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(54) PROCESS FOR PRODUCING TAPERED PLATE

VERFAHREN ZUR HERSTELLUNG EINER KONISCHEN PLATTE

PROCÉDÉ DE PRODUCTION DE PLAQUE CONIQUE

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JP-A- H08 232 016
JP-A- 2000 303 147
JP-A- 2007 051 321
JP-A- 2008 255 458

Description

[Technical Field]

[0001] The present invention relates to a method for manufacturing a tapered plate (also called a tapered steel plate or a LP steel plate (Longitudinally Profiled Steel Plate)) whose plate thickness continuously changes in the longitudinal direction which can be preferably used for shipbuilding or the architecture, for example, and relates to a method for manufacturing a tapered plate having a tensile strength of 570 MPa or more and a difference in thickness between a thicker portion and a thinner portion (a difference of steel plate thickness) in the longitudinal direction of 10 mm or more which has only a small difference in strength throughout the steel plate and can be subjected to high-heat input welding with a welding heat input of more than 300 kJ/cm.

[Background Art]

[0002] Generally, a thick steel plate has a shape which is uniform in both the width and longitudinal directions. However, in the case where the plate thickness continuously changes in the longitudinal direction, there are cases where there is a great effect of decreasing material weight and welding man-hours. This kind of thick steel plate is called a tapered plate, a tapered steel plate, a LP steel plate or the like, and there have been many proposals regarding the method for manufacturing a tapered plate such as those disclose in Patent Literature 1, Patent Literature 2 and Patent Literature 3. These proposals are intended to show how to manufacture a tapered plate with high dimensional accuracy. However, unless the material properties and material uniformity of a steel plate are satisfactory in addition to dimensional accuracy, the steel plate cannot be used in practice.

[0003] Nowadays, quality demands for thick steel plates are becoming stronger, and, in particular, demands for increases in tensile strength and weldability are becoming stronger. In order to meet these demands, a TMCP (Thermo-Mechanical Control Process) such as controlled rolling and controlled cooling is adopted. In this method, heavy reduction in a no-recrystallization temperature range in austenite or an (austenite + ferrite) dual phase temperature range and subsequent transformation from austenite to ferrite (ferrite transformation) are utilized in order to decrease a ferrite grain size, and, further, cooling is performed as needed in order to further increase strength and toughness.

[0004] However, in the case where this method is used to manufacture a tapered plate, since temperature control is very difficult, there is large variation of material properties.

[0005] In particular, in the case of controlled rolling in which heavy reduction is performed in a low temperature range, such as a rolling in a no-recrystallization temperature range in austenite or a rolling in a dual phase (austenite + ferrite) temperature range, there is a remaining problem in that, since a plate thickness changes in the longitudinal direction as is the case with a tapered plate, a difference in the steel plate temperature between the thinner portion and the thicker portion becomes excessively large, which results in a large difference in strength. There have been some proposals for manufacturing a tapered plate having uniform material properties by reducing such inhomogeneity of material.

[0006] For example, Patent Literature 4 discloses a method for cooling a tapered plate, in order to achieve uniform material properties, the method including measuring a temperature distribution in the longitudinal direction before cooling is performed, calculating optimum cooling conditions at respective positions on the basis of the measured temperature distribution and adjusting conveyance speed in cooling in accordance with a plate thickness. Patent Literature 5 discloses a method for cooling a tapered plate, the method including starting cooling the thinner portion and the thicker portion of the steel plate at the same time and changing the time at which the portions leave a cooling apparatus in accordance with their thicknesses, or the method including starting cooling sequentially in order of distance in the longitudinal direction of the steel plate and stopping cooling at the same time. Both of the proposals are intended to decrease the variation of material properties in a steel plate when accelerated cooling is performed.

[0007] On the other hand, an example of approaches to solve the problem described above, which controls a chemical composition of the steel plate, is described in Patent Literature 6. In this technique, it is disclosed that the scatter of strength can be decreased by increasing Nb content up to 0.015% to 0.06%.

[0008] In addition, Patent Literature 7 discloses that the scatter of strength can be decreased by controlling the value of Hv_{20-50} (difference in Hv hardness between steel plates respectively having plate thicknesses of 20 mm and 50 mm after the steel plates have been cooled down to room temperature at a cooling rate equivalent to that of air cooling in a temperature range from 800°C to 500°C), which is expressed by the equation $Hv_{20-50} = -110 + 460C + 44Si + 39Mn - 31Cu - 9Ni + 11Cr + 22Mo + 180V + 9600B - 23000Mo \times B$, to be 15 or less.

[0009] However, in the case of steel materials capable of being subjected to high-heat input welding, the needs for which has been increasing recently, since there are various limitations regarding alloy design in order to achieve toughness in a weld zone, it is not easy to determine alloy design from the viewpoint of decreasing the scatter of strength of a tapered plate, which results there being a problem in that there is a markedly large scatter of strength due to the variation of plate thickness or finishing temperature, in particular in the case of B containing steel materials which are used for high-heat input welding.

[0010] Patent Literature 8 discloses the manufacture of a steel plate with varying thickness containing C, Si, Mn, Cu, Ni, Cr, Mo, V, B, Nb and Ti in a suitable ratio used for construction of ship, building, etc.. The manufacturing method involves tempering where holding time and temperature for the maximum thick part is based on a temperature rise curve.

[Citation List]

[Patent Literature]

[0011]

[PTL 1] Japanese Examined Patent Application Publication No. 50-36826
[PTL 2] Japanese Examined Patent Application Publication No. 60-124
[PTL 3] Japanese Examined Patent Application Publication No. 5-49361
[PTL 4] Japanese Unexamined Patent Application Publication No. 62-166013
[PTL 5] Japanese Unexamined Patent Application Publication No. 7-68309
[PTL 6] Japanese Patent No. 3180944
[PTL 7] Japanese Patent No. 3972553
[PLT 8] Japanese Patent Application No. H10-17932

[Summary of Invention]

[Technical Problem]

[0012] An object of the present invention is, by advantageously solving the problems described above, to provide a method for manufacturing a tapered plate having a difference in thickness (taper amount) between a thicker portion and a thinner portion in the longitudinal direction of 10 mm or more, which has a tensile strength of 570 MPa or more and a small scatter of strength, and which is excellent in terms of toughness in a weld zone formed by performing high-heat input welding with a heat input of more than 300 kJ/cm.

[Solution to Problem]

[0013] The present inventors, in order to solve the problems described above, conducted investigations regarding the influence of the contents of Ti and N on a difference in strength between a thicker portion and a thinner portion of B containing tapered plates having various contents of Ti and N, and found that, in the case where the contents of Ti and N satisfy the relationship $0 \leq N - Ti/3.42 \leq 0.0025$, since an appropriate amount of solid solute B is stably achieved, there is a decrease in difference in strength between a thicker portion and a thinner portion.

[0014] The present invention has been completed on the basis of the knowledge described above and further investigations, and the present invention is as follows.

1. A method for manufacturing a tapered plate having a tensile strength of 570 MPa or more and a difference in thickness between a thicker portion and a thinner portion of 10 mm or more, the method including heating to a temperature of 1000°C or higher and 1200°C or lower, a steel slab having a chemical composition consisting of, by mass%, C: 0.03% or more and 0.12% or less
Si: 0.03% or more and 0.5% or less
Mn: 0.8% or more and 2.2% or less
P: 0.015% or less
S: 0.0005% or more and 0.0050% or less
Al: 0.005% or more and 0.1% or less
Nb: 0.003% or more and 0.014% or less
Ti: 0.003% or more and 0.02% or less
B: 0.0003% or more and 0.0025% or less
N: 0.0030% or more and 0.0070% or less
Ca: 0.0005% or more and 0.0050% or less,
optionally one, two or more selected from among
Cu: 0.05% or more and 1.0% or less
Ni: 0.05% or more and 1.0% or less
Cr: 0.05% or more and 0.5% or less

Mo: 0.05% or more and 0.5% or less, and
V: 0.02% or more and 0.1% or less,
optionally one, two or more selected from among
Mg: 0.0005% or more and 0.005% or less
Zr: 0.003% or more and 0.02% or less, and
REM: 0.003% or more and 0.02% or less,
and optionally O: 0.0030% or less, the balance being Fe and inevitable impurities, in which expression (1) is satisfied, performing hot rolling on the heated slab in which plate thickness changes in the longitudinal direction so as to form a tapered shape at a finishing rolling temperature of 900°C or lower and equal to or higher than the Ar_3 point and then performing accelerated cooling on the hot-rolled steel plate down to a temperature of 500°C or lower:

$$0 \leq N - Ti/3.42 \leq 0.0025 \quad \cdots\cdot (1),$$

where N and Ti respectively represent the contents (mass%) of N and Ti.
2. The method for manufacturing a tapered plate having a tensile strength of 570 MPa or more and a difference in thickness between a thicker portion and a thinner portion of 10 mm or more according to item 1, the steel slab having the chemical composition containing, by mass%, one, two or more selected from among
Cu: 0.05% or more and 1.0% or less
Ni: 0.05% or more and 1.0% or less
Cr: 0.05% or more and 0.5% or less
Mo: 0.05% or more and 0.5% or less, and
V: 0.02% or more and 0.1% or less.
3. The method for manufacturing a tapered plate having a tensile strength of 570 MPa or more and a difference in thickness between a thicker portion and a thinner portion of 10 mm or more according to item 1 or 2, the steel slab having the chemical composition containing, by mass%, one, two or more selected from among
Mg: 0.0005% or more and 0.005% or less
Zr: 0.003% or more and 0.02% or less, and
REM: 0.003% or more and 0.02% or less.
4. The method for manufacturing a tapered plate having a tensile strength of 570 MPa or more and a difference in thickness between a thicker portion and a thinner portion of 10 mm or more according to any one of items 1 to 3, the steel slab having the chemical composition containing, by mass%,
O: 0.0030% or less,
in which the contents of Ca, O and S satisfy expression (2) below:

$$0.3 \leq ACR \leq 0.8 \quad \cdots\cdots (2),$$

where ACR = (Ca - (0.18 + 130×Ca)×O)/1.25/S, and where Ca, O and S respectively represent the contents (mass%) of Ca, O and S.

[Advantageous Effects of Invention]

[0015] According to the present invention, it is possible to manufacture a tapered plate having a difference in thickness (taper amount) between a thicker portion and a thinner portion of 10 mm or more, which has a tensile strength of 570 MPa or more and small difference in strength between a thicker portion and a thinner portion, and which can be subjected to high-heat input welding such as submerged arc welding, electrogas arc welding and electroslag welding, which results in a great advantage in industry.

[Description of Embodiments]

[0016] In the present invention, a chemical composition and manufacturing conditions are specified. In the description, % represents mass%.

[Chemical Composition]

C: 0.03% or more and 0.12% or less

[0017] C is added in an amount of 0.03% or more in order to achieve strength required for structural steel. On the other hand, in the case where the C content is more than 0.12%, since there is a decrease in the toughness of a welded heat affected zone, the C content is set to be 0.03% or more and 0.12% or less, preferably 0.04% to 0.09%.

Si: 0.03% or more and 0.5% or less

[0018] Si is added in an amount of 0.03% or more for the purpose of deoxidation and achieving strength. In the case where the Si content is more than 0.5%, since there is a decrease in toughness due to island martensite (M-A constituent) formed in a welded heat affected zone in the case where high-heat input welding is performed, the Si content is set to be 0.5% or less, preferably 0.4% or less.

Mn: 0.8% or more and 2.2% or less

[0019] Mn is added in an amount of 0.8% or more in order to achieve strength of a base metal. On the other hand, in the case where the Mn content is more than 2.2%, since there is a significant decrease in the toughness of a heat affected zone, the Mn content is set to be 0.8% or more and 2.2% or less, preferably 1.2% to 2.0%.

P: 0.015% or less

[0020] P is an inevitable impurity in the present invention. In the case where the P content is more than 0.015%, since there is a decrease in toughness, in particular in a CTOD (Crack Tip Opening Displacement) property, due to formation of island martensite (M-A constituent) in a heat affected zone formed as a result of performing high-heat input welding, the P content is set to be 0.015% or less, preferably 0.012% or less.

S: 0.0005% or more and 0.0050% or less

[0021] S content is 0.0005% or more in order to form CaS and MnS. On the other hand, in the case where the S content is more than 0.0050%, since there is a decrease in the toughness of a base metal, the S content is set to be 0.0005% or more and 0.0050 or less.

Al: 0.005% or more and 0.1% or less

[0022] Al content is 0.005% or more for the purpose of deoxidation of steel. On the other hand, in the case where the Al content is more than 0.1%, since there is a decrease in the toughness of a base metal and there also is a decrease in the toughness of a weld metal, the Al content is set to be 0.005% or more and 0.1% or less, preferably 0.01% to 0.06%.

Nb: 0.003% or more and 0.014% or less

[0023] Although Nb is effective for achieving strength and toughness of a base metal and strength of a weld joint and it is necessary that the Nb content be 0.003% or more in order to realize these effects, since there is a decrease in the toughness of a welded heat affected zone formed as a result of performing high-heat input welding in the case where the Nb content is more than 0.014%, the Nb content is set to be 0.003% or more and 0.014% or less, preferably 0.005% to 0.013%.

Ti: 0.003% or more and 0.02% or less

[0024] Ti is added in an amount of 0.003% or more, since Ti increases toughness of a base metal by precipitating in a form of TiN at a time of solidification so as to prevent an increase in an austenite grain size in a welded heat affected zone and by providing the nuclei of ferrite transformation so as to precipitate ferrite grains. On the other hand, in the case where the Ti content is more than 0.02%, since there is an increase in TiN grain size, which results in a decrease in toughness, the Ti content is set to be 0.003% or more and 0.02% or less, preferably 0.005% to 0.018%.

B: 0.0003% or more and 0.0025% or less

[0025] Since, when a steel plate is manufactured, B increases the strength of a base metal by forming solid solute B so as to increase hardenability, and when high-heat input welding is performed, B increases the toughness of a base metal by forming BN in a welded heat affected zone so as to decrease the amount of solid solute N and by providing nuclei of ferrite transformation so as to form ferrite grains, B is added in an amount of 0.0003% or more.
[0026] On the other hand, in the case where the B content is more than 0.0025%, since there is a decrease in toughness due to an excessive increase in hardenability, the B content is set to be 0.0003% or more and 0.0025% or less, preferably 0.0005% to 0.0022%.

N: 0.0030% or more and 0.0070% or less

[0027] Since N forms TiN which is effective for increasing toughness, the N content is set to be 0.0030% or more. On the other hand, in the case where the N content is more than 0.0070%, since there is a case where it is impossible to achieve a sufficient amount of solid solute B which increases hardenability when a steel plate is manufactured, and since there is a decrease in toughness due to an increase in the amount of solid solute N in a weld metal as a result of TiN in the vicinity of a weld bond being dissolved when high-heat input welding is performed, the N content is set to be 0.0030% or more and 0.0070% or less.

$$0 \leq N - Ti/3.42 \leq 0.0025$$

[0028] In the present invention, since a steel plate is required to have a tensile strength of 570 MPa or more and a small scatter of strength, and be excellent in terms of toughness in a weld zone formed by performing high-heat input welding with a heat input of more than 300 kJ/cm, this formula is specified in the chemical composition described above in order to meet this requirement. In the case where the relationship between the contents of Ti and N is expressed by $N - Ti/3.42 > 0.0025$, since it is impossible to stably achieve an appropriate amount of solid solute B, there is a large scatter of strength with respect to changes in plate thickness and rolling conditions. On the other hand, in the case where the relationship is expressed by $N - Ti/3.42 < 0$, there is a significant decrease in the toughness of a welded heat affected zone when high-heat input welding is performed. Therefore, the relationship $0 \leq N - Ti/3.42 \leq 0.0025$ shall be satisfied.

Ca: 0.0005% or more and 0.0050% or less

[0029] Ca increases the toughness of a welded heat affected zone when high-heat input welding is performed, since there is an increase in frequency of nuclei formation of ferrite grains as a result of formation of MnS, TiN and BN on CaS. The Ca content is set to be 0.0005% or more in order to realize this effect. On the other hand, in the case where the Ca content is more than 0.0050%, since the effect becomes saturated, the Ca content is set to be 0.0005% or more and 0.0050% or less, preferably 0.0005% to 0.0030%, more preferably 0.0007% to 0.0030%.
[0030] Although the chemical composition described above is the base chemical composition of the present invention and a sufficient effect can be realized with this chemical composition, in order to further improve the properties, one, two or more of Cu, Ni, Cr, Mo, V, Mg, Zr and REM may be added.

Cu: 0.05% or more and 1.0% or less

[0031] Cu is effective for increasing the strength of a base metal, and it is preferable that the Cu content be 0.05% or more in order to realize this effect, but, in the case where the Cu content is more than 1.0%, there is deterioration of the surface quality of a steel plate due to occurrence of hot shortness. Therefore, in the case where Cu is added, it is preferable that the Cu content be 1.0% or less, more preferably 0.1% to 0.8%.

Ni: 0.05% or more and 1:0% or less

[0032] Since Ni increases the strength of a base metal while maintaining high toughness of the base metal, it is preferable that the Ni content be 0.05% or more in order to realize this effect. On the other hand, in the case where the Ni content is more than 1.0%, since the effect becomes saturated, in the case where Ni is added, it is preferable that the Ni content be 0.05% or more and 1.0% or less, more preferably 0.1% to 0.9%.

Cr: 0.05% or more and 0.5% or less

[0033] Cr is effective for increasing the strength of a base metal and it is preferable that the Cr content be 0.05% or more in order to realize this effect, but, in the case where the Cr content is excessively large, there is a decrease in toughness. Therefore, in the case where Cr is added, it is preferable that the Cr content be 0.5% or less, more preferably 0.1% to 0.4%.

Mo: 0.05% or more and 0.5% or less

[0034] Mo is effective for increasing the strength of a base metal and it is preferable that the Mo content be 0.05% or more in order to realize this effect, but there is a decrease in toughness in the case where the Mo content is excessively large. Therefore, in the case where Mo is added, it is preferable that the Mo content be 0.5% or less, more preferably 0.07% to 0.4%.

V: 0.02% or more and 0.1% or less

[0035] V is effective for increasing the strength of a base metal and it is preferable that the V content be 0.02% or more in order to realize this effect, but there is a decrease in toughness in the case where the V content is more than 0.1%. Therefore, in the case where V is added, it is preferable that the V content be 0.1% or less, more preferably 0.04% to 0.08%.

Mg: 0.0005% or more and 0.005% or less

[0036] Mg is a chemical element which is effective for improving toughness as a result of dispersion of oxides. It is preferable that the Mg content be at least 0.0005% or more in order to realize this effect, but the effect becomes saturated in the case where the Mg content is more than 0.005%. Therefore, in the case where Mg is added, it is preferable that the Mg content be 0.005% or less.

Zr: 0.003% or more and 0.02% or less

[0037] Zr is a chemical element which is effective for improving toughness as a result of dispersion of oxides. It is preferable that the Zr content be at least 0.003% or more in order to realize this effect, but the effect becomes saturated in the case where the Zr content is more than 0.02%. Therefore, in the case where Zr is added, it is preferable that the Zr content be 0.02% or less, more preferably 0.004% to 0.018%.
[0038] REM: 0.003% or more and 0.02% or less
[0039] REM is a chemical element which is effective for improving toughness as a result of the dispersion of oxides. It is preferable that the REM content be at least 0.003% or more in order to realize this effect, but the effect becomes saturated in the case where the REM content is more than 0.02%. Therefore, in the case where REM is added, it is preferable that the REM content be 0.02% or less, more preferably 0.004% to 0.018%.

O: 0.0030% or less

[0040] O is contained as an inevitable impurity and decreases cleanliness as a result of being present in the form of oxides in steel. Therefore, it is preferable that the O content be as small as possible in the present invention. In the case where the O content is more than 0.0030%, since there is an increase in the size of CaO containing inclusions, there is a negative effect on toughness. Furthermore, in order to crystallize Ca in the form of CaS in the present invention, since O has strong affinity for Ca, it is preferable that the O content in molten steel be decreased to 0.0030% or less by performing intensive degassing or by adding a deoxidation agent before Ca is added.

$$0.3 \leq ACR \leq 0.8$$

[0041] Here, $ACR = (Ca - (0.18 + 130xCa) \times O)/1.25/S$, where Ca, O and S respectively represent the contents (mass%) of Ca, O and S.
[0042] In order to finely disperse the nuclei of ferrite transformation which are not dissolved even at a high temperature when high-heat input welding is performed and in order to realize an increase in toughness by forming a fine (ferrite + pearlite) structure in a welded heat affected zone, it is necessary that the contents of Ca and S satisfy the relationship $0.3 \leq ACR \leq 0.8$.

[0043] By controlling ACR value to be 0.3 or more and 0.8 or less, since MnS, which is effective as a nucleus of ferrite formation, is precipitated on CaS and finely dispersed, it is possible to realize an increase in toughness by forming a fine (ferrite + pearlite) structure in a welded heat affected zone when high-heat input welding is performed.

[0044] In the case where ACR value is less than 0.3, since CaS is not crystallized, S is precipitated only in the form of MnS. Since MnS is elongated by performing rolling when a steel plate is manufactured, a decrease in the toughness of a base metal is caused. In addition, since MnS is dissolved in a welded heat affected zone, which is the most important zone in the present invention, fine dispersion cannot be realized.

[0045] On the other hand, in the case where ACR value is more than 0.8, since most of S is fixed by Ca, MnS, which is effective as a nucleus of ferrite formation, is not precipitated on CaS, which results in sufficient effect not being realized.

[Manufacturing condition]

[0046] In the present invention, since an appropriate amount of solid solution B can be stably achieved by a chemical composition being controlled as described above, it is possible to decrease the scatter of strength caused by changes in plate thickness and rolling conditions. Therefore, while variation of strength of a steel plate is inevitable as a plate thickness changes from the thicker portion to the thinner portion in the case where accelerated cooling is performed in order to increase the strength of a conventional tapered plate, according to the present invention, it is possible to obtain a high strength tapered plate having a small difference in strength between a thicker portion and a thinner portion in the case where accelerated cooling is performed.

[0047] A steel slab which is used as a raw material of the tapered plate according to the present invention may be manufactured by smelting steel having the chemical composition described above using an ordinary refining process such as a steel converter, an electric furnace or a vacuum melting furnace and then by casting the smelted steel using an ordinary method such as a continuous casting method or an ingot casting-slabbing rolling method, and there is no particular limitations on what methods are used.

[0048] In the present invention, a slab heating temperature, hot rolling conditions and cooling conditions are specified as described hereafter.

Slab heating temperature: 1000°C or higher and 1200°C or lower

[0049] In the case where the slab heating temperature is lower than 1000°C, added components do not sufficiently form solid solutions. On the other hand, in the case where the slab heating temperature is higher than 1200°C, there is an increase in austenite grain size and the grain size is not decreased even by subsequently performing rolling, which results in a decrease in toughness. Therefore, the slab heating temperature is set to the range of 1000°C or higher and 1200°C or lower, preferably to the range of 1030°C to 1180°C.

Hot rolling conditions

[0050] After a steel slab has been heated, hot rolling is performed. In hot rolling, a taper in which a plate thickness changes in the longitudinal direction is provided. Change in plate thickness in the longitudinal direction of a tapered plate is achieved by changing a roll gap while hot rolling in a predetermined pass after starting rolling of the steel plate.

[0051] In the present invention, there is no particular limitation regarding rolling reduction (also called draft) in each pass. The finishing rolling temperature of hot rolling is set to be 900°C or lower and equal to or higher than the Ar_3 point in terms of the surface temperature of a steel plate. In the case where the finishing rolling temperature is lower than the Ar_3 point, it is impossible to achieve the specified strength, and in the case where the finishing rolling temperature is higher than 900°C, there is a decrease in toughness. Therefore, the finishing rolling temperature is set to be 900°C or lower and equal to or higher than the Ar_3 point, preferably to the range of (Ar_3 point + 10°C) to 880°C.

Cooling conditions

[0052] After hot rolling has been finished, accelerated cooling is performed. In the case where a cooling stop temperature is higher than 500°C, since it is impossible to obtain a steel plate having a tensile strength of 570 MPa or more, accelerated cooling is performed until the surface temperature of a steel plate decreases to a temperature of 500°C or lower, preferably to the range of 490°C or lower.

[0053] Incidentally, the surface temperature of a steel plate, which is used to specify the hot rolling conditions and cooling conditions, can be determined using, for example, a radiation thermometer.

[0054] In the present invention, under conditions regarding combination of the chemical composition and the manufacturing conditions described above, since an appropriate amount of solid solute B can be stably achieved so as to realize effects of improving the hardenability and the toughness of a welded heat affected zone formed as a result of performing high-heat input welding, a tapered plate having a tensile strength of 570 MPa or more and excellent toughness of a welded heat-affected zone formed as a result of performing high-heat input welding despite that a difference in thickness (taper amount) between a thicker portion and a thinner portion of the tapered plate is 10 mm or more in the steel plate.

[EXAMPLE 1]

[0055] By performing hot rolling on the steel slabs having the chemical compositions given in Table 1 under the conditions given in Table 2, tapered plates having a thickness of the thicker portion of 60 mm, a thickness of the thinner portion of 50 mm and a taper amount (difference in thickness between the thicker portion and the thinner portion) of 10 mm, were manufactured.

[0056] Specimens described below were respectively cut out from a depth of 1/4 of the plate thickness of a thicker portion and a thinner portion of the tapered plate. Round bar type tensile specimens having a parallel part of $14\phi \times 85$ mm and a gauge length of 70 mm were cut out in a direction perpendicular to the rolling direction, and 2 mm V notched Charpy specimens were cut out in a direction parallel to the rolling direction. The absorbed energy at - 40°C and strength of a base metal were evaluated. The absorbed energy at -40°C was defined by an average value for three specimens.

[0057] Moreover, 2 mm V notched Charpy test was performed in order to evaluate the toughness of a welded heat affected zone (hereinafter also referred to as HAZ), specifically, the toughness of a simulated HAZ. Prepared were test pieces having a width of 80 mm, a length of 80 mm and a thickness of 15 mm that were cut out from these steel plates and then subjected to a weld thermal cycle. This weld thermal cycle includes a cooling step that decreases the temperature of the test pieces, which have been heated to 1450°C, from 800°C to 500°C in 270 seconds (This cycle corresponds to a thermal cycle in which a welded heat affected zone undergoes when a steel plate having a plate thickness of 55 mm is subjected to electrogas arc welding with a heat input of 400 kJ/cm).

[0058] The mechanical properties and toughness after a weld thermal cycle had been performed of the thicker portion and thinner portion of the tapered plates are given in Table 2. In the case of all of the examples of the present invention No. 1 through No. 8, the conditions that YS: 460 MPa or more, TS: 570 MPa or more and absorbed energy at -40°C: 300 J or more (an average value for 3 specimens) were satisfied. Regarding a difference in strength between a thicker portion and a thinner portion, a difference in TS was less than 20 MPa and a difference in YS was less than 30 MPa, which means the both differences were small. Moreover, vTrs was -40°C or lower, which means these examples had excellent toughness of a simulated HAZ.

[0059] On the other hand, in the case of No. 11 and No. 14 where N - Ti/3.42 was more than 0.0025, a difference in strength between a thicker portion and a thinner portion was large. In addition, in the case where a condition regarding appropriate chemical composition or manufacturing conditions was not satisfied, one or more of the conditions that YS: 460 MPa or more, TS: 570 MPa or more, absorbed energy: 300 J or more and vTrs for the toughness of a simulated HAZ: -40°C or lower were unsatisfied.

[EXAMPLE 2]

[0060] By performing hot rolling on the steel slabs having the chemical compositions given in Table 3 under the conditions given in Table 4, tapered plates having a thickness of the thicker portion of 60 mm, a thickness of the thinner portion of 50 mm and a taper amount (difference in thickness between the thicker portion and the thinner portion) of 10 mm, were manufactured.

[0061] Specimens described below were respectively cut out from a depth of 1/4 of the plate thickness of a thicker portion and a thinner portion of the tapered plate. Round bar type tensile specimens having a parallel part of $14\phi \times 85$ mm and a gauge length of 70 mm were cut out in a direction perpendicular to the rolling direction, and 2 mm V notched Charpy specimens were cut out in a direction parallel to the rolling direction. The absorbed energy at - 40°C and strength of a base metal were evaluated. The absorbed energy at -40°C was defined by an average value of three specimens.

[0062] Moreover, 2 mm V notched Charpy test was performed in order to evaluate the toughness of a welded heat affected zone (hereinafter also referred to as HAZ), specifically, the toughness of a simulated HAZ. Prepared were test pieces having a width of 80 mm, a length of 80 mm and a thickness of 15 mm that were cut out from these steel plates and then subjected to a weld thermal cycle. This weld thermal cycle includes a cooling step that decreases the temperature of the test pieces, which have been heated to 1450°C, from 800°C to 500°C in 270 seconds (This cycle corresponds to a thermal cycle in which a welded heat affected zone undergoes when a steel plate having a plate thickness of 55 mm is subjected to electrogas arc welding with a heat input of 400 kJ/cm).

[0063] The mechanical properties and toughness after a weld thermal cycle had been performed of a thicker portion and a thinner portion of the tapered plates are given in Table 4. In the case of both of No. 21 and No. 22 where the specification of ACR was satisfied, the conditions that YS: 460 MPa or more, TS: 570 MPa or more and absorbed energy at -40°C: 300 J or more (an average value for 3 specimens) were satisfied. Regarding a difference in strength between a thicker portion and a thinner portion, a difference in TS was less than 20 MPa and a difference in YS was less than 30 MPa, which means the both differences were small. Moreover, vTrs was -65°C or lower, which means these examples had excellent toughness of a simulated HAZ.

[Table 1-1]

[0064]

Table 1-1

(mass%)

Steel No.	C	Si	Mn	P	S	Al	Cu	Ni	Cr	Mo	V	Nb	Ti	Ca	Classification
1	0.055	0.06	2.05	0.005	0.0022	0.048	-	-	-	-	-	0.013	0.017	0.0022	Example
2	0.100	0.25	1.53	0.011	0.0019	0.032	-	-	-	-	-	0.012	0.013	0.0025	Example
3	0.058	0.07	1. 55	0.006	0.0018	0.053	0.33	0.77	-	-	-	0.014	0.014	0.0018	Example
4	0.051	0.17	1.82	0.004	0.0019	0.036	-	-	0.12	-	-	0.010	0.013	0.0018	Example
5	0.049	0.10	1.98	0.005	0.0021	0.055	-	-	0.20	-	-	0.011	0.011	0.0017	Example
6	0.045	0.07	1.85	0.008	0.0010	0.042	-	-	-	0.2	-	0.012	0.014	0.0031	Example
7	0.042	0.12	1.52	0.006	0.0021	0.036	0.45	0.78	-	-	0.04	0.007	0.011	0.0016	Example
8	0.072	0.08	1.56	0.007	0.0035	0.055	0.38	0.87	-	-	-	0.008	0.008	0.0021	Example
9	0.170	0.07	1.82	0.006	0.0023	0.042	-	-	-	-	-	0.012	0.013	0.0015	Comparative Example
10	0.045	0.09	<u>2.52</u>	0.004	0.0019	0.032	-	-	-	-	-	0.012	0.011	0.0020	Comparative Example
11	0.052	0.06	1.57	0.008	0.0024	0.052	0.65	0.66	-	-	-	0.010	0.009	0.0015	Comparative Example
12	0.075	0.11	1.86	0.014	0.0022	0.044	-	-	-	-	-	0.008	0.012	0.0019	Comparative Example
13	0.052	0.07	1.78	0.006	0.0014	0.037	-	-	-	0.3	-	0.011	0.008	0.0018	Comparative Example
14	0.056	0.10	2.08	0.005	0.0022	0.048	-	-	-	-	-	0.010	0.013	0.0017	Comparative Example
15	0.049	0.08	1.96	0.005	0.0022	0.051	-	-	-	-	-	0.012	0.012	0.0001	Comparative Example
16	0.055	0.08	1.57	0.007	0.0021	0.047	0.35	0.75	-	-	-	0.018	0.011	0.0018	Comparative Example

Note 1 <u>Underlined value</u> is out of the range according to the present invention.
Note 2 Ceq(IIW)=C+Mn/6+(Cr+Mo+V)/5+(Cu+Ni)/15 (%), where an atomic symbol represents the content (mass%) of a chemical element represented by the symbol.
Note 3 Ar_3(°C)=910-273C-74Mn-57Ni-16Cr-9Mo-5Cu, where an atomic symbol represents the content (mass%) of a chemical element represented by the symbol.
Note 4 Expression (1): 0≤N-Ti/3.42≤0.0025, where N and Ti respectively represent the contents (mass%) of N and Ti.

[Table 1-2]

[0065]

Table 1-2

Steel No.	Mg	Zr	REM	B	N	Ceq(IIW)	Expression (1)	Ar_3	Classification
1	-	-	-	0.0008	0.0052	0.397	0.0002	743	Example
2	-	-	-	0.0011	0.0042	0.355	0.0004	769	Example
3	-	-	-	0.0012	0.0046	0.390	0.0005	734	Example
4	-	-	-	0.0014	0.0052	0.378	0.0014	759	Example
5	0.0011	-	-	0.0017	0.0035	0.419	0.0003	747	Example
6	-	-	-	0.0021	0.0063	0.393	0.0022	759	Example
7	-	0.0090	-	0.0012	0.0045	0.385	0.0013	739	Example
8	-	-	0.0070	0.0011	0.0042	0.415	0.0019	723	Example
9	-	-	-	0.0013	0.0048	0.473	0.0010	729	Comparative Example
10	-	-	-	0.0015	0.0042	0.465	0.0010	711	Comparative Example
11	-	-	-	0.0011	0.0057	0.401	0.0031	739	Comparative Example
12	-	-	-	0.0000	0.0052	0.385	0.0017	752	Comparative Example
13	-	-	0.0080	0.0014	0.0022	0.409	-0.0001	761	Comparative Example
14	0.0012	-	-	0.0012	0.0075	0.403	0.0037	741	Comparative Example
15	-	-	-	0.0013	0.0050	0.376	0.0015	752	Comparative Example
16	-	-	-	0.0011	0.0045	0.390	0.0013	734	Comparative Example

Note 1 Underlined value is out of the range accoraing to the present invention.
Note 2 Ceq(IIW)=C+Mn/6+(Cr+Mo+V)/S+(Cu+Ni)/15 (%), where an atomic symbol represents the content (mass%) of a chemical element represented by the symbol.
Note 3 Ar_3(°C)=910-273C-74Mn-57Ni-16Cr-9Mo-5Cu, where an atomic symbol represents the content (mass%) of a chemical element represented by the symbol.
Note 4 Expression (1): 0≤N-Ti/3.42≤0.0025, where N and Ti respectively represent the contents (mass%) of N and Ti.

[Table 2]

[0066]

Table 2

No.	Steel No.	Heating Temperature (°C)	Finishing Temperature (°C)	Cooling Stop Temperature (°C)	Thicker Portion (60 mm)				Thinner Portion (50 mm)				Difference in Strength between Thicker and Thinner Portions		Toughness of Simulated HAZ vTrs (°C)	Classification
					YS (MPa)	TS (MPa)	El (%)	vE-40 (J)	YS (MPa	TS (MPa)	El (%)	vE-40(J)	YS (MPa)	TS (MPa)		
1	1	1130	775	395	497	624	24	345	517	638	22	354	20	14	-55	Example
2	2	1130	837	376	464	584	23	311	468	591	23	308	4	7	-50	Example
3	3	1130	762	338	493	620	24	352	512	636	22	366	19	16	-60	Example
4	4	1150	785	378	478	605	24	345	507	624	23	337	29	19	-50	Example
5	5	1100	823	318	511	645	21	315	534	655	21	324	23	10	-50	Example
6	6	1050	792	341	488	615	24	347	514	634	23	352	26	19	-55	Example
7	7	1170	766	327	488	605	25	335	507	622	24	357	19	17	-50	Example
8	8	1050	754	386	507	644	21	343	535	657	22	347	28	13	-50	Example
9	9	1100	787	355	564	654	16	168	584	678	16	178	20	24	-10	Comparative Example
10	10	1100	765	387	557	662	18	175	576	694	15	154	19	32	0	Comparative Example
11	11	1130	778	367	434	569	25	339	508	627	23	364	74	58	-65	Comparative Example
12	12	1130	810	395	417	555	25	258	421	562	25	278	4	7	-10	Comparative Example
13	13	1170	792	345	498	632	21	335	521	648	22	328	23	16	0	Comparative Example
14	14	1170	780	375	418	552 -	26	245	478	605	23	353	60	53	-65	Comparative Example
15	15	1000	803	346	475	594	25	357	501	617	24	347	26	23	-20	Comparative Example

(continued)

No.	Steel No.	Heating Temperature (°C)	Finishing Temperature (°C)	Cooling Stop Temperature (°C)	Thicker Portion (60 mm)				Thinner Portion (50 mm)				Difference in Strength between Thicker and Thinner Portions		Toughness of Simulated HAZ vTrs (°C)	Classification
					YS (MPa)	TS (MPa)	El (%)	vE-40 (J)	YS (MPa	TS (MPa)	El (%)	vE-40(J)	YS (MPa)	TS (MPa)		
16	16	1130	758	352	512	635	23	321	525	649	21	327	13	14	0	Comparative Example
17	3	1230	785	395	517	634	20	179	524	651	21	205	7	17	-	Comparative Example
18	3	1130	915	357	547	652	21	147	551	667	20	155	4	15	-	Comparative Example
19	3	1130	702	345	423	568	25	338	425	568	25	345	2	0	-	Comparative Example
20	3	1130	760	524	403	545	26	253	418	556	26	254	15	11	-	Comparative Example

Note 1 underlined value is out of the range according to the present invention.

[Table 3]

Table 3

Steel No.	C	Si	Mn	P	S	Al	Cu	Ni	Cr	Mo	V	Nb	Ti	Ca	Mg
21	0.047	0.06	1.93	0.005	0.0016	0.039	0.08	0.33	—	—	—	0.012	0.014	0.0022	—
22	0.053	0.05	1.57	0.004	0.0021	0.042	0.32	0.74	—	0.05	—	0.009	0.015	0.0019	—

(mass%)

Steel No.	Zr	REM	B	N	O	Ceq(IIW)	Expression (1)	ACR	Ar_3	Classification
21	—	—	0.0021	0.0063	0.0019	0.396	0.0022	0.657	735	Example
22	—	—	0.0012	0.0045	0.0025	0.395	0.0001	0.317	735	Example

Note 1 $Ceq(IIW)=C+Mn/6+(Cr+Mo+V)/5+(Cu+Ni)/15$ (%), where an atomic symbol represents the content (mass%) of a chemical element represented by the symbol.

Note 2 $Ar_3(°C)=910-273C-74Mn-57Ni-16Cr-9Mo-5Cu$, where an atomic symbol represents the content (mass%) of a chemical element represented by the symbol.

Note 3 Expression (1): $0 \leq N-Ti/3.42 \leq 0.0025$, where N and Ti respectively represent the contents (mass%) of N and Ti.

Note 4 $ACR=(Ca-(0.18)+130\times Ca)\times O)/1.25/S$, where Ca, O and S respectively represent the contents (mass%) of Ca, O and S.

[Table 4]

Table 4

No.	Steel No.	Heating Temperature (°C)	Finishing Temperature (°C)	Cooling Stop Temperature (°C)	Thicker Portion (60 mm)				Thinner Portion (50 mm)			
					YS (MPa)	TS (MPa)	El (%)	vE-40 (J)	YS (MPa)	TS (MPa)	El (%)	vE-40 (J)
21	21	1080	778	352	492	617	24	336	507	633	23	325
22	22	1130	792	368	478	621	23	328	489	636	23	319

No.	Steel No.	Difference in Strength between Thicker and Thinner Portions		Toughness of Simulated HAZ	Classification
		YS (MPa)	TS (MPa)	vTrs (°C)	
21	21	15	16	-65	Example
22	22	11	15	-70	Example

Claims

1. A method for manufacturing a tapered plate having a tensile strength of 570 MPa or more and a difference in thickness between a thicker portion and a thinner portion of 10 mm or more, the method comprising heating to a temperature of 1000°C or higher and 1200°C or lower, a steel slab having a chemical composition consisting of, by mass%,
   C: 0.03% or more and 0.12% or less
   Si: 0.03% or more and 0.5% or less
   Mn: 0.8% or more and 2.2% or less
   P: 0.015% or less
   S: 0.0005% or more and 0.0050% or less
   Al: 0.005% or more and 0.1% or less
   Nb: 0.003% or more and 0.014% or less
   Ti: 0.003% or more and 0.02% or less
   B: 0.0003% or more and 0.0025% or less
   N: 0.0030% or more and 0.0070% or less
   Ca: 0.0005% or more and 0.0050% or less,
   optionally one, two or more selected from among
   Cu: 0.05% or more and 1.0% or less
   Ni: 0.05% or more and 1.0% or less

Cr: 0.05% or more and 0.5% or less
Mo: 0.05% or more and 0.5% or less, and
V: 0.02% or more and 0.1% or less,
optionally one, two or more selected from among
Mg: 0.0005% or more and 0.005% or less
Zr: 0.003% or more and 0.02% or less, and
REM: 0.003% or more and 0.02% or less,
and optionally O: 0.0030% or less, and the balance being Fe and inevitable impurities,
in which expression (1) is satisfied, performing hot rolling on the heated slab in which plate thickness changes in the longitudinal direction so as to form a tapered shape at a finishing rolling temperature of 900°C or lower and equal to or higher than the Ar_3point and then performing accelerated cooling on the hot-rolled steel plate down to a temperature of 500°C or lower:

$$0 \leqq N - Ti/3.42 \leqq 0.0025 \quad \cdots\cdot \ (1),$$

where N and Ti respectively represent the contents (mass%) of N and Ti.

2. The method for manufacturing a tapered plate having a tensile strength of 570 MPa or more and a difference in thickness between a thicker portion and a thinner portion of 10 mm or more according to Claim 1, the steel slab having the chemical composition containing, by mass%, one, two or more selected from among
Cu: 0.05% or more and 1.0% or less
Ni: 0.05% or more and 1.0% or less
Cr: 0.05% or more and 0.5% or less
Mo: 0.05% or more and 0.5% or less, and
V: 0.02% or more and 0.1% or less.

3. The method for manufacturing a tapered plate having a tensile strength of 570 MPa or more and a difference in thickness between a thicker portion and a thinner portion of 10 mm or more according to Claim 1 or 2, the steel slab having the chemical composition containing, by mass%, one, two or more selected from among
Mg: 0.0005% or more and 0.005% or less
Zr: 0.003% or more and 0.02% or less, and
REM: 0.003% or more and 0.02% or less.

4. The method for manufacturing a tapered plate having a tensile strength of 570 MPa or more and a difference in thickness between a thicker portion and a thinner portion of 10 mm or more according to any one of Claims 1 to 3, the steel slab having the chemical composition containing, by mass%,
O: 0.0030% or less,
in which the contents of Ca, O and S satisfy expression (2) below:

$$0.3 \leqq ACR \leqq 0.8 \quad \cdots\cdot \ (2),$$

where ACR = (Ca - (0.18 + 130×Ca)×O)/1.25/S, and where Ca, O and S respectively represent the contents (mass%) of Ca, O and S.

Patentansprüche

1. Verfahren zur Herstellung einer sich verjüngenden Platte mit einer Zugfestigkeit von 570 MPa oder mehr und einem Dickenunterscheid zwischen einem dickeren Abschnitt und einem dünneren Abschnitt von 10 mm oder mehr, wobei das Verfahren das Aufheizen auf eine Temperatur von 1000°C oder höher und 1200°C oder niedriger einer Stahlbramme, die eine chemische Zusammensetzung aufweist, die, in Massen%, aus C: 0,03% oder mehr und 0,12% oder weniger
Si: 0,03% oder mehr und 0,5% oder weniger
Mn: 0,8% oder mehr und 2,2% oder weniger
P: 0,015% oder weniger
S: 0,0005% oder mehr und 0,0050% oder weniger

Al: 0,005% oder mehr und 0,1% oder weniger
Nb: 0,003% oder mehr und 0,014% oder weniger
Ti: 0,003% oder mehr und 0,02% oder weniger
B: 0,0003% oder mehr und 0,0025% oder weniger
N: 0,0030% oder mehr und 0,0070% oder weniger
Ca: 0,0005% oder mehr und 0,0050% oder weniger,
optional eines, zwei oder mehrere ausgewählt aus
Cu: 0,05% oder mehr und 1,0% oder weniger
Ni: 0,05% oder mehr und 1,0% oder weniger
Cr: 0,05% oder mehr und 0,5% oder weniger
Mo: 0,05% oder mehr und 0,5% oder weniger, und
V: 0,02% oder mehr und 0,1% oder weniger,
optional eines, zwei oder mehrere ausgewählt aus
Mg: 0,0005% oder mehr und 0,005% oder weniger
Zr: 0,003% oder mehr und 0,02% oder weniger, und
REM: 0,003% oder mehr und 0,02% oder weniger,
und optional O: 0,0030% oder weniger, und als Rest aus Fe und unvermeidbaren Verunreinigungen besteht, wobei der Gleichung (1) genügt wird, das Durchführen von Warmwalzen der aufgeheizten Bramme in welchem sich die Plattendicke in Längsrichtung verändert, so dass sich eine sich verjüngende Form bildet, bei einer Endwalztemperatur von 900°C oder niedriger und gleich oder höher als der Ar_3-Punkt und dann das Durchführen beschleunigten Abkühlens der warmgewalzten Stahlplatte auf eine Temperatur von 500°C oder niedriger umfasst:

$$0 \leqq N - Ti/3{,}42 \leqq 0{,}0025 \quad \cdots\cdot \ (1),$$

wobei N und Ti jeweils die Gehalte (Massen%) von N und Ti darstellen.

2. Verfahren zur Herstellung einer sich verjüngenden Platte mit einer Zugfestigkeit von 570 MPa oder mehr und einem Dickenunterscheid zwischen einem dickeren Abschnitt und einem dünneren Abschnitt von 10 mm oder mehr gemäß Anspruch 1, wobei die Stahlbramme die chemische Zusammensetzung aufweist, die, in Massen%,
eines, zwei oder mehrere ausgewählt aus
Cu: 0,05% oder mehr und 1,0% oder weniger
Ni: 0,05% oder mehr und 1,0% oder weniger
Cr: 0,05% oder mehr und 0,5% oder weniger
Mo: 0,05% oder mehr und 0,5% oder weniger, und
V: 0,02% oder mehr und 0,1% oder weniger enthält.

3. Verfahren zur Herstellung einer sich verjüngenden Platte mit einer Zugfestigkeit von 570 MPa oder mehr und einem Dickenunterscheid zwischen einem dickeren Abschnitt und einem dünneren Abschnitt von 10 mm oder mehr gemäß Anspruch 1 oder 2, wobei die Stahlbramme die chemische Zusammensetzung aufweist, die, in Massen%,
eines, zwei oder mehrere ausgewählt aus
Mg: 0,0005% oder mehr und 0,005% oder weniger
Zr: 0,003% oder mehr und 0,02% oder weniger, und
REM: 0,003% oder mehr und 0,02% oder weniger enthält.

4. Verfahren zur Herstellung einer sich verjüngenden Platte mit einer Zugfestigkeit von 570 MPa oder mehr und einem Dickenunterscheid zwischen einem dickeren Abschnitt und einem dünneren Abschnitt von 10 mm oder mehr gemäß einem der Ansprüche 1 bis 3, wobei die Stahlbramme die chemische Zusammensetzung aufweist, die, in Massen%, O: 0,0030% oder weniger enthält,
wobei die Gehalte an Ca, O und S der folgenden Gleichung genügen:

$$0{,}3 \leqq ACR \leqq 0{,}8 \quad \cdots\cdot \ (2),$$

wobei ACR = (Ca - (0,18 + 130×Ca)×O)/1,25/S, und wobei Ca, O, S jeweils die Gehalte (Massen%) von Ca, O und S darstellen.

Revendications

1. Procédé de fabrication d'une plaque effilée présentant une résistance à la traction de 570 MPa ou plus et une différence d'épaisseur entre une partie plus épaisse et une partie plus fine de 10 mm ou plus, le procédé comprenant le chauffage à une température de 1000 °C ou plus et 1200 °C ou moins, d'une brame d'acier présentant une composition chimique consistant en, en % en masse :

   C : 0,03 % ou plus et 0,12 % ou moins
   Si : 0,03 % ou plus et 0,5 % ou moins
   Mn : 0,8 % ou plus et 2,2 % ou moins
   P : 0,015 % ou moins
   S : 0,0005 % ou plus et 0,0050 % ou moins
   Al : 0,005 % ou plus et 0,1 % ou moins
   Nb : 0,003 % ou plus et 0,014 % ou moins
   Ti : 0,003 % ou plus et 0,02 % ou moins
   B : 0,0003 % ou plus et 0,0025 % ou moins
   N : 0,0030 % ou plus et 0,0070 % ou moins
   Ca : 0,0005 % ou plus et 0,0050 % ou moins,
   facultativement un, deux ou plus de deux sélectionnés parmi
   Cu : 0,05 % ou plus et 1,0 % ou moins
   Ni : 0,05 % ou plus et 1,0 % ou moins
   Cr : 0,05 % ou plus et 0,5 % ou moins
   Mo : 0,05 % ou plus et 0,5 % ou moins, et
   V : 0,02 % ou plus et 0,1 % ou moins,
   facultativement un, deux ou plus de deux sélectionnés parmi
   Mg : 0,0005 % ou plus et 0,005 % ou moins
   Zr : 0,003 % ou plus et 0,02 % ou moins, et
   REM : 0,003 % ou plus et 0,02 % ou moins
   et facultativement O: 0,0030 % ou moins, le reste étant Fe et les impuretés inévitables,
   dans laquelle l'expression (1) est satisfaite, par la mise en oeuvre d'un laminage à chaud sur la brame chauffée dans lequel l'épaisseur de la plaque change dans la direction longitudinale afin de former une forme effilée à une température de laminage de finition de 900 °C ou moins et supérieure ou égale au point Ar_3 et ensuite par la mise en oeuvre d'un refroidissement accéléré sur la plaque d'acier laminée à chaud jusqu'à une température de 500 °C ou moins :

   $$0 \leq N - Ti/3{,}42 \leq 0{,}0025 \qquad (1)$$

   où N et Ti représentent respectivement les teneurs (% en masse) de N et Ti.

2. Procédé de fabrication d'une plaque effilée présentant une résistance à la traction de 570 MPa ou plus et une différence d'épaisseur entre une partie plus épaisse et une partie plus fine de 10 mm ou plus selon la revendication 1, la brame d'acier présentant une composition chimique contenant, en % en masse, un, deux ou plus de deux sélectionnés parmi :

   Cu : 0,05 % ou plus et 1,0 % ou moins
   Ni : 0,05 % ou plus et 1,0 % ou moins
   Cr : 0,05 % ou plus et 0,5 % ou moins
   Mo : 0,05 % ou plus et 0,5 % ou moins, et
   V : 0,02 % ou plus et 0,1 % ou moins.

3. Procédé de fabrication d'une plaque effilée présentant une résistance à la traction de 570 MPa ou plus et une différence d'épaisseur entre une partie plus épaisse et une partie plus fine de 10 mm ou plus selon la revendication 1 ou 2, la brame d'acier présentant une composition chimique contenant, en % en masse, un, deux ou plus de deux sélectionnés parmi :

   Mg : 0,0005 % ou plus et 0,005 % ou moins
   Zr : 0,003 % ou plus et 0,02 % ou moins, et

REM : 0,003 % ou plus et 0,02 % ou moins.

4. Procédé de fabrication d'une plaque effilée présentant une résistance à la traction de 570 MPa ou plus et une différence d'épaisseur entre une partie plus épaisse et une partie plus fine de 10 mm ou plus selon l'une quelconque des revendications 1 à 3, la brame d'acier présentant une composition chimique contenant, en % en masse :

O : 0,0030 % ou moins,
dans lequel les teneurs en Ca, O et S satisfont l'expression (2) ci-dessous :

$$0{,}3 \leq ACR \leq 0{,}8 \qquad (2)$$

où ACR = (Ca - (0,18 + 130×Ca)×O)/1,25/S, et où Ca, O et S représentent respectivement les teneurs (% en masse) de Ca, O et S.

REFERENCES CITED IN THE DESCRIPTION

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