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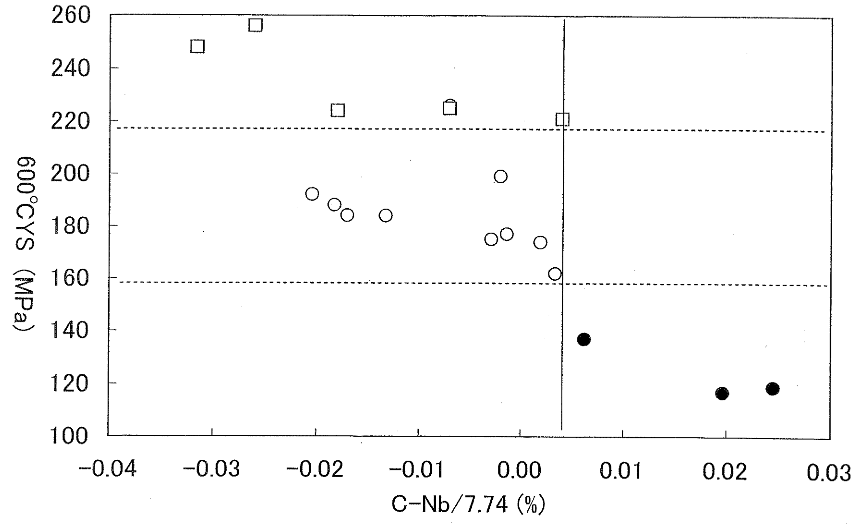
(54) STEEL MATERIAL HAVING EXCELLENT HIGH-TEMPERATURE STRENGTH AND TOUGHNESS, AND METHOD FOR PRODUCTION THEREOF

(57) A steel material superior in high temperature characteristics and toughness is provided, the fire resistant steel material containing by mass%, C: 0.001% to 0.030%, Si: 0.05% to 0.50%, Mn: 0.40% to 2.00%, Nb: 0.03% to 0.50%, Ti: 0.005% to less than 0.040%, and N: 0.0008% to less than 0.0050%, restricting P: 0.030% or less and S: 0.020% or less, and having a balance of Fe and unavoidable impurities, where the contents of C and Nb satisfy $C\text{-}Nb/7.74 \leq 0.004$, and Ti-based oxides of a grain size of 0.05 to 10 µm are present in a density of 30 to 300/mm^2.

Fig.1



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Description

Technical Field

[0001] The present invention relates to a steel material superior in high temperature strength and toughness and a method of production of the same.

Background Art

[0002] Due to the increasingly number of high rise buildings, the greater sophistication of building designs, etc., fire resistant design codes were revised as a major project of the Japan Ministry of Construction. In March 1987, a new fire resistant design code was enacted. Under this, the old restriction relating to fire resistant coverings requiring the temperature of the steel material at the time of a fire be kept to 350°C or less was reevaluated and it was allowed to select a suitable fire resistant covering method from the relationship of the high temperature strength of the steel material and the actual load of the building. For this reason, when possible to secure a high temperature strength satisfying the design standards at 600°C, that is, by using a steel material with a high level high temperature strength at 600°C, it became possible to simplify or eliminate the fire resistant covering.

[0003] To meet with this trend, reinforcing mechanisms of high temperature strength of steel materials at 600°C and fire resistant steel materials utilizing, among (1) increased fineness of ferrite crystal grain size, (2) solution strengthening by alloy elements, (3) dispersion strengthening by hard phases, and (4) precipitation strengthening by fine precipitates, mainly precipitation strengthening are being developed.

[0004] In the past, numerous fire resistant steel materials adding elements contributing to precipitation strengthening such as Mo, Ti, and Nb and using carbides, nitrides, etc. to secure high temperature strength have been proposed, but in recent years the rise in production costs and the drop in weldability due to the addition of large amounts of Mo have become problems.

[0005] To deal with this problem, hot rolled steel strip using reduction of C and Mo and control of the hot rolling end temperature and coiling temperature to secure high temperature strength and improve the toughness and weldability has been proposed (for example, see Japanese Patent Publication (A) No. 7-300618).

[0006] However, this causes the precipitation of fine Mo and Nb carbides at the time of coiling. It does not utilize solid solution Nb, so is not sufficient in high temperature strength. Further, it includes Ti and does not suppress precipitation of nitrides to the weld heat affected zone (HAZ), so a drop in toughness of the HAZ is a concern.

[0007] Further, steel plate and steel pipe reducing the C and Mo, using solid solution Nb to raise the high temperature strength, and reducing the solid solution C and solid solution N to secure formability by cold working have been proposed (for example, see Japanese Patent Publication (A) No. 10-176237, Japanese Patent Publication (A) No. 2000-54061, and Japanese Patent Publication (A) No. 2000-282167). However, these have high Ti/N ratios, so there is the concern that coarse TiN will precipitate and in particular the HAZ toughness will fall.

[0008] Further, to secure high temperature strength, toughness, and weldability, fire resistant steel material reducing the Mo and utilizing the solid solution and precipitation of Cu has also been proposed (for example, see Japanese Patent Publication (A) No. 2002-115022). This does not use the solid solution Nb to raise the high temperature strength, but uses the addition of Nb to lower the recrystallization temperature and increase the fineness of the crystal grains and, further, to utilize the precipitation strengthening of Nb.

[0009] Further, none of the steel materials proposed in the patent literatures mentioned above considered the reheat embrittlement at the HAZ. "Reheat embrittlement" is high temperature embrittlement caused by precipitation of carbides and nitrides when the HAZ is heated again to a high temperature.

[0010] Further, for extremely thick H-section steel used mainly as columns for high rise buildings as well, along with the increase in thickness and size, the production process becomes lower in reduction rate and lower in cooling speeds, so compared with thin-gauge steel material, sufficient working heat treatment becomes more difficult. Therefore, in the prior art, to secure strength, alloy elements had to be added in large amounts. In that case, a drop in toughness, drop in weldability, and other concomitant problems arose.

Summary of Invention

[0011] The present invention provides a steel material superior in reheat embrittlement resistance characteristics and other high temperature characteristics at the weld heat affected zone and toughness of the base material and HAZ able to be used as a fire resistant steel material or extremely thick H-section steel as hot rolled, that is, without cold rolling or quenching, tempering, or other heat treatment for thermal refining after hot rolling, and a method of production of the same.

[0012] The present invention limits the contents of C and N, adds a suitable quantity of Nb to define the relationship of C and Nb, and utilizes the drag effect of the solid solution Nb (phenomenon where the solid solution Nb concentrates at dislocations and other lattice defects, becomes resistance to movement of defects and dislocations, and improves the strength) to raise the high temperature strength, furthermore, utilizes the fine Ti-based oxides for pinning of the crystal grain boundaries and formation of intro-granular ferrite nucleation to suppress coarsening of the HAZ, reduce fluctuation of mechanical characteristics due to thickness, and improve reheat embrittlement resistance and other high temperature characteristics, and further secures toughness of the base material and the HAZ by adjusting the concentration of solute oxygen in the molten steel at the time of addition of Ti to disperse fine oxides of Ti in the steel to provide a steel material and a method of production of the same.

[0013] This gist of the present invention is as follows.

(1) A steel material superior in high temperature characteristics and toughness characterized by containing by mass%, C: 0.001% to 0.030%, Si: 0.05% to 0.50%, Mn: 0.40% to 2.00%, Nb: 0.03% to 0.50%, Ti: 0.005% to less than 0.040%, and N: 0.0008% to less than 0.0050%, restricting P: 0.030% or less and S: 0.020% or less, and having a balance of Fe and unavoidable impurities, where the contents of C and Nb satisfy

$$C-Nb/7.74 \leq 0.004$$

and Ti-based oxides of a grain size of 0.05 to 10 μm are present in a density of 30 to 300/mm^2.

(2) A steel material superior in high temperature characteristics and toughness as set forth in (1) characterized by containing, by mass%, one or both of V: 0.10% or less and Mo: less than 0.10%.

(3) A steel material superior in high temperature characteristics and toughness as set forth in (1) or (2) characterized by containing, by mass%, one or more of Zr: 0.03% or less and Hf: 0.01% or less.

(4) A steel material superior in high temperature characteristics and toughness as set forth in any one of the above (1) to (3) characterized by containing, by mass%, one or more of Cr: 1.5% or less, Cu: 1.0% or less, and Ni: 1.0% or less.

(5) A steel material superior in high temperature characteristics and toughness as set forth in any one of the above (1) to (4) characterized by containing, by mass%, one or more of Mg: 0.005% or less, Al: 0.030% or less, REM: 0.01% or less, and Ca: 0.005% or less.

(6) A steel material superior in high temperature characteristics and toughness as set forth in any one of the above (1) to (5) characterized in that a mass concentration product of Nb and C is 0.0015 or more.

(7) A steel material superior in high temperature characteristics and toughness as set forth in any one of the above (1) to (6) characterized in that the steel material is a fire resistant steel material.

(8) A steel material superior in high temperature characteristics and toughness as set forth in any one of the above (1) to (6) characterized in that the steel material is extremely thick H-section steel with a flange thickness of 40 mm or more.

(9) A method of production of a steel material superior in high temperature characteristics and toughness characterized by adjusting steel comprised of ingredients as set forth in any of the above (1) to (6) to a solute oxygen of 0.003 to 0.015 mass%, then adding Ti, melting, and casting to obtain a steel slab, and heating this to 1100 to 1350°C and hot rolling.

(10) A method of production of a steel material superior in high temperature characteristics and toughness as set forth in (9), characterized by hot rolling by a cumulative reduction rate at 1000°C and below of 10% or more.

(11) A method of production of a steel material superior in high temperature characteristics and toughness as set forth in (9) or (10) characterized by hot rolling, then cooling from 800°C to 500°C temperature range by a 0.1 to 10°C/s average cooling speed.

[0014] According to the present invention, steel material having a sufficient ordinary temperature strength and high temperature strength and superior in base material and HAZ toughness and reheat embrittlement resistance characteristics, in particular, fire resistant H-section steel and extremely thick H-section steel, can be produced without cold working and heat treatment for thermal refining or extremely thick H-section steel having a thickness of a large size, for example, of up to a flange thickness of 140 mm or more can be produced as hot rolled while securing strength and toughness.

[0015] Among steel materials, H-section steel produced by hot rolling is broken down by shape into flange, web, and fillet part locations. The rolling temperature history and cooling speed differ according to these shapes, so even with the same ingredients, the mechanical characteristics will sometimes greatly change depending on the part location, but steel having the composition of ingredients of the present invention has relatively small rolling finishing temperature dependency and cooling speed dependency on the strength and toughness, the variation in quality in cross-sectional part locations in H-section steel can be lightened, and, further, the changes in quality due to thickness can be made smaller, so, in particular, strength and toughness at thicknesses of large sizes such as with extremely thick H-section steel can be secured and variations in quality in the cross-sections of H-section steel can be reduced.

Brief Description of the Drawings

[0016]

FIG. 1 is a view showing the effects of C and Nb on the high temperature strength of a steel material.
FIG. 2 is a view showing the effects of the number density distribution of Ti oxides on the toughness of the HAZ of a steel material.
FIG. 3 is a view showing the effects of the number density distribution of Ti oxides on the reheat embrittlement characteristics of a steel material.
FIG. 4 is a view showing the effects of the relationship between the amount of solute oxygen before addition of Ti and the amount of Ti on the density of Ti-based oxides.
FIG. 5 is a schematic view of a process for production of shaped steel as an example of the layout of facilities for working the method of the present invention.
FIG. 6 is a view showing the cross-sectional shape of H-section steel and the position of sampling a mechanical strength test piece.

Embodiments of Invention

[0017] The inventors studied using the addition of Nb to improve the quenchability and forming one or both of massive ferrite or bainite so as to raise the high temperature strength and ordinary temperature strength and toughness and obtain a steel material superior in reheat embrittlement resistance characteristics and, furthermore, using the drag effect of stolid solution Nb to slow the speed of movement of dislocations at a high temperature and thereby exhibit resistance to softening at a high temperature and secure the high temperature strength required as a fire resistant steel material.

[0018] As a result, they obtained the following discovery for obtaining the effects of Nb to the maximum extent by lowering the C, lowering the N, and adding Ti.

[0019] Lowering the C and lowering the N are effective for suppressing the formation of polygonal ferrite and securing solid solution Nb. The Nb carbide of NbC and nitride of NbN forms the nuclei for formation of polygonal ferrite. Further, due to their precipitation, the solid solution Nb is reduced. In particular, if small amounts of carbides and nitrides of Nb precipitate, this contributes to the improvement of strength by precipitation strengthening, but if heated to a high temperature again after welding, NbC will precipitate at the crystal grain boundaries of the austenite at the HAZ (below, also called "γ grain boundaries") and reheat embrittlement may be exhibited.

[0020] Therefore, to secure reheat embrittlement resistance characteristics, it is extremely important to define the upper limits of the amount of addition of C and the amount of addition of N. Further, the problem was found that if the carbon content exceeds 0.03%, island-shaped martensite partially forms and sometimes the toughness remarkably falls.

[0021] Furthermore, if using controlled deoxidation by Ti to make fine Ti-based oxides disperse in the steel, the crystal grains are pinned and their growth suppressed, so the crystal grain size becomes finer. In particular, it is possible to present crystal grain coarsening in the thermal cycle of heating to 1400˚C and rapid cooling such as seen at the HAZ.

[0022] Due to this, it is learned that not only is the HAZ toughness improved, but also the high temperature embrittlement of the HAZ is suppressed.

[0023] Based on the above findings, the inventors further studied in detail (1) the relationship of C and Nb and the high temperature strength of a steel material and (2) the effects of the grain size and number density distribution of Ti-based oxides on the HAZ toughness and reheat embrittlement resistance characteristics when using primary deoxidation to adjust the solute oxygen, then adding Ti and further deoxidizing.

[0024] The inventors produced steel containing, by mass%, C: 0.001% to 0.030%, Si: 0.05% to 0.50%, Mn: 0.4% to 2.0%, Nb: 0.03% to 0.50%, Ti: 0.005% to less than 0.040%, and N: 0.0008% to less than 0.0050%, restricting P: 0.03% or less and S: 0.02% or less, and having a balance of Fe and unavoidable impurities by changing the amount of solute oxygen when adding Ti, cast this to obtain a steel slab, heated it to 1100 to 1350˚C, and hot rolled this to a cumulative reduction rate at 1000˚C and below of 30% or more to produce steel plate of a thickness of 10 to 40 mm.

[0025] From the steel plate, they obtained tensile test pieces based on JIS Z 2201 and ran ordinary temperature tensile tests based on JIS Z 2241 and 600˚C tensile tests based on JIS G 0567. Further, they obtained small pieces from the steel plate, heated them by a temperature elevation rate of 10˚C/s to 1400˚C and held them there for 1 second, then cooled by a time required for cooling from 800˚C to 500˚C of 10 seconds for heat treatment simulating the heat history of HAZ (referred to as "HAZ reproduction heat treatment"), then worked them into test pieces and ran Charpy impact tests based on JIS 2242. Further, they measured the grain size and density of the Ti-based oxides using a scan type electron microscope.

[0026] FIG. 1 shows the relationship between the contents of C and Nb and the high temperature strength, specifically, the 0.2% proof stress (600˚C YS) at 600˚C, with respect to C-Nb/7.74. In the figure, ○ and • indicate the 600˚C YS of steel materials of an ordinary temperature tensile strength of the 400 MPa class, while □ show the 600˚C YS of steel material of the 490 MPa class.

[0027] From FIG. 1, it is learned that if C-Nb/7.74 becomes 0.004 or less, the ordinary temperature tensile strength becomes the 400 MPa class, the 600˚C 0.2% proof stress of 490 MPa class steel material exceeds the target value, and a good high temperature strength is obtained.

[0028] FIG. 2 shows the effects of the number density distribution of Ti-based oxides of a grain size of 0.05 to 10 μm in the steel on the HAZ toughness. From FIG. 2, it is learned that to obtain a good HAZ toughness, it is necessary to include Ti-based oxides of a grain size of 0.05 to 10 μm by dispersion in a ratio of 30 to 300/mm^2.

[0029] Further, the inventors used rod-shaped tensile test pieces, heated them by a temperature elevation rate of 10˚C/s to 1400˚C and held them there for 1 second, then cooled them to 100˚C while making the time required for cooling from 800˚C to 500˚C 10 second for HAZ reproduction heat treatment, then reheated them by a temperature elevation rate of 10˚C/s to 600˚C and measured them for the draw rate, that is, reheat draw rate.

[0030] As a result, as shown in FIG. 3, it was confirmed that with a steel material superior in HAZ toughness with a dispersion of Ti-based oxides in the above range, a good result of a reheat draw rate of 30% or more is obtained and the reheat embrittlement resistance characteristics are also superior.

[0031] FIG. 4 shows the effects of the relationship between the amount of solute oxygen before the addition of Ti and the amount of Ti on the density of the Ti-based oxides. The numerical values of FIG. 4 show the density of Ti-based oxides of a grain size of 0.05 to 10 μm. From FIG. 4, it is learned that to obtain a steel material having a good HAZ toughness containing Ti-based oxides of a grain size of 0.05 to 10 μm in a ratio of 30 to 300/mm^2, it is necessary to adjust the solute oxygen before addition of Ti and after primary deoxidation to, by mass%, 0.003 to 0.015%, preferably 0.003 to 0.010%, and the content of Ti to 0.005 to less than 0.040%, preferably 0.005 to 0.020%.

[0032] In the above way, it was learned that, in particular in fire resistant shaped steel not containing B, if lowering the C and lowering the N and further optimizing the relationship of C and Nb and the grain size and number density of Ti-based oxides, the solid solution Nb is secured and the precipitation of carbides and nitrides at the γ grain boundary of the HAZ is suppressed, so this is extremely effective for the prevention of reheat embrittlement.

[0033] Further, as further merits of the present system of ingredients, suitability quenchability is maintained by the solid solution Nb and the balance of elements contributing to steel material strength and toughness is extremely good, there is almost no dependency of strength or toughness by the cooling speed in the cooling process after heating, and the variation in characteristics is extremely small, so when applied to large thickness sizes, the strength and toughness can be maintained at a high level at all part positions. It was learned that the chemical ingredients were suitable for extremely thick H-section steel.

[0034] The present invention made based on these discoveries will be explained in detail below. First, Ti-based oxides will be explained.

Grain size and density of Ti-based oxides:

[0035] The present invention provides fire resistant steel which utilizes finely dispersed Ti-based oxides to suppress in particular crystal grain coarsening at the HAZ by the pinning effect and improve the HAZ toughness and reheat embrittlement characteristics. The lower limit of the grain size of the Ti-based oxides effective for pinning is 0.05 μm or more. If the grain size of the Ti-based oxides exceeds 10 μm, the oxides will form starting points of fracture and obstruct toughness.

[0036] Further, for improvement of the HAZ toughness and reheat embrittlement characteristics, 30 to 300/mm^2 is effective. If the density of the Ti-based oxides with a grain size of 0.05 to 10 μm is less than 30/mm^2, the pinning effect is insufficient. On the other hand, if the density of the Ti-based oxides with a grain size of 0.05 to 10 μm is over 300/mm^2, propagation of cracks will be promoted and the toughness will be damaged.

[0037] Note that, "Ti-based oxides" is the general term for TiO_2, Ti_2O_3, complex oxides of these with SiO_2 and other Si-based oxides and Al_2O_3 and other Al-based oxides, and oxides containing Ti in which MnS and other sulfides and TiN and other nitrides have complexly precipitated.

[0038] The grain size and density of Ti-based oxides can be measured by a scan type electron microscope (SEM). Ti-based oxides are preferably identified by an SEM having an energy dispersion type X-ray analyzer. Ti-based oxides precipitate in the liquid phase and are not flattened in the hot rolling either, so are observed as spherical inclusions. If using an energy dispersion type X-ray analyzer, it can be confirmed if spherical inclusions are oxides containing Ti.

[0039] By using an SEM to observe several fields, preferably 20 fields or more, at 5000 to 10000X, counting the number of inclusions, and dividing them by the area of the part position observed, the density can be calculated. Note that inclusions with a grain size of less than 0.05 μm or more than 10 μm do not contribute to improvement of toughness, so are ignored when calculating the density.

[0040] Amount of solute oxygen before addition of Ti:

[0041] To ensure the presence of Ti-based oxides with a grain size of 0.05 to 10 μm and a density of 30 to 300/mm^2 in the steel, the amount of solute oxygen before the addition of Ti when producing the steel is important. If the amount of solute oxygen before the addition of Ti is less than 0.003%, the Ti-based oxides become smaller in grain size and fall in density. On the other hand, if the amount of solute oxygen before the addition of Ti exceeds 0.015%, the Ti-based oxides will coarsen to a grain size exceeding 10 μm and the toughness will be damaged. Therefore, the amount of solute oxygen before the addition of Ti was made 0.003 to 0.015% in range. If performing deoxidation using Si and Mn as deoxidizing agents before adding Ti when producing the steel, the amount of solute oxygen can be made 0.003 to 0.015%.

[0042] Next, the ingredients of fire resistant steel of the present invention will be explained.

[0043] C is an element strengthening the steel. To obtain the strength required as structural steel, addition of 0.001% or more is necessary. On the other hand, if adding over 0.030% of C, coarse carbides form at the HAZ and the toughness and reheat embrittlement resistance are reduced and, further, island-shaped martensite forms between the laths of the bainite phases and the toughness of the base material falls. Therefore, the lower limit of the amount of C was made 0.001% and the upper limit was made 0.030%. Note that, from the viewpoint of securing reheat embrittlement resistance and toughness, the lower limit is preferably made 0.005% and the upper limit 0.020%.

[0044] Si is an important deoxidizing agent in the present invention. Further, it is an element contributing to the improvement of strength as well. To make the solute oxygen of the molten steel before addition of Ti 0.003 to 0.015 mass% and, further, to secure strength of the base material, addition of 0.05% or more of Si is necessary. On the other hand, if the amount of Si exceeds 0.50%, low melting point oxides will form and the descalability will deteriorate. For this reason, the amount of S is made 0.05% to 0.50%. Further, if the amount of Si exceeds 0.40%, unevenness will occur at the time of hot dipping and the beauty will be harmed. Therefore, the upper limit of the amount of Si is preferably made 0.40% or less.

[0045] Mn is an important deoxidizing agent in the present invention. Further, it is an element raising the quenchability and increasing the amount of formation of the bainite structures to contribute to the improvement of strength and toughness. To make the solute oxygen of the molten steel before addition of Ti 0.003 to 0.015 mass% and, further, to secure strength and toughness of the base material, addition of 0.40% or more is required. On the other hand, Mn is an element which easily segregates at the center of the steel slab when producing a steel slab in continuous casting. If adding over 2.00% of Mn, the quenchability of the segregated part will excessively rise and the toughness will deteriorate.

[0046] Therefore, the amount of Mn is made 0.40% to 2.00%. In particular, when the amounts of addition of strengthening elements other than Mn are small, to secure strength by addition of Mn, addition of 1.10% or more is preferable.

[0047] Nb is added for securing the solid solution Nb extremely important in the present invention. By securing the solid solution Nb, the quenchability can be raised to improve the ordinary temperature strength. Further, due to the drag effect of dislocations, the deformation resistance can be increased and strength secured even in the high temperature region. To secure the solid solution Nb for expressing this effect, addition of 0.03% or more of Nb is required. On the other hand, if adding over 0.50% of Nb, the HAZ toughness deteriorates, so the upper limit was made 0.50%. To further raise the high temperature strength, addition of 0.10% or more of Nb is preferable.

[0048] Further, Nb is a powerful carbide-forming element. It precipitates by forming NbC with excessive C, so the solid solution Nb is decreased. For this reason, to secure solid solution Nb and improve the high temperature strength, it is necessary to satisfy

$$C-Nb/7.74 \leq 0.004$$

[0049] Note that, here, C and Nb are the contents of C and Nb in units of mass%.

[0050] The lower limit of C-Nb/7.74 can be found from the lower limit value of C and the upper limit value of Nb, so is not particularly defined.

[0051] The mass concentration product of Nb and C is an indicator of the amount of solid solution Nb. To further improve the high temperature strength, it is preferably made 0.0015 or more. The "mass concentration product of Nb and C" is the product of the contents of Nb and C expressed by mass%. The upper limit of the mass concentration product of Nb and C is found from the upper limit values of the contents of Nb and C, so is not particularly defined.

[0052] Ti is an important element for forming Ti-based oxides in this way. Further, it is an element forming carbides and nitrides and easily forms TiN stable at a high temperature. By the formation of TiN, it is possible to suppress the precipitation of NbN, so addition of Ti is also extremely effective for securing solid solution Nb. To obtain this effect, addition of 0.005% or more of Ti is necessary. On the other hand, if adding 0.040% or more of Ti, the Ti-based oxides and TiN will coarsen and the toughness will be harmed.

[0053] For this reason, the amount of Ti is made 0.005% to less than 0.040%. From the viewpoint of securing the amount of fine Ti-based oxides and improving the toughness, the upper limit is preferably 0.020%.

[0054] N is an impurity element forming nitrides. Reduction of the amount of N is effective for securing the solid solution

Nb. The upper limit is made less than 0.0050%. The content of N is preferably extremely low, but making it less than 0.0008% increases the production costs. Further, from the viewpoint of securing toughness, the upper limit of the amount of N is preferably made 0.0045%.

[0055] P and S are impurities. If included in excess, weld cracks due to solidification segregation and a drop in toughness will occur. Therefore, P and S should be reduced as much as possible. The upper limits of the contents of these are made 0.030% and 0.020%.

[0056] In the present invention, further, this system of ingredients may have further added to it as necessary V, Mo, Zr, Hf, Cr, Cu, Ni, Mg, Al, REM, and/or Ca so as to improve the characteristics. Below, these optionally added ingredients will be explained.

[0057] V is known as a precipitation strengthening element, but in the present invention where the C content is low, it contributes to solution strengthening. V becomes saturated in effect even if added in over 0.10% and detracts from the economy, so the upper limit is preferably made 0.10%.

[0058] Mo is an element contributing to strengthening of the structure by solution strengthening and improvement of the quenchability. It is preferably added in accordance with the targeted strength. However, if adding 0.10% or more of Mo, the economy is detracted from and, further, the toughness and high temperature embrittlement resistance of the HAZ sometimes fall, the upper limit is preferably made less than 0.10.

[0059] Zr is an element forming ZrN - a nitride stabler at high temperature than even TiN. By the formation of ZrN, it is possible to contribute more effectively to the reduction of the solid solution N in the steel compared even with addition of Ti alone and therefore the solid solution B and solid solution Nb can be secured. If the content of Zr is over 0.03%, coarse ZrN forms in the molten steel before casting and the ordinary temperature toughness and HAZ toughness are impaired. Therefore, the concentration of Zr is preferably made 0.03% or less. Further, to suppress the precipitation of NbN and prevent a drop in the high temperature strength and draw rate, addition of 0.005% or more is preferable.

[0060] Hf, like Ti, is an element forming nitrides and contributes to reduction of the solid solution N. However, if adding over 0.01% of Hf, the HAZ toughness sometimes falls. Therefore, the upper limit of Hf is preferably made 0.01%.

[0061] Cr, Cu, and Ni are elements which improve the quenchability and thereby contribute to a rise in strength. Cr and Cu, if added in excess, sometimes detract from the toughness, so their upper limits are preferably made 1.5% and 1.0%. Further, from the viewpoint of economy, the upper limit of Ni is preferably made 1.0%.

[0062] Mg is a powerful deoxidizing element and has the function of forming Mg-based oxides stable at a high temperature, not entering into solid solution in the steel even when heated to a high temperature during welding, and pinning the γ grains. Due to this, it refines the structure of the HAZ and suppresses the drop in toughness. However, if adding over 0.005% of Mg, the Mg-based oxides become coarser and no longer contribute to pinning of the γ grains. They sometimes form coarse oxides and detract from the toughness, so the upper limit is preferably made 0.005%.

[0063] Al is a powerful deoxidizing agent and may be added to control the concentration of solute oxygen after primary deoxidation to 0.003 to 0.015%. However, if including over 0.030% of Al, island-shaped martensite is formed and the toughness is sometimes damaged, so the upper limit is made 0.030%. From the viewpoint of improvement of the toughness, the upper limit is preferably 0.02%.

[0064] REMs (rare earth elements) undergo oxidation reactions and sulfurization reactions in the steel to form oxides and sulfides. These oxides and sulfides are stable at a high temperature. They will not enter solid solution even when heated to a high temperature at the time of welding and have the function of pinning the grain boundaries. Due to this function, it is possible to refine the HAZ structure and suppress the drop in toughness.

[0065] To obtain this effect, addition of a total content of all rare earth elements of 0.001% or more is preferable. On the other hand, if adding REMs over 0.01%, the volume fraction of the oxides and sulfides becomes higher and the toughness is sometimes lowered, so the upper limit is preferably made 0.01%.

[0066] Ca, by addition in a small amount, has the effect of suppressing flattening of the sulfides in the rolling direction during hot rolling. Due to this, the toughness is improved, in particular, this contributes to an improvement of the Charpy value in the thickness direction. To obtain this effect, addition of 0.001% or more of Ca is preferable. On the other hand, if adding over 0.005% of Ca, the volume fraction of the oxides and sulfides will become higher and the toughness will be lowered in some cases, so the upper limit is preferably made 0.005%.

[0067] The metal structure of the steel of the present invention is not particularly limited, but the contents of the elements raising the quenchability should be adjusted to obtain a structure in accordance with the required strength. To raise the strength, raising the area ratio of one or both of the massive ferrite or bainite is preferable.

[0068] Massive ferrite is a structure resulting from the diffusion and transformation of austenite to ferrite of the same composition in the cooling process. Since the compositions before and after the transformation are the same, not the diffusion of C, but the self diffusion of the Fe atoms, that is, the rearrangement of the lattice, becomes the speed setting stage. Therefore, the massive ferrite is formed with a short distance of movement of atoms and a relatively fast transformation speed, so the crystal grain size becomes larger than polygonal ferrite and the dislocation density is high.

[0069] The massive ferrite formed by this mechanism differs from the polygonal ferrite in crystal grain size under observation of the structure under an optical microscope, but is no different in form. Therefore, to clearly differentiate these, observation by a through type electron microscope is necessary. Further, bainite forms plate structures and can be distinguished from massive ferrite and polygonal ferrite by an optical microscope.

[0070] Note that, in addition to massive ferrite, bainite, and polygonal ferrite, small amounts of martensite, residual austenite, and pearlite are sometimes also formed.

[0071] The formation of massive ferrite and bainite is promoted by raising the quenchability of steel. For this reason, making the quenchability indicator Ceq 0.05 or more is preferable. Further, if Ceq is too high, the strength rises and the toughness is sometimes impaired, so the upper limit is more preferably made 0.60 or less. Note that,

$$Ceq=C+Si/24+Mn/6+Ni/40+Cr/5+Mo/4+V/14$$

where C, Si, Mn, Ni, Cr, Mo, and V are the contents of the elements [mass%].

[0072] Next, the method of production will be explained.

[0073] Steel, as explained above, is produced using Si and Mn as deoxidizing agents and adjusting the amount of solute oxygen before the addition of Ti and then is cast into steel slabs. From the viewpoint of productivity, continuous casting is preferable.

[0074] The obtained steel slab is hot rolled into steel plate or shaped steel and then cooled. Note that, the steel material covered by the present invention includes rolled steel plate, H-section steel, I-section steel, angle steel, channel steel, unequal angle steel, and other shaped steel.

[0075] Among these, for building materials where fire resistance and reheat embrittlement resistance characteristics are required, in particular H-section steel is suitable. Further, when used as column materials, steel material of a thickness of a large size such as extremely thick H-section steel is suitable.

[0076] To obtain a steel material of the present invention containing Ti-based oxides with a grain size of 0.05 to 10 μm in a ratio of 30 to 300/mm^2, adjustment of the solute oxygen before the addition of Ti and after primary deoxidation is extremely important. It is necessary to adjust the amount of solute oxygen to a mass% of 0.003 to 0.015%. To form the Ti-based oxides, a 0.003% or more amount of solute oxygen is necessary. If over 0.015%, the grain size of the Ti oxides becomes larger, so a sufficient number of oxides of a grain size of 0.05 to 10 μm can no longer be obtained. From this viewpoint, the upper limit of the solute oxygen is preferably made 0.010%.

[0077] When hot rolling to produce a steel material, to facilitate plastic deformation and ensure the Nb sufficiently enters solid solution, the lower limit of the heating temperature of the steel slab has to be made 1100˚C. Further, when hot working to produce shaped steel, to further facilitate plastic deformation, the heating temperature is preferably made 1200˚C or more. The upper limit of the heating temperature of the steel slab was made 1350˚C in view of the performance of the heating furnace and economy. To refine the microstructure of the steel, the upper limit of the heating temperature of the steel slab is preferably made 1300˚C.

[0078] In the hot rolling, the cumulative reduction rate at 1000˚C and below is preferably made 10% or more. Due to this, recrystallization during the hot working is promoted, the γ grains are made finer, and the toughness and strength can be improved.

[0079] When the thickness of the product is less than 40 mm, there are few restrictions in thickness of the material before rolling. By securing a cumulative reduction rate at 1000˚C and below of 30% or more, the strength can be improved, so when the thickness is less than 40 mm, the cumulative reduction rate range is preferably 30% or more.

[0080] Further, by ending the hot working in the temperature range where the structure of the steel is the single austenite phase (meaning γ single phase region) or ending it in the state where the volume fraction of the ferrite formed by the phase transformation is low, it is possible to avoid a remarkable rise in the yield strength, drop in toughness, anisotropy of toughness, and other deterioration of the mechanical characteristics. Therefore, the end temperature of the hot rolling is preferably made 800˚C or more.

[0081] Further, after hot rolling, controlled cooling is preferably used to make the average cooling speed in the 800 to 500˚C temperature range 0.1 to 10˚C/s. To use controlled cooling after hot rolling to improve the strength and toughness of a steel material further, the average cooling speed in the 800 to 500˚C temperature range is preferably made 0.1˚C/s or more. On the other hand, if the average cooling speed of 800 to 500˚C in temperature range is over 10˚C/s, the structural fraction of the bainite phase or martensite phase rises and the toughness sometimes drops, so the upper limit is preferably made 10˚C/s.

Examples

[0082] Molten steels produced in converters were charged with alloys, then continuously cast to prepare steel slabs of 250 to 300 mm thickness comprised of the ingredients shown in Table 1. Table 1 shows the amount of solute oxygen before addition of Ti (mass%). Further, blank fields in Table 1 mean no optional elements were added.

Table 1

Steel no.	Ingredients (mass)													C- Nb/ 7.74	Solute O before Ti addition	Ti-based oxides /μm^2	Remarks
	C	Si	Mn	P	S	Nb	N	Ti	V,Mo	Zr,Hf	Cr,Cu,Ni	Mg,Al	Ca,REM				
A	0.005	0.25	1.55	0.010	0.005	0.18	0.0020	0.009						-0.018	0.011	167	Inv. steel
B	0.008	0.20	1.55	0.008	0.007	0.22	0.0022	0.013						-0.020	0.005	68	
C	0.014	0.20	1.36	0.009	0.006	0.24	0.0019	0.011						-0.017	0.011	204	
D	0.011	0.25	1.60	0.007	0.004	0.33	0.0023	0.010						-0.032	0.009	158	
EE	0.028	0.10	0.80	0.010	0.008	0.20	0.0022	0.010	Mo:0.05					0.002	0.011	189	
F	0.015	0.15	1.55	0.011	0.010	0.09	0.0032	0.005	v:0.08					0.003	0.010	113	
G	0.018	0.05	1.50	0.009	0.013	0.15	0.0033	0.031		Zr:0.01				-0.001	0.009	181	
H	0.010	0.18	1.40	0.005	0.008	0.18	0.0021	0.026		Hf:0.01				-0.013	0.015	284	
I	0.010	0.20	1.30	0.016	0.009	0.10	0.0019	0.037			Cr:1.2			-0.003	0.007	64	
J	0.002	0.45	1.60	0.010	0.006	0.07	0.0015	0.010			Cu: 0.9,Ni:0.7			-0.007	0.005	102	
K	0.008	0.20	1.45	0.012	0.005	0.03	0.0020	0.014			Cr: 1.5,Cu: 0.8,Ni:0.4			0.004	0.006	94	
L	0.014	0.15	1.60	0.014	0.012	0.16	0.0024	0.010	Mo:0.09			Mg: 0.002		-0.007	0.009	194	
M	0.015	0.10	1.25	0.015	0.014	0.13	0.0031	0.020	V:0.06		Cu: 0.7,Ni:0.3			-0.002	0.010	146	
N	0.008	0.30	1.37	0.013	0.010	0.20	0.0022	0.013		Zr:0.02	Cr:1.3	Al:0.01		-0.018	0.012	176	
O	0.009	0.25	1.55	0.010	0.009	0.27	0.0025	0.015					Ca: 0.003, REM: 0.007	-0.026	0.010	154	

(continued)

Steel no.	Ingredients (mass)													C- Nb/ 7.74	Solute O before Ti addition	Ti-based oxides /μm^2	Remarks
	C	Si	Mn	P	S	Nb	N	Ti	V,Mo	Zr,Hf	Cr,Cu,Ni	Mg,Al	Ca,REM				
P	0.015	0.15	1.55	0.010	0.010	0.08	0.0041	0.022						*0.005*	*0.016*	*323*	Comp. steel
Q	0.018	0.15	1.30	0.012	0.008	0.55	0.0022	0.008						-0.053	0.013	210	
R	0.021	0.20	1.20	0.016	0.016	0.20	0.0036	*0.041*						-0.005	0.011	89	
S	*0.031*	0.25	0.90	0.011	0.011	0.05	0.0029	0.011			Cu: 0.6,Ni:0.4			*0.025*	0.013	201	
T	0.023	0.20	1.50	0.012	0.006	0.13	0.0033	0.020						*0.006*	0.014	231	
U	0.010	0.20	1.55	0.010	0.009	0.21	*0.0053*	0.036						-0.017	*0.018*	*335*	
V	0.008	0.10	1.35	0.015	0.010	*0.02*	0.0033	0.020						*0.005*	0.012	154	
X	0.015	0.33	1.55	0.012	0.003	0.30	0.0025	0.015	V:006 9Mo: 0.05		Cr:0.22 Cu:0.33 Ni:0.21	Al:0.01		-0.024	0.010	186	Inv. steel
Y	0.009	0.39	1.57	0.009	0.004	0.31	0.0021	0.012	V:0.05		Cu:0.34 Ni:0.20	Al:0.02		-0.031	0.011	179	
Z	0.012	0.25	1.45	0.011	0.004	0.29	0.0019	0.014	Mo:0.06		Cu:0.55 Ni:0.40	Al:0.02		-0.025	0.009	91	
AA	*0.035*	0.21	1.57	0.015	0.006	0.25	0.0030	0.019	V:0.05 Mo:0.05		Cu:0.34 Ni:0.20			0.003	0.013	124	Comp. steel
AB	0.012	0.02	1.45	0.011	0.004	*0.56*	0.0019	0.014	V:0.06		Cu:0.7 Ni: 0.6	Al:0.01		-0.060	0.006	78	

[0083] Each obtained steel slab was hot rolled under the conditions shown in Table 2 to obtain H-section steel. Fig. 5 shows the process of production of shaped steel. The steel slab heated by a heating furnace 4 was rough rolled by a rough rolling mill 5, then rolled to H-section steel by a universal rolling mill train comprised of an intermediate universal rolling mill 6 and finish universal rolling mill 8. Mater cooling was performed between the rolling passes by water cooling apparatuses 7 provided before and after the intermediate universal rolling mill 6. The outside surface of the flange was repeatedly spray cooled and reverse rolled. The cooling after the hot rolling was performed by a cooling apparatus 9 set behind the finishing universal rolling mill 8.

[0084] Further, the steels F, K, J, and Z of Table 1 were further hot rolled under the conditions of Table 3, while the steels EE, K, and Z were further hot rolled under the conditions of Table 4.

[0085] In the obtained H-section steel, as shown in FIG. 6, tensile test pieces were taken at the center part of thickness t_2 of the flange 2 ($1/2t_2$) at the positions of 1/4 of the total flange width (B) (called "flange") and 1/2 (called "fillet") based on the JIS Z 2201.

[0086] The ordinary temperature tensile test was performed based on JIS Z 2241, while the 600˚C 0.2% proof stress was measured based on JIS G 0567. Note that the characteristics of these locations were found because those portions are representative portions in the cross-section of H-section steel and can show the average mechanical characteristics of H-section steel and variations in the cross-sections.

[0087] The Charpy impact test (Tables 2 to 4) was performed on small pieces taken from the fillet based on the representative test method of JIS Z 2242 at 0˚C.

[0088] When used as fire resistant steel, the reheat draw rate of the reproduced weld heat affected zone (HAZ) (Tables 2 to 4) is an important characteristic. This was evaluated by subjecting the test steel to a weld heat cycle, heating it again, applying tensile stress at a high temperature, and using the draw rate when breaking.

[0089] That is, a rod shaped tensile test piece taken from the flange was held at 1400˚C for 1 second, then cooled down to 100˚C with a cooling time from 800˚C to 500˚C of 20 seconds as a weld heat cycle, then was further heated as is by a 1˚C/s temperature elevation rate to 600˚C, held at 600˚C for 600 seconds, then given tensile strength to breakage by a 0.5 MPa/s tensile increase rate and measured for draw rate.

[0090] The toughness of the reproduced weld heat affected zone (HAZ) (Table 2), in the same way as the reheat draw rate, was evaluated by subjecting the test steel to a weld heat cycle, then applying a Charpy impact test based on JIS Z 2242 at 0˚C and finding the absorbed energy. That is, V-notch test pieces were taken from small pieces heat treated by holding them at 1400˚C for 1 second, then cooling down to 100˚C with a cooling time from 800˚C to 500˚C of 20 seconds as a weld heat cycle and were used for a Charpy impact test.

[0091] As the strength classes demanded from steel, there are two types. One is the ordinary temperature tensile strength of the 400 MPa class defined as SM400, while the other is the ordinary temperature tensile strength of the 490 MPa class defined as SM490. These are shown separately. On the other hand, extremely thick H-section steel is mostly based on the U.S. ASTM standard and is shown divided into the representative strength classes of Grade 50 and Grade 65.

[0092] Note that, the targets of the JIS standard SM400, that is, the over TS400 MPa class, are an ordinary temperature yield strength YP of 235 MPa or more, preferably 355 MPa or less, a tensile strength TS of 400 to 510 MPa, and a 600˚C 0.2% proof stress PS of 157 MPa or more.

[0093] The targets of SM490, that is, the over TS490 MPa class, are a YP of 325 MPa or more, preferably 445 MPa or less, a TS of 490 to 610 MPa, and a PS of 217 MPa or more. Further, in both the SM400 class and SM490 class, the target value is the 0˚C impact absorption energy is 100J or more and the preferable upper limit of the yield ratio YP/TS is 0.80.

[0094] Further, for the ASTM standard, with the Grade 50, the YP is 345 MPa or more and the TS is 450 MPa or more, while with the Grade 65, the YP is 450 MPa or more and the TS is 550 MPa or more. In addition to the above, regarding the toughness, in each case, an impact absorption energy at the fillet part of the base material at the Charpy test temperature of 0˚C is preferably 54J or more.

[0095] Regarding the reproduced HAZ characteristics, in each standard, the target of the reheat draw rate is 30% or more and the target of the toughness is 27J or more. In particular, when evaluated as fire resistant steel, a reheat draw rate of 50% or more is preferable.

Table 2

Prod. no.	Steel no.	Strength class	Heating temp. (˚C)	Cumulative reduction rate at 1000˚Cand below (%)	Average cooling rate at 800 to 500˚C (˚C/s)	Flange thickness size (mm	Ordinary temperature mechanical characteristics				High temperature mechanical characteristics			Remarks
							Yield strength YP (MPa)	Tensile strength TS (MPa)	Yield ratio YP/TS	0˚C impact absorption energy (J)	600˚C 0.2% PS (MPa)	Reproduced HAZ reheat embrittlement draw rate (%)	Reproduced HAZ toughness (J)	
1	A	SM400	1300	34	Slow cooling 34 (0.05~ 1.0˚C/s)	28	318	417	0.76	314	188	72	101	Inv. steel
2	B	SM400		38		21	341	442	0.77	298	192	69	88	
3	C	SM400		36		24	318	421	0.76	274	184	54	74	
4	D	SM490		31		37	402	546	0.74	277	248	59	89	
5	EE	SM400		38		21	312	411	0.76	231	174	45	55	
6	F	SM400		39		18	360	454	0.79	289	162	48	78	
7	G	SM400		36		24	315	411	0.77	221	177	52	53	
8	H	SM400		34		28	316	421	0.75	297	184	71	42	
9	I	SM400		36		24	295	405	0.73	291	175	68	75	
10	J	SM490		39		18	401	511	0.78	329	225	76	124	
11	K	SM490		38		21	389	504	0.77	302	221	71	105	
12	L	SM400		36		24	403	521	0.77	271	226	56	87	
13	M	SM400		38		21	334	443	0.75	264	199	51	78	
14	N	SM490		36		24	392	503	0.78	197	224	68	44	
15	O	SM490		38		21	403	526	0.77	208	256	74	54	

(continued)

Prod. no.	Steel no.	Strength class	Heating temp. (˚C)	Cumulative reduction rate at 1000˚Cand below (%)	Average cooling rate at 800 to 500˚C (˚C/s)	Flange thickness size (mm	Ordinary temperature mechanical characteristics				High temperature mechanical characteristics			Remarks
							Yield strength YP (MPa)	Tensile strength TS (MPa)	Yield ratio YP/TS	0˚C impact absorption energy (J)	600˚C 0.2% PS (MPa)	Reproduced HAZ reheat embrittlement draw rate (%)	Reproduced HAZ toughness (J)	
16	P	SM400	1300	36	Slow cooling (0.05~ 1.0˚C/s)	24	287	*395*	0.73	*89*	*117*	65	*22*	Comp. steel
17	Q	SM490		36		24	455	607	0.75	181	234	*29*	*11*	
18	R	SM400		38		21	329	442	0.74	*17*	171	*25*	*13*	
19	S	SM400		34		28	336	435	0.77	*78 78*	*119*	*29*	*15*	
20	T	SM400		39		18	325	421	0.77	270	*137*	56	39	
21	U	SM400		31		37	334	436	0.77	*34*	167	*21*	*13*	
22	V	SM400		36		24	304	*396*	0.77	312	*114*	71	62	
35	J	Grade 50	1300	11	Slow cooling (0.03~ 0.3˚C/s)	90	363	493	0.74	169	231	51	59	Inv. steel
36	O	Grade 50		7		125	371	511	0.73	118	245	55	98	
37	X	Grade 65		11		90	470	572	0.82	201	298	41	101	
38	Y	Grade 65		11		90	461	568	0.81	251	301	43	62	
39	Z	Grade 65		7		125	459	564	0.81	312	291	38	62	

(continued)

Prod. no.	Steel no.	Strength class	Heating temp. (˚C)	Cumulative reduction rate at 1000˚Cand below (%)	Average cooling rate at 800 to 500˚C (˚C/s)	Flange thickness size (mm	Ordinary temperature mechanical characteristics				High temperature mechanical characteristics			Remarks
							Yield strength YP (MPa)	Tensile strength TS (MPa)	Yield ratio YP/TS	0˚C impact absorption energy (J)	600˚C 0.2% PS (MPa)	Reproduced HAZ reheat embrittlement draw rate (%)	Reproduced HAZ toughness (J)	
40	Q	Grade 50	1300	7	Cooling 11 (0.03~7 0.3˚C/s)	125	441	590	0.75	107	259	*24*	*23*	Comp, steel
41	AA	Grade 65		11		90	492	615	0.80	*21*	315	*28*	48	
42	AB	Grade 65		7		125	501	592	0.85	61	336	31	*15*	

Table 3

Prod. no.	Steel no.	Strength class	Cumulative reduction rate at 1000˚C and below (%)	Flange thickness size (mm	Ordinary temperature mechanical characteristics				High temperature mechanical characteristics		Remarks
					Yield strength YP (MPa)	Tensile strength TS (MPa)	Yield ratio YP/TS	0˚C impact absorption energy (J)	600˚C 0.2% PS (MPa)	Reproduced HAZ reheat embrittlement draw rate (%)	
23	F	SM400	39	18	360	454	0.79	289	162	48	Inv. steel
24			32		346	449	0.77	274	160	55	
25			29		337	448	0.75	271	157	47	
26	K	SM490	38	21	401	511	0.78	301	225	55	
27			33		389	504	0.77	271	226	56	
28			28		367	492	0.75	249	220	53	
43	J	Grade50	11	90	363	493	0.74	169	231	51	
44			15		372	499	0.75	201	229	49	
45			20		390	511	0.76	249	233	52	
46	Z	rade65	7	125	459	564	0.81	312	291	38	
47			10		479	589	0.81	249	304	41	
48			13		492	602	0.82	249	302	49	

Table 4

Prod. no.	Steel no.	Strength class	Cumulative reduction rate at 1000˚C and below (%)	Flange thickness size (mm	Ordinary temperature mechanical characteristics				High temperature mechanical characteristics		Remarks
					Yield strength YP (MPa)	Tensile strength TS (MPa)	Yield ratio YP/TS	0˚C impact absorption energy (J)	600˚C 0.2% PS (MPa)	Reproduced HAZ reheat embrittlement draw rate (%)	
29	EE	SM400	6.0	15	339	438	0.77	251	179	45	Inv. steel
30			1.0	18	312	411	0.76	231	174	45	
31			0.07	27	306	405	0.76	221	170	44	
32	K	SM490	3.5	18	395	522	0.76	296	229	70	
33			0.8	21	389	504	0.77	302	221	71	
34			0.08	37	385	490	0.79	297	217	72	
49	Z	Grade65	0.13	125	470	589	0.80	311	311	39	
50			0.1	125	459	564	0.81	312	291	38	
51			0.03	125	463	552	0.84	235	302	36	

[0096] As shown in Table 2, each of the steels of the Production Nos. 1 to 15 and 35 to 39 of the present invention has ordinary temperature mechanical characteristics and high temperature mechanical characteristics within the target value ranges. Further, the yield point is the lower limit value of the JIS standard or more, while the yield ratio YP/TS is 0.8 or less or within the preferable range. Furthermore, the Charpy impact value at 0˚C obtained is a value of the target value or more. Furthermore, the reheat draw rate of the reproduced weld heat affected zone of 30% or more is sufficiently satisfied.

[0097] On the other hand, each of the comparative steels, that is, the steels of Production Nos. 16 to 22 and 40 to 42, has ingredients C-Nb/7.74 and a density of Ti-based oxides outside the range of the present invention, so the mechanical characteristics satisfying the target are not obtained.

[0098] As shown in Table 3, in the case of H-section steel with a flange thickness of less than 40 mm, if making the cumulative reduction rate at 1000˚C and below 30% or more, the mechanical characteristics become better than when the cumulative reduction rate is less than 30%.

[0099] Further, in the case of extremely thick H-section steel of a flange thickness of 40 mm or more, as shown in Production Nos. 43 to 48 showing the case of a flange thickness of 90 to 125 mm, along with the increase in the cumulative reduction rate at 1000˚C and below, both the yield strength and the tensile strength rise. With a cumulative reduction rate of 10% or more, the strengths required as Grade 50 and Grade 65 can further be sufficiently satisfied.

[0100] As shown in Table 4, when the flange is less than 40 mm, using water cooling to cool acceleratedly between 800 to 500˚C by a cooling speed of 10˚C/s, compared with using natural cooling etc. to slowly cool between 800 to 500˚C by 0.1˚C/s, enables the ordinary temperature strength and the high temperature strength to be raised.

[0101] Further, in the extremely thick H-section steel, as shown in Production Nos. 49 to 51 showing the case of a flange thickness of a size of 125 mm as a representative example, by acceleratedly cooling from 800 to 500˚C by water cooling up to 0.13˚C/s, both the yield strength and the tensile strength rise and the strength required as grade 65 can be further sufficiently satisfied.

Industrial Applicability

[0102] According to the present invention, a steel material having sufficient ordinary temperature strength and high temperature strength and superior in toughness of the base material and HAZ and reheat embrittlement resistance characteristics, in particular, fire resistant H-section steel, can be produced without cold working and heat treatment for thermal refining or extremely thick H-section steel of a thickness of a large size, for example, a flange thickness of up to 140 mm or so, can be produced as hot rolled while securing strength and toughness. Due to this, it is possible to reduce installation costs, shorten the work period, and thereby greatly cut costs. The improvement in the reliability of large buildings, guarantee of safety, economy, and other industrial effects are extremely remarkable.

Claims

1. A steel material superior in high temperature characteristics and toughness **characterized by** containing by mass%,

C: 0.001% to 0.030%,
Si: 0.05% to 0.50%,
Mn: 0.40% to 2.00%,
Nb: 0.03% to 0.50%,
Ti: 0.005% to less than 0.040%, and
N: 0.0008% to less than 0.0050%, restricting
P: 0.030% or less and
S: 0.020% or less, and
having a balance of Fe and unavoidable impurities, where
the contents of C and Nb satisfy
$C-Nb/7.74 \leq 0.004$

and Ti-based oxides of a grain size of 0.05 to 10 μm are present in a density of 30 to 300/mm^2.

2. A steel material superior in high temperature characteristics and toughness as set forth in claim 1 **characterized by** containing, by mass%, one or both of

V: 0.10% or less and
Mo: less than 0.10%.

3. A steel material superior in high temperature characteristics and toughness as set forth in claim 1 or 2 **characterized by** containing, by mass%, one or more of

Zr: 0.03% or less and
Hf: 0.01% or less.

4. A steel material superior in high temperature characteristics and toughness as set forth in any one of claim 1 to 3 **characterized by** containing, by mass%, one or more of

Cr: 1.5% or less,
Cu: 1.0% or less, and
Ni: 1.0% or less.

5. A steel material superior in high temperature characteristics and toughness as set forth in any one of claims 1 to 4 **characterized by** containing, by mass%, one or more of

Mg: 0.005% or less,
Al: 0.030% or less,
REM: 0.01% or less, and
Ca: 0.005% or less.

6. A steel material superior in high temperature characteristics and toughness as set forth in any one of claims 1 to 5 **characterized in that** a mass concentration product of Nb and C is 0.0015 or more.

7. A steel material superior in high temperature characteristics and toughness as set forth in any one of claims 1 to 6 **characterized in that** the steel material is a fire resistant steel material.

8. A steel material superior in high temperature characteristics and toughness as set forth in any one of claims 1 to 6 **characterized in that** the steel material is extremely thick H-section steel with a flange thickness of 40 mm or more.

9. A method of production of a steel material superior in high temperature characteristics and toughness **characterized by** adjusting steel comprised of ingredients as set forth in any of claims 1 to 6 to a solute oxygen of 0.003 to 0.015 mass%, then adding Ti, melting, and casting to obtain a steel slab, and heating this to 1100 to 1350˚C and hot rolling.

10. A method of production of a steel material superior in high temperature characteristics and toughness as set forth in claim 9, **characterized by** hot rolling by a cumulative reduction rate at 1000˚C and below of 10% or more.

11. A method of production of a steel material superior in high temperature characteristics and toughness as set forth in claim 9 or 10 **characterized by** hot rolling, then cooling from 800˚C to 500˚C temperature range by a 0.1 to 10˚C/s average cooling speed.

Fig.1

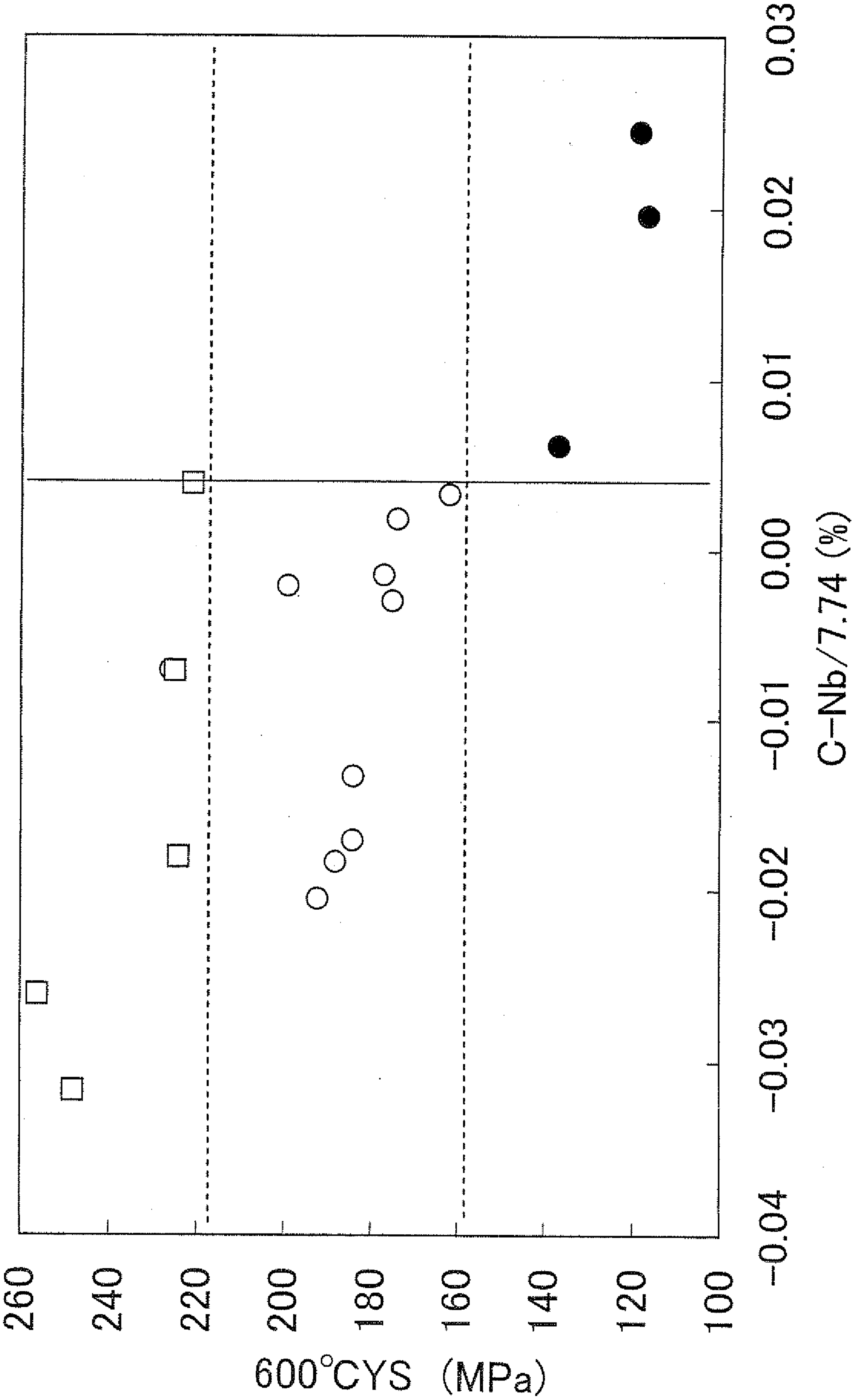

600°CYS (MPa)
260
240
220
200
180
160
140
120
100
C−Nb/7.74 (%)
−0.04
−0.03
−0.02
−0.01
0.00
0.01
0.02
0.03

Fig.2

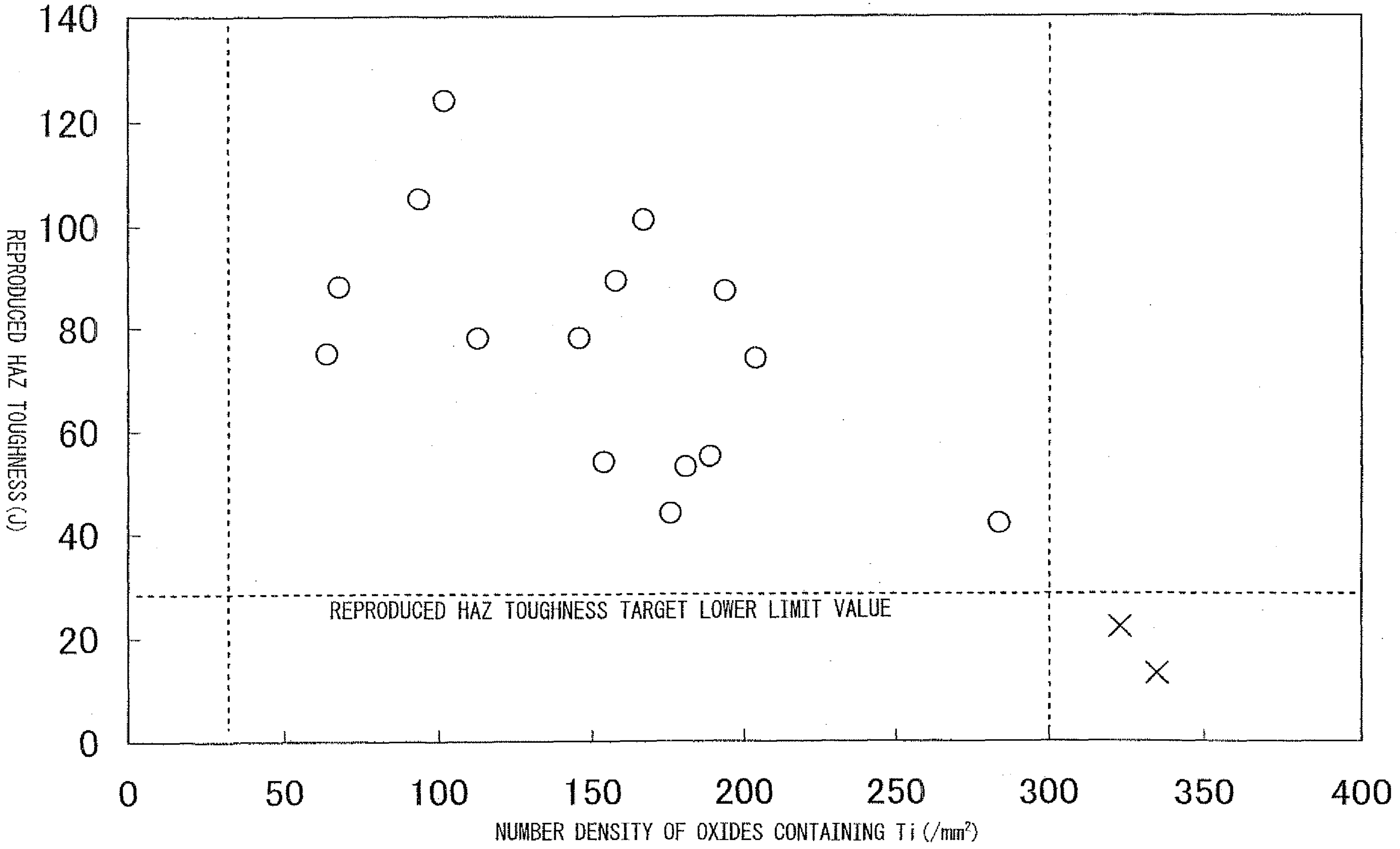

140
120
100
80
60
40
20
0
REPRODUCED HAZ TOUGHNESS (J)
0
50
100
150
200
250
300
350
400
NUMBER DENSITY OF OXIDES CONTAINING Ti (/mm²)
REPRODUCED HAZ TOUGHNESS TARGET LOWER LIMIT VALUE

Fig.3

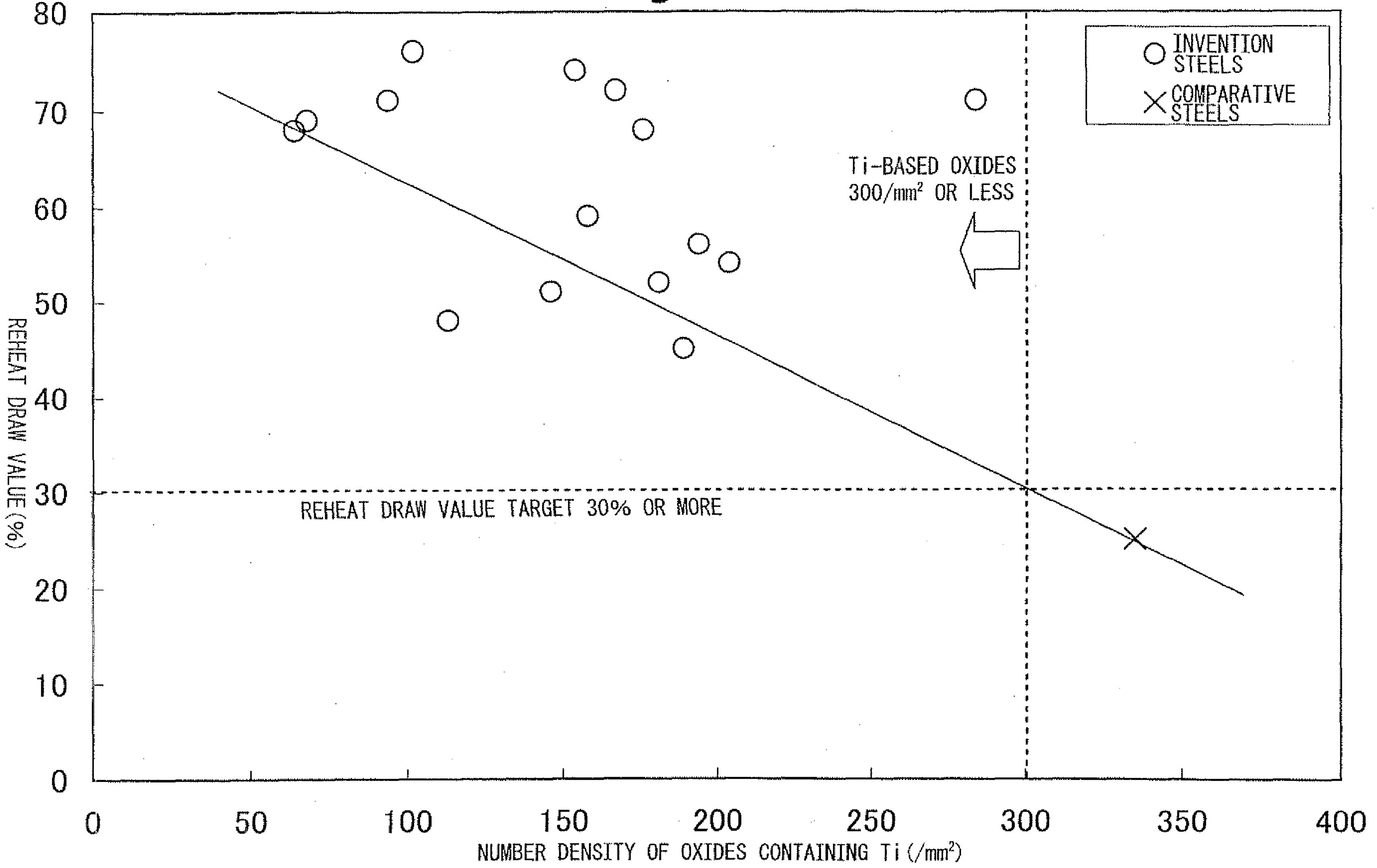

INVENTION STEELS
COMPARATIVE STEELS
Ti-BASED OXIDES 300/mm² OR LESS
REHEAT DRAW VALUE TARGET 30% OR MORE
REHEAT DRAW VALUE (%)
NUMBER DENSITY OF OXIDES CONTAINING Ti (/mm²)
0
10
20
30
40
50
60
70
80
0
50
100
150
200
250
300
350
400

Fig.4

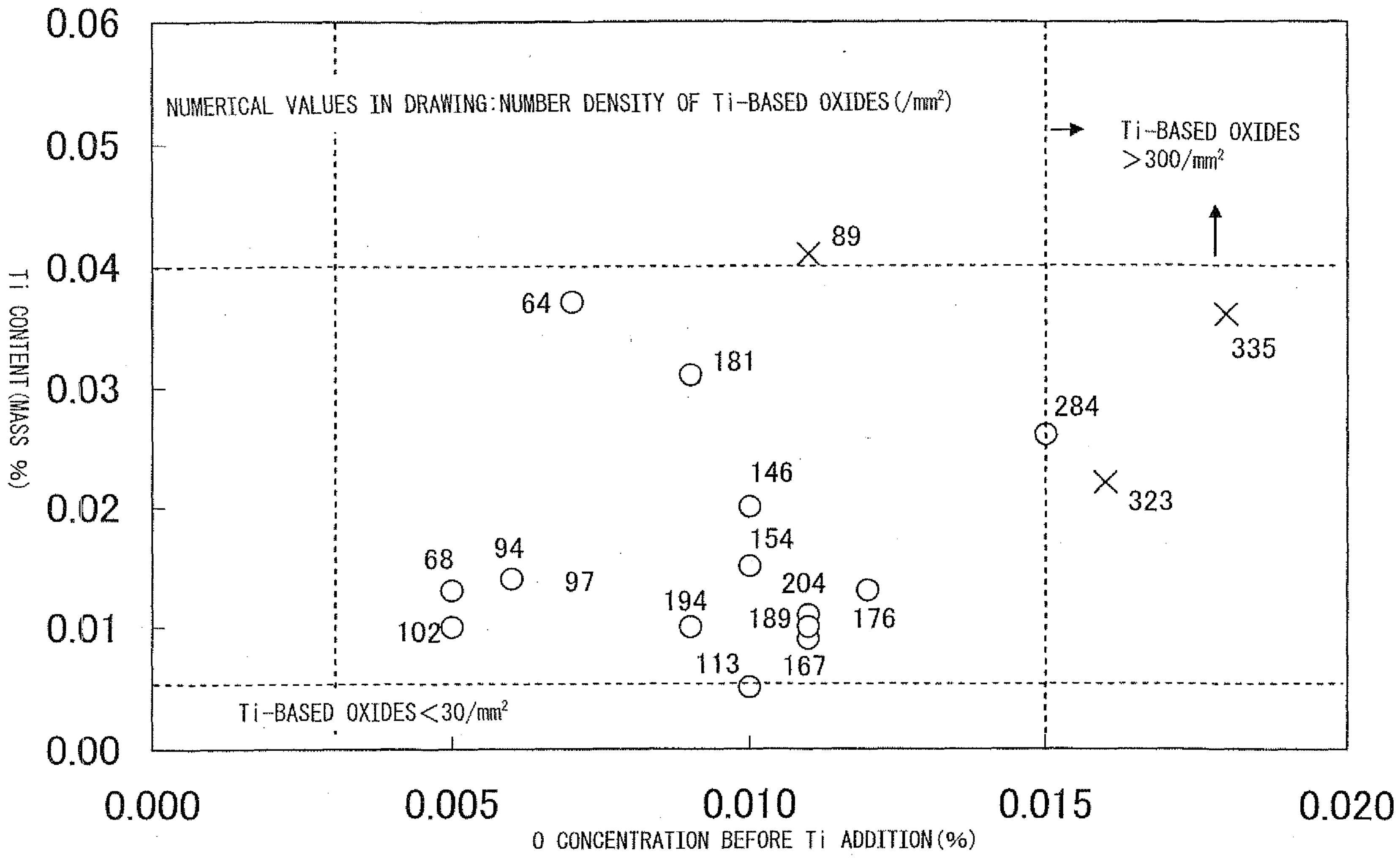

NUMERICAL VALUES IN DRAWING:NUMBER DENSITY OF Ti-BASED OXIDES(/mm²)
Ti-BASED OXIDES >300/mm²
Ti-BASED OXIDES <30/mm²
Ti CONTENT(MASS %)
O CONCENTRATION BEFORE Ti ADDITION(%)
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0.000
0.005
0.010
0.015
0.020
89
64
181
335
284
146
323
154
68
94
97
204
194
189
176
102
113
167

Fig.5

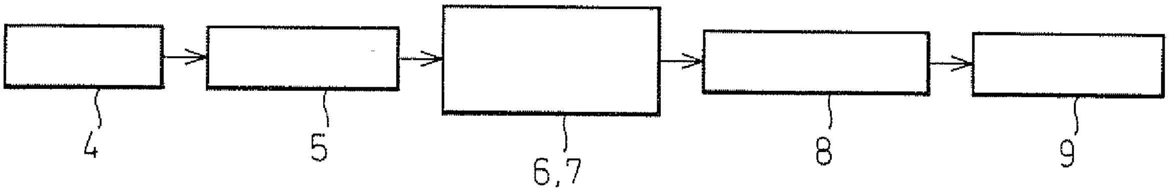
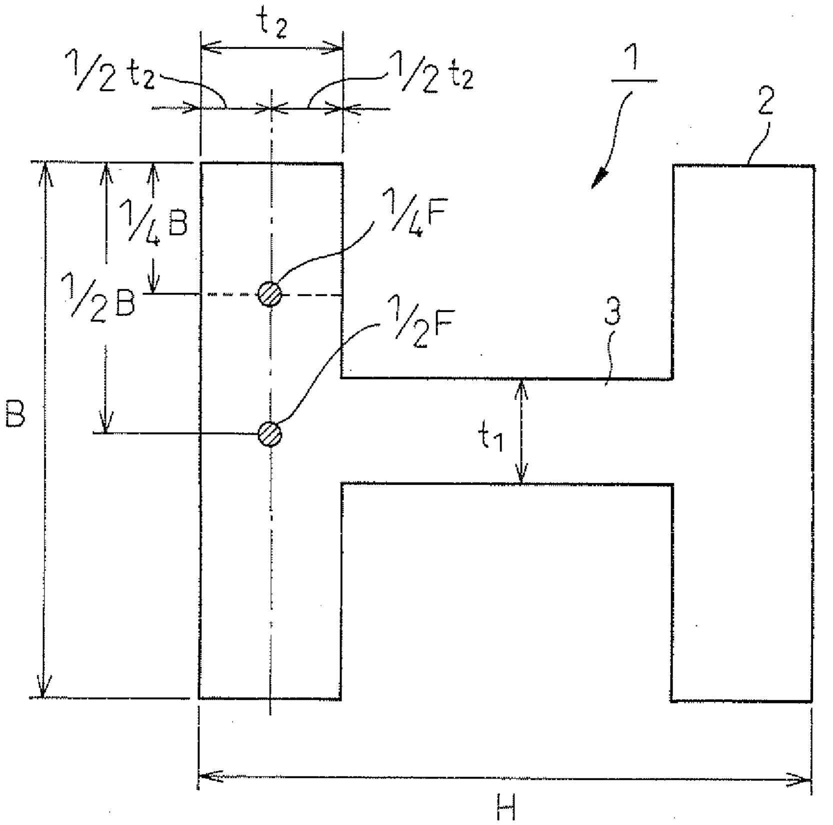


Fig.6



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2008/057563

A. CLASSIFICATION OF SUBJECT MATTER
C22C38/00(2006.01)i, *C21D8/00*(2006.01)i, *C22C38/14*(2006.01)i, *C22C38/58* (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, C21D8/00, C22C38/14, C22C38/58

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	1996-2008
Kokai Jitsuyo Shinan Koho	1971-2008	Toroku Jitsuyo Shinan Koho	1994-2008

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 4-362156 A (Sumitomo Metal Industries, Ltd.), 15 December, 1992 (15.12.92), (Family: none)	1-11
A	JP 2002-212632 A (Nippon Steel Corp.), 31 July, 2002 (31.07.02), (Family: none)	1-11
A	JP 2004-360361 A (Nippon Steel Corp.), 24 December, 2004 (24.12.04), (Family: none)	1-11
A	JP 2004-339549 A (Nippon Steel Corp.), 02 December, 2004 (02.12.04), (Family: none)	1-11

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search 08 July, 2008 (08.07.08)	Date of mailing of the international search report 15 July, 2008 (15.07.08)
Name and mailing address of the ISA/ Japanese Patent Office Facsimile No.	Authorized officer Telephone No.

Form PCT/ISA/210 (second sheet) (April 2007)

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- JP 7300618 A **[0005]**
- JP 10176237 A **[0007]**
- JP 2000054061 A **[0007]**
- JP 2000282167 A **[0007]**
- JP 2002115022 A **[0008]**