(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) **EP 3 815 836 B1**

(12) **EUROPEAN PATENT SPECIFICATION**

(45) Date of publication and mention of the grant of the patent:
22.11.2023 Bulletin 2023/47

(21) Application number: **19824610.0**

(22) Date of filing: **06.06.2019**

(51) International Patent Classification (IPC):
B23K 26/24 (2014.01) ***C22C 38/02*** (2006.01)
C22C 38/44 (2006.01) ***B23K 26/14*** (2014.01)
B23K 26/282 (2014.01) ***C22C 38/04*** (2006.01)
B23K 35/38 (2006.01) *B23K 103/04* (2006.01)

(52) Cooperative Patent Classification (CPC):
B23K 26/282; B23K 26/14; B23K 26/24;
B23K 35/383; B23K 2103/04; C22C 38/02;
C22C 38/04; C22C 38/44

(86) International application number:
PCT/JP2019/022446

(87) International publication number:
WO 2020/003950 (02.01.2020 Gazette 2020/01)

(54) **BUTT WELDED JOINT OF STEEL MATERIAL AND METHOD FOR MANUFACTURING SAME**

STUMPFSCHWEISSVERBINDUNG AUS STAHL UND VERFAHREN ZU IHRER HERSTELLUNG

JOINT SOUDÉ BOUT À BOUT DE MATÉRIAU EN ACIER ET SON PROCÉDÉ DE FABRICATION

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR

(30) Priority: **27.06.2018 JP 2018122414**

(43) Date of publication of application:
05.05.2021 Bulletin 2021/18

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Description

Technical Field

[0001] The present invention relates to a butt-welded joint of steel materials with which the steel materials are welded to each other and to a method for manufacturing the same according to the preamble of claims 1 and 6 respectively (see for example JP 2017 052005 A).

Background Art

[0002] In the related art, in a welded joint for welding together welding target materials, an improvement in a joint strength has been desired, and various attempts have been made to improve the joint strength. For example, PTL 1 discloses a T-joint in which a welded portion has improved fatigue strength, which is achieved by remelting slag on the surface of the weld bead, thereby smoothing the texture of the surface of the weld bead. Furthermore, PTL 2 discloses a lap bonded joint in which a joint portion has improved cross tensile strength, which is achieved by radiating a laser beam onto a metal sheet to form a bond portion that has been melted and solidified and, further, reradiating a laser beam to an inside thereof, thereby providing, near a melt boundary of the bond portion, a reheated solidified portion having excellent toughness. Furthermore, PTL 3 discloses one in which variations in fatigue strength have been corrected as a result of performing rapid heating and rapid cooling repeatedly on the surface of a welded portion, thereby refining the crystal structure of the welded portion. PTL 4 discloses a butt-welded joint, wherein a first weld metal is formed at a butting portion of a pair of steel plates from a first surface side of the plates to a second surface side opposite the first surface side and a second weld metal is formed to cover an end surface of the first surface side of the first weld metal. PTL 5 discloses a method for laser beam welding, in which a weld seam is formed in a workpiece by means of a first laser beam, and the workpiece is post-processed in at least partial region of the weld seam by means of a processing laser beam. On the other hand, regarding the fatigue strength of a butt-welded joint, which is obtained by welding together abutted steel materials that are to be joined together, although a further improvement is desired, weld structures that focus on the improvement in the fatigue strength of butt-welded joints and methods for manufacturing the same have not been known.

Citation List

Patent Literature

[0003]

PTL 1: Japanese Unexamined Patent Application Publication No. 59-110490
PTL 2: Japanese Unexamined Patent Application Publication No. 2017-52006
PTL 3: Japanese Unexamined Patent Application Publication No. 2002-256335
PTL 4: US 2012 / 237287 A1
PTL 5: DE 10 2014 203025 A1

Summary of Invention

Technical Problem

[0004] Technical objects of the present invention are to provide a butt-welded joint of steel materials that has excellent fatigue strength and to provide a method for manufacturing the same.

Solution to Problem

[0005] This problem is solved by a butt-welded joint of steel materials according to claim 1 and a method for manufacturing a butt-welded joint of steel materials according to claim 6. Advantageous embodiments of the invention are provided by the dependent claims. To achieve the technical objects described above, a butt-welded joint of steel materials according to the present invention is provided. Base materials of the butt-welded joint are a pair of the steel materials, with end portions of the steel materials being abutted against each other. The butt-welded joint includes a welded portion formed to extend from surfaces of the base materials to an inner portion of the base materials and straddle the end portions. The base materials have a carbon concentration of 0.1 mass% or greater and 0.35 mass% or less. The welded portion includes a melted and solidified portion, a remelted and solidified portion, and a reheated solidified portion. The melted and solidified portion is a portion resulting from melting and solidification of the end portions of the pair of base materials, the melting being caused as a result of first heating from the surfaces. The remelted and solidified portion is a portion resulting from remelting and resolidification of the melted and solidified portion, the remelting being caused as a result of reheating of the melted and solidified portion from a surface thereof. The reheated solidified portion is a portion formed in an inner region relative to the remelted and solidified portion and having a structure resulting from a change in a structure of the melted and solidified portion, the change being due to the reheating, the change involving no melting. A width W0 of the melted and solidified portion, a depth d0 from a surface of the welded portion to a deepest portion of the melted and solidified portion, a width W1 of the remelted and solidified portion, and a depth d1 from the surface of the welded portion to a deepest portion of the remelted and solidified portion have the following relationships:

$$0.46 \leq W1/W0 \leq 1{,}05$$

$$0.14d0 \leq d1 \leq 0.73d0$$

[0006] In this instance, it is preferable that an average Vickers hardness value of the reheated solidified portion be lower than an average Vickers hardness value of the remelted and solidified portion.

[0007] Furthermore, it is preferable that a residual stress of a surface of the remelted and solidified portion be a compressive stress in a center region in a width direction of the remelted and solidified portion.

[0008] Furthermore, it is preferable that, at a terminal portion in a circumferential direction of the welded portion, a depth h, from the surface of the welded portion, of a recess formed in the remelted and solidified portion and the depth d1 of the remelted and solidified portion have the following relationship:

$$0.32d1 \geq h$$

[0009] Note that in the present invention, it is preferable that the melted and solidified portion be formed as a result of keyhole welding, and the remelted and solidified portion and the reheated solidified portion be formed as a result of heat conduction welding.

[0010] In addition, the butt-welded joint of steel materials according to the present invention can be produced by a method for manufacturing a butt-welded joint of steel materials. The method includes abutting end portions of a pair of base materials made of the steel materials against each other and forming a welded portion in a manner such that the welded portion extends from surfaces of the base materials to an inner portion of the base materials and straddles the end portions. The base materials have a carbon concentration of 0.1 mass% or greater and 0.35 mass% or less. The welded portion is formed by a first step and a second step. The first step includes forming a melted and solidified portion by melting and solidifying the end portions of the pair of base materials, the melting being caused by first heating from the surfaces. The second step includes forming a remelted and solidified portion and a reheated solidified portion by reheating the melted and solidified portion from a surface thereof. The remelted and solidified portion is formed by remelting and resolidification of the melted and solidified portion. The reheated solidified portion is formed in an inner region relative to the remelted and solidified portion, with a structure of the reheated solidified portion resulting from a change in a structure of the melted and solidified portion, the change involving no melting. A width W0 of the melted and solidified portion, a depth d0 from a surface of the welded portion to a deepest portion of the melted and solidified portion, a width W1 of the remelted and solidified portion, and a depth d1 from the surface of the welded portion to a deepest portion of the remelted and solidified portion have the following relationship:

$$0.46 \leq W1/W0 \leq 1{,}05$$

$$0.14d0 \leq d1 \leq 0.73d0$$

[0011] In this instance, it is preferable that, in the first step, the melted and solidified portion be formed by keyhole welding, and in the second step, the remelted and solidified portion and reheated solidified portion be formed by heat conduction welding.

Advantageous Effects of Invention

[0012] With the present invention, a butt-welded joint of steel materials that has higher fatigue strength than a base material can be obtained.

Brief Description of Drawings

[0013]

[Fig. 1] Fig. 1 is a diagram schematically illustrating a welded portion and its vicinity of a butt-welded joint of steel materials of the present invention.
[Fig. 2] Fig. 2 is a diagram schematically illustrating a cross-sectional structure of the welded portion of Fig. 1
[Fig. 3] Fig. 3(a) is a diagram schematically illustrating laser radiation for an instance in which keyhole welding is performed, and Fig. 3(b) is a diagram schematically illustrating laser radiation for an instance in which heat conduction welding is performed.
[Fig. 4] Fig. 4 is a diagram schematically illustrating a sample welded by butt welding.
[Fig. 5] Fig. 5 is a cross-sectional view schematically illustrating a state in which keyhole welding is being performed during the preparation of the sample illustrated in Fig. 4.
[Fig. 6] Fig. 6 is a cross-sectional view schematically illustrating a state in which heat conduction welding is being performed during the preparation of the sample illustrated in Fig. 4.
[Fig. 7] Fig. 7 is a diagram schematically illustrating a sample prepared by integral forming.
[Fig. 8] Fig. 8 is a diagram showing a hardness distribution of a sample welded exclusively by keyhole welding in a first example.
[Fig. 9] Fig. 9 is a diagram showing a hardness distribution of a sample welded by keyhole welding and heat conduction welding in a first example.
[Fig. 10] Fig. 10 is a diagram showing a hardness distribution of a sample welded under heat conduction welding conditions different from the evaluation of the hardness distribution shown in Fig. 9.
[Fig. 11] Fig. 11 is a diagram showing a hardness distribution of a sample welded under heat conduction welding conditions different from the evaluations of the hardness distributions shown in Fig. 9 and Fig. 10.
[Fig. 12] Fig. 12 is a diagram showing a hardness distribution of a sample welded under heat conduction welding conditions different from the evaluations of the hardness distributions shown in Fig. 9 to Fig. 11.
[Fig. 13] Fig. 13 is a diagram showing a hardness distribution of a joint welded under heat conduction welding conditions different from the evaluations of the hardness distributions shown in Fig. 9 to Fig. 12.
[Fig. 14] Fig. 14 is a diagram showing a hardness distribution of a joint welded under heat conduction welding conditions different from the evaluations of the hardness distributions shown in Fig. 9 to Fig. 13.
[Fig. 15] Fig. 15 is a diagram showing a hardness distribution of a joint welded under heat conduction welding conditions different from the evaluations of the hardness distributions shown in Fig. 9 to Fig. 14.
[Fig. 16] Fig. 16 is an enlarged photograph of a solidification terminal portion of a welded portion after keyhole welding was performed in a first example.
[Fig. 17] Fig. 17 is a graph of measurements of a recess depth of the solidification terminal portion shown in Fig. 16.
[Fig. 18] Fig. 18 is an enlarged photograph of a solidification terminal portion of a welded portion after heat conduction welding was performed in a first example.
[Fig. 19] Fig. 19 is a graph of measurements of a recess depth of the solidification terminal portion shown in Fig. 18.
[Fig. 20] Fig. 20 is a diagram showing a hardness distribution of a sample welded exclusively by keyhole welding in S10C of a second example.
[Fig. 21] Fig. 21 is a diagram showing a hardness distribution of a sample welded by keyhole welding and heat conduction welding in S10C of a second example.
[Fig. 22] Fig. 22 is a diagram showing a hardness distribution of a sample welded exclusively by keyhole welding in S15C of a second example.
[Fig. 23] Fig. 23 is a diagram showing a hardness distribution of a sample welded by keyhole welding and heat conduction welding in S15C of a second example.
[Fig. 24] Fig. 24 is a diagram showing a hardness distribution of a sample welded exclusively by keyhole welding in S20C of a second example.
[Fig. 25] Fig. 25 is a diagram showing a hardness distribution of a sample welded by keyhole welding and heat conduction welding in S20C of a second example.
[Fig. 26] Fig. 26 is a diagram showing a hardness distribution of a sample welded exclusively by keyhole welding in S25C of a second example.
[Fig. 27] Fig. 27 is a diagram showing a hardness distribution of a sample welded by keyhole welding and heat

conduction welding in S25C of a second example.

[Fig. 28] Fig. 28 is a diagram showing a hardness distribution of a sample welded exclusively by keyhole welding in S35C of a second example.

[Fig. 29] Fig. 29 is a diagram showing a hardness distribution of a sample welded by keyhole welding and heat conduction welding in S35C of a second example.

Description of Embodiments

[0014] An embodiment of a butt-welded joint of steel materials according to the present invention will be described in detail below with reference to Fig. 1 to Fig. 7. As illustrated in Fig. 1 and Fig. 2, in a butt-welded joint 1 of steel materials (hereinafter also referred to simply as a "joint 1"), according to this embodiment, base materials 2, 2 are a pair of identical steel materials formed to have a cylindrical shape, and end portions 2a, 2a of the base materials 2, 2 are coupled to each other by a welded portion 3. Specifically, the welded portion 3 is formed such that end faces 2b, 2b of the end portions 2a, 2a of the base materials 2, 2 are abutted against each other (positioned to face each other) to be in contact with each other, and welding is performed thereon annularly in a manner such that the welded portion 3 extends from surfaces (outer circumferential surfaces) 2c, 2c of the base materials 2, 2 to an inner portion thereof along the end faces 2b, 2b, which are in contact with each other, and straddles the end portions 2a, 2a.

[0015] To be more specific, the welded portion 3 is formed in a manner in which keyhole welding is performed annularly on the end portions 2a, 2a of the base materials 2, 2 from the surfaces (outer circumferential surfaces) 2c, 2c, and thereafter, heat conduction welding is performed annularly from the surface, in an overlapping manner, on the portion on which the keyhole welding has been performed. In this instance, the keyhole welding and heat conduction welding are both performed with radiation of, for example, a beam 7 having a high power density, as illustrated in Fig. 3(a) and Fig. 3(b); here, an instance in which a laser 7 is used will be described. In the keyhole welding, heating (first heating) is performed with a laser 7 having a high power density, and, accordingly, a depression (keyhole) is formed in the end portions 2a, 2a of the base materials 2, 2. The laser 7 travels to an inner portion of the base materials 2, 2 through the depression, and, accordingly, deeper welding can be accomplished. In this instance, the portion melted by the keyhole welding is solidified by subsequent cooling to form a melted and solidified portion 3d, and a hardness thereof is higher than a hardness prior to the welding.

[0016] On the other hand, in the heat conduction welding, a laser 7 having a lower power density than that for the keyhole welding is used. In the heat conduction welding, the surfaces 2c, 2c and their vicinities of the melted and solidified portion 3d in the end portions 2a, 2a are reheated (second heating) and accordingly remelted and resolidified to form a remelted and solidified portion 5, and, concurrently, an inner region relative to the remelted and solidified portion 5 (a region at a greater depth from the surfaces) is modified by the reheating, without involving melting, to form a reheated solidified portion 4. Thus, as a result of the keyhole welding and the heat conduction welding, the welded portion 3 is formed to straddle the end portions 2a, 2a of the base materials 2, 2.

[0017] That is, the welded portion 3 is formed of the melted and solidified portion 3d, the remelted and solidified portion 5, and the reheated solidified portion 4. The melted and solidified portion 3d is a portion formed as a result of melting and solidification of the end portions 2a, 2a of the pair of base materials 2, 2, the melting being caused as a result of first heating (keyhole welding) from the surfaces 2c, 2c. The remelted and solidified portion 5 is a portion resulting from remelting and resolidification of the melted and solidified portion 3d, the remelting being caused as a result of reheating (heat conduction welding) of the melted and solidified portion 3d from the surfaces. The reheated solidified portion 4 is a portion that is formed in an inner region of the base materials 2, 2 relative to the remelted and solidified portion 5 (a region at a greater depth from the surfaces), and which has a structure resulting from a change in a structure of the melted and solidified portion 3d, the change being due to the reheating, the change involving no melting. In this instance, the structure of the reheated solidified portion 4 is a structure modified by tempering the structure of the melted and solidified portion 3d, which has been martensitized by the keyhole welding, by performing the heat conduction welding, and, therefore, a hardness is lower than that of the melted and solidified portion 3d, which results in improved toughness. On the other hand, a structure of the remelted and solidified portion 5 is a structure resulting from the remelting of the melted and solidified portion 3d, which is caused by the heat conduction welding, and the resolidification thereof, which is caused by the subsequent cooling, and, therefore, a hardness is higher than that of the reheated solidified portion 4.

[0018] Note that the melted and solidified portion 3d is deepest at a center in a width direction thereof (which is the location indicated by the dash-dot line of Fig. 2 and which, in this embodiment, substantially coincides with the location where the end faces 2b, 2b of the base materials 2, 2 are in contact with each other). A depth from the surface 3a of the welded portion 3 (i.e., a surface 5a of the remelted and solidified portion 5) to a deepest portion of the melted and solidified portion 3d is d0. Furthermore, the remelted and solidified portion 5 is also deepest at a center in a width direction thereof (which substantially coincides with the center in the width direction of the melted and solidified portion 3d). A depth from the surface 3a of the welded portion 3 (the surface 5a of the remelted and solidified portion 5) to a deepest portion of the remelted and solidified portion 5 is d1, which is smaller than d0. That is, the welded portion 3, the melted and solidified portion 3d, and the remelted and solidified portion 5 are formed such that the centers in the width directions thereof substantially coincide with one another, with symmetries being substantially formed about the centers, in the width direction.

[0019] It is known that a general property of steel materials such as chromium-molybdenum steel and carbon steel for machine structural use is that in a case where a carbon concentration thereof (i.e., a carbon content, specifically, a mass percentage of the carbon present in a base material) is high, a hardness of the steel material is high whereas a toughness thereof is low, and, on the other hand, in a case where the carbon concentration is low, the hardness of the steel material is low whereas the toughness thereof is high. Accordingly, to improve the fatigue strength of the joint 1, in which steel materials are base materials, it is necessary to ensure that the carbon concentration of the steel material is within a specified range so as to prevent an instance in which one of the hardness of the base material and the toughness thereof is low. Hence, herein, a carbon concentration (carbon content) of the base materials 2, 2 as a whole is specified to be 0.1 mass% or greater and 0.35 mass% or less.

[0020] From the results of an experiment, which will be described later, it was observed that in a case where base materials 2, 2 having a carbon concentration as described above are used, a butt-welded joint 1 having a higher rotating bending fatigue strength than that of the base materials 2, 2 can be obtained, provided that a width W0 of the melted and solidified portion 3d, the depth d0 of the melted and solidified portion 3d, a width W1 of the remelted and solidified portion 5, and the depth d1 of the remelted and solidified portion 5 satisfy the relationships of formula (1) and formula (2) below:

$$0.46 \leq \mathrm{W1/W0} \leq 1,05 \quad ...(1)$$

$$0.14\mathrm{d0} \leq \mathrm{d1} \leq 0.73\mathrm{d0} \quad ...(2)$$

[0021] Furthermore, portions of the surface 5a (i.e., the surface 3a of the welded portion 3) of the remelted and solidified portion 5, which is formed by performing keyhole welding and heat conduction welding in an overlapping manner, have residual stress generated therein. The residual stress is a compressive stress in a center region in the width direction of the remelted and solidified portion 5 (i.e., a center region in the width direction of the welded portion 3) and is a tensile stress in a region outside of the center region in the width direction. As a result, cracks are inhibited from forming in the center and its vicinity in the width direction of the welded portion 3, in the surface 5a of the remelted and solidified portion 5.

[0022] Furthermore, in both the keyhole welding and the heat conduction welding, the welding is carried out in a manner such that a starting portion of the weld and a terminal portion thereof (a solidification terminal portion 6, shown in Fig. 16 and Fig. 18), with respect to a circumferential direction, overlap each other at the same location. In the keyhole welding, a recess due to the radiation of the laser 7 is formed in the terminal portion at the completion of the keyhole welding (see Fig. 17). A depth (maximum depth) h of the recess from the surface of the welded portion can be reduced by, in the heat conduction welding, remelting and solidifying the welded portion resulting from the keyhole welding (i.e., the melted and solidified portion 3d), and, consequently, concentration of the stress that acts on the solidification terminal portion 6 can be inhibited. In addition, from the results of an experiment, which will be described later, it is desirable that the depth h of the recess from the surface 3a of the welded portion 3 and the depth d1 of the remelted and solidified portion 5 have the following relationship:

$$0.32\mathrm{d1} \geq \mathrm{h} \quad ...(3)$$

[0023] Note that in the joint 1, the end faces 2b, 2b of the abutted base materials 2, 2 have a circular shape, but the shape is not limited thereto, and it is sufficient that the surfaces 2c, 2c of the abutted base materials 2, 2 are disposed substantially in the same plane; for example, the end faces 2b, 2b of base materials 2, 2 to be abutted against each other may have substantially the same shape and the same size.

EXAMPLES

[0024] Now, first examples of the present invention (test conditions 2 to 7 in Table 1 and Table 2) and second examples thereof (test conditions 10, 12, 14, 16, and 18 in Table 3 and Table 4) will be described in comparison with first comparative examples (test conditions 1 and 8 in Table 1 and Table 2) and second comparative examples (test conditions 9, 11, 13, 15, and 17 in Table 3 and Table 4), respectively. Specimens 8 used in the first and second examples were prepared as follows: as illustrated in Fig. 4 to Fig. 6, a sample 10, which served as the base material 2, in which a hollow cylindrical body portion 9a was integrally formed with a hollow end portion 9b, which was tapered toward a distal end from the body portion 9a, were used; and end portions 9b of a pair of the samples 10 were butt-welded together by keyhole welding and heat conduction welding as described above.

[0025] In the first examples, laser welding conditions for the heat conduction welding were varied to change a size of the remelted and solidified portion 5, and thus, a variety of physical property values of the welded portion 3, which accordingly changed, were measured with the specimens 8 and evaluated. On the other hand, in the second examples, the carbon concentration (carbon content) of the sample 10 was varied, and thus, a variety of physical property values of the welded portion 3, which accordingly changed, were measured with the specimens 8 and evaluated.

[0026] Note that regarding the sample 10 used, a full length thereof was 80 mm, an outside diameter of the body portion 9a was 20 mm, an outside diameter of the distal end face of the end portion 9b was 14 mm, and inside diameters of the body portion 9a and the end portion 9b were 12 mm.

[0027] The sample 10 used in the first examples was made of chromium-molybdenum steel material (SCM415) and contained 0.13 mass% to 0.18 mass% C, 0.15 mass% to 0.35 mass% Si, 0.60 mass% to 0.90 mass% Mn, 0.030 mass% or less P, 0.030 mass% or less S, 0.25 mass% or less Ni, 0.90 mass% to 1.20 mass% Cr, and 0.15 mass% to 0.25 mass% Mo. In the first examples, under the conditions in which a laser output, a welding speed, a focal point diameter (spot diameter) for the keyhole welding were fixed (i.e., the width W0 and the depth d0 of the melted and solidified portion 3d were fixed), the laser output, the welding speed, and the focal point diameter (spot diameter) for the heat conduction welding were varied to change the width W1 and the depth d1 of the remelted and solidified portion 5; accordingly, the residual stress of the surface 3a of the welded portion 3 and its vicinity, an average hardness of the welded portion 3, the recess depth h of the solidification terminal portion 6 of the welded portion 3, and the rotating bending fatigue strength of the prepared specimens 8 were measured.

[0028] In the keyhole welding and the heat conduction welding, a fiber laser welding machine was used. By radiating a laser 7 by using the welding machine, welding of the sample 10, which served as the base material 2, was carried out. The switching between the keyhole welding and the heat conduction welding was carried out by moving a condenser lens of the welding machine in a direction of an axis L of the joint 1, that is, in a direction perpendicular to an abutting direction, thereby changing the focal point diameter of the laser 7, which was radiated onto the abutted portion of the end portions 9b, 9b of the pair of samples 10, 10 (the contact portion of the end faces). In performing the keyhole welding, which required a higher power density, a laser 7 having a narrowed, small focal point diameter was used, as illustrated in Fig. 3(a). On the other hand, in performing the heat conduction welding, in which the power density needed to be reduced compared with that of the laser 7 for the keyhole welding, a laser 7 having a focal point diameter larger than that for the keyhole welding was used, as illustrated in Fig. 3(b).

[0029] Furthermore, the specimens 8 of the first comparative examples (Conditions 1 and Conditions 8) were prepared from a sample that had the same shape and size and was made of the same material (SCM415) as the sample 10 used in the first examples. In this instance, the specimen 8 for Conditions 1 was prepared by butt-welding a pair of the samples 10 together, exclusively by keyhole welding. On the other hand, the specimen 8 for Conditions 8 was prepared by butt-welding a pair of the samples 10 together, under welding conditions in which the width and the depth of the remelted and solidified portion 5 were reduced compared with those of the specimens 8 of the first examples 1, by changing the laser output, the welding speed, and the focal point diameter for the heat conduction welding that was performed after the keyhole welding. In the first comparative example, for the prepares specimens 8, the residual stress of the surface 3a of the welded portion and its vicinity, an average hardness of the welded porton 3, the recess depth of the solidification terminal portion 6 of the welded portion 3. and the rotatin bending fatigue strength were measured. The welding conditions and the measurement results of the first examples and the first comparative examples are shown in Table 1 and Table 2 below.

[Table 1]

	TEST CONDITIONS	CARBON CONTENT OF MATERIAL wt%	WELDING CONDITIONS								SHAPE OF MELTED AND SOLIDIFIED PORTION			
			KEYHOLE WELDING CONDITIONS				REMELTING CONDITIONS				MELTED AND SOLIDIFIED PORTION (mm)		REMELTED AND SOLIDIFIED PORTION (mm)	
			LASER OUTPUT (W)	WELDING SPEED (mm/s)	FOCAL POINT DIAMETER (mm)	SHIELDING GAS	LASER OUTPUT (W)	WELDING SPEED (mm/s)	FOCAL POINT DIAMETER (mm)	SHIELDING GAS	WIDTH W0	DEPTH d0	WIDTH W1	DEPTH d1
COMPARATIVE EXAMPLE	1	SCM415 CO. 15wt%	850	50	0.5	NITROGEN	-	-	-	NITROGEN	1	1	-	-
EXAMPLE	2						850	50	1.5				1.05	0.23
EXAMPLE	3						850	50	22				1.01	0.16
EXAMPLE	4						850	50	0.9				0.95	0.33
EXAMPLE	5						600	50	1.5				0.82	0.15
EXAMPLE	6						400	50	1.5				0. 46	0.14
EXAMPLE	7						600	50	0.4				0.75	0.73
COMPARATIVE EXAMPLE	8						350	200	0.4				0.35	0.08

[Table 2]

	TEST CONDITIONS	PHYSICAL PROPERTIES							EVALUATION
		RESIDUAL STRESS (MPa)			AVERAGE HARDNESS (Hv)		RECESS DEPTH OF SOLIDIFICATION TERMINAL PORTION (mm)	FATIGUE STRENGTH (BASE MATERIAL: 260MPa)	
		A1	A2	A3	POSITION ①	POSITION ②			
COMPARATIVE EXAMPLE	1	135	288	152	461	-	0.14	130	X
EXAMPLE	2	-263	118	93	460	387	0.01	360	○
EXAMPLE	3	-218	240	125	468	372	0.05	350	○
EXAMPLE	4	-282	205	115	443	384	0.06	300	○
EXAMPLE	5	-100	262	120	470	395	0.03	300	○
EXAMPLE	6	-290	293	194	469	399	0.03	290	○
EXAMPLE	7	-188	250	130	469	362	-	210	○
COMPARATIVE EXAMPLE	8	-45	210	144	498	458	0.02	160	X

[0030] As shown in Table 1, in all of Conditions 1 to 8, the welding conditions for the keyhole welding were such that a laser output was 850 W, a welding speed was 50 mm/s, a focal point diameter was 05. mm, and nitrogen was used as s shielding gas for shielding the welding site from air. Accordingly, melted and solidificated portions 3d having a width W0 of 1mm and a depth d0 of 1 mm were formed. Furthermore, regarding Conditions 1 to 8, the welding conditions for the heat conduction welding were adjusted such that a laser output was 350 W to 850 W, a welding speed was 50 mm/s or 200 mm/s, a laser focal point diameter was 0.4 mm to 2.2 mm, and nitrogen was used as a shielding gas. Accordingly, remelted and solidified portions 5 having different widths W1 and depths d1 were formed.

[0031] The residual stress of the welded portion 3 and its vicinity in the surface were measured by using an X-ray stress measurement method in which an X-ray having a specific wavelength was radiated onto a surface of the specimens 8. As illustrated in Fig. 6, under Conditions 1 to Conditions 8, the residual stress was measured at each of three points, namely, a measurement point A1, which was located on the surface 3a of the center in the width direction of the welded portion 3; a measurement point A2, which was located 1.5 mm to the proximal end side (one end side of the specimens 8) of the sample 10 from the measurement point A1; and a measurement point A3, which was located 1 mm further to the proximal end side from the measurement point A2. In this instance, under Conditions 1, the residual stress at the center point in the width direction of the melted and solidified portion 3d was measured at the measurement point A1, and the residual stress at points where the structure had not been changed by the welding was measured at the measurement point A2 and the measurement point A3. Furthermore, under Conditions 2 to Conditions 8, the residual stress at the center point in the width direction of the remelted and solidified portion 5 was measured at the measurement point A1, and the residual stress at points where the structure had not been changed by the welding was measured at the measurement point A2 and the measurement point A3.

[0032] The results demonstrated that under Conditions 2 to 8, the residual stress at the measurement point A1 was a negative value, that is, a compressive stress was present at and near the measurement point A1. Accordingly, under Conditions 2 to Conditions 8, the formation of cracks can be inhibited at and near the measurement point A1 of the remelted and solidified portion 5. Furthermore, under Conditions 2 to Conditions 7, the residual stress at the measurement point A1 was less than or equal to -100 MPa. Under these conditions, as will be described later, the rotating bending fatigue strengths of the specimens 8 were higher than that of a specimen 11 for comparison (i.e., the base material itself), which had the same shape and size as the specimens 8 and were seamlessly integrally formed of the same material (SCM415) as that for the sample 10. On the other hand, it was demonstrated that in the specimen 8 for Conditions 1, the residual stress at the measurement point A1 of the melted and solidified portion 3d was a positive value, and, therefore, a tensile stress was present at and near the measurement point A1. Accordingly, under Conditions 1, the formation of cracks at and near the measurement point A1 cannot be inhibited, and, moreover, the formation and propagation of cracks may be promoted.

[0033] Regarding the hardness of the specimens 8, the Vickers hardness of the base material that included the reheated solidified portion 4 and the remelted and solidified portion 5 of the specimens 8 was measured and evaluated. For the measurement of the Vickers hardness, a typical Vickers' microhardness tester was used. The specimens 8 were cut along the axial direction, and, on the cut surface, the Vickers hardness was measured at an interval of 0.1 mm in a longitudinal direction (the lateral direction in Fig. 8 to Fig. 15) and in a transverse direction (the vertical direction in Fig. 8 to Fig. 15). As shown in Fig. 9 to Fig. 15, the results indicated that under Conditions 2 to Conditions 8, an average Vickers hardness value of the reheated solidified portion 4 was lower than an average Vickers hardness value of the remelted and solidified portion 5.

[0034] As shown in Fig. 8, a measurement of the Vickers hardness associated with Conditions 1 revealed that the numerical value of the Vickers hardness of the melted and solidified portion 3d, which resulted from melting by keyhole welding and solidification, was higher than the numerical values of the Picker's heights of other portions of the joint. Presumably, this is because the structure of the melted and solidified portion 3d had been martensitized by the keyhole welding. Furthermore, at the site of (0.1 mm, 0.7 mm) and the site of (0.2 mm, 0.5 mm), which corresponds to (vertical, lateral), shown in Fig. 8, the Vickers hardness of the joint was 660 Hv, which was a very high numerical value compared with those of the other sites. Presumably, this is because the two sites were located at or near the boundary between the melted portion associated with the keyhole welding and the heat affected zone, which was hardened under the influence of the heating for the keyhole welding, and, therefore, a cooling rate after the keyhole welding was fast, and, consequently, the structure at and near the boundary was martensitized.

[0035] Furthermore, as shown in Fig. 16 to Fig. 19, the recess depth h of the solidification terminal portion 6 of the welded portion 3 is a maximum height difference of a crater (recess), which was formed in a region onto which the laser was finally radiated when the base materials 2, 2 were welded together. The recess depth h of the solidification terminal portion 6 was 0.14 mm under Conditions 1, in which keyhole welding was exclusively performed, whereas the recess depth h was 0.01 mm to 0.06 mm under Conditions 2 to Conditions 8, in which heat conduction welding was performed after keyhole welding. Furthermore, under Conditions 2 to Conditions 8, the recess depth h of the solidification terminal portion 6 of the remelted and solidified portion 5 and the depth d1 of the remelted and solidified portion 5 had the relationship of formula (3) mentioned above.

[0036] Hence, by performing heat conduction welding after keyhole welding, the recess depth h of the solidification terminal portion 6 can be reduced, and as a result, concentration of the stress that acts on the solidification terminal portion 6 can be inhibited.

[0037] Regarding a rotating bending fatigue test (ISO 1143:2010) for measuring the rotating bending fatigue strength, an ONO-type rotating-bending fatigue tester of the four-point loading type was used. In the tester, both ends of the specimen were held by the distal ends of a pair of spindles, and the load at which breakage occurred (i.e., a maximum value of the cyclic stresses that acted on a center portion (welded portion 3) in the axial direction of the specimen 8) in a case where rotation was performed 20 million times at a rotational speed of 2000 rpm was measured. Furthermore, to evaluate the measured rotating bending fatigue strength of the specimens 8, the rotating bending fatigue strength of the above-mentioned specimen 11 for comparison was measured in a similar manner. The result was that under Conditions 1, the rotating bending fatigue strength of the specimen 8 was a value lower than that of the rotating bending fatigue strength of the specimen 11 for comparison. Presumably, this is because in a case where keyhole welding was exclusively performed, the structure of the welded portion was martensitized and, consequently, had a fragile construction.

[0038] Furthermore, in the cases of Conditions 2 to Conditions 7, that is, in the cases where the width W0 of the melted and solidified portion 3d, the depth d0 of the melted and solidified portion 3d, the width W1 of the remelted and solidified portion 5, and the depth d1 of the remelted and solidified portion 5 simultaneously satisfied the relationships of formula (1) and formula (2) mentioned above, the rotating bending fatigue strengths of all the specimens 8 were higher than the rotating bending fatigue strength of the specimen 11 for comparison (that is, the rotating bending fatigue strength of the base material itself (base material strength). Presumably, this is because as a result of performing heat conduction welding in an overlapping manner on the portion on which keyhole welding had been performed, the reheated solidified portion 4, which was formed in an inner region relative to the remelted and solidified portion 5 in the welded portion 3 (a region at a deeper location with respect to the surface 3a), had a low hardness and, therefore, had a high toughness compared with the remelted and solidified portion 5, which was formed in a region closer to the surface 3a of the welded portion 3, and, consequently, even if cracks had been formed in the surface 3a of the welded portion 3, the cracks would not have easily propagated to an inner portion. On the other hand, under Conditions 8, the rotating bending fatigue strength of specimen 8 was a value lower than that of the rotating bending fatigue strength of the specimen 11 for comparison. Presumably, this is because the energy density of the laser in performing the heat conduction welding was lower than those for the other conditions, and, consequently, the reheated solidified portion 4 was not formed deeply into an inner portion of the welded portion.

[0039] From the measurement results described above, it was determined that under Conditions 2 to Conditions 7, the fatigue strength was improved, because the rotating bending fatigue strengths of the specimens 8, which were prepared by butt-welding together the samples 10, 10, which served as the base materials 2, 2, were higher than the rotating bending fatigue strength of the specimen 11 for comparison (base material itself), which was integrally formed of a single base material. Furthermore, it was determined that under Conditions 1 and Conditions 8, the fatigue strength was not improved, because the rotating bending fatigue strengths of the specimens 8, which were formed by butt-welding together the pair of samples 10, 10, were lower than the rotating bending fatigue strength of the specimen 11 for comparison.

[0040] Now, the second examples of the present invention will be described in comparison with the second comparative examples. In the second examples, a sample 10, which served as the base material 2, was formed from carbon steel for machine structural use, and specimens 12, which were obtained by butt-welding a pair of the samples 10, 10 together by keyhole welding and heat conduction welding, were used. In this instance, the sample 10 used had the same shape and size as that used in the first examples. Furthermore, as the carbon steel for machine structural use that formed the sample 10, S10C, S15C, S20C, S25C, and S35C were used. The S10C contained 0.15 mass% to 0.35 mass% Si, 0.30 mass% to 0.60 mass% Mn, 0.030 mass% or less P, 0.035 mass% or less S, and 0.08 mass% to 0.13 mass% C. The S15C contained the same mass percentages of Si, Mn, P, and S as the S10C and 0.13 mass% to 0.18 mass% C. The S20C contained the same mass percentages of Si, Mn, P, and S as the S10C and 0.18 mass% to 0.23 mass% C. The S25C contained the same mass percentages of Si, Mn, P, and S as the S10C and 0.22 mass% to 0.28 mass% C. The S35C contained the same mass percentages of Si, P, and S as the S10C, 0.60 mass% to 0.90 mass% Mn, and 0.32 mass% to 0.38 mass% C.

[0041] On the other hand, specimens 12 of the second comparative examples were prepared by butt-welding together, exclusively by keyhole welding, a pair of samples 10, 10, which had the same shape and size as the sample 10 used for each of the welding conditions of the second examples and were made of the same carbon steel for machine structural use. For each of the specimens 12 of the second examples and each of the specimens 12 of the second comparative examples, the residual stress of the surface 3a of the welded portion 3 and its vicinity, the average hardness of the welded portion 3, the recess depth h of the solidification terminal portion of the welded portion 3, and the rotating bending fatigue strength were measured and evaluated. The welding conditions and the measurement results of the second examples and the second comparative examples are shown in Table 3 and Table 4 below. Note that regarding S45C, which contained the same mass percentages of Si, Mn, P, and S as the S35C and 0.42 mass% to 0.48 mass% C, cracks were formed in the welded portion at a stage when the melted portion resulting from the keyhole welding was solidified, and thus a tendency for cracking was exhibited; therefore, it was determined at this stage that the fatigue strength was evidently low, and, accordingly, the variety of measurements and associated evaluations were not conducted.

[Table 3]

	TEST CONDITIONS	CARBON CONTENT OF MATERIAL wt%	WELDING CONDITIONS								SHAPE OF MELTED AND SOLIDIFIED PORTION			
			KEYHOLE WELDING CONDITIONS				REMELTING CONDITIONS				MELTED AND SOLIDIFIED PORTION (mm)		REMELTED AND SOLIDIFIED PORTION (mm)	
			LASER OUTPUT (W)	WELDING SPEED (mm/s)	FOCAL POINT DIAMETER (mm)	SHIELDING GAS	LASER OUTPUT (W)	WELDING SPEED (mm/s)	FOCAL POINT DIAMETER (mm)	SHIELDING GAS	WIDTH W0	DEPTH d0	WIDTH W1	DEPTH d1
COMPARATIVE EXAMPLE	9	S10C C0.1wt%	850	50	0. 5	NITROGEN	-	-	-	NITROGEN	1	1	-	-
EXAMPLE	10						850	50	1.5				1.05	0.23
COMPARATIVE EXAMPLE	11	S15C CO. I 5wt%					-	-	-				-	-
EXAMPLE	12						850	50	1.5				1.05	0.23
COMPARATIVE EXAMPLE	13	S20C CO. 20wt%					-	-	-				-	-
EXAMPLE	14						850	50	1.5				1.05	0.23
COMPARATIVE EXAMPLE	15	S25C CO. 25wt%					-	-	<				-	-
EXAMPLE	16						850	50	1.5				1.05	0.23
COMPARATIVE EXAMPLE	17	S35C CO. 35wt%					-	-	-				-	-
EXAMPLE	18						850	50	1.5				1.05	0.23

[Table 4]

	TEST CONDITIONS	PHYSICAL PROPERTIES							EVALUATION	BASE MATERIAL STRENGTH (MPa)
		RESIDUAL STRESS (MPa)			AVERAGE HARDNESS (Hv)		RECESS DEPTH OF SOLIDIFICATION TERMINAL PORTION (mm)	FATIGUE STRENGTH (MPa)		
		A1	A2	A3	POSITION ①	POSITION ②				
COMPARATIVE EXAMPLE	9	-179	139	107	379	-	0.1	240	○	200
EXAMPLE	10	-209	110	95	393	353	0.05	260	○	
COMPARATIVE EXAMPLE	11	-44	237	159	460	-	0.1	170	X	230
EXAMPLE	12	-363	211	140	455	360	0.05	260	○	
COMPARATIVE EXAMPLE	13	-20	213	139	463	-	0.1	180	X	260
EXAMPLE	14	-322	225	130	435	365	0.05	330	○	
COMPARATIVE EXAMPLE	15	-44	258	151	543	-	0.1	290	○	270
EXAMPLE	16	-328	274	149	560	415	0.05	310	○	
COMPARATIVE EXAMPLE	17	-189	213	95	671	-	0.1	370	○	330
EXAMPLE	18	-165	277	134	660	453	0.05	400	○	

[0042] The residual stress of the surface 3a of the welded portion 3 was measured by using a measurement method similar to that for the first examples. In this instance, under Conditions 9, Conditions 11, Conditions 13, Conditions 15, and Conditions 17, which are for the comparative examples, the residual stress at the center point in the width direction of the melted and solidified portion 3d was measured at the measurement point A1, and the residual stress at points where the structure had not been changed by the welding was measured at the measurement point A2 and the measurement point A3. Furthermore, under Conditions 10, Conditions 12, Conditions 14, Conditions 16, and Conditions 18, which are for the examples, the residual stress at the center point in the width direction of the remelted and solidified portion 5 was measured at the measurement point A1, and the residual stress at points where the structure had not been changed by the welding was measured at the measurement point A2 and the measurement point A3.

[0043] The results demonstrated that under all of Conditions 9 to 18, the residual stresses at the measurement point A1 were negative values, that is, a compressive stress was present at and near the measurement point A1. Furthermore, the residual stresses at the measurement point A1 of the specimens 12 under Conditions 10, Conditions 12, Conditions 14, and Conditions 16, that is, the residual stresses at the measurement point A1 of the specimens 12 resulting from the heat conduction welding, which was performed after the keyhole welding, were negative values smaller than the residual stresses at the measurement point A1 of the specimens 12 under Conditions 9, Conditions 11, Conditions 13, and Conditions 15, respectively, that is, the residual stresses at the measurement point A1 of the specimens 12 resulting from the keyhole welding exclusively performed. Accordingly, under Conditions 10, Conditions 12, Conditions 14, and Conditions 16, in which heat conduction welding was performed after keyhole welding, the formation of cracks at and near the measurement point A1 can be inhibited to a further degree than under Conditions 9, Conditions 11, Conditions 13, and Conditions 15, in which keyhole welding was exclusively performed.

[0044] Note that in the cases of Conditions 17 and Conditions 18, that is, in the case where the specimen 12 was formed of S35C, the residual stress at the measurement point A1 in the example (Conditions 18), in which heat conduction welding was performed after keyhole welding, was a negative value slightly greater than the residual stress at the measurement point A1 in the comparative example (Conditions 17), in which keyhole welding was exclusively performed. However, considering the fact that the value was a negative value smaller than those of Conditions 13, Conditions 15, and Conditions 17, which are other comparative examples, inhibition of the formation of cracks at and near the measurement point A1 can also be expected for the example of Conditions 18, in which S35C was used, as with the other examples in which S10C to S25C were used.

[0045] Regarding the hardness of the joint 1 under Conditions 9 to Conditions 18, the Vickers hardness of the base material that included the reheated solidified portion 4 and the remelted and solidified portion 5 of the specimen 12 was measured and evaluated in a manner similar to that for Conditions 1 to Conditions 8 of the first examples. As shown in Fig. 21, Fig. 23, Fig. 25, Fig. 27, and Fig. 29, the results were that under Conditions 10, Conditions 12, Conditions 14, Conditions 16, and Conditions 18, an average Vickers hardness value of the reheated solidified portion 4 was lower than an average Vickers hardness value of the remelted and solidified portion 5. Furthermore, as shown in Fig. 20, Fig. 22, Fig. 24, Fig. 26, and Fig. 28, under Conditions 9, Conditions 11, Conditions 13, Conditions 15, and Conditions 17, the Vickers hardness of the melted and solidified portion 3d was a numerical value higher than that of other portions of the joint that had not been melted by the keyhole welding.

[0046] As shown in Fig. 27, under Conditions 16, at the site of (0.3 mm, 0.4 mm), which corresponds to (vertical, lateral), the hardness was 726 Hv, and at the site of (0.3 mm, 0.5 mm), the hardness was 655 Hv; the numerical values were very high compared with those of the other sites. Presumably, a reason that the Vickers hardness was high at the above-mentioned two sites is similar to a reason that a site having a high hardness was formed under Conditions 1. That is, presumably, this is because these two sites were located at or near the boundary between the melted portion associated with the keyhole welding and the heat affected zone, which was hardened under the influence of the heating for the keyhole welding, and, consequently, the structure at and near the boundary was martensitized.

[0047] Furthermore, the recess depth h of the solidification terminal portion 6 of the welded portion 3 was 0.1 mm under Conditions 9, Conditions 11, Conditions 13, Conditions 15, and Conditions 17, in which keyhole welding was exclusively performed, whereas the recess depth h was 0.01 mm to 0.06 mm under Conditions 10, Conditions 12, Conditions 14, Conditions 16, and Conditions 18, in which heat conduction welding was performed after keyhole welding. Furthermore, the numerical values of the recess depth h of the solidification terminal portion 6 of the remelted and solidified portion 5 and the depth d1 of the remelted and solidified portion 5 were 0.05 mm for h and 0.23 mm for d1 under all of Conditions 10, Conditions 12, Conditions 14, Conditions 16, and Conditions 18. Accordingly, the recess depth h of the solidification terminal portion 6 of the remelted and solidified portion 5 and the depth d1 of the remelted and solidified portion 5 had the relationship of formula (3) mentioned above. Hence, regarding the second examples, too, by performing heat conduction welding after keyhole welding, the recess depth h of the solidification terminal portion 6 can be reduced, and as a result, concentration of the stress that acts on the solidification terminal portion 6 can be inhibited.

[0048] Regarding the rotating bending fatigue strength, specimens 12 formed of the respective materials, S10C to S35C, were prepared, and, in a manner similar to that for the first examples, the specimens 12 were mounted to the

ONO-type rotating-bending fatigue tester, and the load at which breakage occurred (i.e., a maximum value of the cyclic stresses that acted on a center portion (welded portion 3) in the axial direction of the specimen 12) in a case where rotation was performed 20 million times at a rotational speed of 2000 rpm was measured. Furthermore, to evaluate the measured rotating bending fatigue strength of the specimens 12, the rotating bending fatigue test was similarly conducted on each of specimens 13 for comparison, which had the same shape and size as the specimens 12 and were seamlessly integrally formed of the respective materials, S10C to S35C, and thus, the rotating bending fatigue strength of the base material itself (base material strength) was measured.

[0049] The results were that in all of the specimens 12 of Conditions 10, Conditions 12, Conditions 14, Conditions 16, and Conditions 18, the width W0 of the melted and solidified portion 3d, the depth d0 of the melted and solidified portion 3d, the width W1 of the remelted and solidified portion 5, and the depth d1 of the remelted and solidified portion 5 satisfied the relationships of formula (1) and formula (2) mentioned above, and thus, rotating bending fatigue strengths that were higher than those of the integrally formed samples 13 (i.e., the base material itself) were achieved. Presumably, this is because, as with the specimens 8 of the first examples, in the specimens 12 of the second examples, the reheated solidified portion 4, which was formed in an inner region relative to the remelted and solidified portion 5 in the welded portion 3, had a low hardness and, therefore, had a high toughness compared with the remelted and solidified portion 5, which was formed in a region closer to the surface 3a of the welded portion 3, and, consequently, even if cracks had been formed in the surface 3a of the welded portion 3, the cracks would not have easily propagated to an inner portion.

[0050] From the measurement results described above, it was determined that under Conditions 10, Conditions 12, Conditions 14, Conditions 16, and Conditions 18, which were for the second examples, the fatigue strength was improved for all of the steel materials having a carbon concentration (carbon content) in a range of 0.1 mass% to 0.35 mass%, because the rotating bending fatigue strengths of the specimens 12, which were prepared by butt-welding together the samples 10, 10, which served as the base materials 2, 2, were higher than the rotating bending fatigue strength of the specimen 13 for comparison (base material itself), which was integrally formed of a single base material. On the other hand, under Conditions 9, Conditions 15, and Conditions 17, which were for the second comparative examples, the rotating bending fatigue strengths of the specimens 12 were higher than the rotating bending fatigue strengths of specimen 13 for comparison, and, therefore, it can be determined that the fatigue strength was improved; however, in the cases of Conditions 11 and Conditions 13, the rotating bending fatigue strengths of the specimens 12 were lower than that of the specimen 13 for comparison, and, therefore, it cannot be said that the fatigue strength was improved. Accordingly, regarding the specimens 12 obtained by exclusive keyhole welding, it cannot necessarily be said that the fatigue strength was improved for all of the steel materials having a carbon concentration (carbon content) in a range of 0.1 mass% to 0.35 mass%.

Reference Signs List

[0051]

1	Butt-welded joint
2	Base material
3	Welded portion
3d	Melted and solidified portion
4	Reheated solidified portion
5	Remelted and solidified portion
6	Solidification terminal portion
8, 12	Specimen
10	Sample
11, 13	Specimen for comparison

Claims

1. A butt-welded joint of steel materials, base materials of the butt-welded joint being a pair of the steel materials, with end portions of the steel materials being abutted against each other, the butt-welded joint comprising a welded portion formed to extend from surfaces of the base materials to an inner portion of the base materials and straddle the end portions, wherein

    the base materials have a carbon concentration of 0.1 mass% or greater and 0.35 mass% or less,
    the welded portion includes a melted and solidified portion and a remelted and solidified portion, the melted and solidified portion being a portion resulting from melting and solidification of the end portions of the pair of

base materials, the melting being caused as a result of first heating from the surfaces, the remelted and solidified portion being a portion resulting from remelting and resolidification of the melted and solidified portion, the remelting being caused as a result of reheating of the melted and solidified portion from a surface thereof,
wherein the welded portion also includes a reheated solidified portion, the reheated solidified portion being a portion formed in an inner region relative to the remelted and solidified portion and having a structure resulting from a change in a structure of the melted and solidified portion, the change being due to the reheating, the change involving no melting, and
being **characterised in that**:
a width W0 of the melted and solidified portion, a depth d0 from a surface of the welded portion to a deepest portion of the melted and solidified portion, a width W1 of the remelted and solidified portion, and a depth d1 from the surface of the welded portion to a deepest portion of the remelted and solidified portion have the following relationships.

$$0.46 \leq W1/W0 \leq 1{,}05$$

$$0.14d0 \leq d1 \leq 0.73d0$$

2. The butt-welded joint of steel materials according to Claim 1, wherein an average Vickers hardness value of the reheated solidified portion is lower than an average Vickers hardness value of the remelted and solidified portion.

3. The butt-welded joint of steel materials according to Claim 1, wherein a residual stress of a surface of the remelted and solidified portion is a compressive stress in a center region in a width direction of the remelted and solidified portion.

4. The butt-welded joint of steel materials according to Claim 1, wherein, at a terminal portion in a circumferential direction of the welded portion, a depth h, from the surface of the welded portion, of a recess formed in the remelted and solidified portion and the depth d1 of the remelted and solidified portion have the following relationship.

$$0.32d1 \geq h$$

5. The butt-welded joint of steel materials according to Claim 1, wherein the melted and solidified portion is formed as a result of keyhole welding, and the remelted and solidified portion and the reheated solidified portion are formed as a result of heat conduction welding.

6. A method for manufacturing a butt-welded joint of steel materials, the method comprising abutting end portions of a pair of base materials made of the steel materials against each other and forming a welded portion in a manner such that the welded portion extends from surfaces of the base materials to an inner portion of the base materials and straddles the end portions, wherein

the base materials have a carbon concentration of 0.1 mass% or greater and 0.35 mass% or less,
characterised in that:

the welded portion is formed by a first step and a second step, the first step including forming a melted and solidified portion by melting and solidifying the end portions of the pair of base materials, the melting being caused by first heating from the surfaces, the second step including forming a remelted and solidified portion and a reheated solidified portion by reheating the melted and solidified portion from a surface thereof, the remelted and solidified portion being formed by remelting and resolidification of the melted and solidified portion, the reheated solidified portion being formed in an inner region relative to the remelted and solidified portion, with a structure of the reheated solidified portion resulting from a change in a structure of the melted and solidified portion, the change involving no melting,
such that a width W0 of the melted and solidified portion, a depth d0 from a surface of the welded portion to a deepest portion of the melted and solidified portion, a width W1 of the remelted and solidified portion, and a depth d1 from the surface of the welded portion to a deepest portion of the remelted and solidified portion have the following relationships.

$$0.46 \leq W1/W0 \leq 1{,}05$$

$$0.14d0 \leq d1 \leq 0.73d0$$

7. The method for manufacturing a butt-welded joint according to Claim 6, wherein, in the first step, the melted and solidified portion is formed by keyhole welding, and in the second step, the remelted and solidified portion and reheated solidified portion are formed by heat conduction welding.

Patentansprüche

1. Stumpfschweißverbindung aus Stahlwerkstoffen, wobei die Grundwerkstoffe der Stumpfschweißverbindung ein Paar der Stahlwerkstoffe sind, wobei Endabschnitte der Stahlwerkstoffe aneinanderstoßen, wobei die Stumpfschweißverbindung einen Schweißabschnitt umfasst, der so ausgebildet ist, dass er sich von Oberflächen der Grundwerkstoffe zu einem inneren Abschnitt der Grundwerkstoffe erstreckt und die Endabschnitte überspannt, wobei

   die Basismaterialien eine Kohlenstoffkonzentration von 0,1 Massenprozent oder mehr und 0,35 Massenprozent oder weniger aufweisen,
   der geschweißte Abschnitt einen geschmolzenen und verfestigten Abschnitt und einen umgeschmolzenen und verfestigten Abschnitt umfasst, wobei der geschmolzene und verfestigte Abschnitt ein Abschnitt ist, der aus dem Schmelzen und Verfestigen der Endabschnitte des Paars von Basismaterialien resultiert, wobei das Schmelzen als Ergebnis einer ersten Erwärmung von den Oberflächen her verursacht wird, wobei der umgeschmolzene und verfestigte Abschnitt ein Abschnitt ist, der aus dem Umschmelzen und Wiederverfestigen des geschmolzenen und verfestigten Abschnitts resultiert, wobei das Umschmelzen als Ergebnis einer Wiedererwärmung des geschmolzenen und verfestigten Abschnitts von seiner Oberfläche her verursacht wird,
   wobei der geschweißte Abschnitt auch einen wiedererwärmten verfestigten Abschnitt aufweist, wobei der wiedererwärmte verfestigte Abschnitt ein Abschnitt ist, der in einem inneren Bereich relativ zu dem umgeschmolzenen und verfestigten Abschnitt ausgebildet ist und eine Struktur aufweist, die aus einer Änderung in einer Struktur des geschmolzenen und verfestigten Abschnitts resultiert, wobei die Änderung auf das Wiedererwärmen zurückzuführen ist, wobei die Änderung kein Schmelzen beinhaltet, und
   dadurch gekennzeichnet, dass eine Breite W0 des geschmolzenen und verfestigten Abschnitts, eine Tiefe d0 von einer Oberfläche des geschweißten Abschnitts zu einem tiefsten Abschnitt des geschmolzenen und verfestigten Abschnitts, eine Breite W1 des umgeschmolzenen und verfestigten Abschnitts und eine Tiefe d1 von der Oberfläche des geschweißten Abschnitts zu einem tiefsten Abschnitt des umgeschmolzenen und verfestigten Abschnitts die folgenden Beziehungen aufweisen:

$$0{,}46 \leq W1/W0 \leq 1{,}05$$

$$0{,}14d0 \leq d1 \leq 0{,}73d0$$

2. Stumpfschweißverbindung aus Stahlwerkstoffen nach Anspruch 1, wobei ein durchschnittlicher Vickers-Härtewert des wiedererwärmten verfestigten Abschnitts niedriger ist als ein durchschnittlicher Vickers-Härtewert des umgeschmolzenen und verfestigten Abschnitts.

3. Stumpfschweißverbindung aus Stahlwerkstoffen nach Anspruch 1, wobei eine Restspannung einer Oberfläche des umgeschmolzenen und verfestigten Abschnitts eine Druckspannung in einem mittleren Bereich in Breitenrichtung des umgeschmolzenen und verfestigten Abschnitts ist.

4. Stumpfschweißverbindung aus Stahlwerkstoffen nach Anspruch 1, wobei an einem Endabschnitt in Umfangsrichtung des geschweißten Abschnitts die Tiefe h einer in dem umgeschmolzenen und verfestigten Abschnitt ausgebildeten Vertiefung von der Oberfläche des geschweißten Abschnitts und die Tiefe d1 des umgeschmolzenen und verfestigten Abschnitts die folgende Beziehung aufweisen:

$$0{,}32d1 \geq h$$

5. Stumpfschweißverbindung aus Stahlwerkstoffen nach Anspruch 1, wobei der aufgeschmolzene und verfestigte Abschnitt durch Schlüssellochschweißen und der umgeschmolzene und verfestigte Abschnitt und der wiedererwärmte verfestigte Abschnitt durch Wärmeleitungsschweißen gebildet werden.

6. Verfahren zur Herstellung einer stumpfgeschweißten Verbindung von Stahlwerkstoffen, wobei das Verfahren das Aneinanderstoßen von Endabschnitten eines Paares von Basismaterialien, die aus den Stahlmaterialien hergestellt sind, und das Bilden eines geschweißten Abschnitts in einer solchen Weise umfasst, dass sich der geschweißte Abschnitt von Oberflächen der Basismaterialien zu einem inneren Abschnitt der Basismaterialien erstreckt und die Endabschnitte überspannt, wobei

die Basismaterialien eine Kohlenstoffkonzentration von 0,1 Massenprozent oder mehr und 0,35 Massenprozent oder weniger aufweisen,
dadurch gekennzeichnet, dass der geschweißte Abschnitt durch einen ersten Schritt und einen zweiten Schritt gebildet wird, wobei der erste Schritt das Bilden eines geschmolzenen und verfestigten Abschnitts durch Schmelzen und Verfestigen der Endabschnitte des Paars von Basismaterialien umfasst, wobei das Schmelzen durch ein erstes Erhitzen von den Oberflächen her verursacht wird,
dass der zweite Schritt das Bilden eines umgeschmolzenen und verfestigten Abschnitts und eines wiedererwärmten verfestigten Abschnitts durch Wiedererwärmen des geschmolzenen und verfestigten Abschnitts von einer Oberfläche davon umfasst, wobei der umgeschmolzene und verfestigte Abschnitt durch Umschmelzen und Wiederverfestigen des geschmolzenen und verfestigten Abschnitts gebildet wird, wobei der wiedererwärmte verfestigte Abschnitt in einem inneren Bereich relativ zu dem umgeschmolzenen und verfestigten Abschnitt gebildet wird, wobei eine Struktur des wiedererwärmten verfestigten Abschnitts aus einer Änderung in einer Struktur des geschmolzenen und verfestigten Abschnitts resultiert, wobei die Änderung kein Schmelzen beinhaltet,
so dass eine Breite W0 des geschmolzenen und verfestigten Abschnitts, eine Tiefe d0 von einer Oberfläche des geschweißten Abschnitts zu einem tiefsten Abschnitt des geschmolzenen und verfestigten Abschnitts, eine Breite W1 des umgeschmolzenen und verfestigten Abschnitts und eine Tiefe d1 von der Oberfläche des geschweißten Abschnitts zu einem tiefsten Abschnitt des umgeschmolzenen und verfestigten Abschnitts die folgenden Beziehungen aufweisen:

$$0{,}46 \leq W1/W0 \leq 1{,}05$$

$$0{,}14d0 \leq d1 \leq 0{,}73d0$$

7. Verfahren zur Herstellung einer Stumpfschweißverbindung nach Anspruch 6, wobei im ersten Schritt der aufgeschmolzene und verfestigte Abschnitt durch Schlüssellochschweißen und im zweiten Schritt der umgeschmolzene und verfestigte Abschnitt und der wiedererwärmte verfestigte Abschnitt durch Wärmeleitungsschweißen hergestellt werden.

Revendications

1. Joint soudé bout à bout de matériaux en acier, les matériaux de base du joint soudé bout à bout étant une paire de matériaux en acier, avec des portions d'extrémité des matériaux en acier mises en butée les unes contre les autres, le joint soudé bout à bout comprenant une portion soudée formée de manière à s'étendre à partir de surfaces des matériaux de base vers une portion intérieure des matériaux de base et à chevaucher les portions d'extrémité, dans lequel

les matériaux de base présentent une concentration en carbone de 0,1% en masse ou supérieure et de 0,35% en masse ou inférieure,
la portion soudée inclut une portion fondue et solidifiée et une portion refondue et solidifiée, la portion fondue et solidifiée étant une portion résultant d'une fusion et d'une solidification des portions d'extrémité de la paire de matériaux de base, la fusion résultant d'un premier chauffage à partir des surfaces, la portion refondue et

solidifiée étant une portion résultant d'une refusion et d'une solidification de la portion fondue et solidifiée, la refusion résultant d'un réchauffage de la portion fondue et solidifiée à partir d'une surface de celle-ci,
dans lequel la portion soudée inclut également une portion réchauffée solidifiée, la portion réchauffée solidifiée étant une portion formée dans une région intérieure par rapport à la portion refondue et solidifiée et présentant une structure résultant d'une modification d'une structure de la portion fondue et solidifiée, la modification étant due au réchauffage, la modification n'impliquant pas de fusion, et
caractérisé en ce que :
une largeur W0 de la portion fondue et solidifiée, une profondeur d0 à partir d'une surface de la portion soudée jusqu'à une portion la plus profonde de la portion fondue et solidifiée, une largeur W1 de la portion refondue et solidifiée, et une profondeur d1 à partir de la surface de la portion soudée jusqu'à une portion la plus profonde de la portion refondue et solidifiée présentent les relations suivantes :

$$0{,}46 \leq W1/W0 \leq 1{,}05$$

$$0{,}14d0 \leq d1 \leq 0{,}73d0$$

2. Joint soudé bout à bout de matériaux en acier selon la revendication 1, dans lequel une valeur de dureté Vickers moyenne de la portion réchauffée solidifiée est inférieure à une valeur de dureté Vickers moyenne de la portion refondue et solidifiée.

3. Joint soudé bout à bout de matériaux en acier selon la revendication 1, dans lequel une contrainte résiduelle d'une surface de la portion refondue et solidifiée est une contrainte de compression dans une région centrale dans une direction de largeur de la portion refondue et solidifiée.

4. Joint soudé bout à bout de matériaux en acier selon la revendication 1, dans lequel, au niveau d'une portion terminale dans une direction circonférentielle de la portion soudée, une profondeur h à partir de la surface de la portion soudée, d'une cavité formée dans la portion refondue et solidifiée et la profondeur d1 de la portion refondue et solidifiée présentent la relation suivante :

$$0{,}32d1 \geq h$$

5. Joint soudé bout à bout de matériaux en acier selon la revendication 1, dans lequel la portion fondue et solidifiée résulte d'un soudage keyhole, et la portion refondue et solidifiée et la portion réchauffée solidifiée résultent d'un soudage par conduction thermique.

6. Procédé de fabrication d'un joint soudé bout à bout de matériaux en acier, le procédé comprenant la mise en butée de portions d'extrémité d'une paire de matériaux de base constitués de matériaux en acier les unes contre les autres et la formation d'une portion soudée de telle façon que la portion soudée s'étend à partir de surfaces des matériaux de base vers une portion intérieure des matériaux de base et chevauche les portions d'extrémité, dans lequel

les matériaux de base présentent une concentration en carbone de 0,1% en masse ou supérieure et de 0,35% en masse ou inférieure,
caractérisé en ce que :

la portion soudée est formée par une première étape et une deuxième étape, la première étape incluant la formation d'une portion fondue et solidifiée par fusion et solidification des portions d'extrémité de la paire de matériaux de base, la fusion étant causée par un premier chauffage à partir des surfaces,
la deuxième étape incluant la formation d'une portion refondue et solidifiée et d'une portion réchauffée solidifiée par réchauffage de la portion fondue et solidifiée à partir d'une surface de celle-ci, la portion refondue et solidifiée étant formée par refusion et re-solidification de la portion fondue et solidifiée, la portion réchauffée solidifiée étant formée dans une région intérieure par rapport à la portion refondue et solidifiée, avec une structure de la portion réchauffée solidifiée résultant d'une modification d'une structure de la portion fondue et solidifiée, la modification étant due au réchauffage, la modification n'impliquant pas de fusion,
de telle façon qu'une largeur W0 de la portion fondue et solidifiée, une profondeur d0 à partir d'une surface

de la portion soudée jusqu'à une portion la plus profonde de la portion fondue et solidifiée, une largeur W1 de la portion refondue et solidifiée, et une profondeur d1 à partir de la surface de la portion soudée jusqu'à une portion la plus profonde de la portion refondue et solidifiée présentent les relations suivantes :

$$0,46 \leq W1/W0 \leq 1,05$$

$$0,14d0 \leq d1 \leq 0,73d0$$

7. Procédé de fabrication d'un joint soudé bout à bout selon la revendication 6, dans lequel, dans la première étape, la portion fondue et solidifiée est formée par soudage keyhole, et dans la deuxième étape, la portion refondue et solidifiée et la portion réchauffée solidifiée sont formées par soudage par conduction thermique.

FIG. 1

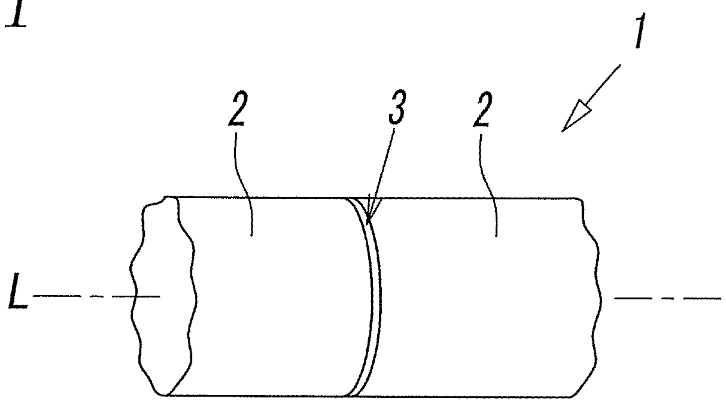
1
2
3
2
L

FIG. 2

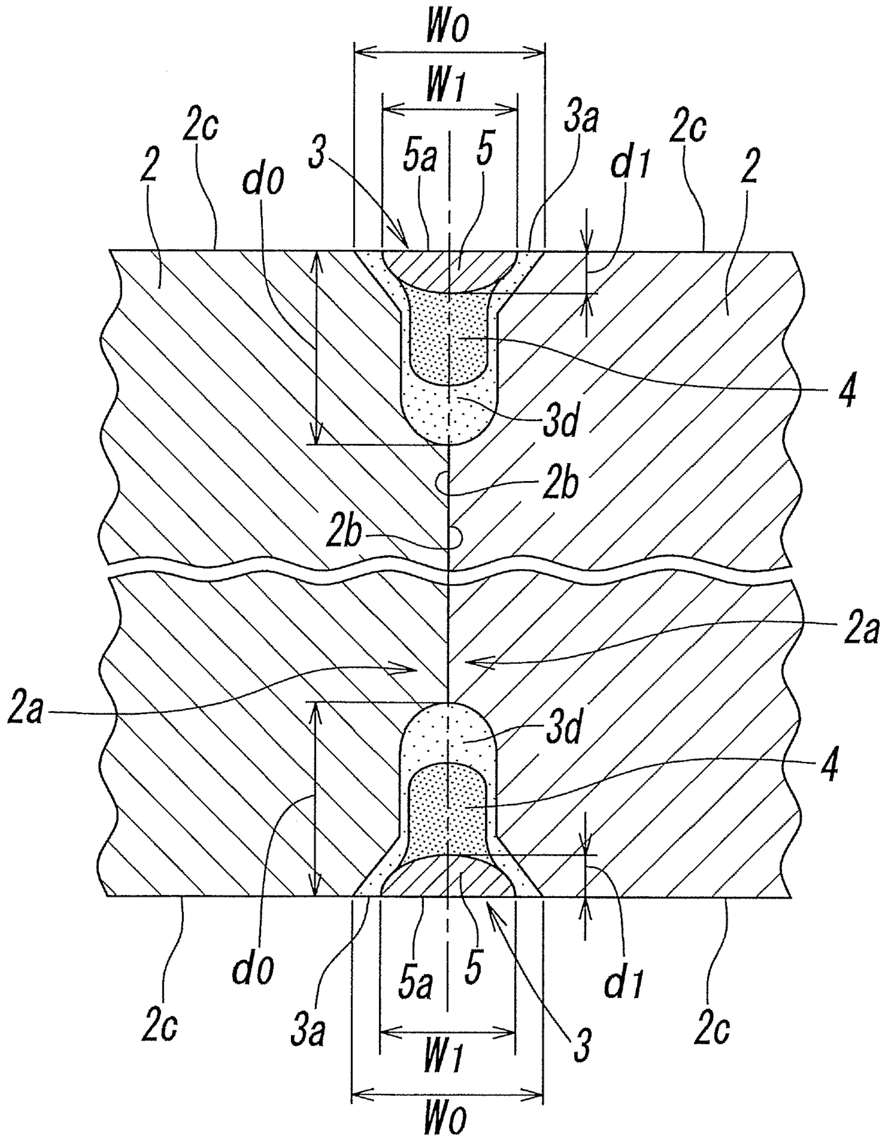
Wo
W1
3a
2c
2c
2
2
3
5a
5
d0
d1
4
3d
2b
2b
2a
2a
3d
4
d0
d1
5a
5
2c
3a
3
2c
W1
Wo

FIG. 3

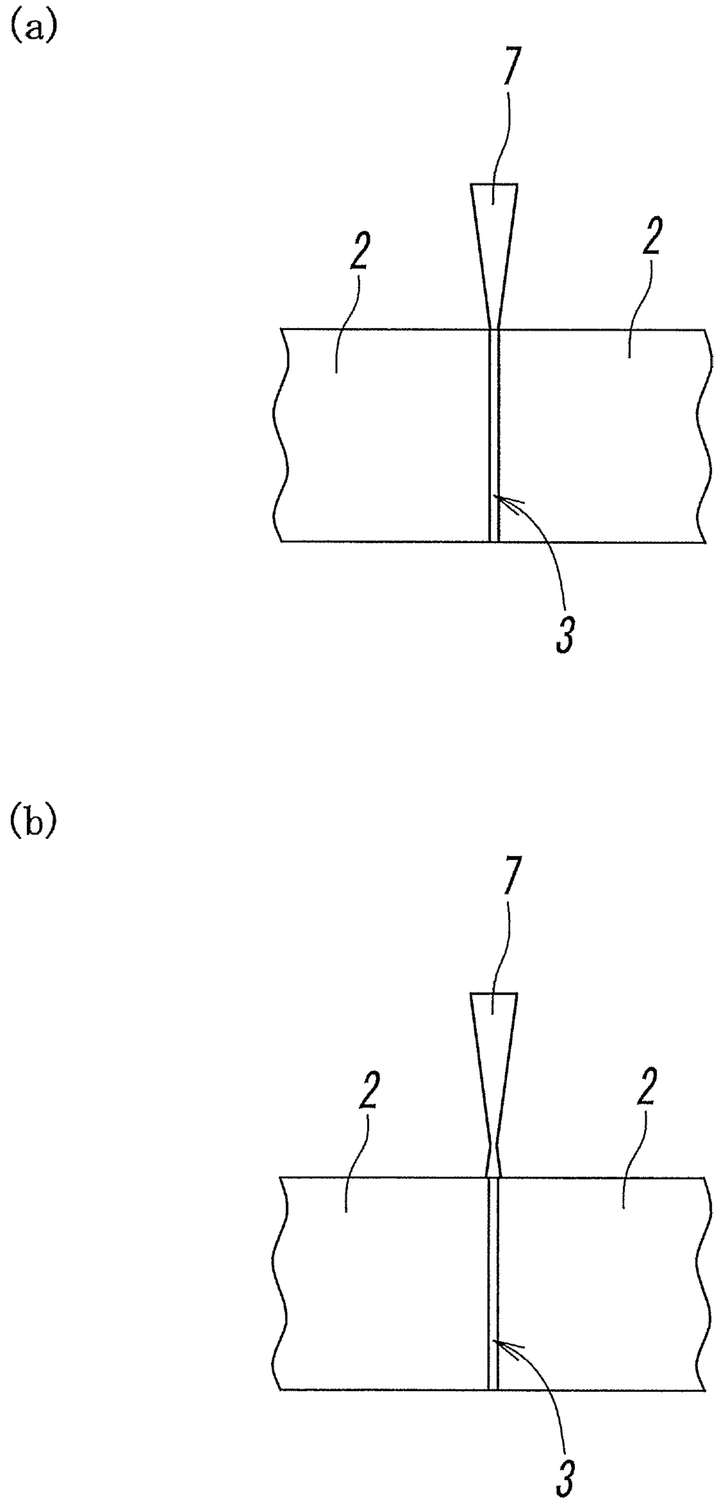

FIG. 4

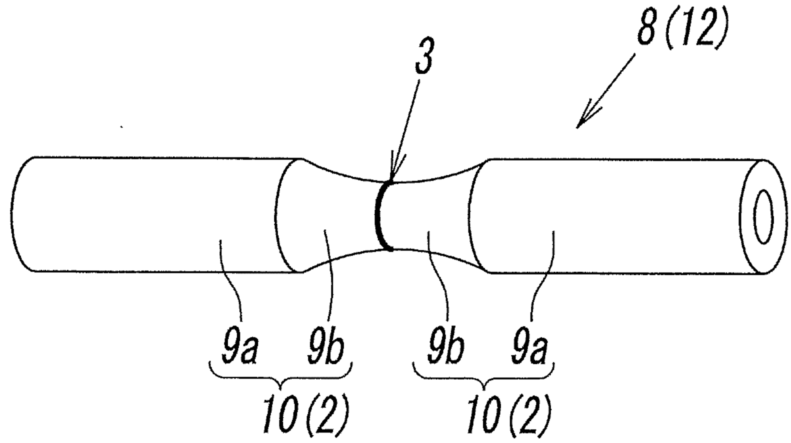

FIG. 5

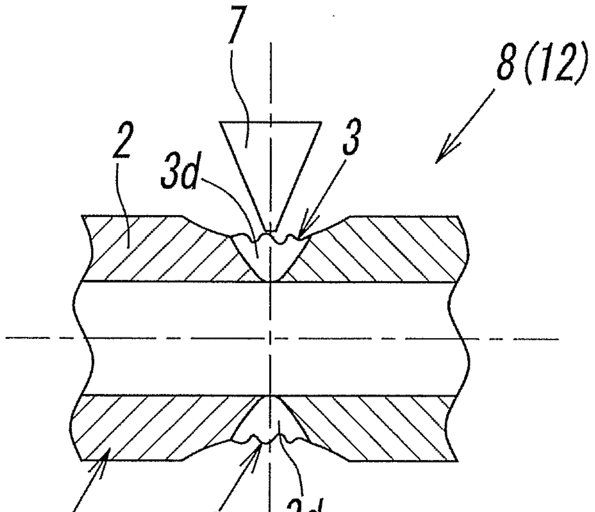

FIG. 6

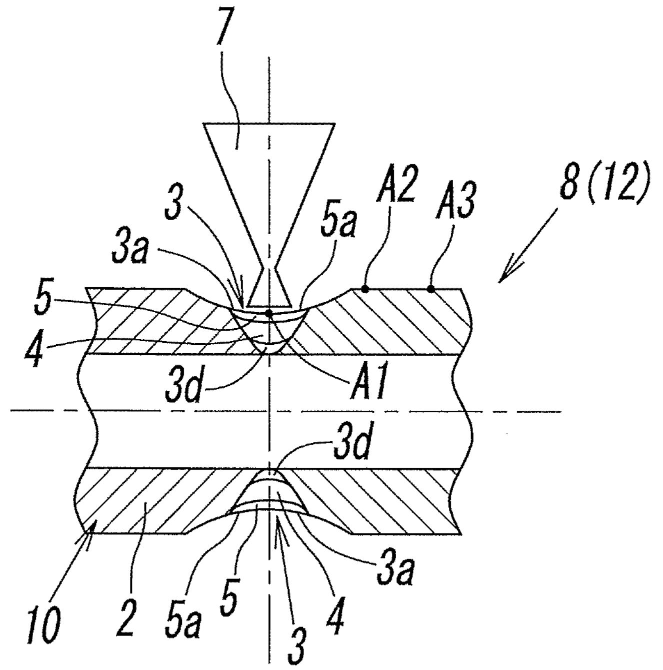

FIG. 7

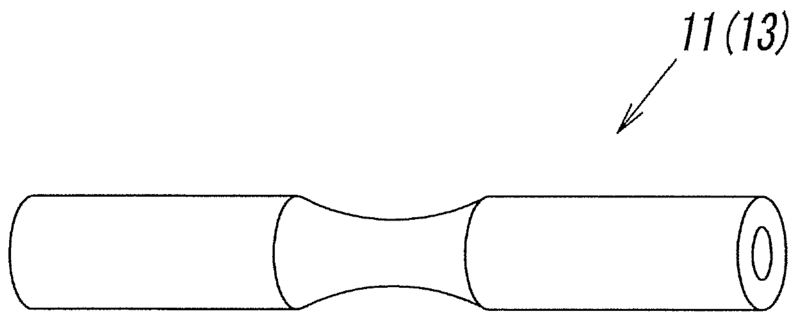

FIG. 8

CONDITION 1

	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
0.1	490	480	485	470	429	348	351	660	234	225	
0.2	495		485		454	660	349	260			
0.3	497	441	468	450	480	289	264				
0.4	485		457								
0.5	480		404		①						
0.6	470		430								
0.7	460		420								
0.8	450		440								
0.9	455		444								
1											

~Hv300
Hv301~350
Hv351~400
Hv401~450
Hv451~

①MELTED AND SOLIDIFIED PORTION 461Hv

FIG. 9

CONDITION 2

	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
0.1	479	460	460	465	460	412	376	336	253	225	
0.2	480		458								
0.3	453	473	458	473	327	271	237	232			
0.4	492		432								
0.5	318		412		①						
0.6	365		347								
0.7	367		370								
0.8	373		396		②						
0.9	385		405								
1											

REMELTED AND SOLIDIFIED PORTION
WIDTH : 1.05mm
DEPTH : 0.23mm

~Hv300
Hv301~350
Hv351~400
Hv401~450
Hv451~

①REMELTED AND SOLIDIFIED PORTION 460Hv
②REHEATED SOLIDIFIED PORTION 387Hv

FIG. 10

CONDITION 3

	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
0.1	460	470	463	473	473	447	339	248	235	225	
0.2	463		476								
0.3	498	498	460	371	329	281	260	221	222	226	
0.4	329		332								
0.5	345		323								
0.6	312		319								
0.7	341		344								
0.8	351		340								
0.9	350		342								
1											

REMELTED AND SOLIDIFIED PORTION
WIDTH : 1.01mm
DEPTH : 0.16mm

~Hv300
Hv301~350
Hv351~400
Hv401~450
Hv451~

①REMELTED AND SOLIDIFIED PORTION 468Hv
②REHEATED SOLIDIFIED PORTION 372Hv

FIG. 11

CONDITION 4

	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
0.1	450	438	438	447	476	386	301	225	226	225	
0.2	441		447								
0.3	457	466	434	386	350	220	222	225	225	224	
0.4	444		453								
0.5	453		429								
0.6	381		387								
0.7	355		359								
0.8	364		364								
0.9	360		370								
1											

REMELTED AND SOLIDIFIED PORTION
WIDTH : 0.95mm
DEPTH : 0.33mm

~Hv300
Hv301~350
Hv351~400
Hv401~450
Hv451~

①REMELTED AND SOLIDIFIED PORTION 443Hv
②REHEATED SOLIDIFIED PORTION 384Hv

FIG. 12

CONDITION 5

	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
0.1	444	485	485	471	333	257	212	227	218	225	
0.2	447		485								
0.3	455	485	471	471	333	257	212	227	218		
0.4	305		308								
0.5	374		377								
0.6	386		389								
0.7	396		399								
0.8	387		390								
0.9	392		395								
1											

REMELTED AND SOLIDIFIED PORTION
WIDTH : 0.82mm
DEPTH : 0.15mm

~Hv300
Hv301~350
Hv351~400
Hv401~450
Hv451~

①REMELTED AND SOLIDIFIED PORTION 470Hv
②REHEATED SOLIDIFIED PORTION 395Hv

FIG. 13

CONDITION 6

	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
0.1	473	473	473	483	352	323	260	249	226	225	
0.2	468		447								
0.3	469	341	388	336	341	404	245	245	226		
0.4	420		465								
0.5	394		412								
0.6	388		408								
0.7	387		420								
0.8	405		410								
0.9	400		405								
1											

REMELTED AND SOLIDIFIED PORTION
WIDTH : 0.46mm
DEPTH : 0.14mm

~Hv300
Hv301~350
Hv351~400
Hv401~450
Hv451~

①REMELTED AND SOLIDIFIED PORTION 469Hv
②REHEATED SOLIDIFIED PORTION 399Hv

FIG. 14

CONDITON 7

	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
0.1	457	458	446	450	458	312	269	243	222	227	213
0.2	492		485								
0.3	509	507	485	457	485	308	252	228	242	220	228
0.4	503		446								
0.5	478		470								
0.6	460		460								
0.7	438		447								
0.8	468		306								
0.9	375		299								
1											

REMELTED AND SOLIDIFIED PORTION
WIDTH : 0.75mm
DEPTH : 0.73mm

~Hv300
Hv301~350
Hv351~400
Hv401~450
Hv451~

①REMELTED AND SOLIDIFIED PORTION 469Hv
②REHEATED SOLIDIFIED PORTION 362Hv

FIG. 15

CONDITION 8

	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
0.1	524	540	432	435	498	438	432	245	230	239	248
0.2	450		473								
0.3	476	435	460	513	463	476	412	280	271	269	238
0.4	441		476								
0.5	466		444								
0.6	470		457								
0.7	463		460								
0.8	476		498								
0.9	498		494								
1											

REMELTED AND SOLIDIFIED PORTION
WIDTH : 0.35mm
DEPTH : 0.08mm

~Hv300
Hv301~350
Hv351~400
Hv401~450
Hv451~

①REMELTED AND SOLIDIFIED PORTION 498Hv
②REHEATED SOLIDIFIED PORTION 458Hv

FIG. 16

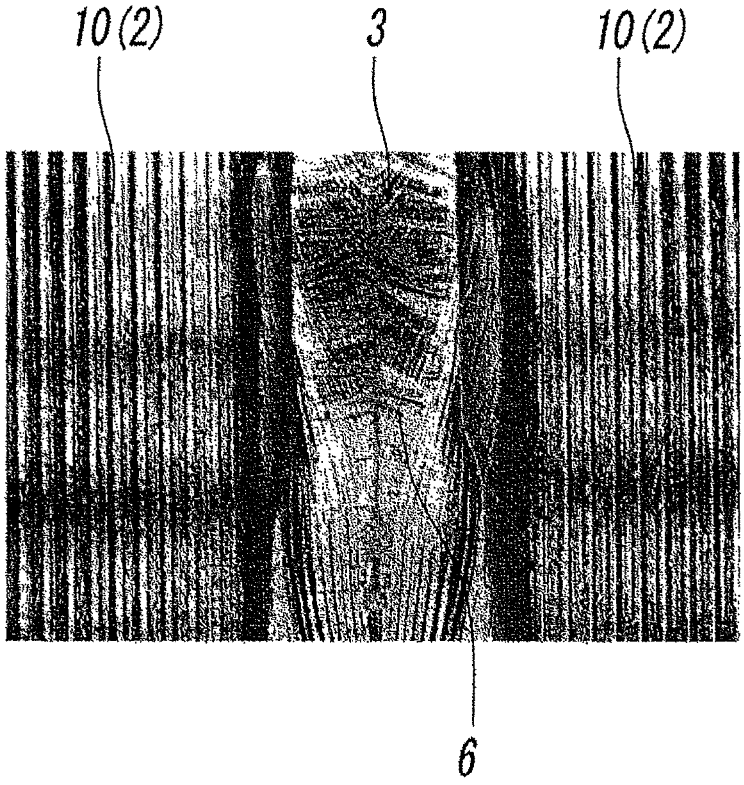

FIG. 17

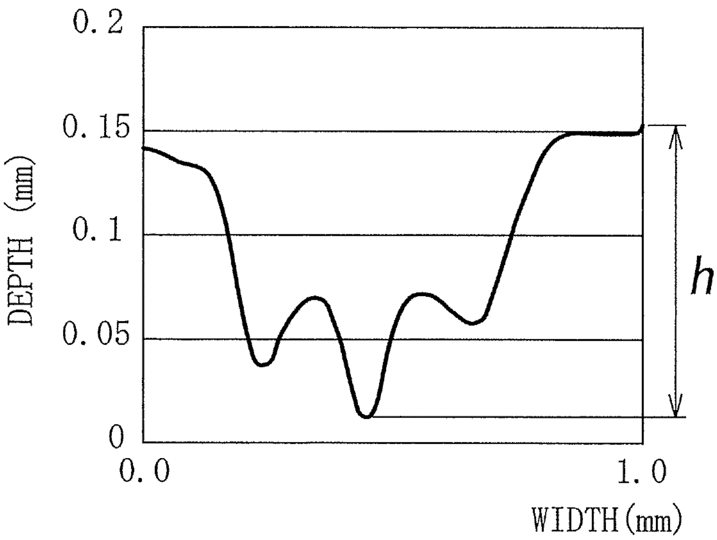

FIG. 18

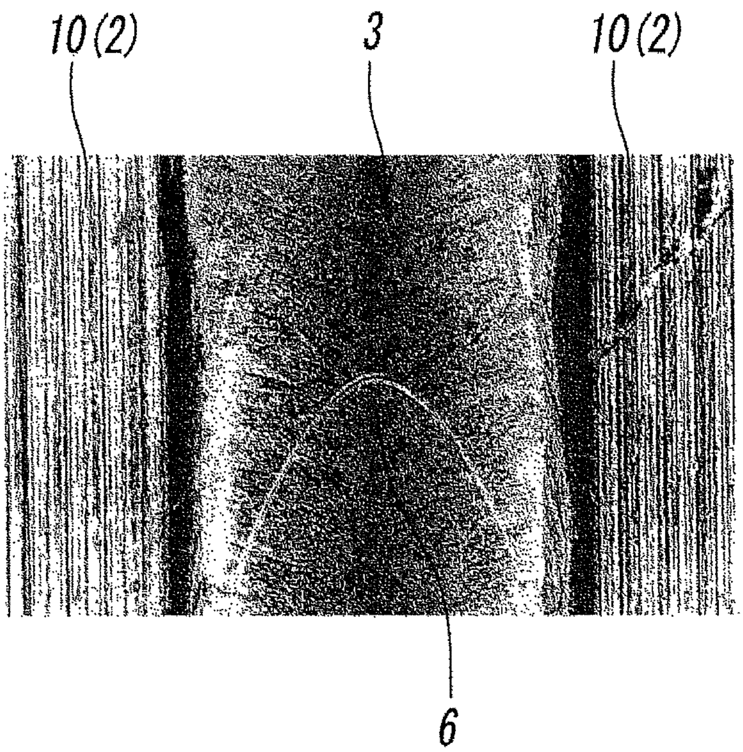

FIG. 19

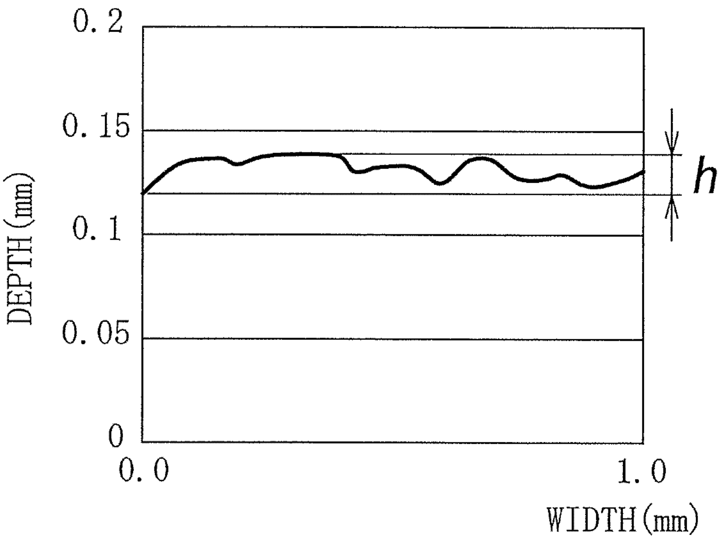

FIG. 20

CONDITION 9

	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
0.1	415	399	388	396	399	182	166	148	157	156	
0.2	399		390	399							
0.3	401	394	396	367	207	198	173	149	153	156	
0.4	404		340	308							
0.5	407		328	330	①						
0.6	396		330	299							
0.7	391		325	268							
0.8	391		336	170							
0.9	381		305	196							
1	395		327	176							

~Hv300
Hv301~350
Hv351~400
Hv401~450
Hv451~

①MELTED AND SOLIDIFIED PORTION 379Hv

FIG. 21

CONDITON 10

	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
0.1	386	405	396	393	360	351	167	186	158	157	
0.2	406			423	①						
0.3	399	385	401	418	213	207	169	167	158	155	
0.4	374		395	423							
0.5	334		325	200	②						
0.6	332		310	226							
0.7	321		330	205							
0.8	323		320	197							
0.9	345		310	199							
1	325		315	176							

REMELTED AND SOLIDIFIED PORTION
WIDTH : 1.05mm
DEPTH : 0.23mm

~Hv300
Hv301~350
Hv351~400
Hv401~450
Hv451~

①REMELTED AND SOLIDIFIED PORTION 393Hv
②REHEATED SOLIDIFIED PORTION 353Hv

FIG. 22

CONDITION 11

	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
0.1	457	460	460	444	444	379	271	208	196	175	163
0.2	432		470	473							
0.3	450	435	516	483	483	369	245	200	178	175	185
0.4	444		521	501							
0.5	444		553	603							
0.6	494		458	463							
0.7	460		451	415							
0.8	457		428	358							
0.9	453		410	420							
1	450		426								

①

~Hv300
Hv301~350
Hv351~400
Hv401~450
Hv451~

①MELTED AND SOLIDIFIED PORTION 460Hv

FIG. 23

CONDITION 12

	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
0.1	457	435	494	435	473	450	598	286	206	189	172
0.2	453		459	420							
0.3	444	473	457	470	483	409	241	217	186	181	185
0.4	487		430	444							
0.5	438		428	447							
0.6	280		295	289							
0.7	289		288	293							
0.8	306		284	294							
0.9	294		265	289							
1	306		276								

①
②

REMELTED AND SOLIDIFIED PORTION
WIDTH : 1.05mm
DEPTH : 0.23mm

~Hv300
Hv301~350
Hv351~400
Hv401~450
Hv451~

①REMELTED AND SOLIDIFIED PORTION 455Hv
②REHEATED SOLIDIFIED PORTION 360Hv

FIG. 24

CONDITION 13

	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
0.1	466	444	494	476	524	313	269	257	221	244	
0.2	476			509							
0.3	494	494	470	470	450	426	248	239	256	262	
0.4	453		450	432							
0.5	505		455	364							
0.6	476		456	353							
0.7	463		430	338							
0.8	418		428	299							
0.9	420		410								
1											

①

～Hv300
Hv301～350
Hv351～400
Hv401～450
Hv451～

①MELTED AND SOLIDIFIED PORTION 463v

FIG. 25

CONDITION 14

	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
0.1	423	447	423	466	424	444	312	209	231	206	211
0.2	435		444	432							
0.3	426	463	435	412	406	288	220	219	224	206	192
0.4	441		410	374							
0.5	438		422	407							
0.6	325		340	301							
0.7	301		345	327							
0.8	321		330	315							
0.9	321		321								
1											

①
②

REMELTED AND SOLIDIFIED PORTION
WIDTH : 1.05mm
DEPTH : 0.23mm

～Hv300
Hv301～350
Hv351～400
Hv401～450
Hv451～

①REMELTED AND SOLIDIFIED PORTION 435Hv
②REHEATED SOLIDIFIED PORTION 365Hv

FIG. 26

CONDITION 15

	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
0.1	553	549	623	536	623	420	319	221	192	208	191
0.2	501		555	516							
0.3	528	528	593	544	598	570	319	213	188	189	206
0.4	509		540	450							
0.5	513		500	516							
0.6	509		542	666							
0.7	494		466	480							
0.8	520		460	401							
0.9	575		456								
1	520		477								

~Hv300
Hv301~350
Hv351~400
Hv401~450
Hv451~

①MELTED AND SOLIDIFIED PORTION 543Hv

FIG. 27

CONDITION 16

	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
0.1	505	553	570	553	589	516	720	589	202	182	
0.2	570		530	544							
0.3	566	570	584	593	726	655	315	199	192	181	164
0.4	593		516	528							
0.5	347		335	310							
0.6	367		364	362							
0.7	376		365	374							
0.8	396		378	362							
0.9	394		394	364							
1			359	353							

REMELTED AND SOLIDIFIED PORTION
WIDTH : 1.05mm
DEPTH : 0.23mm

~Hv300
Hv301~350
Hv351~400
Hv401~450
Hv451~

①REMELTED AND SOLIDIFIED PORTION 560Hv
②REHEATED SOLIDIFIED PORTION 415Hv

FIG. 28

CONDITION 17

	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
0.1	666	677	670	680	685	393	284	285	292	294	
0.2	677			685							
0.3	671	671	695	683	575	396	291	282	285	275	
0.4	670		666	645							
0.5	666		635	598							
0.6	683		625	643							
0.7	671		640	689							
0.8	680		597	707							
0.9	675		625	695							
1	681		505	483							

~Hv300
Hv301~350
Hv351~400
Hv401~450
Hv451~

①MELTED AND SOLIDIFIED PORTION 671Hv

FIG. 29

CONDITION 18

	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
0.1	660	639	666	575	660	675	426	243	259	264	
0.2	666		650	677							
0.3	649	689	700	671	412	381	283	251	245	260	
0.4	677		551	369							
0.5	383		394	336							
0.6	376		399	426							
0.7	385		370	360							
0.8	447		425	450							
0.9	420		410	390							
1	417		435	440							

REMELTED AND SOLIDIFIED PORTION
WIDTH : 1.05mm
DEPTH : 0.23mm

~Hv300
Hv301~350
Hv351~400
Hv401~450
Hv451~

①REMELTED AND SOLIDIFIED PORTION 660Hv
②REHEATED SOLIDIFIED PORTION 453Hv

REFERENCES CITED IN THE DESCRIPTION

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