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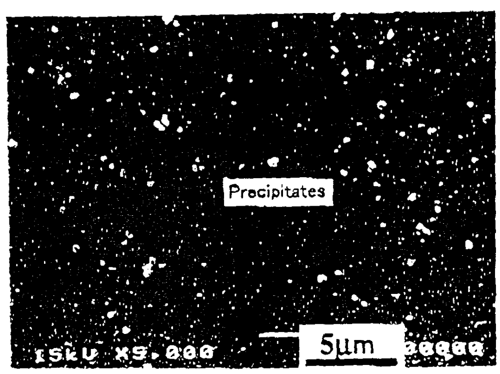
(54) **Heavy wall steel material having superior weldability and method for producing the same**

(57) A tough high strength heavy wall steel material having superior weldability is provided, said steel material has a diameter or a side 5 mm or more in length, and comprises oxides 1 µm or less in particle diameter homogeneously dispersed at a dispersion density in a range of from10,000 to 100,000 particles/mm^2 and uniform ferrite grains 2 µm or less in grain diameter formed over the entire plane making a right angle with respect to the rolling direction.

Fig. 1



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Description

[0001] The invention of the present application relates to a heavy wall steel material having superior weldability and to a method for producing the same. In further detail, the invention of the present application relates to a highly tough high strength heavy wall steel material having superior weldability and to a method for producing the same.

[0002] It is well known that the strength and the toughness of a steel can be improved effectively by reducing the size of ferrite grains. For heavy wall steel materials such as rods, wires, and profiles, there is proposed a process comprising a sequence of steps of hot rolling using a profile mold and recrystallization. By employing this process, it is proposed possible to create a heavy wall steel material having such a plane making a right angle with respect to the rolling direction having a diameter or a side 5 mm or more in length and comprising a ferrite-based texture containing ferrite grains with a nominal grain diameter of 2 μm or less in diameter can be obtained.

[0003] On the other hand, however, when a steel is welded, there is observed a phenomenon as such that coarse acicular Widmanstatten ferrites form in the heat affected zone (HAZ). Such coarsening of crystal grains impairs the toughness of the HAZ.

[0004] Accordingly, an object of the invention according to the present application is to provide the novel type of heavy wall steel material above, having increased strength and toughness and still improved in weldability. Another object of the present invention is to provide a method for producing the same.

[0005] According to the invention of the present application, there is provided a heavy wall steel material having superior weldability, which is a steel material having a diameter or a side 5 mm or more in length and which comprises oxides 1 μm or less in grain diameter homogeneously dispersed at a dispersion density in a range of from 10,000 to 100,000 particles/mm^2 and uniform ferrite grains 2 μm or less in grain diameter formed over the entire plane making a right angle with respect to the rolling direction (Claim 1).

[0006] According to another aspect of the present invention, there is provided a method for producing a heavy wall steel material having superior weldability, which comprises allowing oxide crystals 1 μm or less in grain diameter to form in the texture and uniformly dispersing them at a dispersion density of from 10,000 to 100,000 particles/mm^2, rolling the resulting steel material through a hole profile in the temperature range of 400 °C or higher but not higher than the Ac3 transformation point, and subjecting it to a recrystallization treatment to form uniform ferrite grains 2 μm or less in grain diameter over the plane making a right angle with respect to the rolling direction, thereby obtaining a heavy wall steel material having superior weldability and having a diameter or a side 5 mm or more in length (Claim 2).

[0007] In accordance with other aspects of the present invention, there are provided preferred embodiments for the method for producing a heavy wall steel material having superior weldability as above, wherein the method comprises undercooling a molten steel by placing it inside an oxide slag, thereby allowing oxide crystals 1 μm or less in grain diameter to form in the texture and uniformly dispersing them at a dispersion density of from 10,000 to 100,000 particles/mm^2 (Claim 3), and wherein the molten steel contains:

Carbon (C) at an amount corresponding to a quantity as such that carbides account for 20 % by volume or less in the resulting material;
silicon (Si) accounting for 0.8 % by weight or less;
manganese (Mn) accounting from 0.05 to 3.0 % by weight;
at least one element which forms oxides, which is selected from the group consisting of Ti, Mg, and Al, said elements accounting for 0.3 % by weight either alone or in the form of a mixture thereof; and
balance iron (Fe) together with unavoidable impurities.

BRIEF EXPLANATION OF THE DRAWINGS

[0008]

FIG. 1 shows a micrograph obtained under a scanning electron microscope, provided in the place of a drawing showing the texture of a steel rod material according to Example 1 of the present invention; and
FIG. 2 (a) and FIG. 2 (b) are each a micrograph obtained under a scanning electron microscope provided in the place of a drawing, showing the texture of the reproduced HAZ obtained after the heat treatment of a constitutional rod material according to Example 1 and Comparative Example 2 of the present invention.

[0009] The heavy wall steel material according to the application of the present invention is a steel material which is characterized by its heavy wall and its plane making a right angle with respect to the rolling direction, said plane having a diameter or a short side 5 mm or more in length and comprising ferrite grains 2 μm or less in diameter uniformly dispersed over the entire plane, and characterized by being produced by hot rolling using a series of profile molds and recrystallization treatment. This material is available in various forms, such as a rod, a wire, a profile, etc.

[0010] The heavy wall steel material having superior weldability according to the invention of the present application comprises oxides 1 μm or less in grain diameter homogeneously dispersed at a dispersion density in a range of from 10,000 to 100,000 grains/mm^2.

[0011] These oxides 1 μm or less in grain diameter increase the internal strain which generates during rolling of the material, and thereby divide the recrystallized ferrite grains into finer grains 2 μm or less in grain diameter. By finely reducing the ferrite grains, the strength and the toughness of the heavy wall steel material can be further increased. For instance, a heavy wall steel material having a tensile strength of 660 MPa or higher can be realized. The grain diameter of the oxides is confined to 1 μm or less by taking the strength and the toughness of the heavy wall steel material into account. If the grain diameter of the oxides should exceed 1 μm, on the other hand, the strength and the toughness of the heavy wall steel material suffer unfavorable influences.

[0012] Furthermore, because the oxides 1 μm or less in grain diameter are uniformly dispersed in the texture at a dispersion density in a range of from 10,000 to 100,000 particles/mm^2, the oxides dispersed in the heat affected zone (HAZ) during welding function as nuclei to accelerate the generation of ferrites, and prevent the coarsening of crystal grains from occurring. Thus, the generation of coarse acicular Widmanstatten ferrites can be suppressed to improve the toughness at the HAZ.

[0013] As described above, the heavy wall steel material having superior weldability according to the invention of the present application exhibits a further improved strength and toughness as compared with the conventional products, and yet, has excellent weldability. Such superior characteristics are enabled by uniformly dispersing the oxides at a predetermined grain diameter and at a particular dispersion density and by the ferrite grains of predetermined grain diameter formed over the entire plane making a right angle with respect to the rolling direction, but not by the conventionally employed means, i.e., the addition of a particular alloying element such as nickel (Ni).

[0014] The heavy wall steel material having superior weldability according to the invention of the present application can be produced in the following manner.

[0015] That is, the process comprises allowing oxide crystals 1 μm or less in grain diameter to form in the texture and uniformly dispersing them at a dispersion density of from 10,000 to 100,000 particles/mm^2, rolling the resulting steel material through a hole profile in the temperature range of 400 °C or higher but not higher than the Ac3 transformation point, and subjecting it to a recrystallization treatment to form uniform ferrite grains 2 μm or less in grain diameter over the plane making a right angle with respect to the rolling direction. In this manner, a heavy wall steel material having superior weldability and having a diameter or a side 5 mm or more in length can be obtained.

[0016] Profile rolling using a hole mold is effective for the formation of fine textures in the material, because the steel material can be processed from multiple directions, i.e., the material can be processed multiaxially, such as in the case of grooved roll processing. At the same time, the process steps for producing fine textures can be simplified.

[0017] The process temperature for profile rolling is in a range of 400 °C or higher but not higher than the Ac3 transformation point. If the temperature should be lower than 400 °C, the texture turns into a simple ferrite texture elongated along a single direction and would not form an isometric texture. This results in a strength showing anisotropy. If the temperature exceeds the Ac3 transformation point, on the other hand, the rate of grain growth becomes too high as to coarsen the texture, and this impairs the strength and the toughness of the material.

[0018] Uniform ferrite grains 2 μm or less in grain diameter are available over the entire plane making a right angle with respect to the rolling direction by performing the profile rolling and the recrystallization treatment subsequent thereto.

[0019] In the method for producing the heavy wall steel material having superior weldability according to the invention of the present application, oxide crystals 1 μm or less in grain diameter are formed in the texture and are uniformly dispersed at a dispersion density of from 10,000 to 100,000 particles/mm^2 prior to the sequential profile rolling and recrystallization treatment. This can be realized by various ways, and preferably exemplified among them is the method using undercooling.

[0020] More specifically, undercooling is effected by placing the molten steel inside slag of oxides.

[0021] Undercooling is a state in which the melt is held at a temperature not higher than the melting point. The maximum degree of undercooling is one-fifth of the melting point. The solidification rate of the molten steel to be undercoolod is not only higher than that of rapid solidification, but also a rate non-achievable by rapid solidification. Thus, the aggregation of secondary deoxidized product, which is initially not present in molten steel and which generates by the oxygen discharged from the solid phase portion into the molten steel, can be prevented from occurring. The increase in particle diameter of the oxide can also be suppressed. As a result, the generation of further finer oxides is promoted, and these oxides can bo dispersed at a higher density. In the case of undercooling, the dispersion density of the resulting oxides attain twice or more of that achieved in rapid solidification.

[0022] The undercooling above can be realized, more specifically, by covering the molten steel with the slag, or by flowing the molten steel into the slag.

[0023] Concerning the chemical composition of a molten steel for use in the present invention, there can be exemplified such containing:

carbon (C) at an amount corresponding to a quantity as such that carbides account for 20 % by volume or less in the resulting material;
silicon (Si) accounting for 0.8 % by weight or less;
manganese (Mn) accounting from 0.05 to 3.0 % by weight;
at least one element which forms oxides, which is selected from the group consisting of Ti, Mg, and Al, said elements accounting for 0.3 % by weight either alone or in the form of a mixture thereof; and
balance iron (Fe) together with unavoidable impurities.

[0024] In the chemical composition above, the content of the components is confined in the range above based on the fact as follows.
[0025] In case of carbon (C), if carbides such as cementite accounts for 20 % by volume or more of the material, there occurs a drop in toughness. Accordingly, it is preferred that C is incorporated in the material at a quantity as such that the carbide accounts for 20 % by volume or less in the material.
[0026] If the content of silicon (Si) is present at an amount exceeding 0.8 % by weight, the steel becomes extremely brittle.
[0027] In order to obtain a steel with a sufficiently high strength, manganese (Mn) should be present at an amount of 0.05 % by weight or more. However, the presence of Mn at an amount in excess of 3.0 % by weight considerably impairs the weldability. Accordingly, the content of Mn is preferably in a range of from 0.05 to 3.0 % by weight.
[0028] An element which produces oxides, i.e., titanium (Ti), magnesium (Mg), or aluminum (Al), is incorporated at a concentration of 0.3 % by weight or less, which corresponds to an amount for the case it is present as oxide grains 1 μm or less in diameter dispersed in the texture at a dispersion density of 100,000 grains/mm^2.
[0029] As a matter of course, the molten steel may contain other alloying elements which impart other characteristics to the steel material. However, their addition must be made by taking into consideration that it may not impair the particle diameter and the dispersion density, or the roll processability.
[0030] In practice, a molten steel containing Ti as the oxide generating element was covered with a slag containing a plurality of oxides, and was undercooled by a degrees of 90 K to suppress the generation of nuclei from the surface of molten steel. In this manner, Ti oxide, which is one of the secondary deoxidized products, was dispersed as particles 1 μm or less in diameter and at a dispersion density of 50,000 grains/mm^2 or higher.
[0031] The heavy wall steel material having excellent weldability according to the present invention and the method for producing the same is described in further detail below by making reference to examples.

<u>EXAMPLE 1</u>

[0032] A steel having the chemical composition given in Table 1 below was buried in a mixed oxide powder or granules comprising SiO_2, Al_2O_3, and Na_2O, and was molten in an induction furnace or by resistance heating under a non-oxidizing atmosphere. The resulting molten steel was covered with a slag of glassy mixed oxides, and was heated to a temperature 50 K or higher than the liquidus temperature. The molten steel was allowed to stand still until the primary deoxidized products were adsorbed by the slag.

Table 1

Chemical composition (% by weight)					
C	SI	Mn	P	S	Ti
0.15	0.19	1.51	0.019	0.02	0.08

[0033] Then, the molten steel allowed to stand still was undercooled, and the solidification thereof was initiated at a temperature 60 K lower than the solidus temperature to prepare a cast specimen 40 mm in diameter and 60 mm in length.
[0034] The cast specimen was reheated to 1,200 °C, and was processed into a 30 × 30 × 85 mm specimen by forging. The forged specimen was recrystallized by water-cooling, followed by holding it in the furnace at a temperature of 640 °C for a duration of 300 seconds. Subsequently, the specimen was subjected to grooved rolling at a draught of about 10 % per single pass to perform hole profile rolling. The specimen was subjected to repeated hole profile rolling and the subsequent recrystallization treatment until a total area reduction of 90 % was achieved, and was then water-cooled.
[0035] Thus was obtained a steel rod material 5 mm in diameter (Example 1).
[0036] FIG. 1 is a micrograph obtained with a scanning electron microscopy showing the texture of the steel rod material thus obtained in Example 1.

[0037] The micrograph of FIG. 1 shows the image of the C-cross section, i.e., the cross section vertical to the rolling direction. Referring to FIG. 1, the white colored portion shows the oxides, and the black colored portion shows the texture of mixed ferrite and carbide. The oxides are the Ti-Mn-Si complex oxides, and are dispersed at a density of 54,000 particles/mm^2. From FIG. 1, it is confirmed that the texture of mixed ferrite and carbide has an average diameter of 0.75 μm, and that it is uniformly distributed from the surface layer to the center of the specimen.

[0038] The rod material thus obtained was subjected to the measurement of tensile strength (TS), lower yield strength (LYS), uniform elongation (U.EL), and the total elongation (T.EL). For comparison, the same measurement was performed on a steel rod material (Comparative Example 1) comprising oxides dispersed at a dispersion density of several hundreds of particles per 1-mm^2 area and a texture of mixed ferrite and carbide having an average diameter of 0.79 μm.

[0039] The results are given in Table 2.

Table 2

	Example 1	Comparative Ex. 1
Dispersion density of oxides (particles/mm^2)	54,000	Several hundreds
Diameter of oxides (μm)	≤ 1	≥ 5
Draught (%)	90	90
Ferrite grain diameter (μm)	0.75	0.79
TS (MPa)	775	724
LYS (MPa)	754	685
U.EL (%)	3.58	7.30
T. EL (%)	13.44	14.10

[0040] From Table 2, it is clear that the steel rod material of Example 1 yields a tensile strength (TS) and a lower yield strength (LYS) of 700 MPa or higher, showing that the strength is higher than that of the steel rod material of Comparative Example 1, which contains less oxides dispersed therein. Furthermore, the steel rod material according to Example 1 yields a uniform elongation (U. EL) and a total elongation (T. EL) both at a value of 10 % or higher, and is therefore confirmed that this material exhibits sufficiently high toughness.

[0041] The steel rod materials of Example 1 and Comparative Example 1 were compared with each other for their weldability.

[0042] The rod materials were each heated to 1,400 °C at a heating rate of 100 K/s, and were then cooled therefrom to 900 °C at a cooling rate of 50 K/s, followed by further cooling to 300 °C at a cooling rate of 10 K/s, to thereby reproduce the heat affected zone (HAZ) which form at welding. The results are shown by the scanning electron micrographs given in FIGs. 2(a) and 2(b).

[0043] In the steel rod material according to Example 1, it can be seen that polygonal ferrite having superior toughness is formed therein as indicated by an arrow in the figure. Furthermore, it is confirmed that ferrite is formed inside the austenite grains. The brittle fraction transition temperature, which represents the toughness, is -40 °C; this shows that a sufficiently high toughness is achieved.

[0044] As indicated by an arrow in FIG. 2(b), on the other hand, it can be seen that coarse Widmanstatten ferrites are formed in the steel rod material according to Comparative Example 1. The generation of Widmanstatten ferrites is known as a factor which impairs the toughness of the heat affected zone (HAZ) generated by welding.

[0045] As described in detail above by making reference to a specific example, the invention according to the present application provides a heavy wall steel material in various shapes such as a rod, a wire, a profile, etc., comprising fine oxides uniformly dispersed at a high density and thereby having superior strength as well as toughness, and furthermore improved in weldability.

[0046] while the invention has been described in detail by making reference to specific embodiments, it should be understood that various changes and modifications can be made without departing from the scope and the spirit of the present invention.

Claims

1. A heavy wall steel material having superior weldability, which is a steel material having a diameter or a side 5 mm or more in length and which comprises oxides 1 μm or less in particle diameter homogeneously dispersed at a dispersion density in a range of from 10,000 to 100,000 particles/mm^2 and uniform ferrite grains 2 μm or less in

grain diameter formed over the entire plane making a right angle with respect to the rolling direction.

2. A method for producing a heavy wall steel material having superior weldability, which comprises allowing oxide crystals 1 μm or less in particle diameter to form in the texture and uniformly dispersing them at a dispersion density of from 10,000 to 100,000 particles/mm^2, rolling the resulting steel material through a hole profile in the temperature range of 400 °C or higher but not higher than the Ac3 transformation point, and subjecting it to a recrystallization treatment to form uniform ferrite grains 2 μm or less in grain diameter over the plane making a right angle with respect to the rolling direction, thereby obtaining a heavy wall steel material having superior weldability and having a diameter or a side 5 mm or more in length.

3. A method for producing a heavy wall steel material having superior weldability as claimed in Claim 2, wherein the method comprises undercooling a molten steel by placing it inside an oxide slag, thereby allowing oxide crystals 1 μm or less in particle diameter to form in the texture and uniformly dispersing them at a dispersion density of from 10,000 to 100,000 particles/mm^2.

4. A method for producing a heavy wall steel material having superior weldability as claimed in Claim 3, wherein the molten steel contains:

carbon (C) at an amount corresponding to a quantity as such that carbides account for 20 % by volume or less in the resulting material;
silicon (Si) accounting for 0.8 % by weight or less;
manganese (Mn) accounting from 0.05 to 3.0 % by weight;
at least one element which forms oxides, which is selected from the group consisting of Ti, Mg, and Al, said elements accounting for 0.3 % by weight either alone or in the form of a mixture thereof; and
balance iron (Fe) together with unavoidable impurities.

Fig. 1

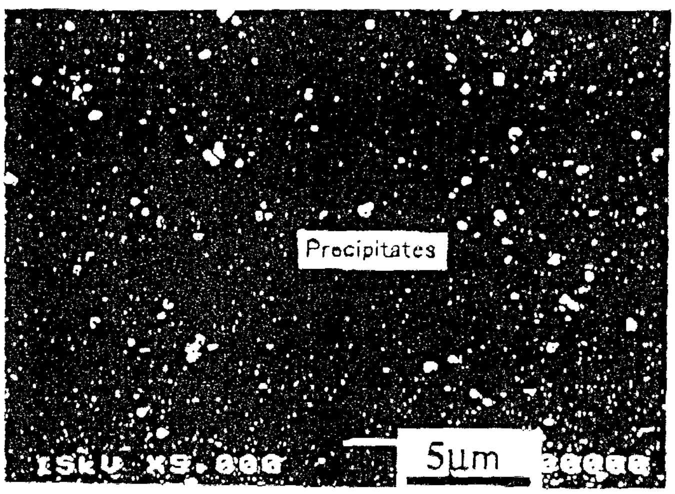
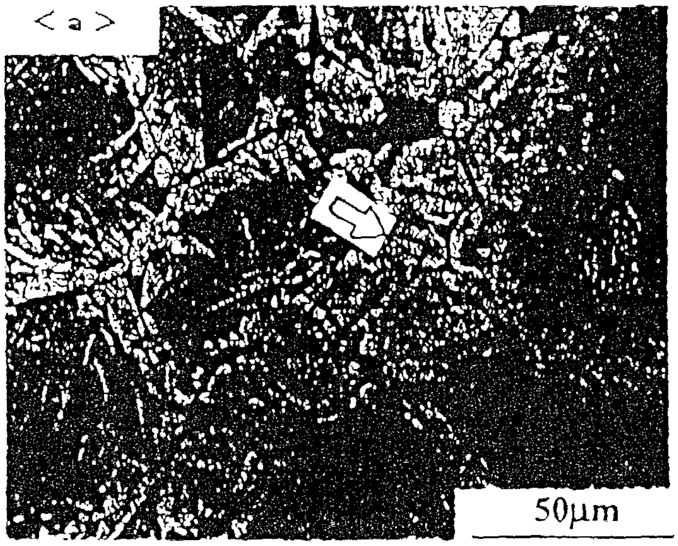


Fig. 2

<a>



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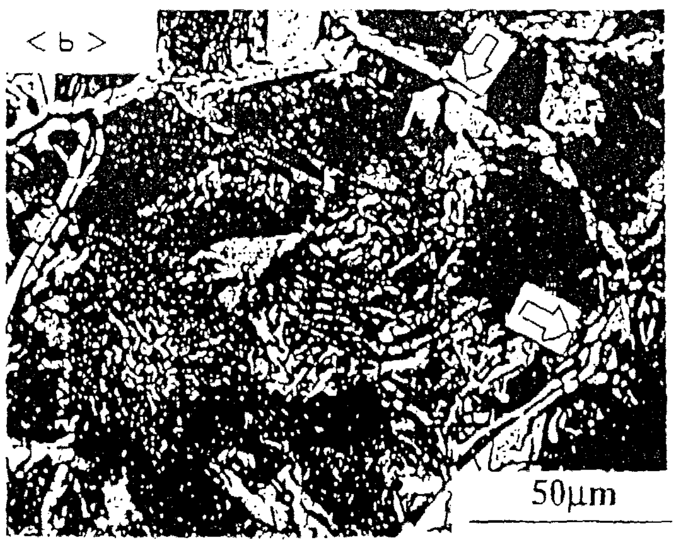

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