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(54) Title: LASER-BASED KEYHOLE WELDING

(57) Abstract: Laser keyhole welding with a prefilled narrow gap is disclosed. Alloying filler material may be applied to an edge of a workpiece before aligning two workpiece edges. The aligned workpiece edges form a prefilled narrow gap. A laser system and a beam delivery system form a laser tool point at the gap to generate a welding keyhole, the laser keyhole is translated along the narrow gap and through the filler material to form a laser weld joint.



WO 2018/227115 A1

LASER-BASED KEYHOLE WELDING

BACKGROUND OF THE INVENTION

Field of the Invention

[001] The field of the invention is laser-based welding. More particularly, the invention relates to high strength keyhole welding.

Background of the Invention

[002] Seam welding is ubiquitous in many economic sectors including energy, transportation, aerospace, chemical processing, construction, and marine applications. Various welding applications include tube and pipe, fittings, plates, panels and sheets, beams, and tanks. In one case, butt welding is used to join lengths of piping in pipeline construction. Methods used to form individual lengths of pipe may include roll forming, cold drawing, turning and milling. While pipe welding is generally a mature technology, laser welding with the increased availability, quality, and portability of high power of welding laser sources is seen as an area for innovation and improvement. High power fiber lasers and fiber coupled lasers provide direct tool point control with a traveling laser welding head in gantry and robotic arm welding systems for joining a range of ferrous and non-ferrous metals including carbon steel, chrome-moly, stainless steel, aluminum, titanium, nickel alloy, bronze alloy, Inconel, and Hastelloy.

[003] In conventional arc welding, there is significant preparation required to each part before welding takes place. Referring to FIG. 1, showing an example of v-groove welding steps, a bevel 11A, 11B is cut into the respective material 12A, 12B at each side of the weld joint. Below the bevel, a root feature 13 is used to form the basis of a root weld 14. The root weld may be intermittently tack welded and then continuously welded to form the root weld. The root weld joins the pipe sections and prepares the joint for filling. Above the root weld, a filler groove 15 is created between the bevels of each pipe section.

[004] With the root weld complete and the weld groove formed, filler material **16** is welded into the weld groove to form a full cross section in the pipe wall and an outer weld bead **17** (if formed). In some weld designs both the pipe OD and ID are welded and an inner groove is welded and filled to generate an inner weld bead **18**. With the root weld, groove filling, and

bead formation, it is apparent that many steps and multiple passes with a variety of welding techniques are required to form the final weld.

[005] Weld joint design may include materials in addition to filler feed stock such as various types of a backer rings at the joint to support the root weld and in particular when welding is single sided. Another type of ring is a consumable insert conforming to a standard profile shape (e.g. one of A, J, K, T and Y shapes). Where the backer ring may be removable, the insert ring is designed to fuse and become an integral part of the weld. The fused consumable insert may form a smooth inner diameter to promote unrestricted material flow, or may form an inner weld bead for increased strength. The T shape may be preferred for orbital welding.

[006] One distinct advantage of laser welding in general is the keyhole welding process. Referring to FIG. 2, two material sections **21A** and **21B** to be joined are butted together to form gap **22**. Laser source **23** is used to generate a processing beam that is transmitted through beam delivery optics **24** to a laser tool point focus **25** at or near the gap. As the material sections heat and melt, a keyhole **26** is formed at the gap from the pressure of vaporize material and deep penetration of the laser is possible. The keyhole is translated along the trajectory of the gap, melting and fusing material along the trajectory to bridge the gap and form the weld **27**. Suitable laser sources and beam delivery optics are available from IPG Photonics Corporation, 50 Old Webster Road, Oxford MA.

[007] Keyhole welding provides a combination of superior depth penetration, narrow weld width, and limited heat affected zone (HAZ). With high power laser sources, keyhole welding makes it possible to weld thick sections of material with simply prepared narrow gap butt joints. Consistent gap thickness and material wall thickness are desirable to maintain keyhole weld quality.

[008] In contrast to conventional arc welding with a large groove to be filled, narrow gap laser keyhole welding can be completed in a single pass from a single side and a double pass from 2 sides depending on materials, weld depth, and laser source used. Thus, keyhole welding can be performed at rates significantly higher than conventional filled groove welds by eliminating the many processing steps and the high volume of consumable materials associated with groove preparation, root welding, and filling.

[009] Many aspects of keyhole welding can be applied to pipe welding. For example, keyhole welding can make use of wire fed filler material. It may be beneficial to use filler wire during

laser welding of steel and other metals. Usually the filler wire contains alloying elements that improve properties of the metal being welded. In this case, the filler wire may be provided directly to the key hole. However, it has been found that during laser welding of thick cross sections the filler wire material is not distributed uniformly along the entire cross section, but concentrates mainly in the top strata of the thickness. As a result, the alloying elements are not distributed uniformly along the cross section and a part of the cross section does not have sufficient concentration of the alloying elements.

[010] What is needed are improved laser welding methods, systems, articles, and materials that provide efficient welding operations and full depth, strongly alloyed welds.

[011]

BRIEF SUMMARY OF THE INVENTION

[012] The present invention provides a keyhole laser welding method for joining a first metallic workpiece and a second metallic workpiece. Alloying filler material is applied to at least one workpiece edge. The workpieces are mechanically clamped in a welding fixture with a first workpiece edge and a second workpiece edge aligned in close proximity forming a narrow prefilled gap along the length a joint to be welded. A laser source and a laser beam delivery system deliver a laser tool point to the narrow gap. The gap is irradiated with the laser tool point to form a laser keyhole through at least a portion of the gap and at least a portion of the alloying filler material. The keyhole is translated along the trajectory of the prefilled gap, and a rigid weld joint comprising alloyed metal is formed.

[013] In at least one embodiment of the present invention, a workpiece edge may be beveled to promote uniform keyhole formation. A tubular workpiece may be circularized to improve narrow gap alignment. The workpiece material may be carbon steel, chrome-moly, stainless steel, aluminum, titanium, nickel alloy, bronze alloy, Inconel, and Hastelloy. The filler material may include aluminum, carbon, chromium, cobalt, copper, iron, manganese, molybdenum, nickel, niobium, phosphorus, silicon, sulfur, tantalum, titanium, vanadium, zinc, and zirconium. The filler material may be stock fed from a spool and applied to a workpiece edge. The filler material may be applied in the form of a preformed shape that conforms to the profile of at least a portion of the weld joint.

[014] In at least one embodiment of the present invention, filler material is applied to a weld groove and melting the filler material in the weld groove to at least partially fill the weld groove, as a portion of a weld joint profile between two workpiece edges.

[015] In at least one embodiment of the present invention, a beam delivery system moves the laser tool point by orbiting the laser tool point around two butted sections of pipe. A shielding gas may be applied to the laser keyhole. The filler material may include micro elements. The filler material may form an interlayer between the workpieces and the interlayer may be a stack of multiple layers having different compositions. The filler material may be an over-alloyed material. The filler material may be supplied in the form of a strip, and the strip may be spot welded to a workpiece edge prior to keyhole welding.

[016] The present invention also provides an efficient keyhole laser welding system for joining a first metallic workpiece and a metallic second workpiece. The system applies alloying filler material to at least one workpiece edge. Mechanical clamps in a welding fixture align a first workpiece edge and a second workpiece edge in close proximity forming a prefilled narrow gap along the length a joint to be welded. A laser source and a laser beam delivery system deliver a laser tool point to the narrow gap to form a laser welding keyhole at the gap, and translate the keyhole along the trajectory of the gap to form a laser welded joint.

BRIEF DESCRIPTION OF THE DRAWINGS

[017] The above and other aspects, features and advantages of the disclosure will become more readily apparent with the aid of the following drawings, in which:

[018] Fig. 1 provides an illustration of prior art root welding.

[019] Fig. 2 provides an illustration of prior art laser keyhole welding.

[020] Fig. 3 provides an illustration of aspects of prefilled gap keyhole laser welding.

[021] Fig. 4 provides an illustration of aspects of prefilled gap welds.

[022] Fig. 5 provides an illustration of wall misalignment.

[023] Fig. 6 provides an illustration of edge beveling.

[024] Fig. 7 provides an illustration of preformed filler materials.

[025] Fig. 8 provides an illustration of weld bead formation.

[026] Fig. 9 provides an illustration of an orbital welding embodiment.

DETAILED DESCRIPTION OF THE INVENTION

[027] Reference will now be made in detail to embodiments of the invention. Wherever possible, same or similar reference numerals or letters are used in the drawings and the description to refer to the same or like parts or steps. The drawings are in simplified form and are not to precise scale. For purposes of convenience and clarity only, directional (up/down, etc.) or motional (forward/back, etc.) terms may be used with respect to the drawings. The term “couple” and similar terms do not necessarily denote direct and immediate connections, but also include connections through intermediate elements or devices.

[028] To meet the needs for improved laser welding methods, systems, articles and materials that provide efficient welding operations and full depth, strongly alloyed welds and other needs, laser-based prefilled laser keyhole welding is provided. In at least one aspect of the invention, as shown in FIG. 3, an alloying material **31** is positioned in the gap **32** of a butt seam between two parts **33A**, **33B** to be welded. A laser source **34** and beam delivery optics **35** form tool point **36** that travels along trajectory **37**, generating a laser keyhole that proceeds along the gap to weld the two parts together. The alloying material **31** in the gap may be in the form of an interlayer of material filling the gap from an inner diameter **38** to and outer diameter **39** or filling a portion of the gap where increased alloy material content is desirable.

[029] The alloying material is not limited to a single interlayer. An example of the positioning of multiple interlayers of alloying elements for a butt welding configuration is shown in FIG. 4. Alloying material in gap **41** contains multiple interlayers **42**, of alloying material. The interlayers may have different properties associated with different positions across or along the gap. For example, the chemical composition of the interlayers may be different. Central layers of the interlayer configuration may have concentrations of alloying elements lower than outer layers of the interlayer stack, but may have concentrations of alloying elements higher than the material being welded.

[030] With differing concentrations of alloying elements, during the welding the material of the outer layers will mix with the material being welded and with the material of the central interlayer forming distributed alloy region **43**. Chemical composition of one or more layers and distribution of the layers may be determined so as to result in a more uniform distribution of the alloying elements along the depth of the key hole as well as perpendicular to the keyhole gap. Distribution of alloying elements within and chemical composition of a layer may not be

uniform. The alloying elements may have the chemical composition similar to that of the standard welding filler wires and may contain microelements 44 in addition to alloying elements. The interlayers may be over-alloyed to account for volatile alloy losses during welding.

[031] Prior to laser welding, the interlayer material of the alloying elements can be attached to the surfaces to be welded using, for example, by spot welding. In at least one embodiment, the interlayer is continuously fed and applied to an edge to be welded, in the form of a filler material strip. The strip may be applied to the end of a pipe covering the end surface in a closed ring shape, or an open ring shape with a small gap or overlap between the start and end of the ring. The interlayer may be an applied wire or other continuous feed form. The interlayer material may be formed into a consumable insert ring for piping applications. Welding with the interlayer can be done from one side or it can be done from both sides of the workpieces.

[032] With a root weld design, positioning offsets are in part managed in pipe preparation such that the root feature is formed with tight tolerances relative to the wall thickness. Then, fill material can be used to bridge pipe sections with the weld bead and strengthen the weld. However as shown in FIG. 5, offsets 51 in a keyhole weld with a narrow pipe to pipe interface gap, pipe cross section offsets can be problematic. Offsets reduce the cross section of the overlapping wall sections which can reduce weld cross section and reduce the weld strength. Secondary filling operations may be needed to bridge the wall thickness deficit.

[033] Offset workpiece material at the gap may adversely affect keyhole formation at the laser tool point by disrupting keyhole formation or perturbing depth and/or keyhole shape. As such, some pipe preparation may be required to present a uniform, non-offset gap to the laser tool. As shown in FIG. 6, edge preparation may include a single or double chamfer, for example chamfers 61 and 62 at respective outer and inner pipe edges on both sides of the weld. This preparation may be a bevel cut to match gap diameters for keyhole welding. In general, these prepared bevels will be small in comparison with root weld designs, so the weld groove volume is significantly less than a conventional weld groove in a root weld design.

[034] During laser keyhole welding with a bevel, some filler material may be conventionally applied to the weld groove. However, even with a reduced material thickness at the gap, the filler material may not penetrate the full depth of the gap, depriving the weld of the full benefits of the applied filler material and associated material alloying. Thus, application of alloying

material to the gap in the form of interlayers **63** can be beneficial when there is a weld groove present.

[035] Referring to FIG. 7, the alloying layers depicted at **71**, **72**, **73**, and **74** may extend onto the chamfer or may protrude outside the gap edge to be melted during the subsequent welding and provide weld some groove filling and weld reinforcement. As shown in FIG. 8, the alloying elements **81** may protrude over the surface of the parts being welded and create reinforcements **82**, **83** on one or on both sides of the weld. The welding can be done either from one side of the weld or on both sides of the weld.

[036] The beveled gap weld design can be filled after keyhole welding with less filler material volume and reduced filler welding time than a conventional root weld groove. It is to be understood that weld groove filling may be performed with laser welding, arc welding, hybrid arc-laser welding, or any other suitable weld filling technique.

[037] For relatively thin wall pipe, and in general large diameter pipe, pipe shape may deviate from a true cylindrical form. Prior to welding, dynamic fixtures may be used to clamp to and align pipe ends at a weld joint sight, apply forces to the pipe to circularize the shape, and bring pipe ends together. This may be used, for example, in welding large diameter pipe with orbital welding machine techniques. Viability of shaping may have practical limits with regard to the size and type of pipe, the weld design and welding application limitation. In any case, shaping cannot accommodate variations in wall thicknesses. To some extent, swaging might be used to modify pipe diameters; however piping of stock diameter meeting applicable standard size schedules generally provides sufficient control over (average) diameters.

[038] Strength of the final pipe joint may be a critical aspect in pipe-line and other pipe joining applications. Strength can be diminished by cracks and defects, temperature stresses, and unevenness. Material in the HAZ near the weld may lose mechanical strength. As a result of material variations, when there are wall thickness and diameter variations between pipe sections, a mismatch condition at the gap can result. When a mismatch generates an offset of pipe wall cross sections, the cross section overlap area is reduced. In keyhole welding with no alloy fill, the reduced cross sectional area of the weld can reduce the strength of the weld. On the other hand, filler material and welded material may have increased strength with hardening and alloy formation. In at least one embodiment of the present invention, the alloying of the weld

provided by the interlayer material increases the strength of the weld and at least in part offsets weld strength lost to positioning and offset errors.

[039] Piping sizes suitable for laser welding can range from fractions of an inch to 100" and more. An exemplary pipe size used in embodiments is on the order of 1 meter in diameter. While descriptions and examples may refer to pipe welding, it is to be understood that benefits of the present invention can be applied to other material forms to be keyhole welded.

[040] It is to be understood that pipe joining is but one aspect of the invention and the interlayers can be used in other laser welding processes between sheets, plates, formed articles and other material shapes to be welded.

[041] Welded pipe joints may need to meet or exceed applicable code specifications such as ASME/ANSI B16.9 relating to factory made wrought steel butt-welding fittings and ASME/ANSI B16.25 relating to butt-welding ends and other applicable local, national, regional, and international codes and standards such as promulgated by AWS (America Welding Society), API (American Petroleum Institute), ISO, EN, DIN etc., for example AWS/ASME 5.30, and MIL-I-23413. Particular specifications on a project basis may have requirements that exceed published standards, for example, welds may be subject to strength testing, stress testing, corrosion testing and other engineering evaluations. Particular project requirements may include operating pressure and temperature ranges, environmental conditions, as well as installation specific needs. Remote installation areas may have more limited power and machinery resources as compared with urban infrastructure applications or factory fabrication.

[042] In at least one embodiment, referring to FIG. 9, a pipe welding system **90** includes a laser source **91**, beam delivery optics **92**, material handling fixtures **93**, and an orbital tool point positioning system **94**. The orbital system moves the tool point around the weld seam relative to the material handling fixtures to form weld **95** around the pipe joint. As mentioned above, the fixtures may include clamping, circularizing and gap closing mechanisms. The material handling systems and orbital positioning system may be configured to move along the pipe axis, for example from one weld joint to the next weld joint. The material handling system and orbital system may be coupled and travel together or may be independently positioned along the pipe axis. Preferably, the orbital system orbits the pipe exterior; however, an internal orbit is within the scope of the invention. The beam delivery system may accommodate a range of motion of the orbital tool point positioning system around the pipe and along pipe sections. The laser

source may travel along the pipe axis to remain in proximity to the orbital system. The welding system may include orbiting pipe end preparation tools, inspection tools, filler material feed, and filler material installation systems.

[043] Those skilled in the art will recognize or be able to ascertain using no more than routine experimentation many equivalents to the specific embodiments of the invention described herein. The disclosed schematics can be used with any laser welding system, but the impetus for the presently disclosed structure lies in prefilled gap keyhole laser welding. It is therefore to be understood that the foregoing embodiments are presented by way of example only and that within the scope of the appended claims and equivalents thereto, the invention may be practiced otherwise than as specifically described. The present disclosure is directed to each individual feature, system, material and/or method described herein. In addition, any combination of two or more such features, systems, materials and/or methods, if such features, systems, materials and/or methods are not mutually inconsistent, is included within the scope of the present invention.

CLAIMS

1. A keyhole laser welding method for joining a first workpiece and a second workpiece at a weld joint, the first and second workpieces being metallic and mechanically clamped in a welding fixture such that a first workpiece edge and a second workpiece edge are aligned in close proximity forming a narrow gap between the first workpiece and the second workpiece along the length the joint to be welded, a laser source and a laser beam delivery system configured to deliver a laser tool point to the narrow gap to form a laser welding keyhole at the gap, the beam delivery system and the welding fixture configured to relatively translate the keyhole along the trajectory of the gap to form a laser welded joint, the method comprising:

applying an alloying filler material to at least one workpiece edge before aligning the workpiece edges for welding;

forming a narrow gap between the edges by aligning the workpieces, wherein the alloying filler at least partially prefills the narrow gap prior to welding,

irradiating the prefilled gap with the laser tool point to form a laser keyhole through at least a portion of the gap and at least a portion of the alloying filler material; and

translating the laser keyhole along the trajectory of the prefilled gap, whereby a rigid weld comprising alloyed metal is formed at the joint between the workpieces.
2. The method as in claim 1, further comprising preparing at least one workpiece edge for laser welding by beveling the edge to promote uniform keyhole formation along the prefilled narrow gap.
3. The method as in claim 1, further comprising circularizing at least one tubular workpiece to improve narrow gap alignment.
4. The method in claim 1, wherein the workpiece material to be welded is a metal selected from the group consisting of carbon steel, chrome-moly, stainless steel, aluminum, titanium, nickel alloy, bronze alloy, Inconel, and Hastelloy.
5. The method as in claim 1, wherein the filler material comprises at least one of aluminum, carbon, chromium, cobalt, copper, iron, manganese, molybdenum, nickel, niobium, phosphorus, silicon, sulfur, tantalum, titanium, vanadium, zinc, and zirconium.
6. The method as in claim 1, wherein filler material stock is fed from a spool and applied to a workpiece edge so as to prefill the gap for laser keyhole welding.

7. The method as in claim 1, wherein the filler material is applied in the form of a preformed shape that conforms to the profile of at least a portion of the weld joint so as to prefill the gap for laser keyhole welding.
8. The method as in claim 1, further comprising applying filler material to a weld groove and melting the filler material in the weld groove to at least partially fill the weld groove, wherein the weld groove is formed as a portion of a weld joint profile between two workpiece edges, the weld groove comprising one or more workpiece edge bevels adjacent to a prefilled narrow gap laser keyhole welded portion of the weld joint profile.
9. The method as in claim 1, wherein the beam delivery system moves the laser tool point by orbiting the laser tool point around two butted sections of pipe at the prefilled narrow gap, the tool point motion moving the laser keyhole along the trajectory of the gap so as to weld the two pipe sections together by forming an alloyed laser welded joint.
10. The method as in claim 1, further comprising applying a shielding gas to the laser keyhole.
11. The method as in claim 1, wherein the filler material comprises micro elements.
12. The method as in claim 1, wherein the filler material forms an interlayer between the workpieces.
13. The method as in claim 1, wherein the filler material is an interlayer stack of multiple layers having different compositions.
14. The method as in claim 1, wherein at least a portion of the filler material is an over-alloyed material.
15. The method as in claim 1, where in the filler material is supplied in the form of a strip, and the strip is spot welded to a workpiece edge prior to keyhole welding.

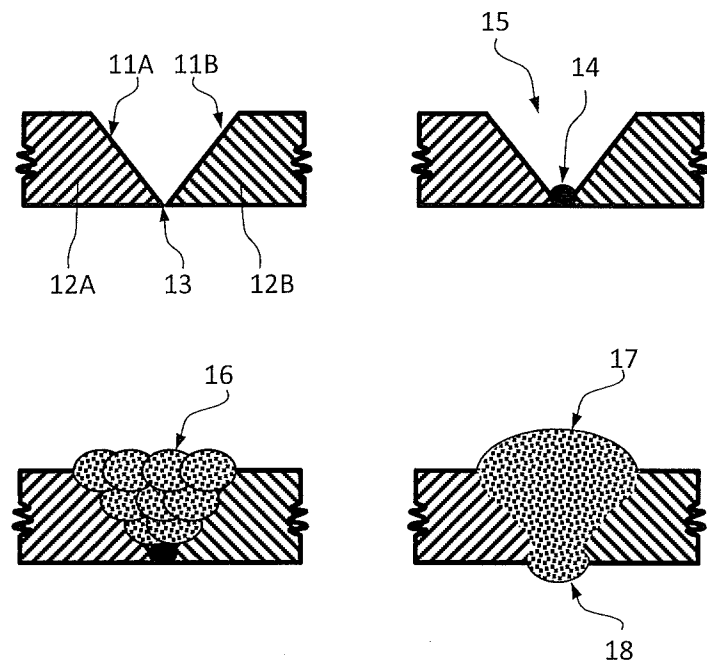


Figure 1 (Prior Art)

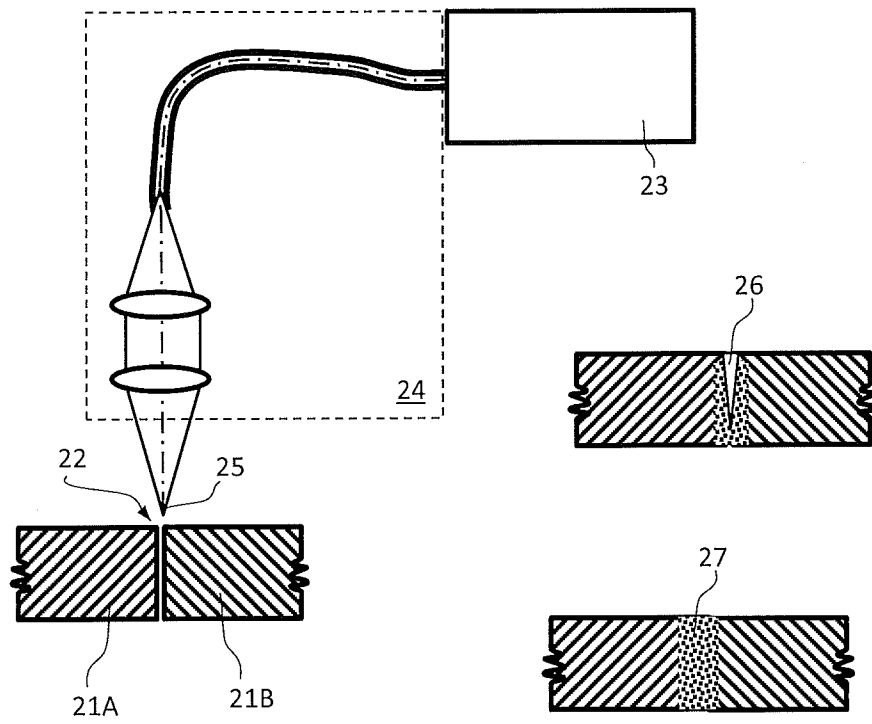


Figure 2 (Prior Art)

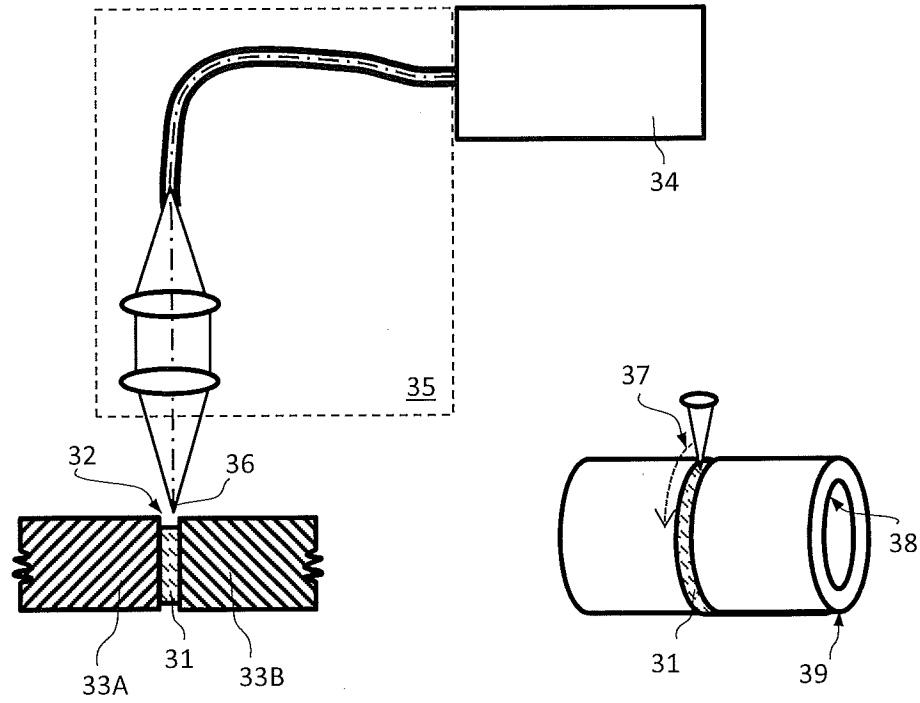


Figure 3

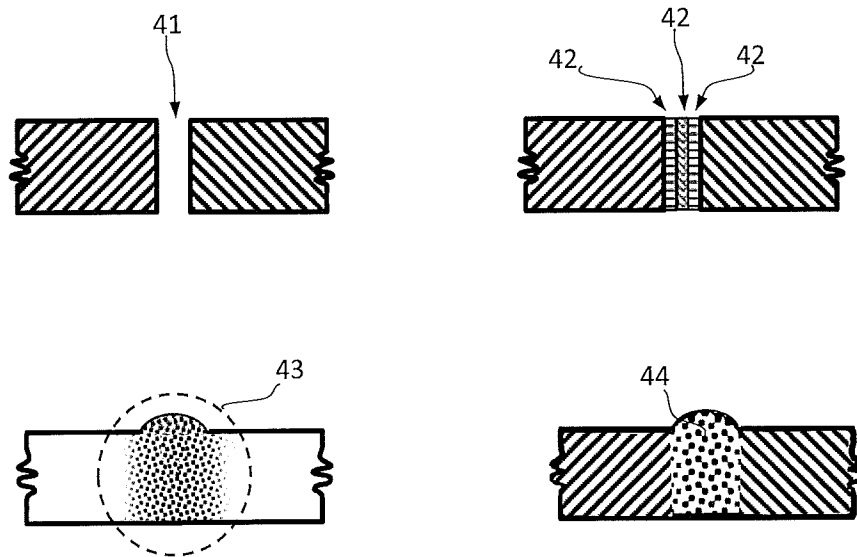


Figure 4

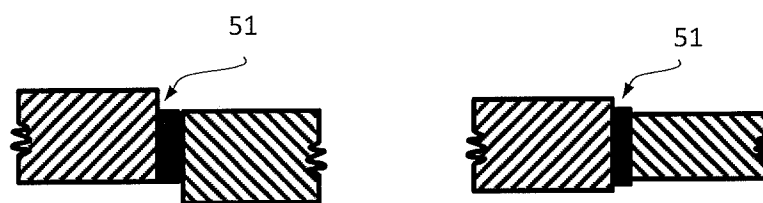


Figure 5

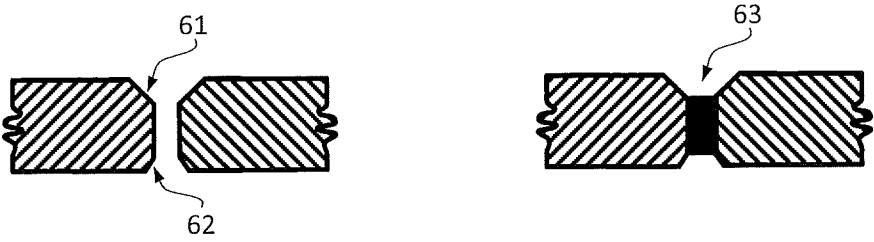


Figure 6

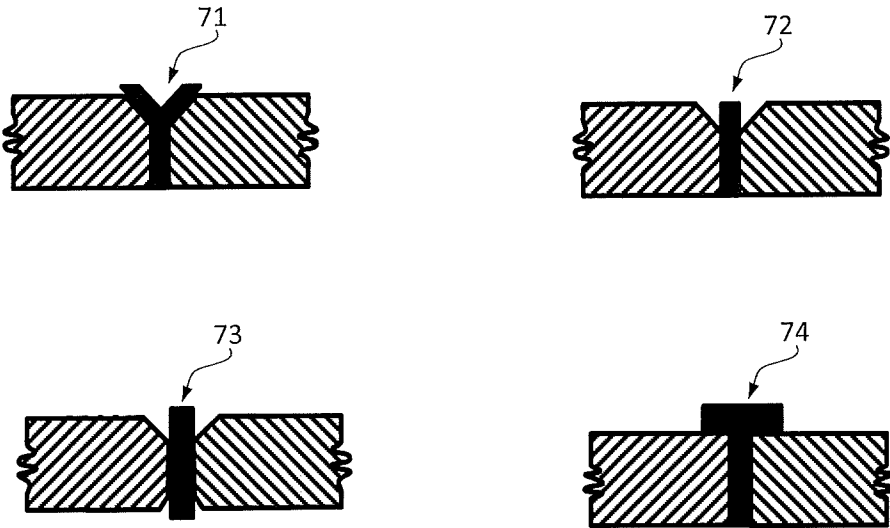


Figure 7

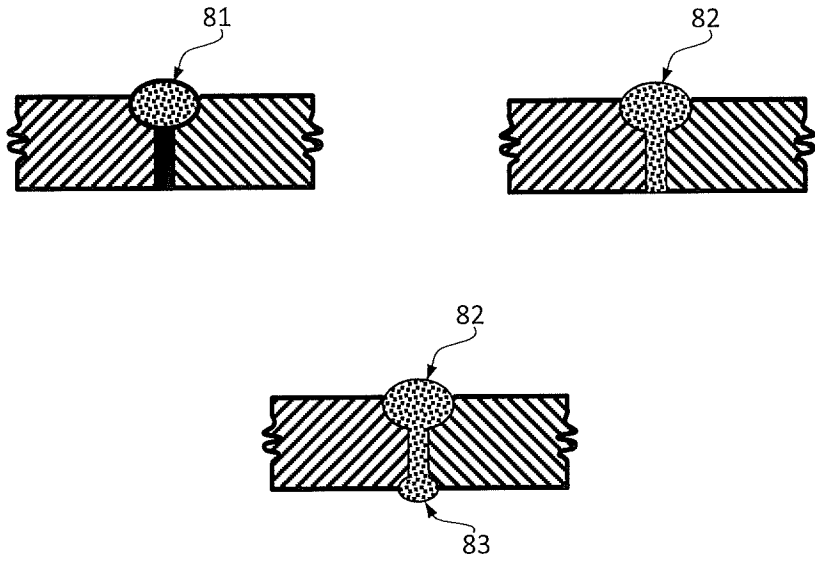


Figure 8

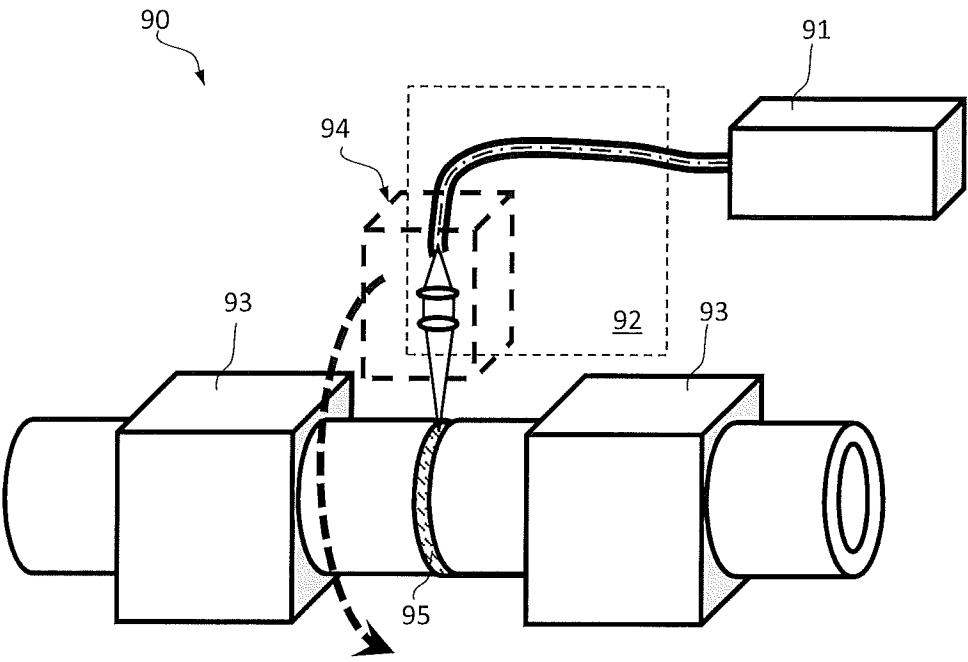


Figure 9

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 2018/036696

A. CLASSIFICATION OF SUBJECT MATTER		
B23K 26/282 (2014.01) B23K 26/211 (2014.01) B23K 33/00 (2006.01) B23K 31/02 (2006.01)		
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)		
B23K 26/00- 26/70, 33/00, 31/00-31/02		
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)		
PatSearch (RUPTO internal), USPTO, PAJ, Esp@cenet, DWPI, EAPATIS, PATENTSCOPE, Information Retrieval System of FIPS		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	EP 2322312 A1 (JFF STEEL CORPORATION) 18.05.2011, abstract, fig.1a,1b	1-15
Y	US 2014/0035279 A1 (LINCOLN GLOBAL INC) 06.02.2014, abstract, fig.3	1-15
Y	US 4219717 A (BBC BROWN BOVERI & CO LTD) 26.08.1980, abstract, fig.	4
Y	RU 2104137 C1 (АКЦИОНЕРНОЕ ОБЩЕСТВО ЗАКРЫТОГО ТИПА «ТЕХНОЛАЗЕР») 10.02.1998, abstract, fig.1, page 2, example 1, 2, page 3, example 3	4-5, 7-9, 12-15
☒ Further documents are listed in the continuation of Box C. ☐ 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
05 September 2018 (05.09.2018)		27 September 2018 (27.09.2018)
Name and mailing address of the ISA/RU: Federal Institute of Industrial Property, Berezhkovskaya nab., 30-1, Moscow, G-59, GSP-3, Russia, 125993 Facsimile No: (8-495) 531-63-18, (8-499) 243-33-37		Authorized officer L. Nazarova Telephone No. (499) 240-25-91

INTERNATIONAL SEARCH REPORT

International application No.

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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	RU 2404887C1(ИНСТИТУТ ТЕОРЕТИЧЕСКОЙ И ПРИКЛАДНОЙ МЕХАНИКИ ИМ.С.А.ХРИСТИАНОВИЧА СИБИРСКОГО ОТДЕЛЕНИЯ РОССИЙСКОЙ АКАДЕМИИ НАУК (ИТПМ СО РАН)) 27.11.2010, abstract, page 4, lines 20-33, 37-55, page 5, lines 1-5, 20-26	5, 10-11