1412 is controlled such that a value of the at least one mechanical property of the first region 1450 is different from a value of the at least one mechanical property of the second region 1452. In other words, compared to traditional rivets having uniform mechanical properties along the length of the rivet, the rivet 1412 includes at least one non-uniform mechanical property along a length of the rivet 1412. As one non-limiting example, a strength of the first region 1450 of the rivet 1412 may be different from a strength of the second region 1452 of the rivet 1412. For example, the first region 1450 may be stronger than the second region 1452 to facilitate penetration of the rivet 1412 through the workpieces (through the first region 1450) while facilitating the flaring of the rivet 1412 (through the less strong second region 1452), thereby promoting better interlocking.

[0050] When the third region 1454 is included, the rivet 1412 is controlled such that a value of the at least one mechanical property of the third region 1454 may be the same as or different from the value of the at least one mechanical property in the first region 1450 and/or the value of the at least one mechanical property in the second region 1452. As one non-limiting example, the strength of the third region 1454 may be the same as the strength of the first region 1450 to promote flushness of the head 118 in the first workpiece 1402. In other examples, the value of the at least on mechanical property of the third region 1454 is different from the value of the first region 1450 and the value of the second region 1452.

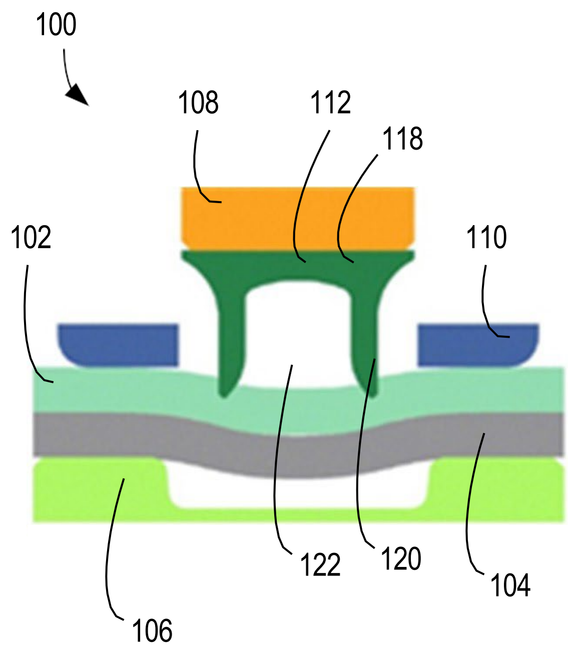


FIG. 1A

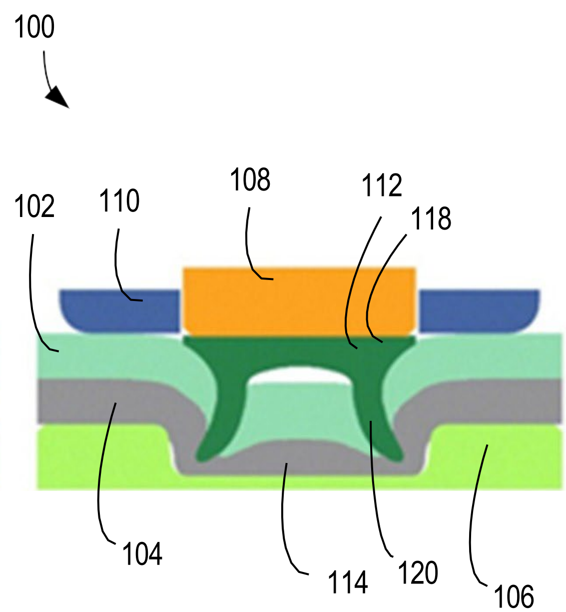


FIG. 1B

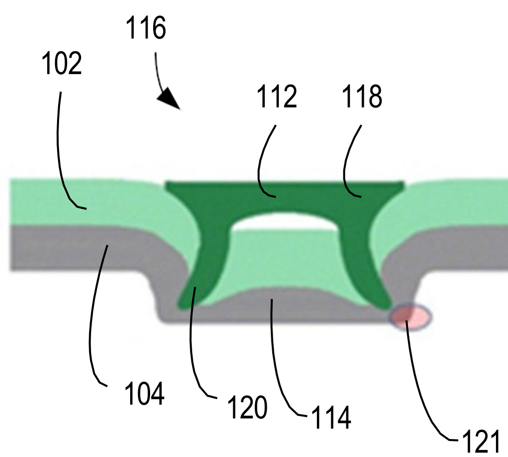


FIG. 1C

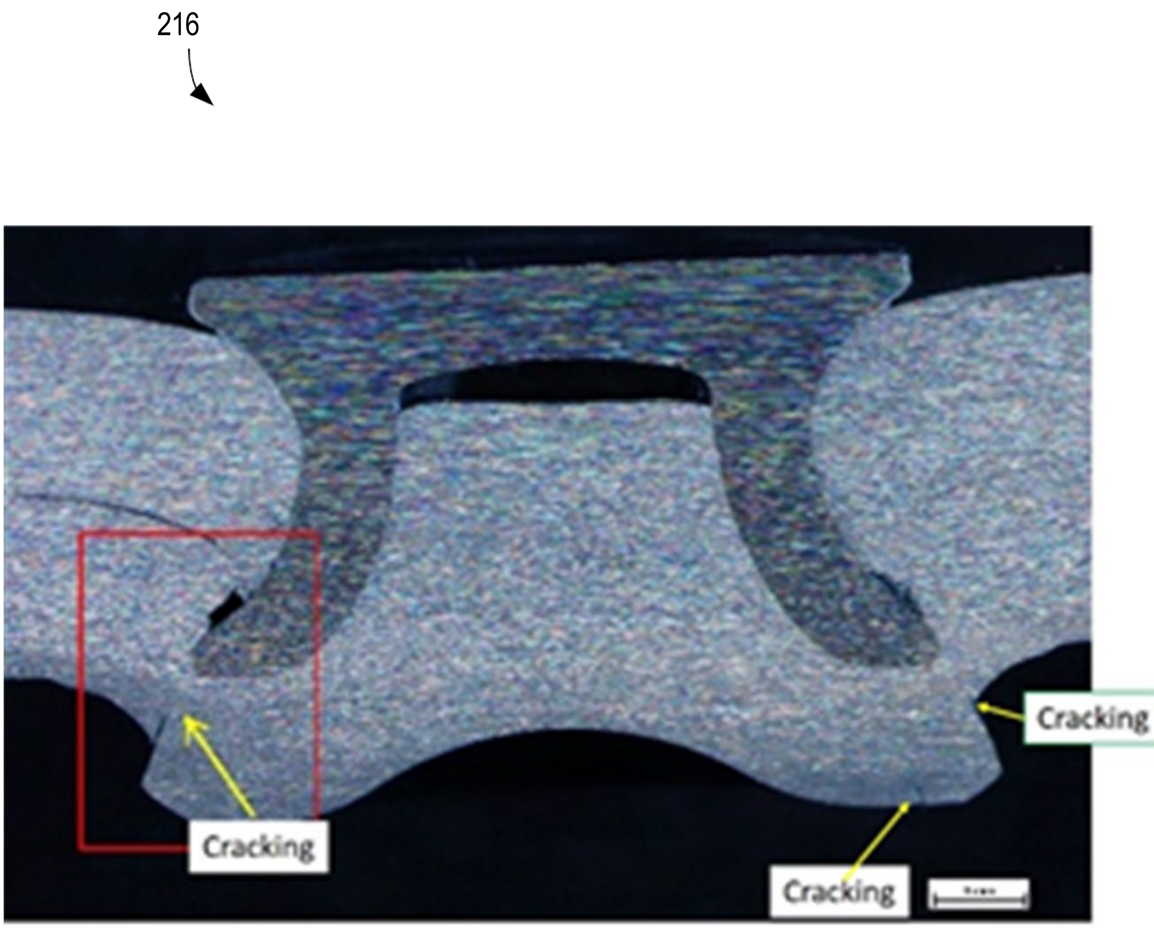


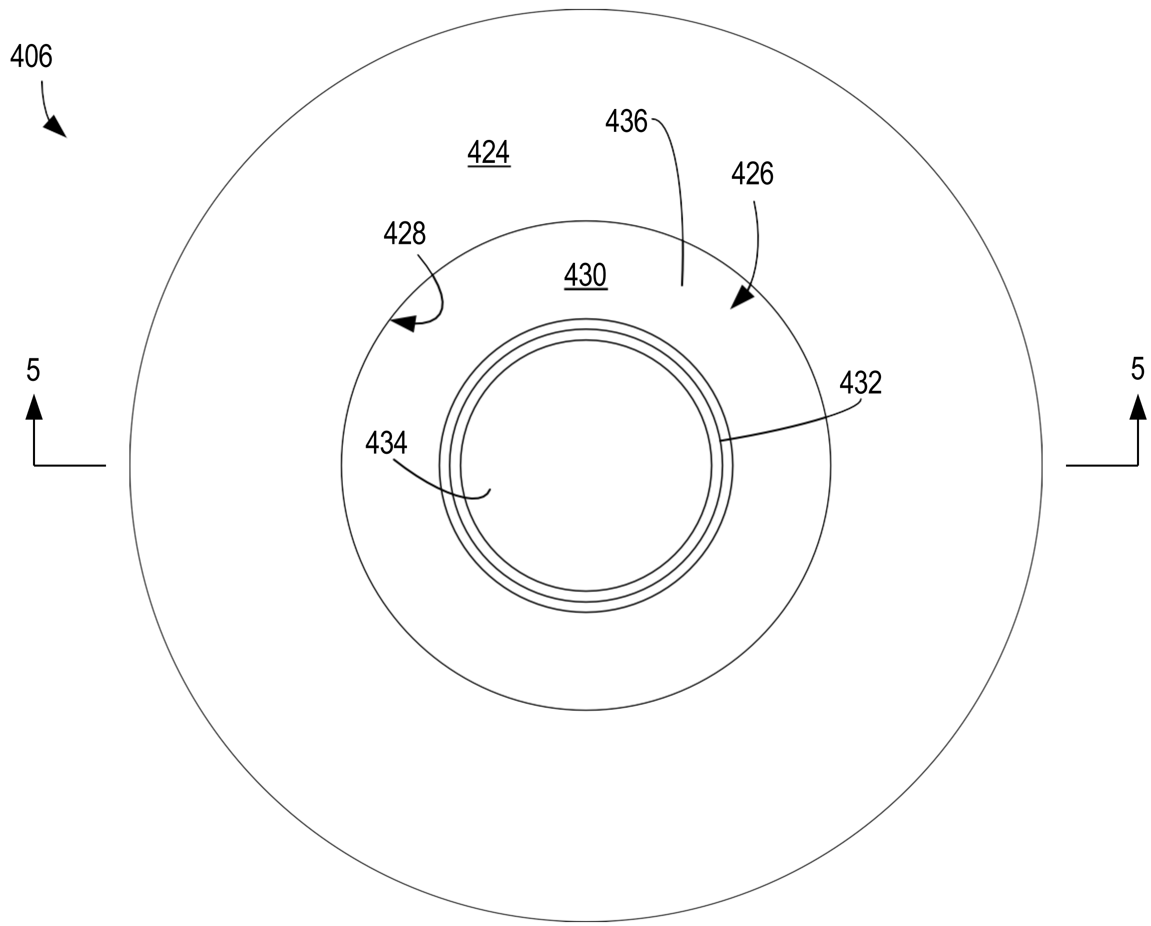
FIG. 2

FIG. 3A

FIG. 3B

FIG. 3C

FIG. 3D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436
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428
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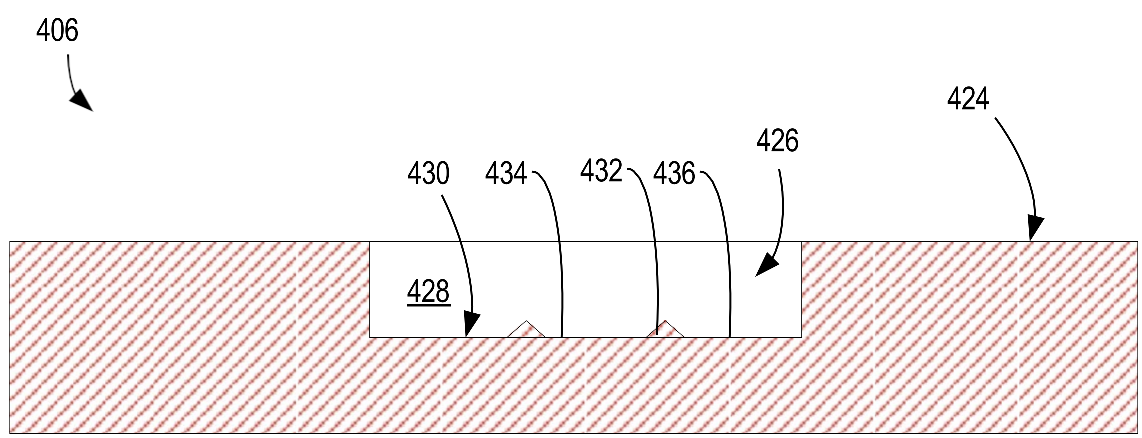
5
432
5
434

FIG. 4


406
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436
428

FIG. 5

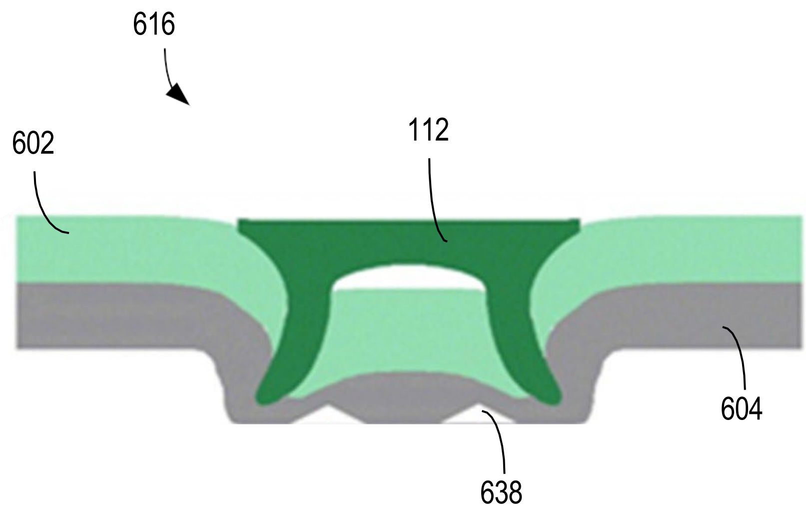


FIG. 6

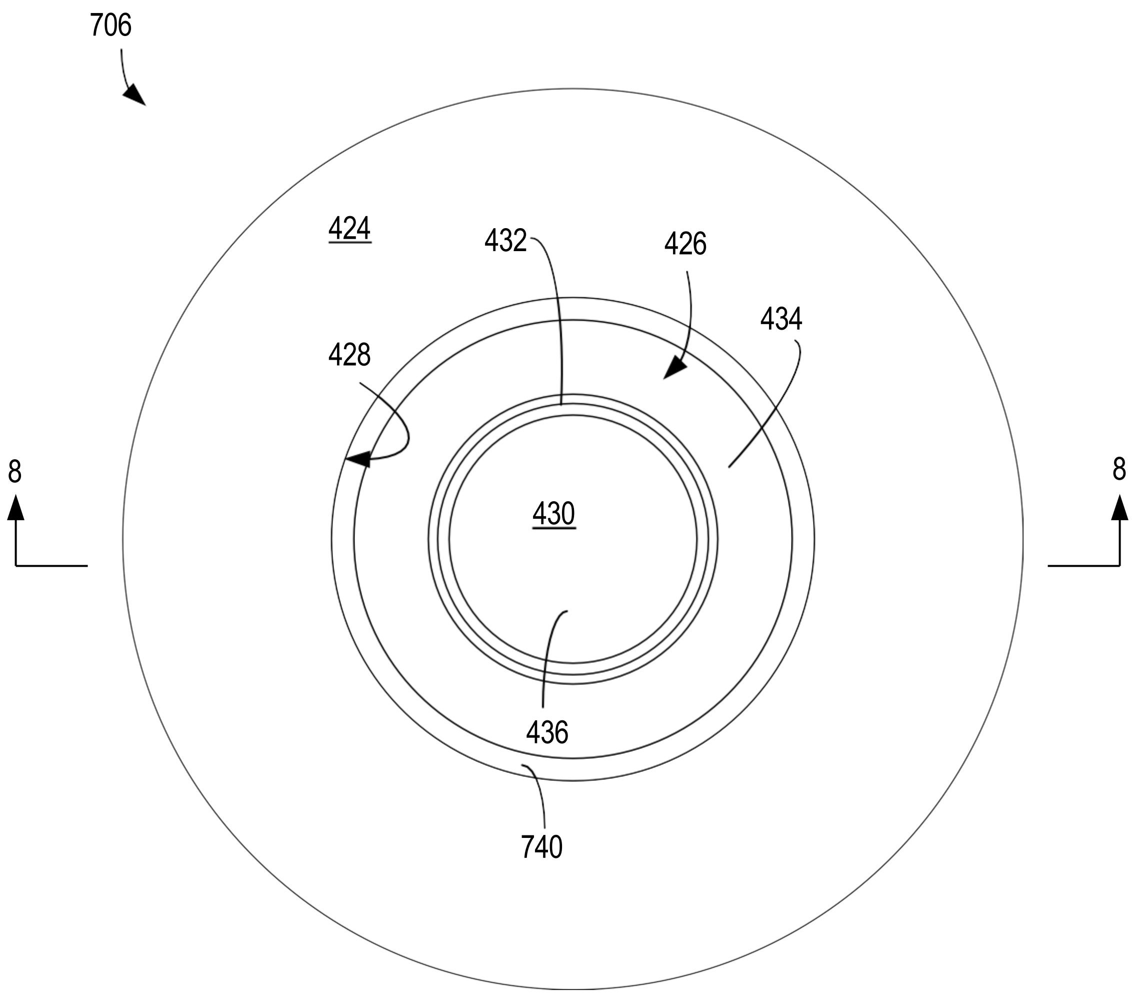


FIG. 7

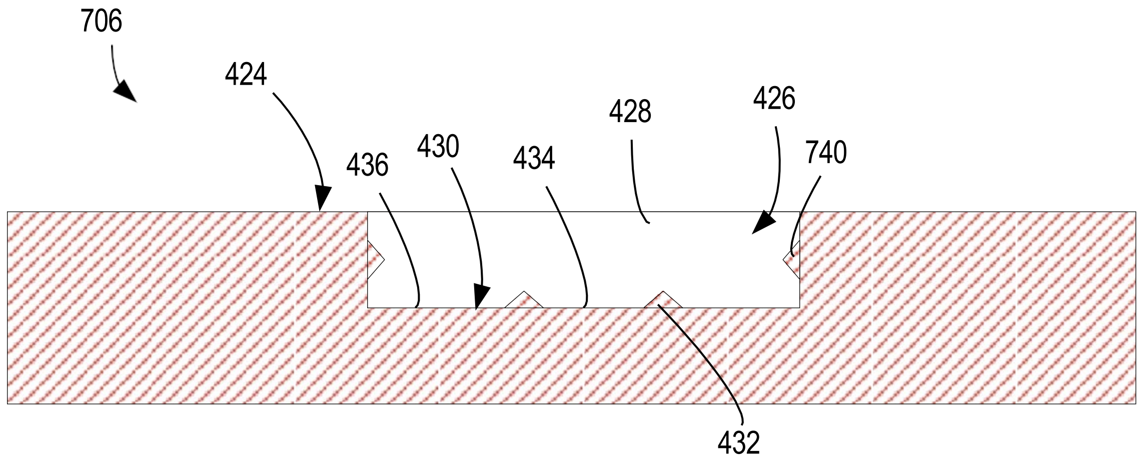


FIG. 8

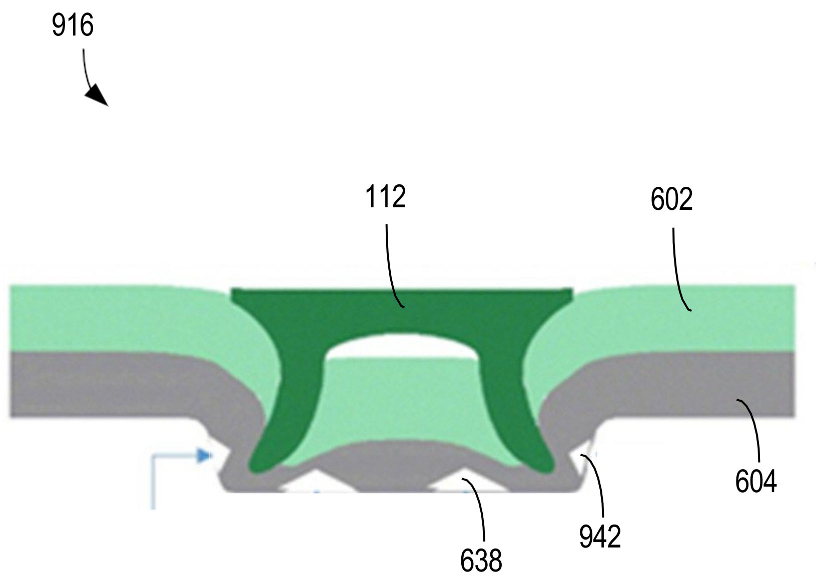
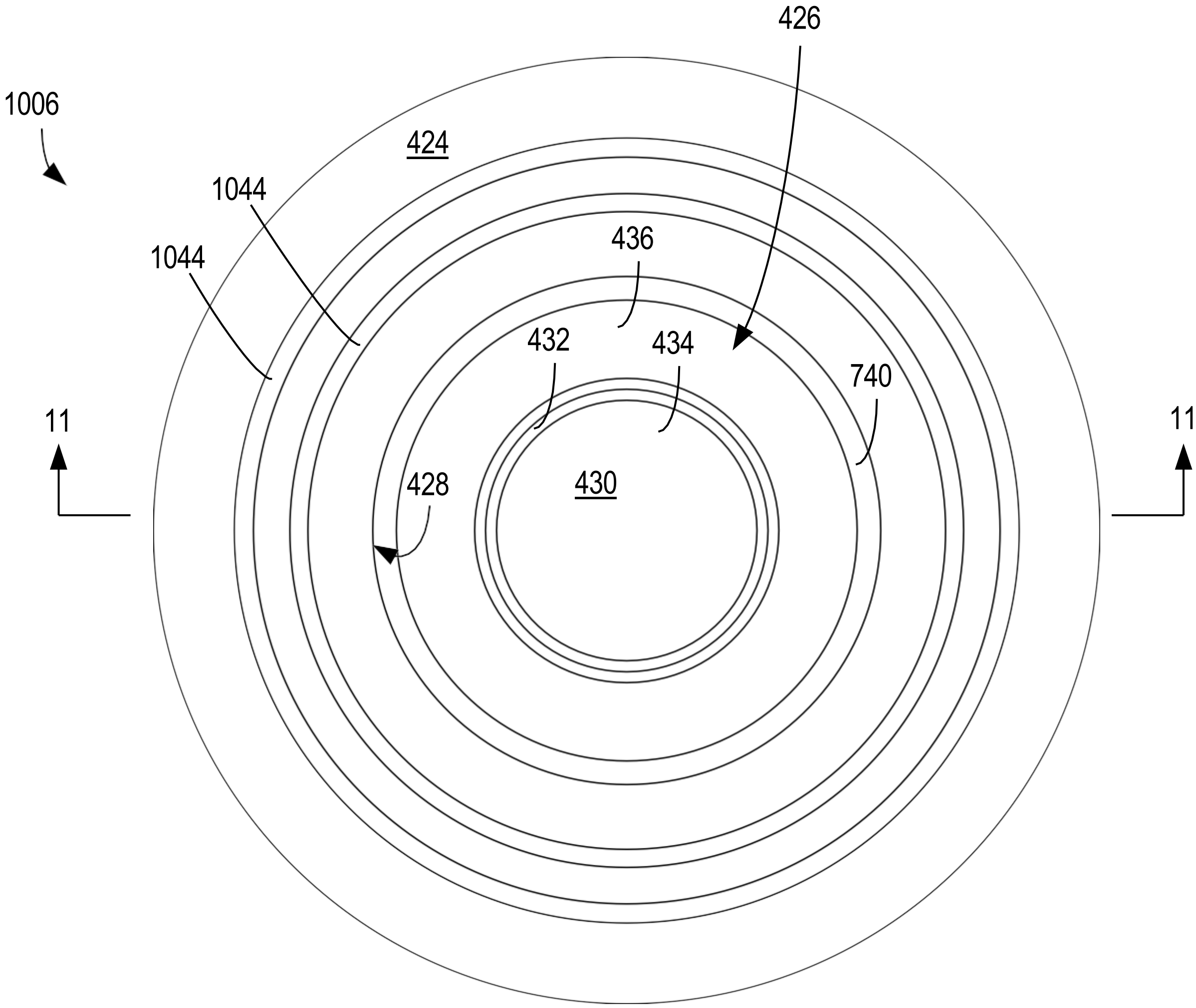


FIG. 9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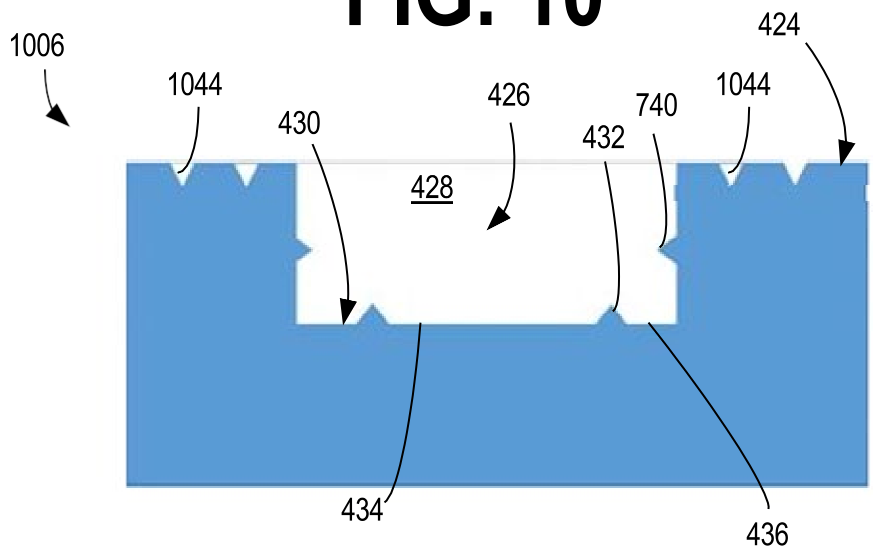
1006
424
1044
1044
436
432
434
740
11
11
428
430

FIG. 10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424
1044
426
740
1044
430
432
428
434
436

FIG. 11

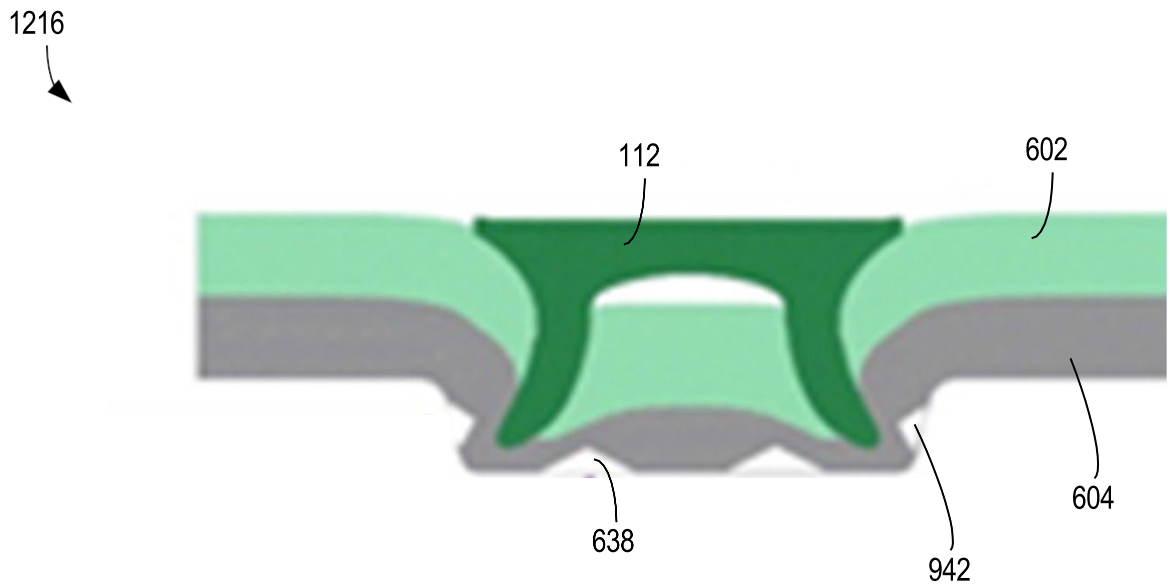

FIG. 12

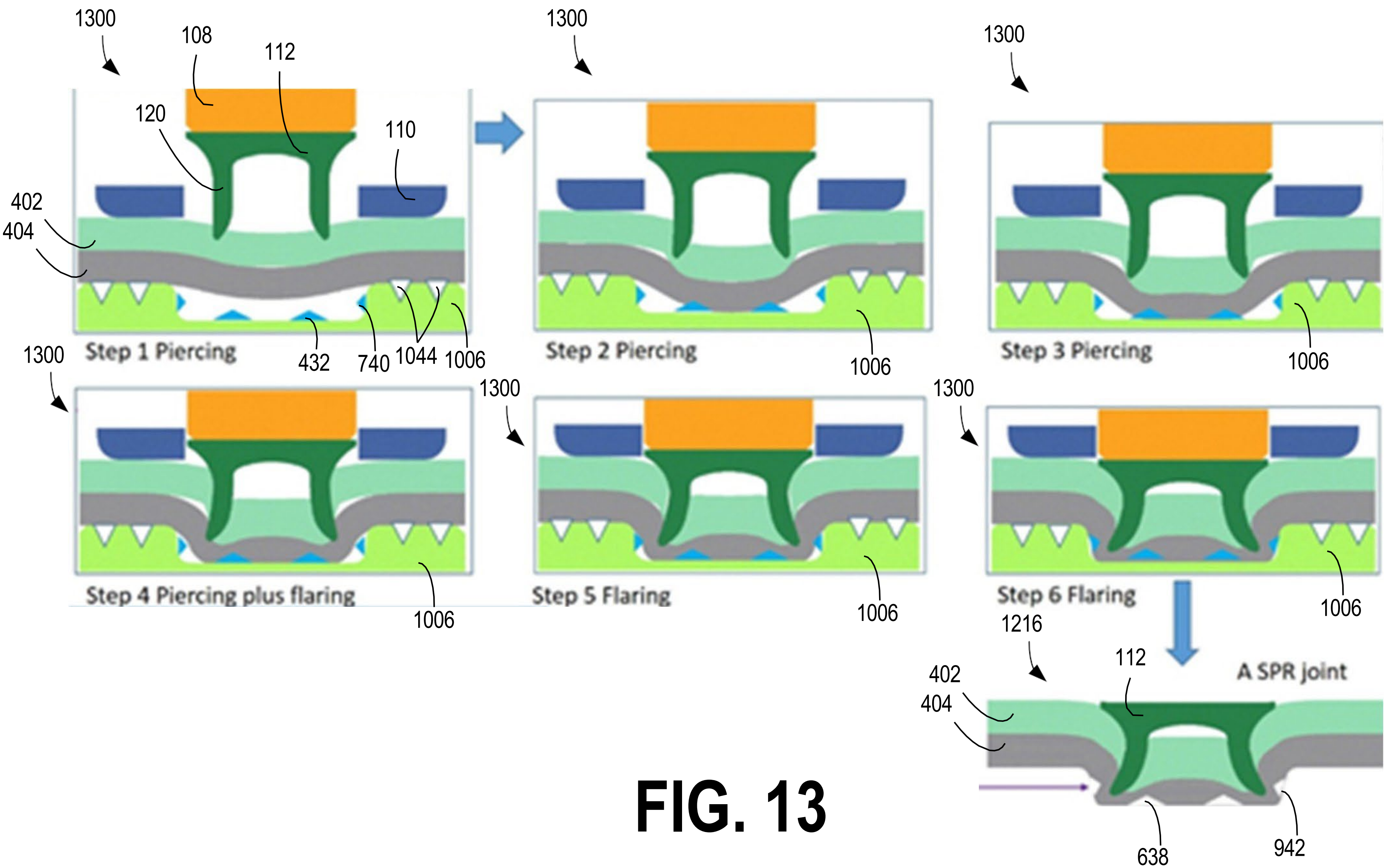
1300
108
112
120
110
402
404
Step 1 Piercing
432
740
1044
1006
1300
Step 2 Piercing
1006
1300
Step 3 Piercing
1006
1300
Step 4 Piercing plus flaring
1006
1300
Step 5 Flaring
1006
1300
Step 6 Flaring
1006
1216
112
A SPR joint
402
404
638
942

FIG. 13

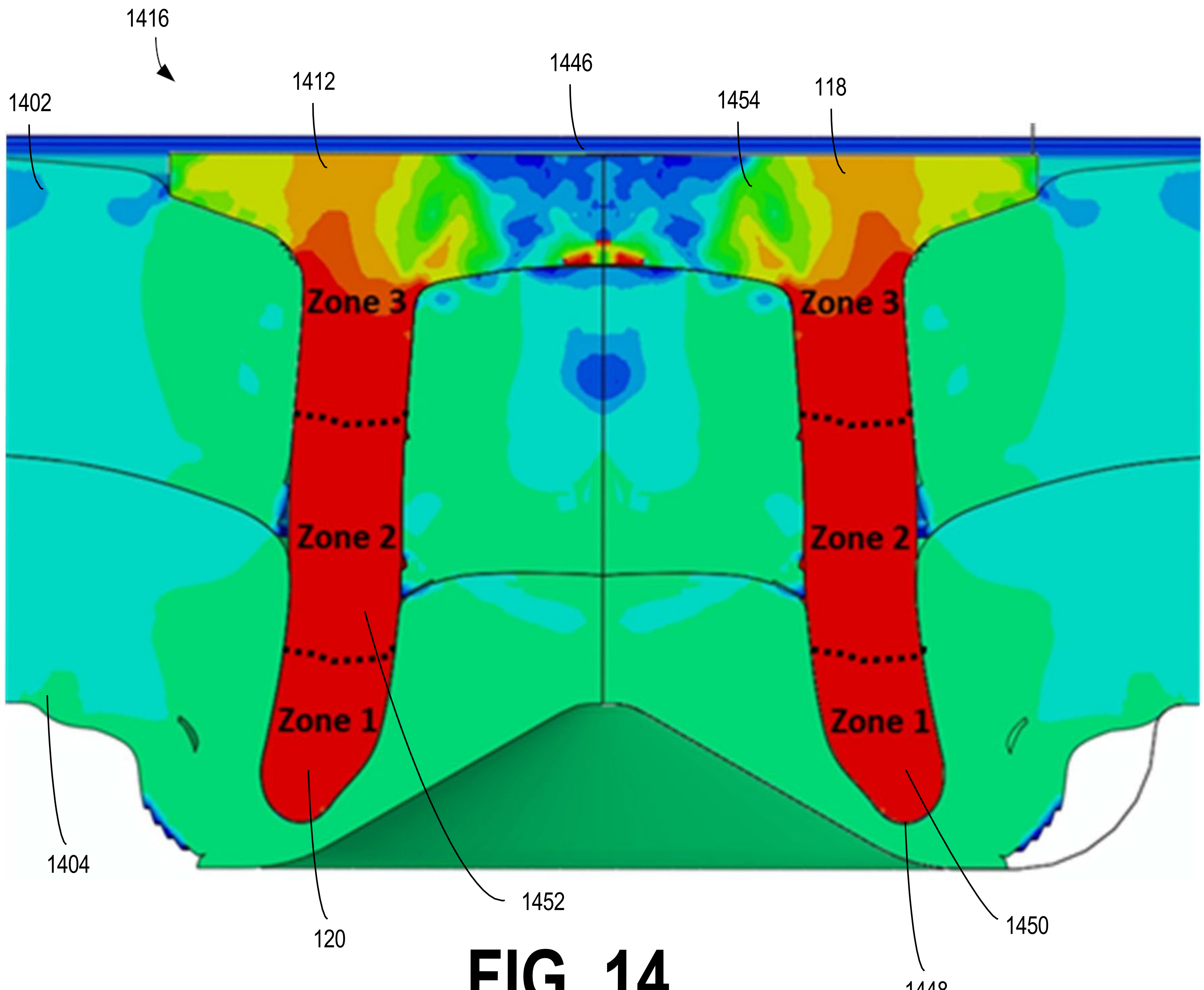
1416
1402
1412
1446
1454
118
Zone 3
Zone 3
Zone 2
Zone 2
Zone 1
Zone 1
1404
120
1452
1450
1448

FIG. 14