

WELDED JOINT AND METHOD FOR MANUFACTURING SAME

Technical Field

[0001]

The present invention relates to a welded joint. More specifically, it relates to a welded joint of a steel structure.

Background Art

[0002]

In a welded joint where steel materials are joined together by welding, it is general to make a joint (welded joint) in which welding is performed such that the tensile strength of weld metal exceeds the lower specification limit of the tensile strength of the steel materials (over-matching). This is to prevent early fracture in the weld and to sufficiently satisfy the predetermined design strength by making the tensile strength of the weld metal of the weld stronger than that of the steel materials to be welded. As such an invention, the invention of Patent Literature 1 below has been proposed.

[0003]

In recent years, high strength steel materials have been developed and used. When using high strength steel materials and performing welding so as to over-match the tensile strength of the steel materials, it is difficult to control the welding conditions and the working efficiency is

remarkably deteriorated. In addition, for ultrahigh strength steel materials having the tensile strength of 780 MPa or more, welding materials that can be used safely are scarce and it is currently difficult to even obtain them.

[0004]

Regarding these problems in the case of using high strength steel materials, the inventions of Patent Literatures 2 and 3 below have been proposed for fillet welding.

Citation List

Patent Literature

[0005]

Patent Literature 1: Japanese Patent No. 3752616

Patent Literature 2: Japanese Unexamined Patent Application Publication No. 2013-139047

Patent Literature 3: Japanese Unexamined Patent Application Publication No. 2014-8515

Summary of Invention

Technical Problem

[0006]

However, in the inventions described in Patent Literatures 2 and 3, there is a problem that since stress concentrates easily at the weld toe of the reinforcing weld metal due to its shape, there is a high possibility that brittle fracture occurs when tensile stress acts.

[0007]

At a weld of high strength steel materials, the penetration amount tends to be small due to welding at low heat input. In addition, when the reinforcing weld metal as disclosed in Patent Literature 2 is formed by a single weld bead by gas shielded arc welding, there also arises a problem that the toughness of the base metal heat-affected zone in the vicinity of the weld toe decreases, and there is concern about early brittle fracture at the weld.

[0008]

An object of the present invention is to provide a welded joint in which the welded joint strength is ensured and brittle fracture can be prevented even when the tensile strength of the weld metal is lower than the tensile strength of the steel materials (under-matching).

Solution to Problem

[0009]

In order to solve the above problem, the present invention has devised the following measures: 1) providing such a weld reinforcement that weld strength (= total thickness of weld reinforcement, steel material plate thickness, back surface penetration depth and the like  $\times$  weld metal strength) exceeds the steel material strength (= plate thickness  $\times$  steel material stress) so that fracture in steel material precedes fracture in the weld,

2) providing reinforcing beads having a predetermined width on the steel material surface so that the steel material fracture precedes more reliably, and 3) in order to prevent brittle fracture at the reinforcing weld bead toe, the flank angle of the reinforcing weld bead toe is a predetermined value.

[0010]

By the above measures, the following effects can be obtained: 1) weld metal has sufficient strength even if it has lower tensile strength than steel material, 2) stress/strain concentration at reinforcing weld bead toe can be reduced, and 3) even for ultrahigh strength steel materials, the operation conditions are relaxed (residual heat in over-matching welding is reduced, high heat input welding is made possible, and the welding process is simplified), and joint strength can be ensured.

[0011]

Based on the above findings, the present inventors made further studies and completed the present invention. The summary of the present invention is as follows.

[0012]

[1] A welded joint comprising two steel materials and a weld metal at the joint therebetween, wherein at least one of the surfaces is provided with a weld reinforcement built up on the surfaces of both steel materials, wherein the

width of each reinforcing bead that is a weld reinforcement built up on the surfaces of the steel materials is equal to or larger than the weld reinforcement thickness at the ends of the surfaces of the steel materials, wherein the flank angle  $\theta$  of each reinforcing weld bead toe is  $145^\circ$  to  $170^\circ$ , wherein the tensile strength of the weld metal is lower than the tensile strength of each steel material, and wherein the condition of the following expression (1) is satisfied.

[0013]

[Expression 1]

$$(a+t+d) \times \sigma_{uw} \geq \alpha \times t \times T_{sl} \cdots (1)$$

[0014]

In the expression (1),  $a$  is the maximum thickness (mm) of the weld reinforcement,  $t$  is the thickness (mm) of the steel materials,  $\sigma_{uw}$  is the tensile strength (MPa) of the weld metal,  $\alpha$  is the safety factor (no unit) and is a value defined by 1.01 to 1.20, and  $T_{sl}$  is the tensile strength (MPa) of the steel materials.  $d$  is greater than or equal to 0 and is the maximum thickness (mm) of the other weld reinforcement when there are weld reinforcements on both surfaces.

[0015]

[2] The welded joint according to [1], wherein  $\alpha$  is the safety factor (no unit) and is a value defined by 1.03 to

1.20.

[0016]

[3]The welded joint according to [1] or [2], further comprising a recess-type backing metal having a recess on the surface opposite to the surface having the weld reinforcement, wherein d in the expression (1) is the filling depth (mm) in the recess-type backing metal.

[0017]

[4]The welded joint according to [1] or [2], further comprising a backing metal on the surface opposite to the surface having the weld reinforcement, wherein the backing metal has penetration, and d in the expression (1) is the penetration depth (mm) in the penetration.

[0018]

[5]The welded joint according to any one of [1] to [4], wherein at least one of the steel materials has a groove having a bevel angle  $\phi$  of 15° to 35°.

[0019]

[6]A method for manufacturing the welded joint according to any one of [1] to [5], wherein a weld metal is formed in a root gap between both steel materials, and a weld reinforcement built up on the surfaces of both steel materials is formed on at least one of the surfaces.

[0020]

[7]The method for manufacturing the welded joint

according to [6], wherein welding is performed by providing a backing metal or a recess-type backing metal in the root gap.

#### Advantageous Effects of Invention

[0021]

According to the present invention, it is possible to secure the welded joint strength at an under-matching welded joint using a high-strength steel material, to provide a welded joint capable of preventing brittle fracture and relaxing welding operation conditions.

#### Brief Description of Drawings

[0022]

[Fig. 1] Fig. 1 is a schematic diagram illustrating an embodiment of the present invention.

[Fig. 2] Fig. 2 is a schematic diagram illustrating the dimensions and the like of the welded joint.

[Fig. 3] Fig. 3 is a schematic diagram illustrating the dimensions and the like of the welded joint.

[Fig. 4] Fig. 4 is a diagram showing the relationship between the flank angle of the reinforcing weld bead toe and the stress concentration factor.

[Fig. 5] Fig. 5 is a schematic diagram illustrating an embodiment of the present invention.

[Fig. 6] Fig. 6 is a schematic diagram illustrating an embodiment of the present invention.

[Fig. 7] Fig. 7 is a schematic diagram illustrating an embodiment of the present invention.

[Fig. 8] Fig. 8 is an example of a two-dimensional plane strain element model.

[Fig. 9] Fig. 9 is a schematic diagram illustrating a gauge for examining the flank angle.

#### Description of Embodiments

[0023]

Hereinafter, the present invention will be described in detail. The present invention is an under-matching welded joint in which the tensile strength of the weld metal is smaller than the tensile strength of the steel materials. The present invention can also be applied to high strength steel materials, to which application has been difficult conventionally, and can also be applied to those having a large difference in tensile strength between the steel materials and the weld metal. Specifically, the present invention is preferably applicable to those in which the tensile strength of the steel materials is as high as 600 to 900 MPa, and the tensile strength of the steel materials is more preferably 600 to 800 MPa. The tensile strength of the weld metal is, for example, 550 MPa or more, and the upper limit thereof is, for example, 800 MPa. From the viewpoint of welding workability and the like, the tensile strength of the weld metal is practically, for example, 550 to 700 MPa.

In the present invention, the difference in tensile strength between the steel materials and the weld metal can exceed 200 MPa. Needless to say, the present invention can also be applied to those in which the difference in tensile strength between the steel materials and the weld metal is 200 MPa or less. The difference in tensile strength between the steel materials and the weld metal is preferably 250 MPa or less. In the present invention, the tensile strength of the steel materials is determined according to JIS Z 2241, metal material tensile test method. The tensile strength of the weld metal is determined according to JIS Z 2241 metal material tensile test method using JIS Z 3111 A0 test piece, A1 test piece, or A2 test piece.

[0024]

Fig. 1 is a sectional schematic view of a welded joint in butt welding, and is a schematic diagram illustrating an embodiment of the present invention. As shown in Fig. 1, the welded joint of the present invention is made by butt welding and is made by complete penetration welding in which penetration extends over the entire thickness of the base metals (steel materials). The welded joint shown in Fig. 1 has a substantially bilaterally symmetrical shape. In the following description of the present invention, depiction of the weld heat-affected zone is omitted.

[0025]

The welded joint 1 has two steel materials 4 and weld metal 3 at the joint therebetween, that is, the welded joint 1 has weld metal 3 and steel materials 4 on both sides thereof. In the weld metal 3, the region of the width shown by the dotted line (between the ends of the steel materials 4 closest to the weld metal 3) is a widthwise central portion 2. Such a welded joint can be obtained by performing welding in a state where a backing metal 6 is provided in the root gap between the steel materials 4. The "backing metal" is, before welding, a flat plate (for example, flat steel) having no recess in the surface thereof facing the steel material to be welded. Part of it is melted by welding, and it forms a shape having a recess as shown in Fig. 1.

[0026]

The upper surface in Fig. 1 has a weld reinforcement having a maximum thickness,  $a$ , and built-up weld reinforcements (reinforcing beads 5) are provided on the surfaces of both steel materials 4. The weld reinforcement thickness at the ends of the surfaces of the steel materials is shown by double arrows 9. The distance from the ends of the surfaces of the steel materials to the weld toe 8 is the width of the reinforcing beads. The flank angle of the weld toe 8 is denoted by  $\theta$ , and the bevel angle of the groove of the steel materials 4 is denoted by  $\phi$ . On the surface

opposite to the surface having the weld reinforcement, a backing metal 6 is provided, and the backing metal has penetration 7 having a depth, d.

[0027]

With reference to Fig. 2, a preferred embodiment will be further described with respect to the weld reinforcement above the widthwise central portion 2, the weld reinforcements at the ends of the surfaces of the steel materials, and the reinforcing bead width. In Fig. 2, the horizontal axis shows X, and at the center of the widthwise central portion 2,  $X = 0$ .  $X_1$  is the position of the tip of the groove,  $X_2$  is the position of the end of the surface of the steel material, and  $X_3$  is the position of the reinforcing weld bead toe.

[0028]

In Fig. 2, a is the maximum thickness of the weld reinforcement, and it is preferable that the weld reinforcement has the maximum thickness above the widthwise central portion 2 (just above the widthwise central portion 2). From the viewpoint of causing fracture in the steel material to precede that in the weld, the welded joint of the present invention satisfies the condition of the following expression (1). The width of each reinforcing bead is equal to or larger than the weld reinforcement thickness at the end of the surface of the steel material.

[0029]

[Expression 2]

$$(a+t+d) \times \sigma_{uw} \geq \alpha \times t \times T_{sl} \cdots (1)$$

[0030]

In the expression (1),  $a$  is the maximum thickness (mm) of the weld reinforcement,  $t$  is the thickness (mm) of the steel materials,  $\sigma_{uw}$  is the tensile strength (MPa) of the weld metal,  $\alpha$  is a safety factor (no unit) and is a value defined by 1.01 to 1.20, and  $T_{sl}$  is the tensile strength (MPa) of the steel materials.  $d$  is greater than or equal to 0 and is the maximum thickness (mm) of the other weld reinforcement when there are weld reinforcements on both surfaces. That is,  $d$  is the maximum thickness (mm) of the weld reinforcement on the back surfaces of the steel materials (when a backing metal is provided on the back surface, the penetration depth of the backing metal), and is 0 when there is no weld reinforcement on the back surface. In Fig. 1,  $d$  is the penetration depth (mm) in the penetration. In the case where a backing metal is not provided or there is no penetration in a backing metal,  $d$  may be 0. In the expression (1),  $\alpha$  is the safety factor (no unit) and is preferably a value defined by 1.03 to 1.20. When  $\alpha$  is 1.03 to 1.20, the effects of the present invention, that is, the effects of ensuring the welded joint strength

at the under-matching welded joint using high strength steel materials, preventing brittle fracture, and providing a welded joint capable of relaxing welding conditions can be exerted more reliably.

[0031]

In Fig. 2, the weld reinforcement thickness at the position  $X_2$  is the weld reinforcement thickness of the end of the surface of the steel material. It is preferable that the groove weld reinforcement,  $a_x$ , at an arbitrary position between  $X_1$  and  $X_2$  in Fig. 2 satisfies the condition of the following expression (2).

[0032]

[Expression 3]

$$\begin{array}{l} \text{Weld reinforcement thickness} \\ a_x \text{ (mm) of groove} \end{array} : (t - t_x + a_x) \times \sigma_{uw} + t_x \times T_{sl} \geq \alpha \times t \times T_{sl} \quad \dots (2)$$

[0033]

Here,  $t$  is the thickness (mm) of the steel material,  $t_x$  is the thickness (mm) of the steel material in the groove,  $\sigma_{uw}$  is the tensile strength (MPa) of the weld metal,  $\alpha$  is the safety factor (no unit) and is a value defined by 1.01 to 1.20, and  $T_{sl}$  is the tensile strength (MPa) of the steel material. In the expression (2),  $\alpha$  is the safety factor (no unit) and is preferably a value defined by 1.03 to 1.20. When  $\alpha$  is 1.03 to 1.20, the effects of the present invention can be exerted more reliably.

[0034]

$X_3 - X_2$  in Fig. 2 is the width (mm) of the reinforcing bead. It is preferable that the width of the reinforcing bead satisfies the condition of the following expression (3).

[0035]

[Expression 4]

$$\text{Width (mm) of reinforcing bead} : x_3 - x_2 \geq \frac{a_{x2}}{\tan(180-\theta)} \dots (3)$$

[0036]

In the above expression (3),  $a_{x2}$  is the weld reinforcement thickness (mm) at the end of the surface of the steel material, and  $\theta$  is the flank angle.

[0037]

Fig. 3 is a schematic diagram illustrating the dimensions and the like of the welded joint, and is a graph showing the relationship between the weld reinforcement height (thickness) and the distance from the center of the widthwise central portion at a plurality of plate thicknesses in the embodiment of the present invention. The conditions are as follows. The graph of Fig. 3 was obtained by the following expressions (1) to (3) under the following conditions.

· The widthwise distance of the widthwise central portion 2 (the distance between the ends of the steel materials closest to the weld metal) = 7.0 mm, the bevel angle  $\phi = 35^\circ$ ,

the flank angle  $\theta = 150^\circ$ , the thickness of the steel materials = 25 to 50 mm,  $d = 0$  mm

- The lower specification limit,  $T_{sl}$ , of the tensile strength of the steel materials = 780 MPa, the weld metal tensile strength  $\sigma_{uw} = 650$  MPa
- The safety factor  $\alpha = 1.1$

As shown in Fig. 3, as described above, it is preferable that the weld reinforcement height becomes maximum at any position in the widthwise central portion (0 to  $X_1$  in Fig. 3). The weld reinforcement height in the widthwise central portion (the maximum thickness,  $a$ , of the weld reinforcement) is 8.0 mm when  $t = 25$  mm, 9.0 mm when  $t = 28$  mm, 10.2 mm when  $t = 32$  mm, 11.5 mm when  $t = 36$  mm, 12.8 mm when  $t = 40$  mm, 14.4 mm when  $t = 45$  mm, and 16.0 mm when  $t = 50$  mm.

[0038]

The weld reinforcement height at the end of the surface of the steel material ( $X_2$  in Fig. 3) (the thickness,  $a_{x2}$ , of the weld reinforcement at the end of the surface of the steel material) is 3.0 mm when  $t = 25$  mm, 3.4 mm when  $t = 28$  mm, 3.8 mm when  $t = 32$  mm, 4.3 mm when  $t = 36$  mm, 4.8 mm when  $t = 40$  mm, 5.4 mm when  $t = 45$  mm, and 6.0 mm when  $t = 50$  mm.

[0039]

The distance from the center of the widthwise central

portion to the reinforcing weld bead toe is 26.2 mm when  $t = 25$  mm, 28.9 mm when  $t = 28$  mm, 32.6 mm when  $t = 32$  mm, 36.2 mm when  $t = 36$  mm, 39.8 mm when  $t = 40$  mm, 44.4 mm when  $t = 45$  mm, and 48.9 mm when  $t = 50$  mm.

[0040]

The width,  $X_3 - X_2$ , of the reinforcing bead is 5.2 mm when  $t = 25$  mm, 5.8 mm when  $t = 28$  mm, 6.6 mm when  $t = 32$  mm, 7.5 mm when  $t = 36$  mm, 8.3 mm when  $t = 40$  mm, 9.4 mm when  $t = 45$  mm, and 10.4 mm when  $t = 50$  mm.

[0041]

In the present invention, from the viewpoint of ensuring the strength of the weld, the maximum value of the weld reinforcement height (maximum thickness,  $a$ , of the weld reinforcement) is preferably 7.0 to 20.0 mm, more preferably 15 mm to 20 mm.

[0042]

From the viewpoint of prevention of fracture at the reinforcing weld bead toe, the weld reinforcement thickness,  $a_{x2}$ , at the end of the surface of the steel material is preferably 2.5 to 10 mm, more preferably 5 mm to 10 mm.

[0043]

From the viewpoint of relaxing the stress concentration at the reinforcing weld bead toe, it is preferable that the width,  $X_3 - X_2$ , of the reinforcing bead is 5.0 mm to 50 mm.

[0044]

From the viewpoint of reinforcing bead welding workability, the thickness  $t$  of the steel material is preferably 12 to 80 mm, more preferably 12 to 60 mm.

[0045]

Further, from the viewpoint of ensuring the weld penetration amount, it is preferable that the widthwise distance of the widthwise central portion (root gap) is 3.0 mm to 10.0 mm.

[0046]

Next, the flank angle will be described. In the present invention, the flank angle is obtained using a radius gauge. The flank angle is the angle,  $\theta$ , formed between the tangent of the reinforcing bead 5 at the reinforcing weld bead toe 8 and the surface of the steel material 4.

[0047]

For the welded joint having the configuration shown in Fig. 1, the flank angle and the stress concentration factor (how many times larger is the stress than the average stress acting on the welded joint member) of the reinforcing weld bead toe were analyzed by FEM elasto-plastic analysis. The model was analyzed by changing the flank angle from  $180^\circ$  to  $140^\circ$  in a two-dimensional plane strain element model. Fig. 8 is an example of an element model. As an example of analysis results, the results in the case where the steel material plate thickness is 32 mm, the steel material

strength is 780 MPa, and the weld metal strength is 700 MPa are shown in Fig. 4.

[0048]

It is confirmed from previous experiments that if the stress concentration factor in FEM elastic analysis is 3 or less, substantially the maximum fracture stress is maintained at the actual welded joint portion due to the effect of plasticization. In the present invention, the flank angle  $\theta$  is set such that the stress concentration factor is 2.5 or less in consideration of safety.

[0049]

The flank angle  $\theta$  is  $145^\circ$  or more in order to reduce stress and strain concentration at the reinforcing weld bead toe to prevent brittle fracture. On the other hand, from the viewpoint of welding workability, the flank angle  $\theta$  is  $170^\circ$  or less. The flank angle is preferably  $145^\circ$  to  $160^\circ$ .

[0050]

In the welded joint 1 in Fig. 1, each steel material 4 has a one-side groove. In order to prevent a pear-shaped crack or the like, the bevel angle  $\phi$  is preferably  $15^\circ$  to  $35^\circ$ .

[0051]

In the welded joint 1 in Fig. 1, the lower surface is provided with the backing metal 6, and from the viewpoint of causing fracture in the steel material to precede that in

the weld, the backing metal 6 has penetration 7 of a depth  $d$ . The depth  $d$  is preferably 2 mm or more, and more preferably 3 mm or more. In the case where the steel material strength is 780 MPa or more, or when the thickness ( $t$ ) of the steel material is 19 mm to 40 mm, it is more preferable that the depth  $d$  is 5 mm to 10 mm (deep penetration) from the viewpoint of avoiding an excessive weld reinforcement with respect to the plate thickness. When forming the deep penetration, it is preferable to determine the welding condition in advance and to check to what extent penetration extends. When determining the weld reinforcement height in consideration of the penetration depth  $d$ , it is preferable to use a material having strength of 590 to 780 MPa for the backing metal 6 from the viewpoint of ensuring the weld metal strength.

[0052]

Fig. 5 is a schematic diagram showing a modification of the embodiment shown in Fig. 1. In the embodiment shown in Fig. 5, the upper and lower surfaces of the steel materials are provided with weld reinforcements, and each surface has the same configuration as in the embodiment based on Fig. 1 described above. In the above expression (1),  $d$  is not the penetration depth in the penetration but the height (mm) of the weld reinforcement. That is, in the above expression (1), the weld reinforcement heights of the upper and lower

surfaces are respectively a and d.

[0053]

Hereinafter, other embodiments will be described. Also in the following embodiments, it is possible to provide the configuration already described. In any of the embodiments, as shown in Fig. 5, weld reinforcements may be provided on both upper and lower surfaces of the steel materials.

[0054]

Fig. 6 is a schematic diagram illustrating an embodiment of the present invention. In this embodiment, a recess-type backing metal 6 having a recess is used. The recess may be located on the widthwise central portion 2. Inside the recess is a filling portion 10 for the weld metal. The depth d of the recess (filling portion 10) is not particularly limited, and is preferably 5 mm to 10 mm. Note that the depth (filling depth) d of the filling portion 10 and the depth d of the penetration are common in that they are provided from the viewpoint of causing fracture in the steel material to precede that in the weld. The embodiment shown in Fig. 6 is preferably applied in the case where the steel material strength is 780 MPa or more or the steel material thickness (t) is 40 mm to 80 mm from the viewpoint of welding workability.

[0055]

Fig. 7 is a schematic diagram illustrating an

embodiment of the present invention. The steel materials 4 differ in thickness, and one of the steel materials 4 does not have a groove, that is, a single bevel groove is formed. Even in this case, reinforcing beads 5 are provided on both sides. The weld reinforcement thickness  $a_0$  at the end of the surface of the left steel material (thicker steel material) can be obtained from the weld reinforcement thickness  $a_{x2}$  at the end of the surface of the right steel material (thinner steel material) and the thicknesses  $t_1$  and  $t_2$  of both steel materials (the thickness of the thinner steel material is  $t_1$ , and the thickness of the thicker steel is  $t_2$ ) ( $a_0 = a_{x2} - (t_2 - t_1)$ ). The width (mm) of each of the left and right reinforcing beads 5 is equal to or larger than the weld reinforcement thickness at the end of the surface of the steel material. When one of the steel materials does not have a groove, the bevel angle  $\phi$  of the other steel material is preferably  $25^\circ$  to  $35^\circ$  from the viewpoint of welding workability.

[0056]

In the embodiment shown in Fig. 7, the weld reinforcement thickness in the widthwise central portion 2 is not uniquely determined. However, if the weld reinforcement thickness in the widthwise central portion 2 is determined to be larger than or equal to the weld reinforcement thickness  $a_0$  on the basis of the left steel

material, and the weld reinforcement thickness in the widthwise central portion 2 is determined to be larger than or equal to the weld reinforcement thickness  $a_{x2}$  on the basis of the right steel material, it can be determined that "the weld reinforcement is maximum above the widthwise central portion 2." In the above expression (1), the thinner plate thickness is used.

[0057]

In the present invention, the steel materials can be appropriately selected and used. For example, as a combination of steel materials, a combination of a steel plate and a steel plate, or an H-shaped steel flange and a steel plate can be used. The present invention may be applied as a welded joint between UOE steel pipes or spiral steel pipes.

[0058]

The manufacturing method, that is, the forming method (welding method) of the welded joint of the present invention is not particularly limited. For example, it can be manufactured by a method of manufacturing a welded joint according to the present invention in which a weld metal is formed in the root gap between both steel materials, and, on at least one of the surfaces, built-up weld reinforcements are formed on the surfaces of both steel materials. At that time, it is preferable to perform welding by providing a

backing metal or a recess-type backing metal in the root gap. Specifically, it can be formed by submerged arc welding, for example. A welded joint may be formed by one pass at a heat input of 50 to 200 kJ/cm, or a welded joint may be formed by a plurality of two or more passes at a heat input of 10 to 40 kJ/cm.

#### EXAMPLE

[0059]

Tensile test of welded joint was carried out. Specifically, as shown in Fig. 1, first, two identical steel plates (steel plates having tensile strength of 780 MPa class, a plate thickness of 25 mm, a width of 400 mm, and a length of 200 mm) were butt welded together such that the weld reinforcement target value is 10 mm (safety factor  $\alpha = 1.1$  aim), 8 mm (safety factor  $\alpha = 1.01$  aim), and 4 mm to obtain a welded joint (welded member). Then, as a test specimen, a test part was cut out from the obtained welded joint by machining so as to have a width of 75 mm. From the macro test of the obtained test specimen (the test of observing the cross section of the weld), in each of the specimens No. 1 to No. 3, the flank angle  $\theta$  of the reinforcing weld bead toe was  $145^\circ$ . By using the gauge 20 made of stainless steel as shown in Fig. 8 for the flank angle  $\theta$ , it is also possible to easily check whether the angle is within a predetermined range. Fig. 8 is a

schematic diagram illustrating a gauge for examining the flank angle. For example, by using a gauge having an angle  $Z$  of  $145^\circ$  and a gauge having an angle  $Z$  of  $170^\circ$ , it is possible to easily determine whether or not the flank angle,  $\theta$ , is within the range of  $145^\circ$  to  $170^\circ$ . The groove and welding conditions are as follows.

<Groove>

Groove shape: single V groove, groove angle (bevel angle  $\phi$ ):  $35^\circ$ , root gap (RG): 5 mm, backing metal: thickness 9 mm  $\times$  width 25 mm

<Welding Conditions>

Welding material: 680 N/mm<sup>2</sup> grade solid wire, diameter = 1.4 mm

Current: 280 to 300 (A), voltage: 28 to 30 (V), speed: 18 to 30 (cm/min), inter-pass temperature: maximum  $250^\circ\text{C}$

The tensile strength, the measurement result of the weld, and the tensile test result are shown in Table 1. The tensile strength of the base metal (steel material) and the weld metal were each obtained by the above-mentioned method. The yield strength of the base metal (steel material) and the 0.2% proof stress of the weld metal were each obtained in accordance with the requirements of JIS Z 2241. In No. 3, there was no reinforcing bead.

[0060]

As shown in Table 1, it was confirmed that, in the

specimens manufactured according to the present invention, that is, No. 1 specimen and No. 2 specimen having a safety factor  $\alpha$  slightly lower than that of No. 1 specimen, in which the width of the reinforcing beads is equal to or larger than the weld reinforcement thickness at the end of the surface of the steel material, the flank angle of the reinforcing weld bead toe is  $145^\circ$  or more and  $170^\circ$  or less, and the tensile strength of the weld metal is lower than the tensile strength of each steel material, and which satisfy the condition of the above expression (1), even if the weld metal strength is low, fracture in the base metal (steel material) precedes. On the other hand, in the No. 3 specimen having small weld reinforcement thickness, fracture in the weld metal preceded. From the test results, the effects of the present invention were confirmed.

[0061]

[Table 1]

|       | Maximum thickness a (mm) of weld reinforcement | Weld reinforcement thickness $a_{x2}$ (mm) at end of surface of steel material | Penetration depth d (mm) in penetration | Reinforcing bead width $X_3 - X_2$ (mm) | Base material strength (MPa) |                  | Weld metal strength (MPa) |                  | Fracture strength (MPa) | Fracture part               |
|-------|------------------------------------------------|--------------------------------------------------------------------------------|-----------------------------------------|-----------------------------------------|------------------------------|------------------|---------------------------|------------------|-------------------------|-----------------------------|
|       |                                                |                                                                                |                                         |                                         | Yield stress                 | Tensile strength | 0.2% proof stress         | Tensile strength |                         |                             |
| No. 1 | 11.2                                           | 3.6                                                                            | 2.0                                     | 6.1                                     | 676                          | 891              | 626                       | 681              | 904                     | Base metal (steel material) |
| No. 2 | 8.8                                            | 1.5                                                                            | 2.0                                     | 2.0                                     |                              |                  |                           |                  | 901                     | Base metal (steel material) |
| No. 3 | 3.0                                            | 0.0                                                                            | 2.0                                     | -                                       |                              |                  |                           |                  | 786                     | Weld metal                  |

Reference Signs List

[0062]

- 1 welded joint
- 2 widthwise central portion
- 3 weld metal
- 4 steel material
- 5 reinforcing bead
- 6 backing metal
- 7 penetration
- 8 toe of reinforcing bead
- 9 weld reinforcement thickness of end surface of steel  
material
- 10 filling portion

CLAIMS

[Claim 1]

A welded joint comprising two steel materials and a weld metal at the joint therebetween, wherein at least one of the surfaces is provided with a weld reinforcement built up on the surfaces of both steel materials,

wherein the width of each reinforcing bead that is a weld reinforcement built up on the surfaces of the steel materials is equal to or larger than the weld reinforcement thickness at the ends of the surfaces of the steel materials,

wherein the flank angle  $\theta$  of each reinforcing weld bead toe is  $145^{\circ}$  to  $170^{\circ}$ ,

wherein the tensile strength of the weld metal is lower than the tensile strength of each steel material, and

wherein the condition of the following expression (1) is satisfied:

[Expression 1]

$$(a+t+d) \times \sigma_{uw} \geq \alpha \times t \times T_{sl} \cdots (1)$$

where  $a$  is the maximum thickness (mm) of the weld reinforcement,  $t$  is the thickness (mm) of the steel materials,  $\sigma_{uw}$  is the tensile strength (MPa) of the weld metal,  $\alpha$  is the safety factor (no unit) and is a value defined by 1.01 to 1.20,  $T_{sl}$  is the tensile strength (MPa) of the steel materials, and  $d$  is greater than or equal to 0 and

is the maximum thickness (mm) of the other weld reinforcement when there are weld reinforcements on both surfaces.

[Claim 2]

The welded joint according to Claim 1, wherein  $\alpha$  is the safety factor (no unit) and is a value defined by 1.03 to 1.20.

[Claim 3]

The welded joint according to Claim 1 or 2, further comprising a recess-type backing metal having a recess on the surface opposite to the surface having the weld reinforcement, wherein  $d$  in the expression (1) is the filling depth (mm) in the recess-type backing metal.

[Claim 4]

The welded joint according to Claim 1 or 2, further comprising a backing metal on the surface opposite to the surface having the weld reinforcement, wherein the backing metal has penetration, and  $d$  in the expression (1) is the penetration depth (mm) in the penetration.

[Claim 5]

The welded joint according to any one of Claims 1 to 4, wherein at least one of the steel materials has a groove having a bevel angle  $\phi$  of  $15^\circ$  to  $35^\circ$ .

[Claim 6]

A method for manufacturing the welded joint according

to any one of Claims 1 to 5, wherein a weld metal is formed in a root gap between both steel materials, and a weld reinforcement built up on the surfaces of both steel materials is formed on at least one of the surfaces.

[Claim 7]

The method for manufacturing the welded joint according to Claim 6, wherein welding is performed by providing a backing metal or a recess-type backing metal in the root gap.