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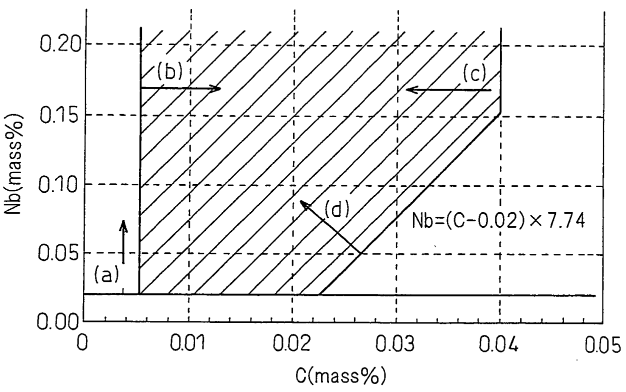
(54) FIRE-RESISTANT HIGH-STRENGTH ROLLED STEEL MATERIAL AND METHOD FOR PRODUCTION THEREOF

(57) A fire resistant high strength rolled steel material superior in fire resistance and toughness used for a structural member of a building etc. containing, by mass%,
C: 0.005% to less than 0.04%,
Mn: 0.8 to 1.7%,
Si: 0.05 to less than 0.4%,
Nb: 0.02 to 1%,
Ti: 0.005 to 0.02%,
N: 0.005% or less,
B: 0.0003 to 0.003%, and
Al: 0.005% to 0.03%,
and a balance of Fe and unavoidable impurities, and having the ratio Ti/N of 2 to 8, the value C-Nb/7.74 of 0.02% or less, and having the ratio of the 0.2% yield strength at 600°C to the yield strength at room temperature of 0.50 or more.

Fig.1



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Description

TECHNICAL FIELD

[0001] The present invention relates to a fire resistant high strength rolled steel material used for the structural member of a building and a method of production of the same.

BACKGROUND ART

[0002] So-called "fire resistant steel" is a steel material for building use which has a predetermined strength even when the building catches fire etc. and the material becomes a high temperature. Here, fire resistant steel envisioning a temperature of a building at the time of a fire of 600°C and able to maintain its strength at that temperature will be explained.

[0003] Now, the methods of strengthening steel materials include mainly the 1) method of grain refinement of the ferrite, the 2) solution strengthening method using alloy elements, the 3) dispersion strengthening method using a hardening phase, and the 4) method using fine precipitates. Deformation of a steel material, seen microscopically, is caused by movement of dislocations in the crystal grains. Each of these methods is a method strengthening the resistance to such movement of dislocations.

[0004] Therefore, first the 1) method of grain refinement of the ferrite will be explained.

[0005] The dislocations moving in the crystal grains stop once at the grain boundaries, then move to the adjoining crystal grains, so the crystal grain boundaries provide resistance to the movement of dislocations. Therefore, if the crystal grains become finer, the frequency of moving dislocations meeting crystal grain boundaries rises, so the resistance increases. This method of strengthening is the 1) method of grain refinement of the ferrite.

[0006] Note that, generally, the strength is evaluated by the following equation known as the Hall-Petch equation:

$$\sigma=\sigma_0+k \times d^{-0.5}$$

[0007] Here, σ is the yield strength, σ_0 is the constant stress value, the relative constant k is called the locking parameter and is an indicator of the resistance at the crystal grain boundaries, and d is the crystal grain size.

[0008] Next, the 2) the solution strengthening method using alloy elements will be explained.

[0009] When there are solute atoms of different sizes such as alloy elements on the plane of movement of the dislocations, called the "slip plane", a resistance acts with respect to the movement of the dislocations. Further, due to the distribution of the alloy elements in the steel, an elastic stress field is formed and acts as a drag resistance with respect to movement of the dislocations. It is known that the size of the drag resistance is affected by the solute atom concentration, misfit due to the solute/solvent atom size, and diffusion coefficient of the solute atoms.

[0010] The method of strengthening by increasing this alloy element on the slip plane resistance or the drag resistance by alloy elements is referred to as the 2) solution strengthening method using alloy elements.

[0011] Further, as the solution strengthening method strengthening the structure by the increase of the drag resistance, there is the technology of utilizing of the drag effect of the dissolved Nb. The technology of utilizing the drag effect of this dissolved Nb is used for the production of thin-gauge fire resistant steel and is described in for example Japanese Patent Publication (A) No. 2000-054061 and Japanese Patent Publication (A) No. 2000-248335.

[0012] The drag effect of dissolved Nb is the phenomenon of the dissolved Nb concentrating at dislocations and other lattice defects and forming resistance to movement of defects and dislocations to thereby improve the strength.

[0013] The present inventors discovered the possibility of the drag resistance due to this dissolved Nb effectively functioning in the temperature region up to about 600°C and thereby developed the Nb-based fire resistant steel of the present invention, but discovered that to make the drag effect of this dissolved Nb fully function and achieve fire resistant steel having sufficient fire resistance, it is necessary to satisfy the following conditions.

[0014] First, the amount of dissolved C must be made a low value. This is because if the amount of dissolved C is high, it forms NbC and reduces the amount of dissolved Nb.

[0015] Second, B has to be added. Part of the contained Nb cannot be maintained in the solid solution state, but segregates at the crystal grain boundaries and cannot concentrate at the dislocations and other lattice defects, but if adding B, the B segregates at the crystal grain boundaries instead of Nb and helps the Nb maintain its dissolved state.

[0016] Third, the amount of dissolved N must be reduced. This is because the added B reacts with N and ends up producing BN so loses the ability to segregate at the crystal grain boundaries. To reduce the amount of dissolved N, the means of adding Ti to cause the formation of TiN and reduce the amount of dissolved N is used.

[0017] Furthermore, the 3) dispersion strengthening method using a hardening phase will be explained.

[0018] A macrostructure comprised of a hard phase and soft phase mixed together (complex phase structure) generally changes in strength according to the volume fractions of the phases. This is due to the fact that, compared with a soft phase, the dislocations in the crystal grains of the hard phase tend to be difficult to move during deformation, that is, the resistance required for deformation is large. The method of increasing the resistance using the presence of this hard phase is the 3) the dispersion strengthening method using a hardening phase.

[0019] For example, with a composite phase structure made of ferrite and pearlite, if the hard phase, that is, the pearlite, increases in volume fractions, the soft phase, that is, the ferrite structure, relatively falls and the strength rises.

[0020] Finally, the 4) method of using fine precipitates will be explained.

[0021] If the precipitate is distributed on the slip plane at the time of movement of dislocations in the crystal grains, it blocks the dislocations and acts as resistance to movement of the dislocations. The method of strengthening by increasing the resistance due to precipitates will be referred to as the 4) method of using fine precipitates.

[0022] In this conventional fire resistant steel, the 4) method of using fine precipitates by adding Mo to form Mo carbides is used. The fire resistant steel strengthened by the 4) method of using fine precipitates using Mo and its method of production etc. are described in Japanese Patent Publication (A) No. 2005-272854 and Japanese Patent Publication (A) No. 09-241789.

[0023] In these conventional fire resistant steels, the amount of C contained is a high value of about 0.1%, so the property of alloy elements not dissolving and precipitates ending up being produced is utilized.

DISCLOSURE OF THE INVENTION

[0024] However, in recent years, the soaring price of Mo has resulted in the technique of the use of Mo as the main factor in the strengthening method of alloy elements starting to lose price competitiveness.

[0025] Therefore, the inventors engaged in intensive research on inexpensive fire resistant steel using inexpensive Nb instead of expensive Mo as the dissolved element and methods of production of the same. As a result, they discovered that there were the following problems in making steel containing Nb as a dissolved element a fire resistant steel able to be used for thick steel materials.

[0026] The first problem is that problems arise in toughness if the amounts of addition of Ti and Al are outside predetermined ranges when applying the drag effect of dissolved Nb to thick fire resistant steel. When producing thick-gauge fire resistant steel, this toughness becomes a problem when the thickness of the steel plate is 7 mm or more, in particular when the thickness of the steel plate is 12 mm or more.

[0027] The second problem is the definition of the suitable amount of dissolved C for efficiently obtaining the drag effect of Nb.

[0028] The third problem is the definition of the surface properties, in particular the amount of addition of Si for preventing surface defects due to rolled-in scale at the time of reheating in a heating furnace.

[0029] The present invention adjusts the balance of ingredients of C, Nb, B, and Ti and the content of the deoxidizing elements (Si, Al) to achieve the target room temperature yield point, high temperature strength, high toughness, and good surface properties.

[0030] The inventors engaged in intensive research and development and as a result discovered methods for solving the above problems.

[0031] First, for the first problem, the inventors discovered that by making the content of B 0.0003 to 0.003%, controlling the content of Al to 0.005% to 0.03%, and adjusting the contents of Ti and N so that Ti/N is 2 to 8 in range, it is possible to secure the targeted toughness.

[0032] Next, for the second problem, the inventors discovered that to prevent the dissolved Nb from forming carbides such as NbC precipitates and to remain in solid solution so as to concentrate at the dislocations and other lattice defects, it is necessary to make the value of C-Nb/7.74 for example 0.02 or less. This corresponds to dissolved C of 0.02% or less

[0033] Finally, for the third problem, the inventors discovered that when making Ti/N an amount of 2 to 8 in range, to secure the strength of the matrix material and suppress the formation of scale defects, it is sufficient to make the content of Si less than 0.4%.

[0034] Furthermore, the inventors discovered that if the dissolved C is 0.02% or less, the solid solution of Nb causes the drag resistance against disclocations to increase and promises great solution strengthening. They discovered that this drag resistance is affected by the concentration of the solute atoms, misfit due to the solute/solvent atom size, and diffusion coefficient of the solute atoms and that under these conditions, Nb has a great effect. In addition, they discovered that the strengthening effect due to the drag effect of dissolved Nb is about 5 to 8 times the strengthening effect due to the addition of Mo in conventional fire resistant steel and that it is possible to secure the equivalent high temperature strength by addition of a smaller amount of alloy.

[0035] Above, according to the present invention, by adjusting the balance of the ingredients C, Nb, B, Ti, Al, and Si, it is possible to achieve the targeted room temperature yield point, high temperature strength, and high toughness and good surface properties.

[0036] Based on this discovery, according to the present invention, there is provided a fire resistant high strength rolled steel material containing, by mass%, C: 0.005% to less than 0.04%, Mn: 0.8 to 1.7%, Si: 0.05 to less than 0.4%, Nb: 0.02 to 1%, Ti: 0.005 to 0.02%, N: 0.005% or less, B: 0.0003 to 0.003%, and Al: 0.005% to 0.03%, and a balance of Fe and unavoidable impurities, and having the ratio, Ti/N of 2 to 8, the value C-Nb/7.74 of 0.02% or less by mass%, and the ratio of the 0.2% yield strength at 600°C to the yield point strength at room temperature of 0.50 or more.

[0037] Note that when the room temperature yield point is unclear, the 0.2% yield strength is used, but for calculation of the 0.2% yield strength, the offset method of JIS Z 2241 is used.

[0038] This fire resistant high strength rolled steel material may further contain, by mass%, one or more of Cr: 0.4% or less, Cu: 1% or less, and Ni: 1.0% or less.

[0039] Further, according to the present invention, there is provided a method of production of a fire resistant high strength rolled steel material comprising preparing a cast slab containing, by mass%, C: 0.005% to less than 0.04%, Mn: 0.8 to 1.7%, Si: 0.05 to less than 0.4%, Nb: 0.02 to 1%, Ti: 0.005 to 0.02%, N: 0.005% or less, B: 0.0003 to 0.003%, and Al: 0.005% to 0.03%, and a balance of Fe and unavoidable impurities, and having the ratio of Ti/N of 2 to 8, the value C-Nb/7.74 of 0.02% or less, heating this to a temperature region of 1250 to 1350°C, then starting rolling and rolling to give a cumulative reduction rate at 1000°C or less of 30% or more to thereby give the ratio of the 0.2% yield strength at 600°C to the yield point strength at room temperature of 0.50 or more.

[0040] Furthermore, according to the present invention, there is provided a method of production of a fire resistant high strength rolled steel material comprising preparing a cast slab containing, by mass%, C: 0.005% to less than 0.04%, Mn: 0.8 to 1.7%, Si: 0.05 to less than 0.4%, Nb: 0.02 to 1%, Ti: 0.005 to 0.02%, N: 0.005% or less, B: 0.0003 to 0.003%, and Al: 0.005% to 0.03%, and a balance of Fe and unavoidable impurities, and having the ratio Ti/N of 2 to 8, the value C-Nb/7.74 of 0.02% or less by mass%, heating this to a temperature region of 1250 to 1350°C, then starting rolling, and cooling, after the end of said rolling, at 800 to 500°C in temperature range by a 0.1 to 10°C/sec average cooling rate to thereby give the ratio of the 0.2% yield strength at 600°C to the yield point strength at room temperature of 0.50 or more.

[0041] Note that in these methods of production, if the yield point at room temperature is unclear the 0.2% yield strength is used.

[0042] In these methods of production, said cast slab may further contain, by mass%, one or more of Cr : 0.4% or less, Cu: 1% or less, and Ni: 1.0% or less.

[0043] According to the present invention, there may be provided a steel material superior in fire resistance which has a high strength and high toughness and brings out the drag effect of dissolved Nb to the maximum extent and thereby give a yield strength of 1/2 or more of that at room temperature even at 600°C by just solid solution of Nb without adding at all the Mo generally added for fire resistant steel.

BRIEF DESCRIPTION OF THE DRAWINGS

[0044]

FIG. 1 is a view showing a suitable range in the relationship of Nb and C.

FIG. 2 is a view showing a suitable range in the relationship of Ti and N.

FIG. 3 is a view for explaining the drag effect of Nb, wherein (a) is a view of the case of adding Nb and B and (b) is a view of the case of simply adding only Nb.

FIG. 4 is a schematic view showing an example of the layout of apparatuses for working the method of the present invention.

FIG. 5 is a view showing the cross-sectional shape of an H-beam and the sampling position of mechanical test pieces.

BEST MODE FOR CARRYING OUT THE INVENTION

[0045] Below, the ranges of ingredients in the fire resistant steel of the present invention and the conditions for control of the ranges of ingredients will be explained. Note that the ranges of ingredients are shown by mass%.

[0046] C raises the hardenability. In order to give the strength required for a structural steel material, 0.005% or more is necessary. Preferably, the C content is 0.01% or more.

[0047] However, to obtain a strengthening effect due to the drag effect of the dissolved Nb, it must be less than 0.04%. If 0.04% or more, there will be a high possibility of a large amount of Nb ending up precipitating as NbC and the amount of dissolved Nb contributing to solution strengthening ending up being reduced. To obtain the strengthening effect due to the drag effect of dissolved Nb, 0.02% or less is preferable.

[0048] Note that, as explained later, if C-Nb/7.74 is 0.02% or less in range, the amount of dissolved Nb is secured. Further, by reducing the C content, there is also the effect that the later added B prevents the precipitation of $Fe_{23}(CB)_6$.

[0049] Mn raises the hardenability. To secure the strength and toughness of the matrix material, 0.8% or more has to be added, but Mn is an element causing center precipitation when producing cast slabs by continuous casting. If added over 1.7%, the hardenability excessively rises at the precipitated parts and the toughness deteriorates. Considering the above, the range of content was made 0.8% to 1.7%.

[0050] If Si becomes 0.4% or more, it produces the low melting point Fe_2SiO_4 compound during the reheating of the cast slab, causes worse scale peeling, and forms surface defects, but to secure the strength of the matrix material and for preparatory deoxidation in the case of restricting the amount of addition of Al as explained later, 0.05% or more has to be added. If the later mentioned Ti/N is 2 to 8 in range, to secure the strength of the matrix material and suppress the formation of scale defects, the content of Si should be made less than 0.4%, so the Si content was made 0.05% to less than 0.4%. To further improve the surface properties by the prevention of scale defects, the Si content is preferably made 0.2% or less.

[0051] Nb is an element important in the present invention. The copresence of dissolved Nb and B remarkably raises the hardenability and thereby increases the room temperature yield point. Further, for employing the drag effect to increase the high temperature strength, 0.02% or more is added. However, if over 1%, the effect of addition of Nb is saturated, so the upper limit was made 1%. In the present invention, it is possible to draw out the effect of the dissolved Nb required for fire resistant steel to the maximum extent, so in general is 0.1% or less. If the balance with the other ingredients is good, a 0.05% or less amount of addition of Nb gives a sufficient effect. To secure a sufficient fire resistance by the drag effect of Nb, it is necessary to not only define the amount of addition of Nb, but also satisfy the following conditions for sufficiently obtaining the amount of dissolved Nb.

[0052] When Nb is dissolved, the drag effect of the dissolved Nb is improved and contributes to strength. However, Nb is a strong carbide forming element, so if C is present, forms NbC. The dissolved Nb is reduced and the strengthening mechanism due to the drag effect ends up being weakened.

[0053] In the present invention, to obtain dissolved Nb sufficient for strengthening, the inventors found that, for the relationship between the amount of addition of Nb to the amount of addition of C, it is necessary to make C-Nb/7.74 0.02 mass% or less. Here, when C-Nb/7.74 is 0.02% or less in range, the Nb and C separate, the required amount of dissolution of Nb can be secured, and the solution strengthening required for the fire resistance is contributed to.

[0054] Organizing the above, the amounts of addition of Nb and C and the suitable range of balance of addition becomes as shown in FIG. 1. That is, the amount of addition of C has to be to 0.005% or more to secure the strength (b) and has to be less than 0.04% to secure the toughness (c). To secure the high temperature strength, the amount of addition of Nb has to be 0.02% or more (a) and the amount of addition of Nb to the amount of addition of C has to be restricted so that Nb becomes (C-0.02) x 7.74 or more (d).

[0055] N forms NbN and BN nitrides and reduces the hardenability by Nb and B. Further, it causes the formation of high carbon island-shaped martensite at the lath boundaries of the bainite phase to degrade the toughness. Therefore, the N content was restricted to 0.005% or less. Note that the unavoidable impurities generally include 20 to 30 ppm or so of N, so N is preferably suppressed to 0.003% or less.

[0056] Al deoxidizes molten steel and is added to sufficiently obtain room temperature and high temperature strength. Therefore, 0.005% or more has to be added. However, in particular in the case of steel shapes or thick-gauge steel plate, when adding over 0.03%, this forms island-shaped martensite to degrade the toughness. Further, this has a detrimental effect on the high temperature strength of the weld zone, so the amount has to be 0.03% or less. When further toughness of the matrix material as a thick-gauge steel material or reheating embrittlement characteristics of the weld zone are required, this may be limited to 0.015% or less. If further limited to less than 0.01%, the maximum effect can be obtained from the viewpoint of the amount of addition of Al.

[0057] There are two main effects of addition of Ti.

[0058] First, this is added for increasing the fineness of the γ-grains by precipitation of TiN and for suppressing the precipitation of BN and NbN to increase the amount of dissolved B and improve the effect of B in raising the hardenability by the reduction of the dissolved N. Due to this, the room temperature yield point and high temperature strength are raised. If the amount of addition is less than 0.005%, the amount of precipitation of TiN is insufficient and these effects are not exhibited, so the lower limit of the amount of Ti was made 0.005%. Excessive Ti over 0.02% precipitates as coarse Ti(CN) which degrades the toughness of the matrix material and weld heat affected zone, so the amount was limited to 0.02% or less.

[0059] Second, this is added to reduce the amount of dissolved N weakening the drag effect of Nb.

[0060] The inventors engaged in intensive research and as a result learned that, by mass%, a Ti/N of 2 to 8 in range is suitable. If Ti/N is less than 2, the dissolved N is not immobilized as TiN, while if Ti/N is over 8, the excessive Ti forms coarse Ti(CN) which degrades the toughness. By limiting the Ti/N in this way, the toughness as a thick-gauged steel material can be sufficiently secured and the hardenability by B can be utilized to the maximum to obtain high temperature strength as a fire resistant steel. If making Ti/N 2.5 to 6, further preferable characteristics can be obtained.

[0061] Organizing the above, the ranges of suitable amounts of addition of Ti and Nb are as shown in FIG. 2. That is, the amount of addition of Ti has to be 0.005% or more to secure the amount of precipitation of TiN (a) and has to be 0.02% or less to suppress the precipitation of coarse Ti(CN) (b). The N content has to be 0.005 or less (c), while Ti/N as to be 2 (e) to 8 (d).

[0062] There are two objects of the addition of B.

[0063] The first object is, through composite addition with Nb, further raising the hardenability and contributing to the rise in strength. The inventors engaged in intensive research and as a result found that if less than 0.0003%, this effect is not sufficient, while if over 0.003%, iron-boron compounds are produced and the hardenability is reduced.

[0064] The second object is to draw out the drag effect of Nb to the maximum extent. As shown in FIG. 3(b), part of the Nb contained in the steel cannot maintain its dissolved state in the ferrite and segregates at the crystal grain boundaries 8, so the drag effect cannot be exhibited. However, as shown in FIG. 3(a), if adding B, B, in place of Nb, segregates at the crystal grain boundaries 8 to suppress the segregation of Nb. It thereby assists Nb in maintaining its dissolved state in ferrite. For this object as well, the content of B should be made 0.0003 to 0.003%.

[0065] In the sense of achieving both the first and the second objects to the maximum extent, 0.001 to 0.002% of B is preferably added.

[0066] Cr is effective for strengthening the matrix material by the improvement of the hardenability. However, excessive addition over 0.4% is harmful from the viewpoint of the toughness and hardenability, so the upper limit was made 0.4%.

[0067] Cu is effective for strengthening the matrix material by the improvement of the hardenability. However, excessive addition over 1% is harmful from the viewpoint of the toughness and hardenability, so the upper limit was made 1%.

[0068] Ni is effective for strengthening the matrix material by the improvement of the hardenability. However, the upper limit was made 1.0% from the viewpoint of economy.

[0069] The P and S contained as unavoidable impurities are not particularly limited in amount, but their solidification segregation cause weld cracks and a drop in toughness, so they should be reduced as much as possible. The amount of P is preferably 0.03% or less, while the amount of S is preferably 0.02% or less.

[0070] A cast slab having the above composition and having a balance of Fe and unavoidable impurities is heated to a temperature region where the surface temperature becomes 1250 to 1350°C, then is started to be rolled. The reason for reheating to a temperature region where the surface temperature of the cast slab becomes 1250 to 1350°C is that heating to 1250°C or more is preferable for making the Nb dissolve in a short time and obtaining the dissolved Nb required for strengthening the matrix material and heating to 1250°C or more is required for facilitating plastic deformation when producing steel shapes by hot working. Note that, from the performance of the heating furnace and economy, the upper limit of the heating temperature was made 1350°C.

[0071] The cast slab heated to a temperature region of a surface temperature of 1250 to 1350°C in this way is hot rolled. In this hot rolling, the steel is rolled at a cumulative reduction rate at 1000°C or less of 30% or more, whereby it is made finer in γ grains by work recrystallization. Due to this, it is possible to make the steel higher in toughness and higher in strength.

[0072] After the end of this hot rolling, the steel is cooled at a temperature range of 800 to 500°C by a 0.1 to 10°C/sec average cooling rate. The reason for making the temperature range of the cooling 800 to 500°C is to secure the dissolved Nb. Further, the reason for making the cooling rate 0.1 to 10°C/sec is that if the average cooling rate is less than 0.1°C/sec, the hardenability becomes insufficient, while if the average cooling rate is over 10°C/sec, martensite is produced and the toughness of the matrix material is remarkably lowered.

[0073] The characterizing feature of the steel ingredients of the present invention is the ability to secure sufficient hardenability even with an average cooling rate of 0.1°C/sec. The invention may also be applied to a thick-gauge steel material, for example, extremely thick H-section steel having a flange thickness of 125 mm. Further, in the present invention, due to the addition of B and Nb, the start of transformation is delayed in the continuous cooling process. By using the above cooling rate, the untransformed γ is maintained as with the rapid cooling until a relatively low temperature. By the drop in the diffusion rate of Nb, NbC does not precipitate and Nb dissolves in the supersaturated state.

[0074] The fire resistant high strength rolled steel material of the present invention is suitably used as a structural member of a building etc. Specifically, it is embodied as H-section steel, I-section steel, angle steel, channel-section steel, unequal side unequal thickness angle steel, and other steel shapes, for example, thick gauge steel plate of a thickness of 7 mm or more.

[0075] Further, for example, under the above conditions, when producing H-section steel as an example of the fire resistant high strength rolled steel material of the present invention, the H-section steel has sufficient strength and toughness even at the flange thickness 1/2 part and width 1/2 part where the mechanical test characteristics are hardest to guarantee.

[0076] Further, due to the strengthening effect based on the drag effect of the dissolved Nb, it is possible to obtain high strength fire resistant rolled H-section steel having a superior fire resistance ability and toughness. Furthermore, this H-section steel is superior in high temperature characteristics, so when used for a fire resistant material for building use, a sufficient fire resistant object with a coating thickness of 50% or less of the past can be achieved.

EXAMPLES

[0077] Below, the effects of the present invention will be shown further by examples.

[0078] A cast slab of each of the various steel types shown in Table 1 was heated and rolled. Specifically, prototype steel was produced in a converter, alloy ingredients were added, Ti and B were added, then continuous casting was used to cast a 240 to 300 mm thick cast slab. The cast slab was heated, then hot rolled to obtain H-section steel (web height 414 mm x flange width 405 mm x web thickness 18 mm x flange thickness 28 mm).

[0079] In the rolling, in the universal rolling mill train shown in FIG. 4, the material to be rolled (cast slab) 5 exiting from the heating furnace 1 is passed through the rough rolling mill 2, intermediate rolling mill 3, and finishing rolling mill 4.

[0080] In the rolling mills, as shown in FIG. 5, H-section steel having an H cross-sectional shape comprised of a web 6 and a pair of flanges 7 was rolled.

[0081] Note that in water cooling between rolling passes, water cooling systems were provided before and after the intermediate rolling mill 3, and the flange outside surfaces were repeatedly spray cooled and reverse rolled. Accelerated cooling after rolling was performed after the end of rolling by the final rolling mill 4 by a cooling system provided at the back surface by spray cooling of the flange outside surfaces.

[0082] In the steel materials (H-section steels), test pieces were taken from the positions of the center ($1/2t_2$) of thickness t_2 of the flange 7 and half of the total length B of the flange width (1/2B) to investigate the mechanical characteristics.

[0083] This location was judged as optimum for evaluating the mechanical test characteristics of the H-section steel because the flange 1/2B part is lowest in mechanical characteristics of the H-section steel.

[0084] As the mechanical test characteristics of the steel material (H-section steel), room temperature (21°C) yield point (yield point stress YP (MPa), when unclear, the 0.2% yield strength is used) and the tensile strength (TS (MPa)), 600°C 0.2% yield strength (600YS (MPa)), the ratio of the 600°C yield strength (600YS) and room temperature (21°C) yield point (yield point stress YP) (600YS/YP ratio (%)), impact value (vE0°C (J)), and yield ratio (YR) are shown.

[0085] As the passing standards for the mechanical test characteristics, a room temperature (21°C) tensile strength TS of 400 MPa or more, a yield point (YP) of a high strength of 235 MPa or more, a 600°C 0.2% yield strength (600YS) of 50% or more of the room temperature (21°C) yield point (yield point stress YP), and a 0°C Charpy impact absorption energy value (vE0) of 47J or more were demanded. This is because if these passage standards, the material can be judged as suitable as a steel material for a fire resistance.

Table 1

No.	Chemical compositions															YP (MPa)	TS (MPa)	600YS (MPa)	600YS/ YP ratio (%)	vE0 (J)	Remarks
	C	Si	Mn	P	S	Ti	Al	Nb	B	N	Cr	Cu	Ni	C-Nb/ 7.74	Ti/N						
Inv. ex. 1	0.011	0.10	1.53	0.012	0.004	0.009	0.007	0.020	0.0018	0.0040				0.008	2.3	334	462	177	53	243	
Inv. ex. 2	0.018	0.10	1.51	0.009	0.004	0.014	0.016	0.057	0.0023	0.0032				0.011	4.4	465	597	297	64	225	
Inv. ex. 3	0.019	0.11	1.49	0.010	0.004	0.010	0.025	0.055	0.0020	0.0024				0.012	4.2	458	605	300	66	91	
Inv. ex. 4	0.017	0.09	1.49	0.009	0.005	0.020	0.015	0.055	0.0009	0.0027				0.010	7.4	478	610	305	64	108	
Inv. ex. 5	0.012	0.11	1.55	0.011	0.004	0.010	0.012	0.025	0.0005	0.0040				0.009	2.5	328	455	169	52	286	
Inv. ex. 6	0.018	0.12	0.85	0.014	0.004	0.011	0.008	0.900	0.0009	0.0041				-0.098	2.7	305	429	195	64	216	
Inv. ex. 7	0.014	0.37	1.60	0.013	0.003	0.012	0.006	0.059	0.0010	0.0039				0.006	3.1	457	573	278	61	265	
Inv. ex. 8	0.013	0.21	1.50	0.012	0.004	0.005	0.007	0.030	0.0018	0.0020				0.009	2.5	396	511	215	54	128	
Inv. ex. 9	0.013	0.10	1.52	0.012	0.004	0.008	0.005	0.030	0.0019	0.0039				0.009	2.1	374	489	203	54	276	
Inv. ex. 10	0.020	0.10	1.65	0.010	0.004	0.009	0.006	0.039	0.0017	0.0039				0.015	2.3	393	531	231	59	288	
Inv. ex. 11	0.037	0.10	1.62	0.011	0.004	0.008	0.005	0.140	0.0018	0.0039				0.019	2.1	418	529	243	58	298	
Inv. ex. 12	0.006	0.10	1.62	0.015	0.005	0.015	0.006	0.050	0.0018	0.0029				0.000	5.2	320	421	196	61	111	
Inv. ex. 13	0.014	0.14	0.97	0.013	0.004	0.010	0.006	0.090	0.0009	0.0042		0.64	0.40	0.002	2.4	468	587	273	58	146	Claim 2
Inv. ex. 14	0.013	0.13	0.80	0.015	0.005	0.009	0.008	0.087	0.0010	0.0040	0.60	0.20	0.41	0.002	2.3	448	565	275	61	95	Claim 2
Comp.ex. 15	0.004	0.10	1.62	0.015	0.005	0.015	0.006	0.039	0.0017	0.0041				-0.001	3.7	315	396	187	59	55	C insuf., TS insuf.
Comp.ex. 16	0.040	0.15	1.60	0.015	0.005	0.018	0.008	0.160	0.0019	0.0032				0.019	5.6	436	543	235	54	45	C excess., tough.insuf.
Comp.ex. 17	0.018	0.40	1.55	0.013	0.006	0.009	0.010	0.035	0.0015	0.0035				0.013	2.6	425	550	259	61	106	Si excess., scale
Comp.ex. 18	0.012	0.10	0.70	0.012	0.005	0.012	0.010	0.025	0.0012	0.0040				0.009	3.0	286	385	153	53	86	Mn insuf., TS insuf.
Comp.ex. 19	0.013	0.10	1.81	0.013	0.004	0.010	0.008	0.050	0.0019	0.0038				0.007	2.6	458	608	296	65	12	Mn excess.,tough.insuf.
Comp.ex. 20	0.018	0.10	1.57	0.014	0.005	0.022	0.005	0.030	0.0015	0.0042				0.014	5.2	423	525	237	56	28	Ti excess..tough.insuf.
Comp.ex. 21	0.020	0.10	1.62	0.015	0.005	0.009	0.035	0.039	0.0017	0.0039				0.015	2.3	402	535	233	58	40	Al excess.,tough.insuf.
Comp.ex. 22	0.013	0.10	1.52	0.011	0.004	0.010	0.007	0.018	0.0018	0.0040				0.011	2.5	345	462	165	48	257	Nb insuf.. high temp. strength drop
Comp.ex. 23	0.012	0.11	1.55	0.010	0.005	0.010	0.012	0.025	0.0003	0.0041				0.009	2.4	285	390	145	51	297	B insuf., strength insuf.
Comp.ex. 24	0.012	0.11	1.55	0.010	0.005	0.010	0.012	0.025	0.0050	0.0039				0.009	2.6	351	465	197	56	19	B excess.,tough.insuf.
Comp.ex. 25	0.012	0.10	1.53	0.012	0.004	0.015	0.007	0.030	0.0018	0.0060				0.008	2.5	330	435	145	44	196	N excess., high temp. strength drop
Comp.ex. 26	0.027	0.10	1.62	0.011	0.004	0.008	0.004	0.040	0.0018	0.0036				0.022	2.2	414	535	204	49	135	C-Nb/7.74>0.02. high temp. strength drop
Comp.ex. 27	0.035	0.09	1.63	0.010	0.050	0.008	0.008	0.100	0.0018	0.0026				0.022	3.1	408	509	201	49	298	C-Nb/7.74>0.02, high temp. strength drop
Comp.ex. 28	0.012	0.10	1.52	0.012	0.004	0.007	0.005	0.040	0.0018	0.0038				0.007	1.8	405	489	196	48	146	Ti/N<2, high temp. strength drop
Comp.ex. 29	0.015	0.10	1.52	0.012	0.005	0.018	0.005	0.030	0.0023	0.0021				0.011	8.6	422	518	235	56	45	Ti/N>8. toughness drop

[0086] Table 1 shows the chemical ingredients of the various steels used in the Examples and the mechanical characteristics of the H-section steels.

[0087] The Nos. 1 to 14 H-section steels in the scope of the present invention all satisfied the passage standards. The H-section steels in the scope of the present invention had sufficient strength and toughness even at the flange thickness 1/2t2 and width 1/2B parts of the rolled steel shapes where the mechanical test characteristics are hardest to guarantee and were superior in fire resistance and toughness.

[0088] Comparative Example No. 17 satisfied the mechanical test characteristics, but primary scale produced during the heating remained in close contact to the surface until the final product resulting in scale defects, so the steel was not of a level suitable for the use as a steel material for building use.

Table 2

No.	Chemical compositions															Size web thickness/ flange thickness	Heat temp. (°C)	Cumul. reduction below 1000°C (%)	Cooling rate after rolling °C/sec	YP (MPa)	TS (MPa)	600YS (MPa)	600/ RT ratio (%)	vE0 (J)	Remarks
	C	Si	Mn	P	S	Ti	Al	Nb	B	N	Cr	Cu	Ni	C-Nb/ 7.74	Ti/N										
Inv. ex. 1	0.011	0.10	1.53	0.012	0.004	0.009	0.007	0.020	0.0018	0.0040				0.008	2.3	18/28	1300	40	-	334	462	177	53	243	
Comp.ex. 30	0.011	0.10	1.53	0.012	0.004	0.009	0.007	0.020	0.0018	0.0040				0.008	2.3	18/28	1230	40	-	355	452	173	49	126	Heating temp.insuf., high temp. strength drop
Comp.ex. 31	0.011	0.10	1.53	0.012	0.004	0.009	0.007	0.020	0.0018	0.0040				0.008	2.3	18/28	1260	25	-	385	501	176	48	85	Below 1000°C cumul. reduction insuf., high temp. strength drop
Inv. ex. 13	0.014	0.14	0.97	0.013	0.004	0.010	0.006	0.090	0.0009	0.0042		0.64	0.40	0.002	2.4	18/28	1300	40	-	468	587	273	58	146	
Comp.ex. 32	0.014	0.14	0.97	0.013	0.004	0.010	0.006	0.090	0.0009	0.0042		0.64	0.40	0.002	2.4	18/28	1200	40	-	376	467	163	43	226	Heating temp.insuf., high temp.strength drop
Comp.ex. 33	0.014	0.14	0.97	0.013	0.004	0.010	0.006	0.090	0.0009	0.0042		0.64	0.40	0.002	2.4	18/28	1300	25	-	316	451	143	45	107	Below 1000°C cumul. reduction insuf., high temp.strength drop
Inv. ex. 9	0.013	0.10	1.52	0.012	0.004	0.008	0.005	0.030	0.0019	0.0039				0.009	2.1	18/28	1300	-	0.8	374	489	203	54	276	
Inv. ex. 34	0.013	0.10	1.52	0.012	0.004	0.008	0.005	0.030	0.0019	0.0039				0.009	2.1	18/28	1300	-	8.0	420	565	271	65	108	
Inv. ex. 35	0.013	0.10	1.52	0.012	0.004	0.008	0.005	0.030	0.0019	0.0039				0.009	2.1	90/125	1300	-	0.1	395	502	219	55	247	
Comp.ex. 36	0.013	0.10	1.52	0.012	0.004	0.008	0.005	0.030	0.0019	0.0039				0.009	2.1	18/28	1300	-	15	459	618	325	71	21	Cooling rate excess.. toughness insuf.
Comp.ex. 37	0.013	0.10	1.52	0.012	0.004	0.008	0.005	0.030	0.0019	0.0039				0.009	2.1	90/125	1300	-	0.05	390	479	176	45	167	Cooling rate insuf.. high temp. strength drop
Inv. ex. 14	0.013	0.13	0.80	0.015	0.005	0.009	0.008	0.087	0.0010	0.0040	0.60	0.20	0.41	0.002	2.3	18/28	1300	-	0.8	448	565	275	61	98	
Comp.ex. 38	0.013	0.13	0.80	0.015	0.005	0.009	0.008	0.087	0.0010	0.0040	0.60	0.20	0.41	0.002	2.3	18/28	1300	-	15	486	631	349	72	13	Cooling rate excess.. toughness insuf.
Comp.ex. 39	0.013	0.13	0.80	0.015	0.005	0.009	0.008	0.087	0.0010	0.0040	0.60	0.20	0.41	0.002	2.3	90/125	1300	-	0.05	411	515	195	47	98	Cooling rate insuf.. high temp. strength drop

[0089] Next, the examples described in Table 2 will be explained.

[0090] The steels of Nos. 1 and 13 of Table 1 were rolled at different heating temperatures and cumulative reduction rates at 1000°C or less to obtain different H-section steels (web height 414 mm x flange width 405 mm, web thickness 18 mm x flange thickness 28 mm) which were then investigated for mechanical test characteristics. Nos. 1 and 13 of Table 2 are examples of production of the present invention and satisfy the standards of the characteristics of the present invention.

[0091] As shown by Nos. 30, 31, 32, and 33 of Table 2, when the heating temperature is less than 1250°C and the cumulative reduction rate at 1000°C or less is less than 30%, the standards of the characteristics of the present invention cannot be satisfied.

[0092] The steels of Nos. 9 and 14 of Table 1 were rolled by a heating temperature of 1300°C and different average cooling rates in the temperature range of 800 to 500°C after rolling to obtain H-section steel (web height 414 mm x flange width 405 mm x web thickness 18 mm x 28 mm and web height 608 mm x flange width 477 mm x web thickness 90 mm x flange thickness 125 mm) which were then investigated for mechanical test characteristics. Nos. 9, 14, 34, and 35 of Table 2 are examples of production of the present invention and satisfy the standards of the characteristics of the present invention.

[0093] As shown by Nos. 36, 37, 38, and 39 of Table 2, when the average cooling rate is outside of the range of 0.1 to 10°C/sec such as 0.05°C/sec to 15.00°C/sec, it is not possible to satisfy the standards of the characteristics of the present invention.

[0094] Note that in the examples, the typical rolled steel material of H-section steel was studied, but the rolled steel materials covered by the present invention is not limited to the H-section steel of the above examples. It may also be applied to I-section steel, angle steel, channel-section steel, unequal side unequal thickness angle steel, and other steel shapes, thick gauge steel plate, and other such steel materials. Production is also possible even when the thickness is relatively large.

INDUSTRIAL APPLICABILITY

[0095] According to the present invention, it becomes possible to produce steel shapes having fire resistance and toughness by rolling. By utilizing the fire resistant steel material of the present invention for the structural member of a building etc., a great reduction in the costs can be realized by reduction of the installation costs and shortening of the work period and improvement of the reliability of large buildings, safety, and improvement of the economicalness etc. can be achieved.

Claims

1. A fire resistant high strength rolled steel material containing, by mass%,
   C: 0.005% to less than 0.04%,
   Mn: 0.8 to 1.7%,
   Si: 0.05 to less than 0.4%,
   Nb: 0.02 to 1%,
   Ti: 0.005 to 0.02%,
   N: 0.005% or less,
   B: 0.0003 to 0.003%,
   Al: 0.005% to 0.03%,
   and the balance of Fe and unavoidable impurities, and having the ratio Ti/N of 2 to 8, the value C-Nb/7.74 of 0.02% or less by mass%, and having the ratio of the 0.2% yield strength at 600°C to the yield point strength (when the yield point is unclear, 0.2% yield strength) at room temperature of 0.50 or more.

2. A fire resistant high strength rolled steel material as set forth in claim 1, further containing, by mass%, one or more of
   Cr: 0.4% or less,
   Cu: 1% or less, and
   Ni: 0.7% or less.

3. A method of production of a fire resistant high strength rolled steel material comprising preparing a cast slab containing, by mass%,
   C: 0.005% to less than 0.04%,
   Mn: 0.8 to 1.7%,
   Si: 0.05 to less than 0.4%,

Nb: 0.02 to 1%,
Ti: 0.005 to 0.02%,
N: 0.005% or less,
B: 0.0003 to 0.003%, and
Al: 0.005% to 0.03%,
and the balance of Fe and unavoidable impurities, and having the ratio Ti/N of 2 to 8, the value C-Nb/7.74 of 0.02% or less by mass%, heating this to a temperature region of 1250 to 1350°C, then starting rolling and rolling to give a cumulative reduction rate at 1000°C or less of 30% or more to thereby give the ratio of a 0.2% yield strength at 600°C and a yield point strength (when yield point is unclear, a 0.2% yield strength) at room temperature of 0.50 or more.

4. A method of production of a fire resistant high strength rolled steel material as set forth in claim 3, wherein said cast slab further contains, by mass%, one or more of
Cr: 0.4% or less,
Cu: 1% or less, and
Ni: 0.7% or less.

5. A method of production of a fire resistant high strength rolled steel material comprising preparing a cast slab containing, by mass%,
C: 0.005% to less than 0.04%,
Mn: 0.8 to 1.7%,
Si: 0.05 to less than 0.4%,
Nb: 0.02 to 1%,
Ti: 0.005 to 0.02%,
N: 0.005% or less,
B: 0.0003 to 0.003%, and
Al: 0.005% to 0.03%,
and a balance of Fe and unavoidable impurities, and having the Ti/N of 2 to 8, the value C-Nb/7.74 of 0.02% or less by mass%, heating this to a temperature region of 1250 to 1350°C, then starting rolling, and cooling, after the end of said rolling, at 800 to 500°C in temperature range by a 0.1 to 10°C/ sec average cooling rate to thereby give a ratio of 0.2% yield strength at 600°C and yield point strength (when yield point is unclear, 0.2% yield strength) at room temperature of 0.50 or more.

6. A method of production of a fire resistant high strength rolled steel material as set forth in claim 5, wherein said cast slab further contains, by mass%, one or more of
Cr: 0.4% or less,
Cu: 1% or less, and
Ni: 0.7% or less.

Fig.1

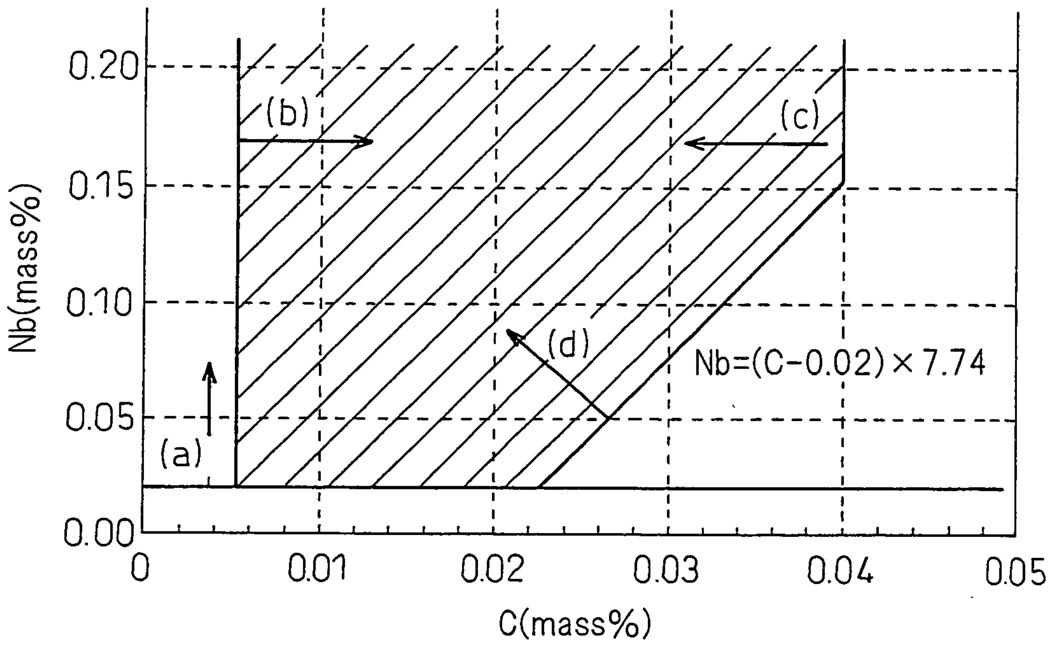

0.20
0.15
0.10
0.05
0.00
Nb(mass%)
(b)
(c)
(d)
(a)
Nb=(C-0.02)×7.74
0
0.01
0.02
0.03
0.04
0.05
C(mass%)

Fig.2

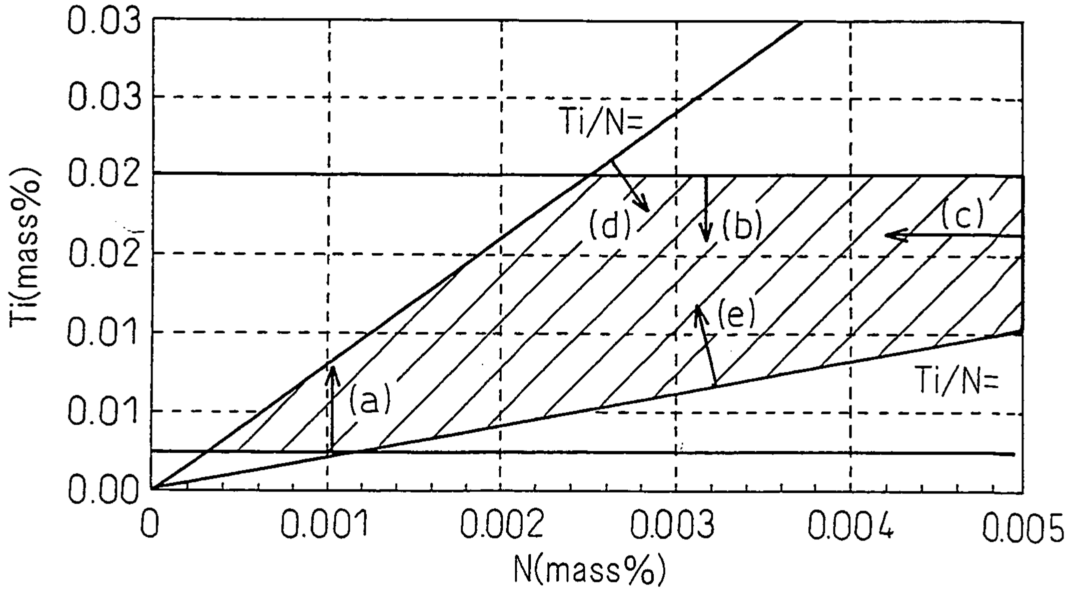

0.03
0.03
0.02
0.02
0.01
0.01
0.00
Ti(mass%)
Ti/N=
(d)
(b)
(c)
(e)
(a)
Ti/N=
0
0.001
0.002
0.003
0.004
0.005
N(mass%)

Fig.3

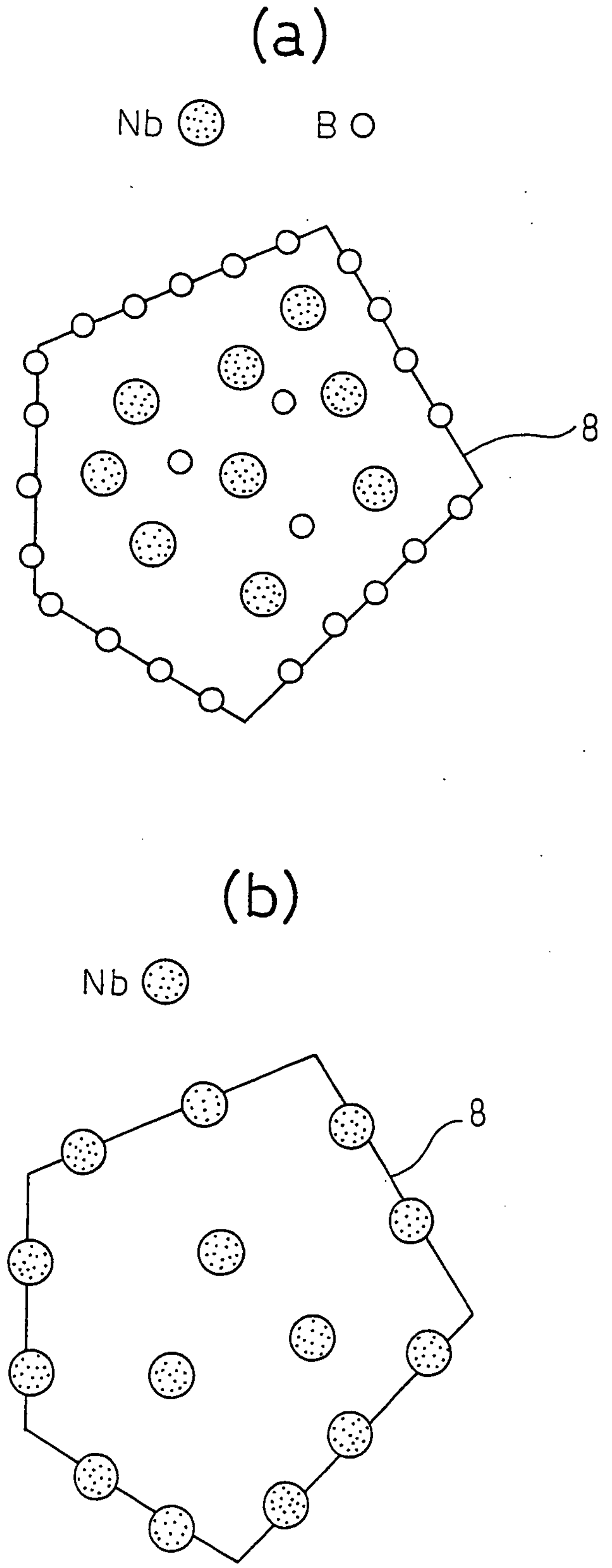


Fig. 4

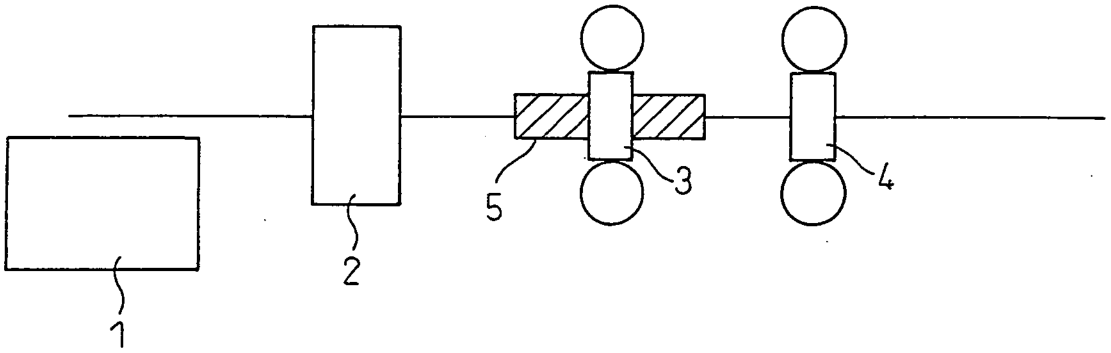
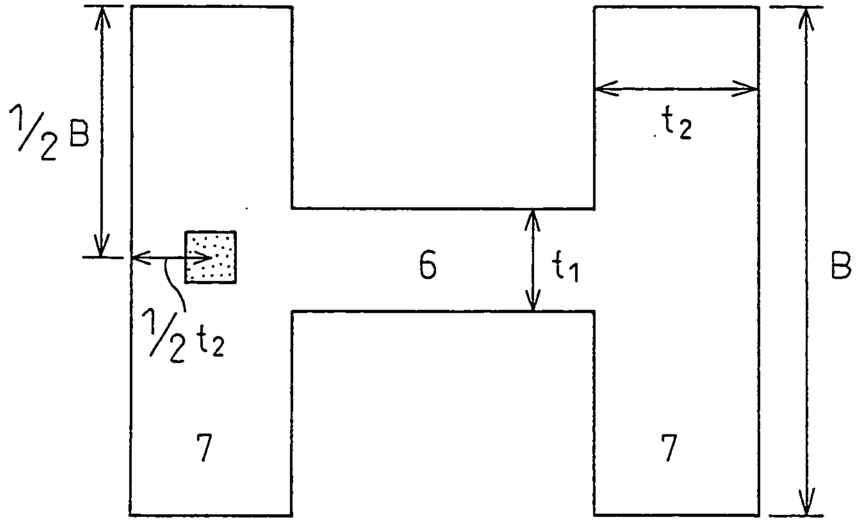


Fig. 5



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2007/052658

A. CLASSIFICATION OF SUBJECT MATTER
C22C38/00(2006.01)i, *C22C38/14*(2006.01)i, *C22C38/58*(2006.01)i, *C21D8/00*(2006.01)i, *B21B3/00*(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)
C22C38/00-38/60, C21D8/00-8/10, B21B3/00

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	1996-2007
Kokai Jitsuyo Shinan Koho	1971-2007	Toroku Jitsuyo Shinan Koho	1994-2007

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2000-248335 A (Nippon Steel Corp.), 12 September, 2000 (12.09.00), Claims (Family: none)	1-6
A	JP 2000-282167 A (Nippon Steel Corp.), 10 October, 2000 (10.10.00), Claims (Family: none)	1-6
A	JP 7-286233 A (Nippon Steel Corp.), 31 October, 1995 (31.10.95), Claims (Family: none)	1-6

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

* Special categories of cited documents:
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"&" document member of the same patent family

Date of the actual completion of the international search 15 May, 2007 (15.05.07)	Date of mailing of the international search report 05 June, 2007 (05.06.07)
Name and mailing address of the ISA/ Japanese Patent Office	Authorized officer
Facsimile No.	Telephone No.

Form PCT/ISA/210 (second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2007/052658

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	JP 2005-194869 A (Nippon Steel Corp.), 21 July, 2005 (21.07.05), Claims (Family: none)	1-6
A	JP 2005-272949 A (JFE Steel Corp.), 06 October, 2005 (06.10.05), Claims (Family: none)	1-6

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- JP 2000248335 A **[0011]**
- JP 2005272854 A **[0022]**
- JP 9241789 A **[0022]**