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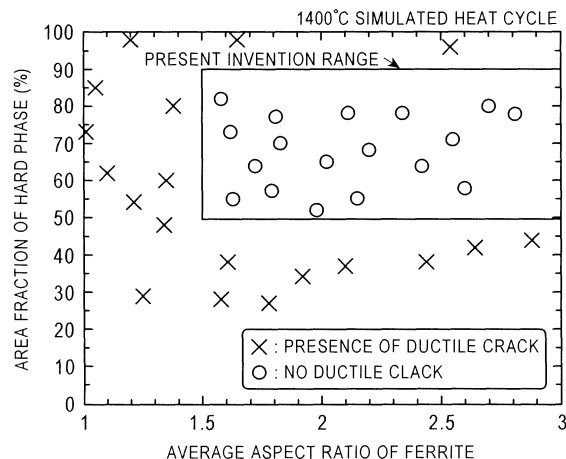
(54) **STEEL WITH EXCELLENT ANTI-DUCTILE CRACK GENERATION CHARACTERISTICS IN WELD HEAT-AFFECTED ZONE AND BASE MATERIAL AND MANUFACTURING METHOD THEREFOR**

(57) This invention relates to steel materials suitable for use in welded structures, such as pipelines, bridges, and architectural structures, requiring structural safety and a method for manufacturing the same and particularly relates to improvement of resistance of ductile crack initiation from welded heat affected zone and a base material.

Specifically, a steel material has a composition of C: 0.02 to 0.2%, Si: 0.01 to 0.5%, Mn: 0.5 to 2.5%, P: 0.05% or lower, S: 0.05% or lower, Al: 0.1% or lower, and N:

0.01% or lower and, as required, one or two or more elements selected from Cu: 0.01 to 2%, Ni: 0.01 to 5%, Cr: 0.01 to 3%, Mo: 0.01 to 2%, Nb: 0.1% or lower, V: 0.1% or lower, Ti: 0.1% or lower, B: 0.01% or lower, Ca: 0.01% or lower, and REM: 0.1 % or lower in terms of % by mass, and the balance Fe with inevitable impurities, in which the microstructure at the 1/4 position of the plate thickness contains ferrite and a hard phase, the area fraction of the hard phase is 50 to 90%, and the average aspect ratio of the ferrite is 1.5 or more.

FIG. 2



Description

Technical Field

[0001] The present invention relates to steel materials suitable for use in welded structures, such as pipelines, bridges, and architectural structures, requiring structural safety and a method for manufacturing the same and particularly relates to one excellent in resistance of ductile crack initiation from welded heat affected zone and a base material. Specifically, the invention is targeted to steel materials for structures having excellent resistance of ductile crack initiation from welded heat affected zone and a base material and having strength of Tensile strength: 490 MPa or more in TS and high toughness of Ductile-brittle fracture transition temperature of Charpy impact test (according to the regulation of JIS Z 2242): $vTrs$ of 0°C or lower.

Background Art

[0002] It is known that when the welded structures, such as pipelines, bridges, and buildings, are exposed to large external force of an earthquake or the like, ductile crack initiates in a stress concentration zone, such as a weld toe, and the generated ductile crack serves as a trigger to cause brittle fracture, resulting in break and fracture of the structures in some cases.

[0003] In order to avoid such break and fracture of the welded structures, it is important that steel materials constituting the same are excellent in resistance of ductile crack initiation.

[0004] Patent Document 1 discloses a high tensile-strength steel material excellent in resistance of ductile crack initiation in which, in the microstructure a steel material surface zone, the ferrite area fraction is 10 to 40%, the bainite area fraction is 50% or more, and the average grain size is 5 μm or lower.

[0005] Patent Document 2 discloses a steel plate excellent in arrestability and resistance of ductile fracture in which the microstructure is substantially constituted by a ferrite structure, a pearlite structure, and a bainite structure and, when divided into three layers of both surface zones and the central zone in the plate thickness direction of the steel plate, each zone has a specific microstructure.

[0006] Both the surface zones of the steel plate are constituted by a layer which has 50% or more of a ferrite structure containing ferrite grains in which the equivalent (circle) diameter is 7 μm or lower and the aspect ratio is 2 to 4 over 5% or more of the plate thickness of each of the structure zones and in which the bainite area fraction of the portion is 5 to 25% or lower. The central zone in the plate thickness direction of the steel plate is constituted by a layer which contains ferrite grains in which the equivalent (circle) diameter is 4 to 10 μm and the aspect ratio is 2 or lower over 50% or more of the plate thickness and in which the bainite area fraction of the zones is 10% or lower.

More specifically, the technique of Patent Document 2 is directed to a steel plate in which three layers having a ferrite/pearlite structure containing ferrite grains different in the aspect ratio are present in the plate thickness direction from the plate surface of the steel plate and further in which a bainite structure which is a hard phase is appropriately dispersed in a soft phase which is the ferrite/pearlite structure. The technique increases the arrestability by positively forming processed ferrite grains having a high aspect ratio and also appropriately dispersing a bainite structure on each of both the surface zones of the three zones of the steel plate and, in contrast, increases extension characteristics, which are important to ductile fracture at room temperature, by controlling the central zone of the steel plate to have a uniform equiaxed ferrite grain structure and also suppressing a bainite structure, and thus satisfies both opposite characteristics of "arrestability" and "ductile fracture characteristics" by controlling both the surface zones and the central zone of the steel plate to the three-layer structure.

[0007] Also the technique of Patent Document 3 is directed to a technique of obtaining deformed ferrite grains on the steel plate surface zone of ferrite/pearlite steel and also controlling the microstructure of the central zone to a uniform equiaxed ferrite grain structure similarly as the technique of Patent Document 2.

More specifically, Patent Document 3 discloses a method for manufacturing a thick steel plate excellent in arrestability and ductile fracture characteristics, in which the rolling conditions are strictly controlled so that the steel plate surface zone has a specific microstructure.

[0008] Specifically, when the thickness during plate rolling is defined as t , an equivalent plastic strain ϵ of $\epsilon \geq 0.5$ in a non-recrystallization temperature zone of Ar_3 transformation point or more and 900°C or lower is given to a surface layer zone of 0.05 t or more and 0.15 t or lower from both the surfaces in the plate thickness direction.

[0009] Thereafter, the surface layer zone is cooled to a temperature range of 450 to 650°C at a cooling rate of 2 to 15°C/s while maintaining the temperature of the central zone defined as $t/4$ to $3t/4$ of the plate thickness at the Ar_3 transformation point or more within a period of time when the residual and cumulative equivalent plastic strain ϵ_r of the surface layer zone satisfies $\epsilon_r \geq 0.5$, and subsequently rolling is restarted.

[0010] In the restarted rolling, the residual and cumulative equivalent plastic strain ϵ_r of 0.35 $\leq \epsilon_r < 0.55$ is given to the central zone to complete the rolling at the Ar_3 transformation point or more and also the surface layer is recuperated

to the Ar_3 transformation point or lower by processing heat and internal sensible heat, and thereafter cooling is performed in such a manner that the average cooling rate is 1 to 10°C/s.

The techniques of Patent Documents 1 to 3 all relate to techniques of forming fine subgrains in austenite to miniaturize the structure after transformation by performing rolling in a non recrystallization zone (fine grain temperature zone) of austenite or performing rolling at a rolling finish temperature Ar_3 or more.

Citation List

Patent Literature

[0011]

[Patent Document 1] Japanese Unexamined Patent Application Publication No. 2008-202119

[Patent Document 2] Japanese Unexamined Patent Application Publication No. 2000-328177

[Patent Document 3] Japanese Unexamined Patent Application Publication No. 2003-221619

Disclosure of Invention

Problems to be Solved by the Invention

[0012] However, according to the techniques of Patent Documents 1 to 3, when the surface layer structure changes to the welded heat affected zone by welding or the like, there is a concern that the effect of resistance of ductile crack initiation is lost.

[0013] Moreover, in all of a scale breaker for use in treatment of the surface of a slab extracted from a heating furnace described in Examples of Patent Document 1, two-stage rolling of rolling in a pulverization temperature range and rolling in a set temperature zone described in Examples of Patent Document 2, and various kinds of rolling or temperature control for separately creating the structure of a surface layer and the structure inside a steel plate described in Patent Document 3, the manufacturing process is complicated.

[0014] Then, in view of the problems of such former techniques, it is an object of the present invention to provide steel materials excellent in resistance of ductile crack initiation from the welded heat affected zone and a base material by a simple method and a method for manufacturing the same.

Means for Solving the Problems

[0015] In order to achieve the object, the present inventors have conducted extensive researches on a microstructure of base material excellent in resistance of ductile crack initiation of a welded heat affected zone and have found that, when a microstructure of base material has ferrite and a hard phase in which the average aspect ratio of the ferrite and the area fraction of the hard phase are specified at the 1/4 position of the plate thickness exhibiting an average structure in the plate thickness direction of a steel plate, the resistance of ductile crack initiation is excellent also in a welded heat affected zone and such a steel material is excellent also in the resistance of ductile crack initiation of the base material, and further manufacturing conditions of a steel plate having the microstructure.

[0016] The present invention has been accomplished based on the findings and further researches and is more specifically directed to:

(1) A steel material excellent in resistance of ductile crack initiation from welded heat affected zone and a base material has a composition of C: 0.02 to 0.2%, Si: 0.01 to 0.5%, Mn: 0.5 to 2.5%, P: 0.05% or lower, S: 0.05% or lower, Al: 0.1% or lower, and N: 0.01% or lower in terms of % by mass, and the balance Fe with inevitable impurities, in which the microstructure at the 1/4 position of the plate thickness contains ferrite and a hard phase, the area fraction of the hard phase is 50 to 90%, and the average aspect ratio of the ferrite is 1.5 or more.

(2) The steel material excellent in resistance of ductile crack initiation from welded heat affected zone and a base material according to (1), further contains, in the chemical composition, one or two or more elements selected from Cu: 0.01 to 2%, Ni: 0.01 to 5%, Cr: 0.01 to 3%, Mo: 0.01 to 2%, Nb: 0.1% or lower, V: 0.1% or lower, Ti: 0.1% or lower, B: 0.01% or lower, Ca: 0.01% or lower, and REM: 0.1 % or lower in terms of % by mass.

(3) In the steel material excellent in resistance of ductile crack initiation from welded heat affected zone and a base material according to (1) or (2) above, the structure on the surface of a steel plate contains ferrite and a hard phase, the area fraction of the ferrite exceeds 40%, and the average aspect ratio of the ferrite grain size exceeds 2.

(4) A method for manufacturing a steel material excellent in resistance of ductile crack initiation from welded heat affected zone and a base material includes reheating a steel base material having the chemical compositions of (1)

or (2) to 1000°C or more, rolling the same in such a manner that the rolling reduction rate in a temperature range of 900°C or more is 50% or more and the rolling finish temperature is Ar_3 point to $Ar_3-50^\circ C$, starting water cooling at $Ar_3-10^\circ C$ to $Ar_3-70^\circ C$, and terminating the water cooling at 500°C or lower.

(5) The method for manufacturing a steel material excellent in resistance of ductile crack initiation from welded heat affected zone and a base material according to (4) further includes, after the water cooling, performing tempering treatment at a temperature of lower than the highest heating temperature Ac_1 point.

Advantages

[0017] According to the invention, a steel material capable of suppressing ductile crack initiation from welded heat affected zone and a base material that can suppress ductile crack initiation from a stress concentration zone, such as a weld toe, and prevent collapse or break of steel structures even when the steel structures greatly deform due to an earthquake or the like, for example, can be easily and stably mass-produced and industrially remarkable effects are demonstrated.

Brief Description of Drawings

[0018]

[Fig. 1] Fig. 1 is a view illustrating a ductile crack initiation test method of a welded heat affected zone.

[Fig. 2] Fig. 2 is a view illustrating influence of the area fraction of a hard phase and the average aspect ratio of ferrite on ductile crack initiation of a 1400°C simulated heat cycle material.

[Fig. 3] Fig. 3 is a view illustrating a ductile crack initiation test method of a base material.

[Fig. 4] Fig. 4 is a view illustrating influence of the area fraction of a hard phase and the average aspect ratio of ferrite on ductile crack initiation of a base material. Best Modes for Carrying Out the Invention

[0019] In the invention, the chemical composition and the microstructure are specified. In the description of the chemical composition, % by mass is simply represented by % unless otherwise specified.

[Chemical composition]

C: 0.02 to 0.2%

[0020] C is an element having an action of increasing the strength of steel and, particularly in the invention, contributes to the generation of a hard phase. In order to obtain such an effect, the C content of 0.02% or more is required. In contrast, when the C content exceeds 0.2%, the ductility or the bending workability are reduced and also the weldability decreases. Therefore, the C content is limited in the range of 0.02 to 0.2%. More preferably, the C content is 0.02 to 0.18%.

Si: 0.01 to 0.5%

[0021] Si acts as a deoxidizing agent and has an action of forming a solid solution to increase the strength of steel. In order to obtain such an effect, the Si content of 0.01% or more is required. In contrast, when the Si content exceeds 0.5%, the toughness is reduced and also the weldability is reduced. Therefore, Si is limited in the range of 0.01 to 0.5%. More preferably, the Si content is 0.01 to 0.4%.

Mn: 0.1 to 2.5%

[0022] Mn has an action of increasing the strength of steel and also increasing the toughness through an increase in hardenability. In order to obtain such an effect, the Mn content of 0.1% or more is required. In contrast, when the Mn content exceeds 2.5%, the weldability is reduced. Therefore, Mn is limited in the range of 0.1 to 2.5%. More preferably, the content is 0.5 to 2.0%.

P: 0.05% or lower

[0023] Since P causes degradation of toughness, the P content is preferably reduced as much as possible, but the content up to 0.05% is permissible. Therefore, the P content is limited to 0.05% or lower. More preferably, the content is 0.04% or lower.

S: 0.05% or lower

[0024] Since S is present as an inclusion in steel and degrades the ductility and the toughness, the S content is preferably reduced as much as possible. However, the content up to 0.05% is permissible. Therefore, the S content is limited to 0.05% or lower. More preferably, the content is 0.04% or lower.

Al: 0.1% or lower

[0025] Al is an element that acts as a deoxidizing agent and also contributes to pulverization of crystal grains. However, an excessive content of Al in a proportion exceeding 0.1% causes a reduction in toughness. Therefore, the Al content is limited to 0.1% or lower. More preferably, the content is 0.05% or lower.

N: 0.01% or lower

[0026] N is an element that increases the strength of steel by solid solution strengthening similarly as C. However, an excessive content of N causes a reduction in toughness. Therefore, the N content is limited to 0.01% or lower. More preferably, the content is 0.005% or lower.

[0027] The chemical compositions described above are basic chemical compositions but, in the invention, one or two or more elements selected from Cu: 0.01 to 2%, Ni: 0.01 to 5%, Cr: 0.01 to 3%, Mo: 0.01 to 2%, Nb: 0.1% or lower, V: 0.1% or lower, Ti: 0.1% or lower, B: 0.01% or lower, Ca: 0.01% or lower, and REM: 0.1% or lower may be further contained according to the desired properties.

Cu: 0.01 to 2%

[0028] Cu is an element that has an action of increasing the strength of steel through an increase in hardenability or solid solution. In order to secure such an effect, the content of 0.01% or more is required. In contrast, when the content exceeds 2%, the weldability decreases and also cracks are likely to generate during manufacturing of steel materials. Therefore, when Cu is added, the content is in the range of 0.01 to 2%. More preferably, the content is 0.01 to 1%.

Ni: 0.01 to 5%

[0029] Ni is added as required, because Ni contributes to an increase in low temperature toughness, an increase in hardenability, and prevention of hot ductility of Cu when Cu is contained. Such an effect is recognized when Ni is contained in the proportion of 0.01% or more. However, the addition of 5% or more causes a reduction in steel material cost and also a reduction in weldability. Therefore, when Ni is added, the content is in the range of 0.01 to 5%. More preferably, the content is 0.01 to 4.5%.

Cr: 0.01 to 3%

[0030] Cr is added as required in order to increase the strength of steel materials through an improvement of hardenability or an increase in tempering softening resistance. Such an effect is recognized when Cr is contained in the proportion of 0.01% or more. In contrast, the addition exceeding 3% reduces weldability and toughness. Therefore, when Cr is added, the content is in the range of 0.01 to 3%. More preferably, the content is in the range of 0.01 to 2.5%.

Mo: 0.01 to 2%

[0031] Mo is added as required in order to increase the strength of steel materials through an improvement of hardenability or an increase in tempering softening resistance. Such an effect is recognized when Mo is contained in the proportion of 0.01% or more. In contrast, the addition exceeding 2% reduces weldability or toughness. Therefore, when Mo is added, the content is in the range of 0.01 to 2%. More preferably, the content is in the range of 0.01 to 1%.

Nb: 0.1% or lower

[0032] Nb is an element that precipitates as a carbide or a carbonitride in tempering and increases the strength of steel through precipitation strengthening. Moreover, Nb also has an effect of pulverizing austenite grains during rolling to increase toughness. In order to obtain the effects, the content of 0.001% or more is preferable. However, the content exceeding 0.1% reduces toughness. Therefore, when Nb is added, the content is 0.1% or lower. More preferably, the content is 0.05% or lower.

V: 0.1% or lower

[0033] V is an element that precipitates as a carbide or a carbonitride in tempering and increases the strength of steel through precipitation strengthening. Moreover, V also has an effect of pulverizing austenite grains during rolling to increase toughness. In order to obtain the effects, the content of 0.001% or more is preferable. However, the content exceeding 0.1% reduces toughness. Therefore, when Nb is added, the content is 0.1% or lower. More preferably, the content is 0.05% or lower.

Ti: 0.1% or lower

[0034] Ti is added as required because Ti has an effect of pulverizing austenite in a welded heat affected zone to increase toughness. In order to obtain the effect, the content of 0.001% or more is preferable. However, the addition exceeding 0.1% reduces toughness and also causes a sudden rise of steel material cost. Therefore, when Ti is added, the content is 0.1% or lower. More preferably, the content is 0.05% or lower.

B: 0.01% or lower

[0035] B is added as required because B has an effect of increasing hardenability and increasing the strength of steel with a small content thereof. In order to obtain the effect, the content is preferably 0.0001% or more. However, the addition exceeding 0.01% reduces weldability. Therefore, when B is added, the content is 0.01% or lower. More preferably, the content is 0.005% or lower.

Ca: 0.01% or lower

[0036] Ca is added as required because Ca increases the base material toughness by controlling the shape of a CaS inclusion and further increase the toughness of a welded heat affected zone. In order to obtain the effects, the content of 0.0001% or more is preferable. However, the addition exceeding 0.01% reduces toughness due to an increase in the amount of the CaS inclusion. Therefore, when Ca is added, the content is 0.01% or lower. More preferably, the content is 0.009% or lower.

REM: 0.1% or lower

[0037] REM is an element that increases the toughness of a welded heat affected zone and is added as required. In order to obtain the effect, the content is preferably 0.0001% or more. However, the addition exceeding 0.1% causes a reduction in toughness. Therefore, when REM is added, the content is 0.1% or lower. More preferably, the content is 0.05% or lower.

[0038] REM is a general term of Y, Ce and the like that are rare earth elements and the addition amount as used herein refers to the total amount of these rare earth elements.

[Microstructure]

[0039] The steel material according to the invention has a microstructure in which the structure at the 1/4 position of the plate thickness contains ferrite and a hard phase, the area fraction of the hard phase is 50 to 90%, and the average aspect ratio of the ferrite grain size is 1.5 or more. When the area fraction of the hard phase is lower than 50% and exceeds 90% or the aspect ratio of the ferrite grain size is lower than 1.5, there is a possibility that ductile crack initiation occurs.

The upper limit of the average aspect ratio of the ferrite grain size does not need to particularly specify and is 5 or lower in view of the capability and the like of a rolling mill. The area fraction of the hard phase is more preferably 52 to 90% and the average aspect ratio of the ferrite grain size is more preferably 1.6 or more. The average aspect ratio is more preferably 1.7 or more.

[0040] In a two phase mixed structure containing ferrite and a hard phase, the yield ratio(or Y/T ratio) of a base material decreases, and the strain concentration in a stress concentration zone is eased even in the base material as it is or even after a simulated heat cycle of simulating the welded heat affected zone. Such an effect is not obtained in the case of a single phase of ferrite or a single phase of a hard phase.

[0041] In the steel material according to the invention, the structure of the surface of a steel plate (1 mm position from the plate surface) contains ferrite and a hard phase, in which the area fraction of the ferrite exceeds 40% and is more preferably 50% or more. The average aspect ratio of the ferrite grain size exceeds 2. When the area fraction of the ferrite is lower than 40% or the average aspect ratio of the ferrite grain size is 2 or lower, the resistance of ductile crack initiation

in a welded heat affected zone is poor.

[0042] In the invention, the hard phase is bainite, martensite, or a bainite/martensite mixed structure and contains 5% or lower, in terms of area fraction, of an island martensite (M-A constituent) (MA).

[0043] Fig. 2 illustrates the results of examining the resistance of ductile crack initiation using a simulated heat cycle specimen of a welded zone (highest heating temperature of 1400°C). As illustrated in Fig. 2, when the area fraction of the hard phase of the base material is 50 to 90% and the average aspect ratio of the ferrite thereof is 1.5 or more, ductile crack initiation is not observed also after the simulated heat cycle.

[0044] The results illustrated in Fig. 2 were obtained by specimens of 12 mm thickness (= plate thickness direction) × 12 mm width × 200 length from the 1/4 center of the plate thickness (1/2 center of the plate thickness in the case of a plate thickness of 25 mm or lower) from the steel materials obtained by producing steel having a composition in the range of the invention by various manufacturing methods and changing the microstructure, and then giving a simulated heat cycle (time for reaching the highest heating temperature: 6 s, cooling rate from the highest heating temperature to room temperature: 40°C/s) of a welded zone thereto by a Gleeble tester to obtain sample materials.

[0045] Fig. 1 illustrates the specimen shape and the test conditions. The sample material (specimen 1), to which the simulated heat cycle was given, in which a single through-thickness edge notch is introduced with the length of 3 mm in the plate thickness direction into the center of a simulated heat cycle zone 2 of the sample material (specimen 1) was fixed with clamps 5, then a tensile load (arrow 6) was applied to 0.6 mm in terms of displacement of a clip gage 3 between knife-edges 4 that are screwed, the load was removed, and then the specimen was ground to the central zone and mirror polished. Then, the presence of crack initiation at the notch tip was evaluated. The case where the ductile crack from the notch bottom was 50 μm or more was defined as crack initiation.

[0046] It is considered that the results illustrated in Fig. 2 are obtained due to the fact that the yield ratio (or Y/T ratio) (0.2% proof stress/tensile strength) decreased also in the structure after the simulated heat cycle and the degree of distortion concentration at the notch tip zone decreased by the use of the base material having a complex structure of ferrite and a hard phase.

[0047] Such outstanding characteristics were observed in common also in a base material to which the simulated heat cycle was not given.

More specifically, Fig. 4 illustrates the results of examining the influence of the microstructure of the base material exerted on the resistance of ductile crack initiation. As illustrated in Fig. 4, when the area fraction of the hard phase of the base material is 50 to 90% and the average aspect ratio of the ferrite is 1.5 or more, ductile crack initiation is not accepted.

The results of the base material illustrated in Fig. 4 were obtained by specimens of 12 mm thickness (= plate thickness direction) × 12 mm width × 200 length from the 1/4 center of the plate thickness (1/2 center of the plate thickness in the case of a plate thickness of 25 mm or lower) from steel materials obtained by producing steel having a composition in the range of the invention by various manufacturing methods and changing the microstructure.

[0048] Fig. 3 illustrates the specimen shape and the test conditions. The sample material (specimen 1) in which a single through-thickness edge notch is introduced into the center was fixed with clamps 5, then a tensile load (arrow 6) was applied to 0.8 mm in terms of displacement of a clip gage 3 between knife-edges 4 that are screwed, the load was removed, and then the specimen was ground to the central zone and mirror polished. Then, the presence of crack initiation at the notch tip was evaluated. The case where the ductile crack from the notch bottom was 50 μm or more was defined as crack initiation.

It is considered that the results illustrated in Fig. 4 are obtained due to the fact that the yield ratio (or Y/T ratio) (0.2% proof stress/tensile strength) decreased and the degree of distortion concentration at the notch tip zone decreased by the use of a base material having a complex structure of ferrite and a hard phase.

[0049] Moreover, it is also considered to be one of the factors that the slip plane greatly leaned to the crack initiation direction in the base material as it is and also after the simulated heat cycle by increasing the average aspect ratio of the ferrite, i.e., the development of the specific aggregate structure. The aspect ratio refers to the ferrite grain size in the rolling direction (major axis)/the ferrite grain size in the plate thickness direction (minor axis) in a cross section parallel to the rolling direction.

[0050] The same results as those of Fig. 2 were obtained also when the highest heating temperature of the simulated heat cycle was 760°C, 900°C, and 1200°C.

[0051] The steel material according to the invention is obtained by successively subjecting the steel material of the above-described chemical compositions to a hot rolling process, a water cooling process, or further a tempering process.

[0052] The hot rolling includes reheating to 1000°C or more and performing rolling in such a manner that the rolling reduction rate in a temperature range of 900°C or more is 50% or more and the rolling finish temperature becomes Ar₃ to Ar₃-50°C. A more preferable rolling finish temperature is lower than Ar₃ to Ar₃-40°C. By setting the rolling finish temperature in the invention range, processing strain (or residual strain) can be added to ferrite generated during rolling to thereby increase the aspect ratio of the ferrite. When the reheating temperature is lower than 1000°C, hot rolling that gives a desired cumulative rolling reduction rate cannot be performed to the steel material.

[0053] When the cumulative rolling reduction rate at 900°C or more is lower than 50%, desired strength and toughness cannot be secured. When the rolling finish temperature exceeds A_{r3} , the aspect ratio of ferrite does not reach 1.5 or more. When the rolling finish temperature is lower than $A_{r3}-50^{\circ}\text{C}$, the area fraction of the hard phase obtained by the subsequent water cooling does not reach 50% or more.

[0054] In the water cooling process, the water cooling is started at $A_{r3}-10^{\circ}\text{C}$ to $A_{r3}-70^{\circ}\text{C}$ immediately after hot rolling, and then the water cooling is terminated at 500°C or lower. When the water cooling start temperature exceeds $A_{r3}-10^{\circ}\text{C}$, ferrite of lower than 10% in terms of area fraction (hard phase exceeding 90% in terms of area fraction) precipitates. When the water cooling start temperature is lower than $A_{r3}-70^{\circ}\text{C}$ or water cooling is not started immediately after (within 300 seconds) hot rolling, ferrite exceeding 50% in terms of area fraction (hard phase not reaching 50% in terms of area fraction) or pearlite, which is not intended to precipitate in the invention, precipitates. Thus, desired characteristics cannot be satisfied.

[0055] After performing the cooling, tempering treatment can be further performed at a temperature of lower than the A_{c1} point. By performing tempering treatment, toughness and ductility increase, and desired strength and toughness can be achieved. When the tempering temperature exceeds the A_{c1} point, a large amount of island martensite generates to reduce the toughness.

[0056] The A_{r3} point and the A_{c1} point can be calculated by the following equation based on the content (% by mass) of each chemical composition.

$$A_{r3} (^{\circ}\text{C}) = 910 - 310\text{C} - 80 \text{ Mn} - 20 \text{ Cu} - 15 \text{ Cr} - 55 \text{ Ni} - 80 \text{ Mo}$$

$$A_{c1} (^{\circ}\text{C}) = 723 - 14 \text{ Mn} + 22 \text{ Si} - 14.4 \text{ Ni} + 23.3 \text{ Cr}$$

Hereinafter, the invention will be described in more detail based on Examples.

[EXAMPLES]

[0057] Steel materials containing the chemical compositions shown in Table 1 were subjected to hot rolling at the conditions shown in Table 2 to thereby obtain steel plates having a plate thickness of 12 to 100 mm.

[0058] The obtained steel plates were subjected to microstructure observation, a tensile test, a toughness test, a ductile crack initiation test after a simulated heat cycle, and a ductile crack initiation test of base materials. The test methods were performed as described in the following items (1) to (5).

(1) Microstructure observation

[0059] From the obtained steel plates, specimens were extracted in the cross section parallel to the rolling direction. Then, the specimens were mirror polished, and then etched with nital. Thereafter, the microstructure at the 1/4 position of the plate thickness and the microstructure 1 mm below the surface were observed. The observation of each of the positions was performed with Field number: 20 fields of view. The area fraction was determined by binarizing the ferrite and the hard phase and observing at a magnification of 200x. The average aspect ratio of the ferrite was determined by determining the length in the rolling direction and the length in the plate thickness direction of each ferrite present in the field of view at a magnification of 400x, determining the length in the rolling direction/the length in the plate thickness direction, and then determining the average value thereof.

(2) Tensile test

[0060] From the obtained steel plates, full thickness JIS No. 5 specimens were extracted so that the tensile direction was perpendicular to the rolling direction of the steel plate according to the regulation of JIS Z 2201 (1998). The tensile test was performed according to JIS Z 2241 (1998), and then the 0.2% proof ($\sigma_{0.2}$) and the tensile strength (TS) were determined to evaluate the static tensile properties.

(3) Toughness test

[0061] From the obtained steel plates, V notch specimens were extracted so that the longitudinal direction was in parallel to the rolling direction according to the regulation of JIS Z 2242 (2005), and then the ductile-brittle fracture transition temperature was determined to evaluate the toughness. The specimens were extracted in such a manner that the 1/4 position of the plate thickness when the plate thickness was 20 mm or more or the 1/2 position of the plate thickness when the plate thickness was lower than 20 mm was the center.

(4) Ductile crack initiation test after simulated heat cycle

[0062] From the obtained steel plates, specimens of 12 mm thickness (= plate thickness direction = t) $\times$ 12 mm width and 200 mm in full length were extracted at the 1/4 center of the plate thickness (1/2 center of the plate thickness when the plate thickness was 25 mm or lower). The specimens were subjected to a simulated heat cycle of a welded heat affected zone in which the highest heating temperature was 760°C, 900°C, 1200°C, and 1400°C (time for reaching the highest heating temperature: 6s, Cooling rate from the highest heating temperature to room temperature: 40°C/s) using a Gleeble tester.

Thereafter, as illustrated in Fig. 1, a single through-thickness edge notch was introduced with the length of 3 mm in the plate thickness direction into the center of the simulated heat cycle zone. The notch processing was carried out by electrical discharge machining, and the notch tip radius was 0.1 mm.

In the test, a tensile load was applied while gripping the specimens with both right and left ends thereof with a constraint length of 50 mm. During the test, the displacement between the knife-edges screwed near the notch was measured with the clip gage. A tensile load was applied to 0.6 mm in terms of clip gage displacement, and then the load was removed. Thereafter, the specimen was ground to the width center and mirror polished. Then, the crack initiation state at the notch bottom was analyzed under a microscope with a magnification of 50x. It was defined that the ductile crack initiation occurred when a ductile crack extended in the length of 50 μ m or more from the notch bottom.

(5) Ductile crack initiation test of base material

[0063] From the obtained steel plates, specimens of 12 mm thickness (= plate thickness direction = t) $\times$ 12 mm width and 200 mm in full length were extracted at the 1/4 center of the plate thickness (1/2 center of the plate thickness when the plate thickness was 25 mm or lower).

To the obtained specimens, a single through-thickness edge notch was introduced with the length of 3 mm in the plate thickness direction into the center of the specimens as illustrated in Fig. 3. The notch processing was carried out by electrical discharge machining, and the notch tip radius was 0.1 mm.

In the test, a tensile load was applied while gripping the specimens with both right and left ends thereof with a constraint length of 50 mm. During the test, the displacement between the knife-edges screwed near the notch was measured with the clip gage. A tensile load was applied to 0.8 mm in terms of clip gage displacement, and then the load was removed. Thereafter, the test was ground to the width center and mirror polished. Then, the crack initiation state at the notch bottom was analyzed under a microscope with a magnification of 50x. It was defined that the ductile crack initiation occurred when a ductile crack extended in the length of 50 μ m or more from the notch bottom.

[0064] With respect to the specimens that were subjected to the simulated heat cycle, the obtained experimental results are shown in Table 3. All of the steel plates of Nos. 1 to 10 produced using the chemical compositions and the manufacturing method specified in the invention have the structure specified in the invention. It is found that the steel plates have excellent strength and toughness and have excellent resistance of ductile crack initiation of a welded heat affected zone.

In contrast, the steel plate (Steel type K*) of No. 11 in which the C content does not satisfy the lower limit of the range of the invention has low tensile strength. The steel plate (Steel type L*) of No. 12 in which the content of each of C, P, and S exceeds the upper limit of the range of the invention has low toughness and has poor ductile crack initiation characteristics of a welded heat affected zone.

The steel plate of No. 13 in which the reheating temperature of slab is lower than the invention and the cumulative rolling reduction rate at 900°C or more is outside the range of the invention has low toughness. In the steel plate of No. 14 in which the rolling finish temperature and the water cooling start temperature exceed the range of the invention, ferrite is not generated, the microstructure specified in the invention is not obtained, and the resistance of ductile crack initiation of a welded heat affected zone is poor.

In the steel plate of No. 15 in which the cooling start temperature is lower than the range of the invention and the steel plate of No. 16 in which the water cooling stop temperature exceeds the range of the invention, the hard phase area fraction and the average aspect ratio of ferrite do not satisfy the values specified in the invention and both the steel plates have low tensile strength and have poor resistance of ductile crack initiation of welded heat affected zones. In

the steel plate of No. 17 in which the tempering temperature exceeds the range of the invention, since a large amount of island martensite is generated, the toughness is low and the resistance of ductile crack initiation of a welded heat affected zone is poor.

[0065] The obtained experimental results of the base material are shown in Table 4. All of the steel plates of Nos. 18 to 27 produced using the chemical compositions and the manufacturing method specified in the invention have the structure specified in the invention. It is recognized that the steel plates have excellent strength and toughness and have excellent resistance of ductile crack initiation of a welded heat affected zone. In contrast, the steel plate (Steel type W*) of No. 28 in which the C content does not satisfy the lower limit of the range of the invention has low tensile strength. The steel plate (Steel type X*) of No. 29 in which the content of each of C, P, and S exceeds the upper limit of the range of the invention has low toughness. The steel plate of No. 30 in which the reheating temperature of slab is lower than the range of the invention and the cumulative rolling reduction rate at 900°C or more does not satisfy the range of the invention has low toughness.

In the steel plate of No. 31 in which the rolling finish temperature and the water cooling start temperature exceed the range of the invention, ferrite is not generated, the microstructure specified in the invention is not obtained, and the resistance of ductile crack initiation is poor.

In the steel plate of No. 32 in which the cooling start temperature is lower than the range of the invention and the steel plate of No. 33 in which the water cooling stop temperature exceeds the range of the invention, the hard phase area fraction and the average aspect ratio of ferrite do not satisfy the values specified in the invention and both the steel plates have low tensile strength and have poor resistance of ductile crack initiation. In the steel plate of No. 34 in which the tempering temperature exceeds the value of the invention, a large amount of island martensite (M-A constituent) is generated, and thus the toughness is low and the resistance of ductile crack initiation is poor.

Reference Signs List

[0066]

1. Specimen
2. Simulated heat cycle zone
3. Clip gage
4. Knife-edge
5. Clamp
6. Tensile load

[0067] [Table 1]

Table 1

	Chemical composition (mass%)																	Ar ₃ [°C] Note (1)	Ac ₁ [°C] Note (2)
Steel type	C	Si	Mn	P	S	Cu	Ni	Cr	Mo	Nb	V	Ti	B	Ca	REM	Al	N		
A	0.14	0.33	1.59	0.005	0.002	-	-	-	-	-	-	-	-	-	-	0.033	0.0048	739	729
B	0.06	0.11	1.96	0.009	0.001	0.25	0.14	0.04	0.21	0.046	0.005	0.011	0.0003	-	-	0.032	0.0042	705	697
C	0.18	0.04	1.16	0.006	0.005	-	-	-	-	-	0.048	-	-	-	-	0.044	0.0029	761	708
D	0.12	0.39	0.54	0.008	0.003	-	-	0.22	0.35	-	-	-	-	-	0.097	0.029	0.0041	798	729
E	0.03	0.26	0.52	0.003	0.005	-	4.49	-	-	0.012	-	0.049	-	-	-	0.018	0.0029	612	657
F	0.09	0.31	1.32	0.042	0.007	0.98	1.33	-	-	0.022	0.015	-	-	0.0089	0.031	0.022	0.0031	684	692
G	0.08	0.24	1.18	0.002	0.009	0.98	-	2.48	0.98	0	0.018	-	-	-	-	0.025	0.0028	675	770
H	0.11	0.18	1.22	0.001	0.004	-	0.52	0.16	0.21	0.015	0.033	0.017	0.0046	-	-	0.018	0.0035	731	706
I	0.05	0.32	1.38	0.002	0.043	-	2.43	-	0.25	0.033	0.019	-	-	0.0033	0.044	0.022	0.0028	630	676
J	0.09	0.25	1.44	0.005	0.002	-	-	0.08	0.11	0.022	0.038	0.013	0.0011	-	-	0.032	0.0041	757	710
K*	0.1*	0.21	1.56	0.004	0.003	-	-	-	-	-	-	-	-	-	-	0.028	0.0039	782	706
L*	0.32*	0.18	0.55	0.193*	0.183*	-	0.15	0.23	0.14	-	-	-	-	0.0022	0.008	0.022	0.0038	739	722
M	0.15	0.32	1.58	0.006	0.001	0.25	-	-	-	-	-	-	-	-	-	0.032	0.0048	737	729
N	0.06	0.12	1.95	0.008	0.004	-	0.15	0.02	0.21	0.045	0.004	0.012	0.0002	-	-	0.031	0.0041	706	697
O	0.19	0.02	1.15	0.005	0.005	0.22	-	-	-	-	0.047	-	-	-	-	0.048	0.0029	759	707
P	0.11	0.38	0.52	0.007	0.003	-	-	0.21	0.33	-	-	-	-	-	0.098	0.028	0.0042	85	729
Q	0.03	0.25	0.51	0.003	0.004	-	4.51	-	-	0.018	-	0.048	-	-	-	0.016	0.0028	612	656
R	0.08	0.31	1.33	0.041	0.006	-	1.26	-	-	0.025	0.011	-	-	0.0091	0.032	0.017	0.0041	691	693
S	0.09	0.20	1.14	0.003	0.004	0.95	-	2.45	0.97	-	0.009	-	-	-	-	0.022	0.0032	677	769
T	0.12	0.16	1.25	0.004	0.003	-	0.55	0.15	0.22	0.043	0.032	0.018	0.0048	-	-	0.011	0.0035	723	705

(continued)

	Chemical composition (mass%)															Ar ₃ [°C] Note (1)	Ac ₁ [°C] Note (2)		
Steel type	C	Si	Mn	P	S	Cu	Ni	Cr	Mo	Nb	V	Ti	B	Ca	REM	Al	N		
U	0.05	0.27	1.37	0.001	0.042	-	2.42	-	0.28	0.032	0.019	-	-	0.0032	0.048	0.023	0.0028	629	675
V	0.09	0.22	1.44	0.003	0.003	-	-	0.07	0.15	0.028	0.042	0.012	0.0015	-	-	0.032	0.0041	754	709
W*	0.01*	0.25	1.55	0.005	0.004	-	-	-	-	-	-	-	-	-	-	0.031	0.0039	783	707
X*	0.31*	0.15	0.51	0.180*	0.173*	0.23	0.11	0.21	0.15	-	-	-	-	0.0021	0.011	0.028	0.0037	747	722
Note: The cells marked by * are outside the range of the invention and the steel types K, L, W, and X are comparative steels.																			
Note (1): Ar3(°C) = 910 - 310C - 80 Mn - 20 Cu - 15 Cr - 55 Ni - 80 Mo Each alloy element amount indicates the content (%)																			
Note (2): Ar1(°C) = 723 - 1 Mn + 22 Si - 14.4 Ni + 13.3 Cr Each alloy element amount indicates the content (%)																			

[0068] [Table 2]

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Table 2

No.	Steel type	Plate thickness (mm)	Slab reheating temperature [°C]	Cumulative rolling reduction rate at 900°C or more [%]	Rolling finish temperature [°C]	Water cooling start temperature [°C]	Water cooling stop temperature [°C]	Tempering temperature [°C]
1	A	14	1160	87	702	683	431	-
2	B	22	1190	75	679	665	378	-
3	C	12	1210	92	731	687	298	-
4	D	100	1150	56	782	779	421	-
5	E	75	1240	62	583	578	72	620
6	F	35	1190	73	672	634	388	-
7	G	24	1150	81	641	623	28	580
8	H	68	1240	55	701	687	426	-
9	1	34	1170	72	607	598	426	-
10	J	18	1160	82	718	704	388	-
11	K*	22	1120	78	748	726	315	-
12	L*	45	1180	68	725	706	248	-
13	C	73	970*	34*	741	732	42	650
14	A	14	1160	87	785*	777*	413	-
15	B	28	1230	72	695	600*	388	-
16	J	19	1240	78	712	699	638*	-
17	D	75	1090	64	768	749	62	760*
18	M	15	1150	86	695	681	401	-
19	N	20	1180	76	686	664	308	-
20	O	12	1200	91	721	697	498	-
21	P	100	1130	55	792	777	418	-
22	Q	75	1250	61	602	589	25	600
23	R	35	1200	72	668	643	418	-

(continued)

No.	Steel type	Plate thickness (mm)	Slab reheating temperature [°C]	Cumulative rolling reduction rate at 900 °C or more [%]	Rolling finish temperature [°C]	Water cooling start temperature [°C]	Water cooling stop temperature [°C]	Tempering temperature [°C]
24	S	25	1160	73	647	625	72	500
25	T	72	1250	58	708	697	457	-
26	U	37	1170	71	618	605	412	-
27	V	15	1150	83	723	703	378	-
28	W*	25	1100	84	758	748	258	-
29	X*	48	1200	69	721	710	243	-
30	O	75	930*	33*	737	717	23	600
31	M	15	1150	88	755*	747*	428	-
32	N	25	1220	71	679	605*	352	-
33	V	18	1250	77	715	703	658*	-
34	P	77	1080	62	776	748	245	750*
Note: The steel types marked by * are outside the range of the invention.								

[0069] [Table 3]

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Table 3

No.	Microstructure of 1/4 Plate thickness/4				Microstructure 1 mm below the surface			$\sigma_{0.2}$ [MPa]	TS [MPa]	$vTrs$ [°C]	Ductile crack initiation characteristics Note (2)				Classification
	Hard phase structure Note (1)	Hard phase fraction [%]	Ferrite average aspect ratio		Hard phase structure Note (1)	Ferrite phase fraction [%]	Ferrite average aspect ratio				760 °C	900 °C	1200 °C	1400 °C	
1	B	59	1.9		B	55	2.4	428	548	-57	○	○	○	○	Present invention example
2	B	75	2.2		B	68	3.1	563	728	-105	○	○	○	○	Present invention example
3	B,M	54	2.3		B,M	77	4.8	521	689	-33	○	○	○	○	Present invention example
4	B	64	1.6		B	48	2.2	408	521	-29	○	○	○	○	Present invention example
5	TB	90	1.7		TM	41	2.6	555	667	-98	○	○	○	○	Present invention example
6	B	62	1.8		B	59	2.3	473	621	-47	○	○	○	○	Present invention example
7	TM	55	2.1		TM	72	2.4	481	582	-92	○	○	○	○	Present invention example
8	B	83	1.8		B	42	2.1	529	683	-64	○	○	○	○	Present invention example

(continued)

No.	Microstructure of 1/4 Plate thickness/4			Microstructure 1 mm below the surface			$\sigma_{0.2}$ [MPa]	TS [MPa]	vT_{rs} [°C]	Ductile crack initiation characteristics Note (2)				Classification
	Hard phase structure Note (1)	Hard phase fraction [%]	Ferrite average aspect ratio	Hard phase structure Note (1)	Ferrite phase fraction [%]	Ferrite average aspect ratio				760 °C	900 °C	1200 °C	1400 °C	
9	B	87	1.7	B	40	2.2	433	538	-41	○	○	○	○	Present invention example
10	B	75	2.5	M	58	3.3	428	548	-72	○	○	○	○	Present invention example
11	B	73	2.2	B	53	3.0	325	421*	-18	○	○	○	○	Comparative example
12	B,M	72	1.7	B,M	43	2.3	677	991	15*	○	×	×	×	Comparative example
13	TM	72	2.3	TM	40	2.5	521	609	8*	○	○	○	○	Comparative example
14	B	100*	-	B	0*	-*	548	678	-21	×	×	×	×	Comparative example
15	P	14*	1.1*	P	87	1.4*	344	472*	-11	×	×	×	×	Comparative example
16	P	21**	1.3*	P	81	1.4*	388	488*	-18	×	×	×	×	Comparative example
17	B,MA	63	1.8	M,MA	48	2.8	521	622	6*	×	×	×	×	Comparative example
Note: The cells marked by * are outside the range of the invention. Note (1): B: Bainite., M: Martensite, P: Pearlite, TB: Tempered bainite, TM: Tempered martensite, MA: Island martensite Note (2): ○: No ductile crack initiation × : Ductile crack initiation														

[0070] [Table 4]

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Table 4

No.	Microstructure of 1/4 Plate thickness			Microstructure 1 mm below the surface			$\sigma_{0.2}$ [MPa]	TS [MPa]	vT_{rs} [°C]	Ductile crack initiation characteristics Note (2)	Classification
	Hard phase structure Note (1)	Hard phase fraction [%]	Ferrite average aspect ratio	Hard phase structure Note (1)	Ferrite phase fraction [%]	Ferrite average aspect ratio					
18	B	55	1.8	B	57	3.1	436	528	-48	○	Present invention example
19	B	72	2.1	B	42	4.9	573	726	-121	○	Present invention example
20	B,M	52	2.2	B,M	66	3.9	511 1	698	-21	○	Present invention example
21	B	62	1.6	B	48	2.2	359	515	-28	○	Present invention example
22	TB	89	1.8	TM	41	4.1	552	628	-111	○	Present invention example
23	B	68	1.9	B	49	2.8	487	615	-35	○	Present invention example
24	TM	59	2.0	TM	57	3.1	472	577	-98	○	Present invention example
25	B	84	1.6	B	42	2.7	507	641	-63	○	Present invention example
26	B	88	1.7	B	43	2.9	402	513	-34	○	Present invention example

(continued)

No.	Microstructure of 1/4 Plate thickness			Microstructure 1 mm below the surface			$\sigma_{0.2}$ [MPa]	TS [MPa]	vT_{rs} [°C]	Ductile crack initiation characteristics Note (2)	Classification
	Hard phase structure Note (1)	Hard phase fraction [%]	Ferrite average aspect ratio	Hard phase structure Note (1)	Ferrite phase fraction [%]	Ferrite average aspect ratio					
27	B	77	2.4	B	53	3.3	425	538	-66	○	Present invention example
28	B	74	2.1	M	58	3.7	368	411 *	-38	○	Comparative example
29	B,M	78	1.8	M	55	2.2	687	983	10*	○	Comparative example
30	TM	69	2.4	TM	42	2.4	513	618	7*	○	Comparative example
31	B	100*	-	B	0*	-*	558	688	-18	○	Comparative example
32	P	12*	1.2*	P	89	1.4*	358	451 *	-13	×	Comparative example
33	P	18*	1.4*	P	83	1.4*	398	473*	-21	×	Comparative example
34	B,MA	68	1.7	M,MA	44	2.8	535	637	5*	×	Comparative example

Note: The cells marked by * are outside the range of the invention.

Note (1): B: Bainite., M : Martensite, P: Pearlite, TB: Tempered bainite, TM: Tempered martensite, MA: Island martensite

Note (2): ○ : No ductile crack initiation × : Ductile crack initiation

Claims

1. A steel material excellent in resistance of ductile crack initiation from welded heat affected zone and a base material, the steel material comprising a composition of C: 0.02 to 0.2%, Si: 0.01 to 0.5%, Mn: 0.5 to 2.5%, P: 0.05% or lower, S: 0.05% or lower, Al: 0.1% or lower, and N: 0.01% or lower in terms of % by mass, and the balance Fe with inevitable impurities, the microstructure at the 1/4 position of the plate thickness containing ferrite and a hard phase, the area fraction of the hard phase being 50 to 90%, and the average aspect ratio of the ferrite being 1.5 or more.
2. The steel material excellent in resistance of ductile crack initiation from welded heat affected zone and a base material according to Claim 1, further comprising, in the chemical composition, one or two or more elements selected from Cu: 0.01 to 2%, Ni: 0.01 to 5%, Cr: 0.01 to 3%, Mo: 0.01 to 2%, Nb: 0.1% or lower, V: 0.1% or lower, Ti: 0.1% or lower, B: 0.01% or lower, Ca: 0.01% or lower, and REM: 0.1 % or lower in terms of % by mass.
3. The steel material excellent in resistance of ductile crack initiation from welded heat affected zone and a base material according to Claim 1 or 2, wherein the microstructure on the surface of a steel plate contains ferrite and a hard phase, the area fraction of the ferrite exceeds 40%, and the average aspect ratio of the ferrite grain size exceeds 2.
4. A method for manufacturing a steel material excellent in resistance of ductile crack initiation from welded heat affected zone and a base material comprising: reheating a steel base material having the chemical compositions of Claim 1 or 2 to 1000°C or more, rolling the same in such a manner that a rolling reduction rate in a temperature range of 900°C or more is 50% or more and a rolling finish temperature is Ar_3 point to $Ar_3-50^\circ C$, starting water cooling at $Ar_3-10^\circ C$ to $Ar_3-70^\circ C$, and terminating the water cooling at 500°C or lower.
5. The method for manufacturing a steel material excellent in resistance of ductile crack initiation from welded heat affected zone and a base material according to Claim 4 further comprising, after the water cooling, performing tempering treatment at a temperature of lower than the highest heating temperature Ac_1 point.

FIG. 1

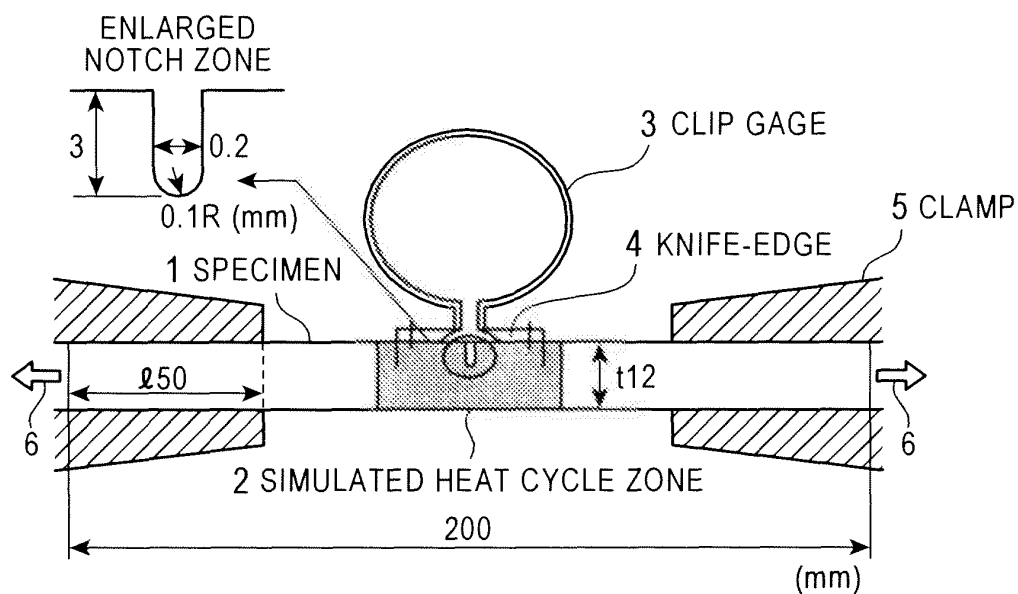


FIG. 2

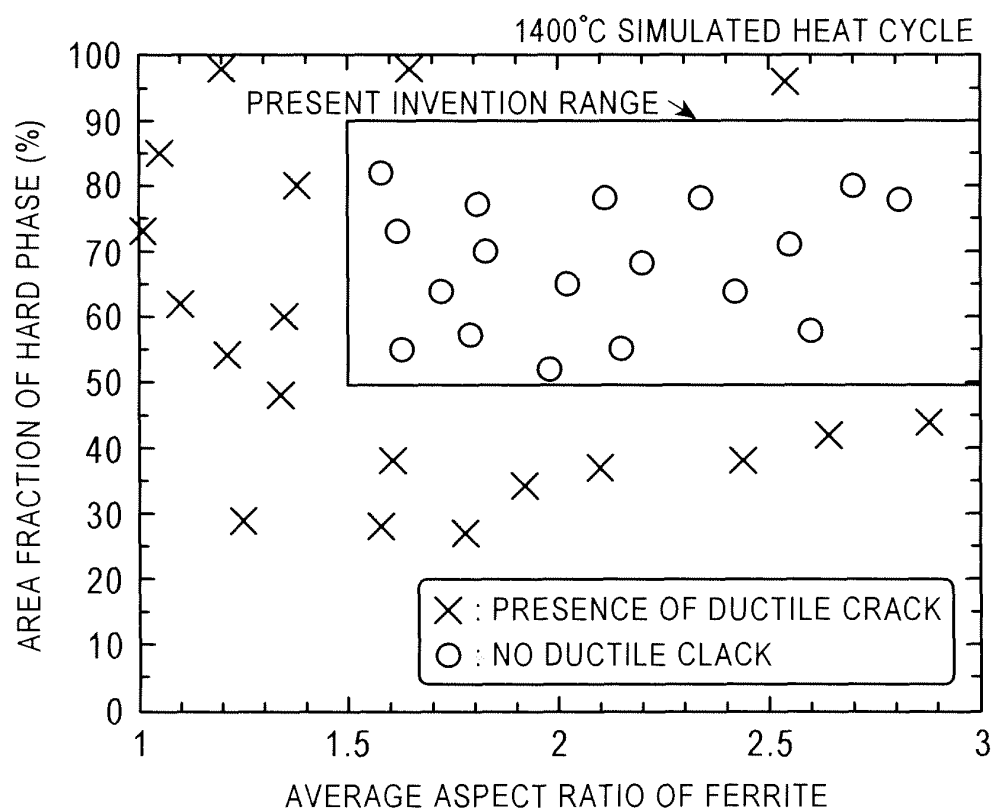


FIG. 3

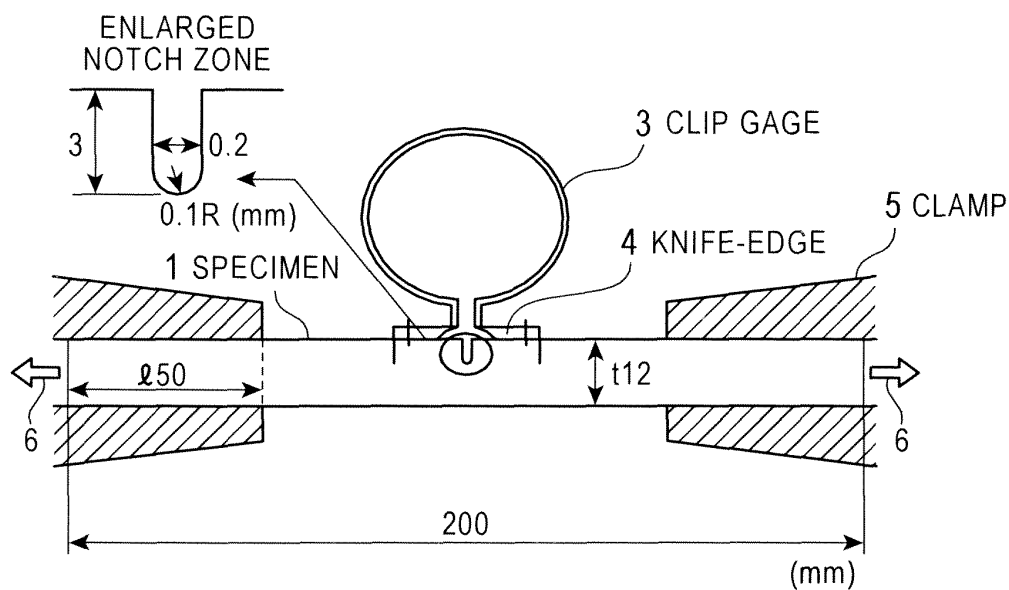
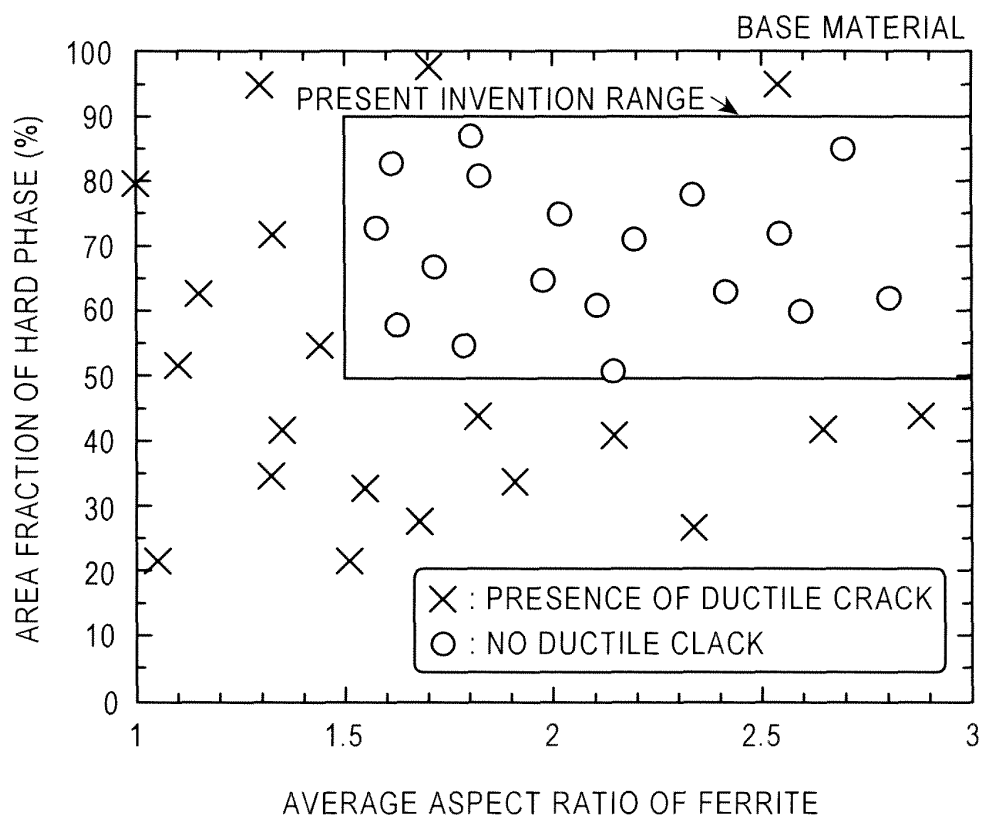


FIG. 4



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2009/071908

A. CLASSIFICATION OF SUBJECT MATTER

C22C38/00(2006.01) i, C21D8/02(2006.01) i, C22C38/60(2006.01) i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C22C38/00, C21D8/02, C22C38/60

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho 1922-1996 Jitsuyo Shinan Toroku Koho 1996-2010

Kokai Jitsuyo Shinan Koho 1971-2010 Toroku Jitsuyo Shinan Koho 1994-2010

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2008-202119 A (Sumitomo Metal Industries, Ltd.), 04 September 2008 (04.09.2008), (Family: none)	1-5
A	JP 2007-197777 A (JFE Steel Corp.), 09 August 2007 (09.08.2007), (Family: none)	1-5
A	JP 2006-274372 A (JFE Steel Corp.), 12 October 2006 (12.10.2006), (Family: none)	1-5
A	JP 11-92858 A (NKK Corp.), 06 April 1999 (06.04.1999), (Family: none)	1-5

☐ Further documents are listed in the continuation of Box C.☐ See patent family annex.

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Date of the actual completion of the international search
25 March, 2010 (25.03.10)Date of mailing of the international search report
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REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 2008202119 A [0011]
- JP 2000328177 A [0011]
- JP 2003221619 A [0011]