(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 4 338 862 A1

(12) EUROPEAN PATENT APPLICATION
published in accordance with Art. 153(4) EPC

(43) Date of publication:
20.03.2024 Bulletin 2024/12

(21) Application number: **22784173.1**

(22) Date of filing: **11.05.2022**

(51) International Patent Classification (IPC):
B21B 1/18 *(2006.01)* ***C22C 38/02*** *(2006.01)*

(86) International application number:
PCT/CN2022/092306

(87) International publication number:
WO 2022/214107 (13.10.2022 Gazette 2022/41)

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
KH MA MD TN

(30) Priority: **12.05.2021 CN 202110519204**

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(54) METHOD FOR ROLLING HIGH-TOUGHNESS HIGH-STRENGTH LOW-ALLOY STEEL

(57) The method for rolling a high-toughness high-strength low-alloy steel, sequentially comprising the following steps: heating, descaling, rough rolling, continuous rolling, first water cooling, finish rolling, second water cooling, and cold hearth cooling; and using a converter continuous casting billet as a raw material, the continuous casting billet comprising the following chemical components in percentage by mass: C≤0.20, Si≤0.60, Mn: 1.00-1.70, Cr≤0.30, P≤0.020, S≤0.020, V: 0.05-0.10, Al≤0.03, and N≤0.025, with the balance being Fe and inevitable impurities. By using the rolling method, the actual grain size of the high-strength low-alloy steel can be refined; the comprehensive performance of the high-strength low-alloy steel is excellent; the metallographic structure is fine ferrite and pearlite; the grain size reaches 9.0 or above; the impact energy at -20°C is greater than 100 J, and the impact energy at -40°C is greater than 80 J.

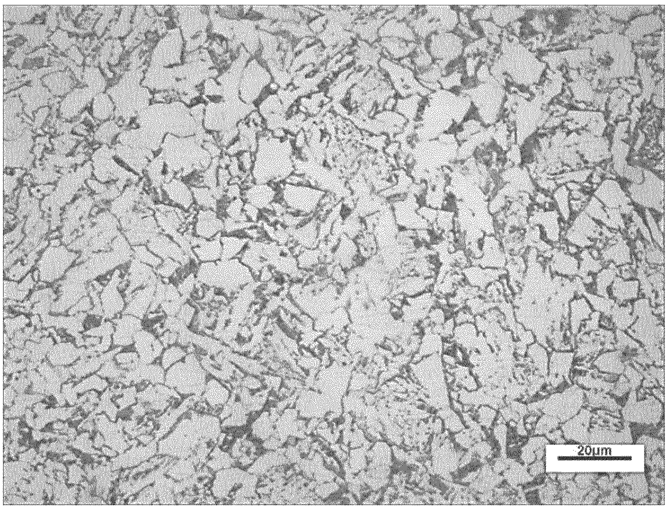

Fig 3

Processed by Luminess, 75001 PARIS (FR)

Description

FIELD OF INVENTION

[0001] The invention relates to the field of steel rolling, particularly relates to a method for rolling high-toughness high-strength low-alloy steel (rolling method for a high-toughness high-strength low-alloy steel).

BACKGROUND OF THE INVENTION

[0002] With the economic development of society and progress of science and technology, steel materials are already widely used in various fields, wherein, due to its high strength, good plasticity and toughness, a high-strength low-alloy steel is already widely used in high-end fields such as aerospace and ships, especially in infrastructures such as oil pipes, bridges, large buildings, and engineering fields such as vehicles, containers, and machinery, chemical, medical, light industrial devices, it is also used broadly. The high-strength low-alloy steel is widely used in machinery devices, vehicles, and tubulation fields and so on due to its high strength, superior formability, and stable combination property.

[0003] At present, ways to increase strength of steel materials are solution strengthening, dislocation strengthening, refined crystalline strengthening, and precipitation hardening of a second-phase particle and so on; wherein, the effect of refined crystalline strengthening is most obvious, the steel after refined crystalline strengthening has better strength and toughness. With the increase of grain refinement resistance, crack propagation resistance, the fatigue strength, toughness of the steel increases, temperature of brittleness turning point decreases. A fine-grained steel has good coordination between strength and toughness, and is broadly used in fields such as vehicles, ships, bridges, and engineering machinery.

[0004] In prior art, there is a trade-off between strength and toughness of a high-strength low-alloy steel, the prior art only relates to a rolling method of a steel plate and strip, not relates to a rolling method of a round bar steel, and an off-line normalizing step is necessary during the rolling, production cost is high, which is adverse to energy saving and cost reduction and green manufacturing.

SUMMARY

[0005] With respect to deficiencies of the prior art, the purpose of the invention is to provide a rolling method for a high-toughness high-strength low-alloy steel. It successfully develops a rolling method for producing a high-toughness high-strength low-alloy steel by making a reasonable production process control through micro-alloy elements and control rolling and control cooling processes. During manufacturing of a production, it eliminates the off-line normalizing step, reduces the manufacturing process, saves manufacturing cost; for the high-strength low-alloy steel manufactured through this process and method, its metallographic structure is fine ferrite and pearlite, its tensile strength is more than 630MPa, its yield strength is more than 500MPa, its grain size after rolling is fine and uniform, the grain size reaches 9.0 or above, comprehensive mechanical properties are far superior to conventional rolling processes.

[0006] To achieve the above purpose, the invention provides the following technical solution:

A rolling method for high-toughness high-strength low-alloy steel, the rolling method sequentially comprises the following steps: heating, descaling, rough rolling, continuous rolling, first water cooling, finish rolling, second water cooling, and cold hearth cooling.

[0007] Using a converter continuous casting billet as a raw material, the continuous casting billet of the high-toughness high-strength low-alloy steel comprises the following chemical components and contents in percentage by mass: C≤0.20, Si≤0.60, Mn:1.37~1.70, Cr≤0.30, P≤0.020, S≤0.020, V:0.05~0.10, Al≤0.03, N≤0.025, with others being Fe and inevitable impurities.

[0008] In the above rolling method for high-toughness high-strength low-alloy steel, as a preferable embodiment, the step of the heating is divided into four sections, which are sequentially as follows: pre-heating zone, heating first zone, heating second zone, and soaking zone.

[0009] In the above rolling method for a high-toughness high-strength low-alloy steel, as a preferable embodiment, the temperature of the pre-heating zone is less than or equal to 750°C.

[0010] In the above rolling method for a high-toughness high-strength low-alloy steel, as a preferable embodiment, the temperature of the heating first zone is 900~1050°C.

[0011] In the above rolling method for a high-toughness high-strength low-alloy steel, as a preferable embodiment, the temperature of the heating second zone is 1050~ 1150°C.

[0012] In the above rolling method for a high-toughness high-strength low-alloy steel, as a preferable embodiment, the temperature of the soaking zone is 1150~1210°C.

[0013] In the above rolling method for a high-toughness high-strength low-alloy steel, as a preferable embodiment, the total heating time of the step of the heating is 3~5h.

[0014] In the above rolling method for a high-toughness high-strength low-alloy steel, as a preferable embodiment, the soaking time of the soaking zone is 30~80min.

[0015] In the above rolling method for a high-toughness high-strength low-alloy steel, as a preferable embodiment, the step of the heating is performed in a four-section walking beam heating furnace.

[0016] In the above rolling method for a high-toughness high-strength low-alloy steel, as a preferable embodiment, in the step of the rough rolling, the entry temperature of the rough rolling is 950~1050°C, the pass of the rough rolling is 5~7, preferably, the number of rough-rolling mills provided in the step of the rough rolling is 6.

[0017] In the above rolling method for a high-toughness high-strength low-alloy steel, as a preferable embodiment, the step of the continuous rolling includes intermediate rolling and pre-finish rolling.

[0018] In the above rolling method for a high-toughness high-strength low-alloy steel, as a preferable embodiment, the entry temperature of the rough rolling is 900~1000°C.

[0019] In the above rolling method for a high-toughness high-strength low-alloy steel, as a preferable embodiment, the number of intermediate-rolling mills provided in the step of the intermediate rolling is 6, the pass of the intermediate rolling is 5~7, preferably, the pass of the intermediate rolling is 6.

[0020] In the above rolling method for a high-toughness high-strength low-alloy steel, as a preferable embodiment, outlet temperature of the pre-finish rolling is 850~950°C.

[0021] In the above rolling method for a high-toughness high-strength low-alloy steel, as a preferable embodiment, the number of pre-finish-rolling mills provided in the step of the pre-finish rolling is 4, the pass of the pre-finish rolling is 3~5, preferably, the pass of the pre-finish rolling is 4.

[0022] In the above rolling method for a high-toughness high-strength low-alloy steel, as a preferable embodiment, during the first water cooling, the first water cooling is performed with incoming materials after the step of the continuous rolling, wherein, the water cooling rate is 25~50°C/s, the hydraulic pressure is 0.2~0.6MPa.

[0023] In the above rolling method for a high-toughness high-strength low-alloy steel, as a preferable embodiment, in the step of the finish rolling, rolling-start-temperature at the entry of the finish rolling is 800~850°C.

[0024] In the above rolling method for a high-toughness high-strength low-alloy steel, as a preferable embodiment, a reducing and sizing mill set is used for the finish rolling.

[0025] In the above rolling method for a high-toughness high-strength low-alloy steel, as a preferable embodiment, the reducing and sizing mill set is a three-roller reducing and sizing mill set.

[0026] In the above rolling method for a high-toughness high-strength low-alloy steel, as a preferable embodiment, during the second water cooling, the second water cooling is performed with the steel after the step of the finish rolling, wherein, water cooling rate is 25~100°C/s, hydraulic pressure is 0.2~0.6MPa.

[0027] In the above rolling method for a high-toughness high-strength low-alloy steel, as a preferable embodiment, in the step of the descaling, high-pressure water descaling is used with the aim to descaling, the hydraulic pressure of the high-pressure water is 15~20MPa.

[0028] Furthermore, preferably, the hydraulic pressure of the high-pressure water is 17~ 20MPa.

[0029] In the above rolling method for a high-toughness high-strength low-alloy steel, as a preferable embodiment, a high-toughness high-strength low-alloy steel bar is obtained by the rolling method, the specification of the steel bar is Ø60~120mm.

[0030] In the above rolling method for a high-toughness high-strength low-alloy steel, as a preferable embodiment, the cold hearth cooling means the steel after the second water cooling is cooled on the cold hearth.

[0031] Compared with the prior art, the beneficial effects of the invention are as follows:

(1)adding the micro-alloy element vanadium V into the chemical components of the continuous casting billet, in order to improve hardenability of the steel, reduce deformation of the steel, avoid cracking, and to enhance the impact toughness; because the micro-alloy element vanadium V has a delayed action on recrystallization only under 900°C, after austenitic transformation, the micro-alloy element vanadium V almost dissolves completely, at the same time, the micro-alloy element N further enhances the impact toughness of micro-alloy elements, and precipitation strengthening effects of the micro-alloy element vanadium V, nitrogen N are exploited to the full, by adding the content of the micro-alloy element V to improve the impact toughness, at the meantime, it would have a strengthening effect when the micro-alloy element vanadium V is dissolved into the ferrite, thus forming stable carbon compounds and refining grains.

[0032] At this point, applying the on-line TMCP process, controlling the precipitation process of nitrides, forming the ferrite and pearlite structure, grains are refined again by exploiting the low end rolling temperature and cooling rate. During the refinement of grains, the strength of the steel is improved, its plasticity and impact toughness are also enhanced, thus achieving high-strength control to mechanical properties.

[0033] The actual grain size of the high-strength low-alloy steel can be refined by adopting this rolling method, the comprehensive property of the obtained high-strength low-alloy steel is excellent, the metallographic structure is fine ferrite and pearlite, the tensile strength is more than 630MPa, the yield strength is more than 500MPa, the grain size after rolling is fine and uniform, the grain size reaches 9.0 or above, the impact energy at -20°C is greater than 100J, the impact energy at -40°C is greater than 80J, its comprehensive mechanical properties are far superior to conventional rolling processes.

[0034] (2)Without performing the off-line normalizing during the rolling, the mechanical properties also can meet the utilizing requirements, this can not only save the machining time, but also can reduce the cost and improve the effect.

BRIEF DESCRIPTION OF THE DRAWINGS

[0035]

Fig. 1 is a metallographic structure obtained by rolling Ø80mm specification in comparative example 2;
Fig.2 is the grain size (7.5) obtained by rolling Ø80mm specification in comparative example 2;
Fig.3 is a metallographic structure obtained by rolling Ø80mm specification in embodiment2 of the present invention;
Fig.4 is the grain size (9.0) obtained by rolling Ø80mm specification in embodiment2 of the present invention.

DETAILED DESCRIPTION OF THE EMBODIMENTS

[0036] The technical solutions of embodiments of the invention will be described clearly and fully in combination with drawings of embodiments of the invention below, obviously, the described embodiments are only some of the embodiments of the invention, not the all embodiments. Based on the embodiments of the invention, all the other embodiments obtained by those skilled in the art without doing any creative work will fall in the protection scope of the invention.

[0037] The rolling method disclosed in the invention results in a superior structural form and excellent structural mechanical properties of a necessary product by designing according to the process parameters of the continuous rolling, combining solid-state phase transformation and plastic deformation of the rolling principle, plastic forming through adopting the heating process system and the rolling reduction system of four-section stepwise heating furnace, forming through the deformation system of the rough rolling, the intermediate rolling, the finish rolling, finally controlling metal solid phase transformation through the cooling process.

[0038] The technical solution of the invention is further detailed in combination with drawings through the embodiments below.

[0039] A rolling method for a high-toughness high-strength low-alloy steel, the rolling method sequentially comprises the following steps: heating, descaling, rough rolling, continuous rolling, first water cooling, finish rolling, second water cooling, and cold hearth cooling; and using a converter continuous casting billet as a raw material, the continuous casting billet comprises the following chemical components and contents in percentage by mass: C≤0.20, Si≤0.60, Mn:1.00~1.70, Cr≤0.30, P≤0.020, S≤0.020, V:0.05~0.10, Al≤0.03, N≤0.025, with others being Fe and inevitable impurities.

[0040] By adding the micro-alloy element vanadium V into the chemical components of the continuous casting billet to improve hardenability of the steel, reduce steel deformation and cracks, and to enhance the impact toughness; because the micro-alloy element vanadium V has a delayed action on recrystallization only under 900°C, after austenitic transformation, the micro-alloy element vanadium V almost dissolves completely, the micro-alloy element N further enhances the impact toughness of micro-alloy elements at the same time, and precipitation strengthening effects of the micro-alloy element vanadium V, nitrogen N are exploited to the full.

[0041] The reason that grain refinement can improve plasticity and toughness is the fine grain provides a better condition for the occurrence and spread of plastic deformation. Elements those make temperature Ar3 decrease all have a tendency of grain refinement, temperature Ar3 causes austenite to transform into the ferrite. By adding the content of the micro-alloy element V to improve the impact toughness, at the meantime, it would have a strengthening effect when the micro-alloy element vanadium V is dissolved into the ferrite, thus forming stable carbon compounds and refining grains.

[0042] The rolling method sequentially comprises the following steps:

(1) Heating

[0043] The step of the heating is performed in a four-section stepwise heating furnace; the step of the heating is divided into four sections, which are sequentially as follows: pre-heating zone, heating first zone, heating second zone, and soaking zone.

[0044] The temperature of the pre-heating zone is less than or equal to 750°C(for example. 600°C, 650°C, 665°C, 700°C, 750°C and interval zones or points between any two of those temperatures); that is, if the temperature of the furnace exceeds 750°C, because thermal conductivity of the billet is too fast, the temperature difference between the billet and the heating furnace is too large, the surface of the casting billet or the final rolled steel may be caused to crack.

[0045] The temperature of the heating first zone is 900~1050°C (for example. 900°C, 950°C, 980°C, 1000°C, 1010°C, 1050°C and interval zones or points between any two of those temperatures). The temperature of the heating second zone is 1050~ 1150°C(for example. 1050°C, 1080°C, 1100°C, 1110°C, 1130°C, 1150°C and interval zones or points between any two of those temperatures). The main roles of the heating first zone and the heating second zone are to: reduce the energy consumption, reduce the oxidation burning loss of the billet.

[0046] The temperature of the soaking zone is 1150 - 1210°C (for example. 1150°C, 1160°C, 1165°C, 1170°C, 1185°C, 1190°C, 1205°C, 1210°C and interval zones or points between any two of those temperatures). The main role of the soaking heating section is to: reduce the energy consumption, reduce the oxidation burning loss of the billet, reduce the decarburization of the billet at the same time.

[0047] The total heating time of the step of the heating is 3~5h (for example. 3.5h, 4h, 4.5h, 4.8h and time points between any two of those times); the soaking time of the soaking zone is 30~80min (for example. 30min, 35min, 40min, 45min, 50min, 55min, 60min, 70min, 75min, 80min and time points between any two of those time periods).

[0048] The step of the heating achieves the following four purposes: firstly, the energy consumption may be reduced and the cost can be lowed when eliminating the step of the off-line normalizing; secondly, the oxidation burning loss of the billet can be reduced due to the four-zone heating process; thirdly, the decarburization of the billet can be reduced; fourthly, the surface cracks of the final billet brought by too long heating time can be reduced.

(2) Descaling

[0049] The billet after heating is descaled by employing the high-pressure water in order to deoxidate the iron sheet, the pressure of the high-pressure water is 15~ 20MPa (for example 15MPa, 16.5MPa, 17MPa, 18MPa, 20MPa and the pressure value between any two of those pressure values); the pressure value of the high-pressure water is preferably 17~20MPa. The oxidized iron sheet on the surface of the steel is removed by the high-pressure water. The oxidized iron sheet on the surface cannot be cleared cleanly and thoroughly when the pressure is below 15MPa, thus affecting the rolling effect of the steel.

(3) Rough rolling

[0050] Preferably, 6 rough rolling mills are provided in the step of the rough rolling; wherein, the entry temperature of the rough rolling is 950~ 1050°C(for example, 950°C, 980°C, 1000°C, 1020°C, 1035°C, 1050°C and interval zones or points between any two of those temperatures), the pass of the rough rolling is 5~7; the pass of the rough rolling is preferably 6. A method of continuous rolling is adopted in the step of the rough rolling, the surface size of the steel billet is changed mainly through plastic deformation, the pass design adopts a box pass design, the sectional shape of the billet is changed and reduced through the high-pressure process.

(4) Continuous rolling

[0051] The step of the continuous rolling includes intermediate rolling and pre-finish rolling, the entry temperature of the intermediate rolling is 900~1000°C(for example, 905°C, 920°C, 940°C, 950°C, 970°C, 1000°C and interval zones or points between any two of those temperatures), 6 intermediate rolling mills are preferably provided in the step of the intermediate rolling, the pass of the intermediate rolling is 5~7, the pass of the intermediate rolling is preferably 6. The pass design mainly adopts an oval and circle pass design, the sectional shape of the billet is made close to the finished form through the rolling process.

[0052] The outlet temperature of the pre-finish rolling is 850~950°C(for example, 855°C, 870°C, 890°C, 900°C, 910°C, 920°C, 930°C, 940°C, 950°C and interval zones or points between any two of those temperatures); 4 pre-finish rolling mills are preferably provided in the step of the pre-finish rolling, the pass of the pre-finish rolling is 3~5, the pass of the pre-finish rolling is preferably 4. The pass design mainly adopts an oval and circle pass design, the sectional shape of the billet is made close to the finished form through the rolling process.

(5) First water cooling

[0053] The first water cooling is performed with incoming materials after the step of the continuous rolling, the temperature after the first water cooling is 750~800°C(for example, 750°C, 765°C, 780°C, 795°C, 798°C, 800°C and interval zones or points between any two of those temperatures), wherein, during the first water cooling, the water cooling rate is 25~50°C/s, the hydraulic pressure is 0.2 -0.6MPa. The target temperature as required in the finish rolling is obtained by controlling the temperature of the first water cooling and the water cooling rate, controlling the temperature of the steel before the pre-finish rolling.

(6) Finish rolling

[0054] The rolled steel obtained in the step (5) is rolled in a reducing and sizing finish rolling mill set, the reducing and sizing finish rolling mill set is preferably a three-roller reducing and sizing mill set, i.e. KOCKS reducing and sizing finish rolling mill set, entry temperature of initial rolling is 800~850°C (for example, 800°C, 810°C, 820°C, 824°C, 832°C, 850°Cand interval zones or points between any two of those temperatures). Adopting the three-roller reducing and sizing mill set can achieve low-temperature rolling better, thus improving non-quenched and tempered steel grain size, comprehensive mechanical properties, providing its excellent performance for the production of the non-quenched and tempered steel.

(7) Second water cooling

[0055] The second water cooling is performed with the steel after the finish rolling, the temperature under which the steel performs the second water cooling after the step of the finish rolling is 600~700°C (for example, 600°C, 625°C, 640°C, 662°C, 683°C, 700°Cand interval zones or points between any two of those temperatures), wherein, the water cooling rate is 25~100°C/s, the hydraulic pressure is 0.2~0.6MPa. The metallographic structure and mechanical properties as finally required by the steel are obtained by performing the second water cooling after the finish rolling and controlling the temperature and the water cooling rate of the second water cooling, and controlling the temperature of the steel.

(8) Cold hearth cooled is the cold hearth cooling

[0056] The steel obtained after the second water cooling is made to cool on the cold hearth, the finish steel is finally obtained.

[0057] The technology of controlling rolling and controlling cooling as described in the step (1) to the step (8) is the main steps of refining the grain size of the high-carbon steel grade, by integrally controlling the heating temperature, deformation extent, and cooling rate, the target of refining the actual grain size, improving stiffness and roughness of the steel is reached.

[0058] At the same time, applying the on-line TMCP process (i.e. thermal mechanical control process), controlling the precipitation process of nitrides, forming the uniform ferrite and pearlite structure, grains are refined again by exploiting the low end rolling temperature and cooling rate, during the refinement of grains, the strength of the steel is improved, its plasticity and impact toughness are also enhanced, thus achieving high-strength control to mechanical properties.

[0059] The invention provides a rolling method for a high-toughness high-strength low-alloy steel, this method is unique, adopts the micro-alloy elements and the control rolling and control cooling technology of the thermal mechanical control process to act collectively so as to implement the on-line control, adopting this process method can refine the actual grain size of the high-toughness high-strength low-alloy steel, the comprehensive performance of the high-strength low-alloy steel is excellent; the metallographic structure is fine ferrite and pearlite, the tensile strength is more than 630MPa, the yield strength is more than 500MPa,the grain size after rolling is fine and uniform, the grain size reaches 9.0 or above, Charpy V impact energy at -20°C is greater than 100J, and Charpy V impact energy at -40°C is greater than 80J, its comprehensive mechanical properties are far superior to conventional rolling methods. The high-toughness high-strength low-alloy steel is not performing the off-line normalizing during the manufacturing, the mechanical properties also can meet the request for utilization, this can not only save the machining time, but also can reduce the cost and improve the effect.

Embodiment 1

[0060] Embodiment 1 provides a rolling method for a high-toughness high-strength low-alloy steel, the specification of the required finished form is Ø65mm, and 300×400mm sectional continuous casting billet is selected; wherein, the continuous casting billet comprises the chemical components in percentage by mass, as shown in Table 2, the mass percentage is totally 100%, comprising the following steps:

(1) Heating: the sectional continuous casting billet after being cut off is placed into a four-zone stepwise heating furnace by the way of cold delivery to heat, the temperature of the pre-heating section is 685°C, the temperature of the heating first zone is 1005°C, the temperature of the heating second zone is 1086°C, and the temperature of the soaking zone is 1175°C; the total heating time in the step of the heating is 3.8h, the soaking time of the soaking zone is 43min.

(2) Descaling: The billet after heating is descaled by employing the high-pressure water in order to descale the iron sheet, the pressure of the high-pressure water is 18.0 MPa.

(3) Rough rolling: the steel after being descaled is delivery into the high-stiffness rough rolling mill (6 sets) to perform the rough rolling, so as to get the rough rolling steel; the entry temperature of the rough rolling is 1015°C, the pass of the rough rolling is 6.
(4) Continuous rolling: the rough rolling steel obtained in the step (3) is delivered into the continuous rolling mill set, the entry temperature of the intermediate rolling is 925°C, the pass of the intermediate rolling is 6, the outlet temperature of the pre-finish rolling steel is 910°C, the pass of the pre-finish rolling steel is 4.
(5) First water cooling: the first water cooling is performed with the rolled steel after the pre-finish rolling; the temperature is cooled to 790°C; the water cooling rate is 40°C/s, the hydraulic pressure is 0.5MPa.
(6) Finish rolling: the rolled steel of Ø80mm specification obtained after the pre-finish rolling is rolled by KOCKS reducing and sizing mill set, the entry temperature of the rolled steel is 845°C when the reducing and sizing mill set is performing rolling, the steel bar of Ø65mm specification is obtained.
(7) Second water cooling: the second water cooling is performed with the rolled steel after the finish rolling; the temperature is cooled to 685°C; the water cooling rate is 75°C/s, the hydraulic pressure is 0.6MPa.
(8) Cold hearth cooled (cold hearth cooling): the steel bar of Ø65mm specification obtained in the step (7) is cooled in the cold hearth, the finished steel bar is finally obtained.

[0061] The hot-rolled structure of the high-toughness high-strength low-alloy steel obtained in embodiment1 is a uniform ferrite and pearlite, the actual grain size is 9.0, its mechanical properties of the steel product are as shown in Table 3. The hot-rolled structure of the high-toughness high-strength low-alloy steel obtained in embodiment1 is a uniform ferrite and pearlite, the actual grain size is 9.0, as seen from Table 3, its mechanical properties of the steel product are excellent.

Embodiment 2

[0062] Embodiment 2 provides a rolling method for a high-toughness high-strength low-alloy steel, the specification of the required finished form is Ø80mm, and 300×400mm sectional continuous casting billet is selected; wherein, the continuous casting billet comprises the chemical components in percentage by mass, as shown in Table 2, the mass percentage is totally 100%; the rolling method sequentially comprises the following steps: (1) heating, (2) descaling, (3) rough rolling, (4) continuous rolling, (5) first water cooling, (6) finish rolling, (7) second water cooling, and (8) cold hearth cooled (cold hearth cooling), the processing step of example 2 is the same as that of example 1, see Table 1 for its processing parameters of specific steps, its mechanical properties of the steel product are as shown in Table 3.
[0063] The hot-rolled structure of the high-toughness high-strength low-alloy steel obtained in example 2 is a uniform ferrite and pearlite, as shown in Fig. 3; the actual grain size is 9.0, as shown in Fig. 4. As seen from Table 3, its mechanical properties of the steel product are excellent.

Embodiments

[0064] Embodiment 3 provides a rolling method for a high-toughness high-strength low-alloy steel, the specification of the required finished form is Qj 100mm; and 300×400mm sectional continuous casting billet is selected; wherein, the continuous casting billet comprises the chemical components in percentage by mass, as shown in Table 2, the mass percentage is totally 100%; the rolling method sequentially comprises the following steps: (1) heating, (2) descaling, (3) rough rolling, (4) continuous rolling, (5) first water cooling, (6) finish rolling, (7) second water cooling, and (8) cold hearth cooled (cold hearth cooling), the processing step of embodiments is the same as that of embodiment1, see Table 1 for its processing parameters of specific steps, its mechanical properties of the steel product are as shown in Table 3.
[0065] The hot-rolled structure of the high-toughness high-strength low-alloy steel obtained in embodiment 3 is a uniform ferrite and pearlite, the actual grain size is 9.0, as shown in Fig. 3, its mechanical properties of the steel product are excellent.
[0066] The specific parameters of the processing step in embodiments 1-3 is shown in Table 1.

Table 1 The specific parameters of the processing step in embodiments 1-3

Processing parameters	Embodiment 1	Embodiment 2	Embodiments
Size of the steel billet(mm×mm)	300×400	300×400	300×400
Temperature of pre-heating (°C)	685	705	732
Temperature of heating first zone (°C)	1005	975	1015
Temperature of heating second zone (°C)	1086	1055	1103

(continued)

Processing parameters	Embodiment 1	Embodiment 2	Embodiments
Temperature of soaking zone (°C)	1175	1189	1178
Time of soaking zone (min)	43	50	65
Total time of heating (h)	3.8	4.1	4.5
Hydraulic pressure of descaling (MPa)	18.0	18.5	18.3
Entry temperature of rough rolling (°C)	1015	993	1002
Entry temperature of intermediate rolling (°C)	925	965	950
Temperature of pre-finish rolling (°C)	910	935	930
Temperature of first water cooling (°C)	790	775	760
Water cooling rate(°C /s)/Hydraulic pressure (MPa)	40/0.5	32/0.5	28/0.5
Entry temperature of finish rolling (°C)	845	840	825
Temperature of second water cooling (°C)	685	682	675
Water cooling rate (°C /s)/ Hydraulic pressure (MPa)	75/0.6	68/0.5	60/0.5
Specification of the steel(mm)	Ø65mm	Ø80mm	Ø100mm

[0067] Chemical components of the continuous casting billet selected and used in embodiments1-3 are shown in Table 2.

Table 2 Chemical components of the continuous casting billet selected and used in embodiments 1-3

Chemical components (percentage by mass %)		Embodiment 1	Embodiment 2	Embodiment 3
C	≤0.20	0.16	0.16	0.16
Si	≤0.60	0.30	0.28	0.30
Mn	1.00-1.70	1.40	1.37	1.41
Cr	≤0.30	0.13	0.13	0.15
V	0.05-0.10	0.06	0.07	0.06
N	≤0.025	0.010	0.008	0.011
Al	≤0.03	0.020	0.022	0.02
P	≤0.020	<0.020	≤0.020	<0.020
s	≤0.020	≤0.020	≤0.020	≤0.020
Fe	the balance being Fe			

[0068] Each property of the high-toughness high-strength low-alloy steel obtained in embodiments 1-3 is shown in Table 3.

Table 3 Parameters of mechanical properties of the steel obtained in embodiments 1-3

Parameters of Properties	Standar d value	Embodiment 1	Embodiment 2	Embodiment 3
Yield strength (MPa)	≥420	523	525	525
Tensile strength (MPa)	≥520	648	654	654
Spread (%)	≥19	32	28	28
Charpy V impact energy at -20°C(J)	≥47	135	132	132
Charpy V impact energy at -40°C (J)	≥31	103	105	105

Embodiments 4-7

[0069] Embodiments 4-7 provide a rolling method for a high-toughness high-strength low-alloy steel, the rolling method sequentially comprises the following steps: (1) heating, (2) descaling, (3) rough rolling, (4) continuous rolling, (5) first water cooling, (6) finish rolling, (7) second water cooling, and (8) cold hearth cooled (cold hearth cooling), the processing step and the mechanical parameters of embodiments 4-7 are the same as those of embodiment 1; the continuous casting billet of embodiments 4-7 comprises the chemical components in percentage by mass, as shown in Table 4, the mass percentage is totally 100%.

Table 4 Chemical components of the continuous casting billet selected and used in examples 4-7

Chemical components of the continuous casting billet (%)		Embodiment 4	Embodiment 5	Embodiment 6	Embodiment 7
C	≤ 0.20	0.17	0.16	0.15	0.16
Si	≤ 0.60	0.31	0.30	0.28	0.32
Mn	1.00 -1.70	1.42	1.40	1.37	1.38
Cr	≤ 0.30	0.15	0.15	0.16	0.14
V	0.05 -0.10	0.07	0.07	0.06	0.06
N	≤ 0.025	0.010	0.010	0.010	0.009
Al	≤ 0.03	0.020	0.020	0.023	0.020
P	≤ 0.020	≤0.020	≤0.020	≤0.020	≤0.020
S	≤ 0.020	≤0,020	≤0.020	≤0.020	≤0.020
Fe	The balance being Fe				

[0070] Each property of the high-toughness high-strength low-alloy steel obtained in embodiments 4-7 is shown in Table 5.

Table 5 Parameters of mechanical properties of the steel obtained in embodiments 4-7

Parameters of properties	Standard Value	Embodiment 4	Embodiment 5	Embodiment 6	Embodiment 7
Yield strength (MPa)	≥420	530	537	528	525
Tensile strength (MPa)	≥520	658	649	660	652
Spread (%)	≥ 19	30	29	31	30
Charpy V impact energy at -20°C(J)	≥47	129	135	130	132
Charpy V impact energy at -40°C(J)	≥31	104	108	110	106

[0071] As known from Table 5, the hot-rolled structure of the high-toughness high-strength low-alloy steel obtained in embodiments 4-7 is a uniform ferrite and pearlite, the actual grain size is 9.0, its mechanical properties of the steel product are excellent.

Comparative example 1

[0072] The specification of the required finished form is Ø65mm, select 300×400mm sectional continuous casting billet; the chemical components and contents of the continuous casting billet are: C0.45, Si 0.28, Mn1.46, Cr 0.16, V0.06, N0.010, Al 0.020, P≤0.020, S≤0.020, with the balance being Fe and inevitable impurities. The processing step and parameters of the alloy steel are shown in Fig. 7.
As shown in Table 6, because the content of carbon C in the chemical components of the continuous casting billet is 0.45%, i.e., C >0.20, as shown in Table 8, the ductility of the rolled steel is 18%, Charpy V impact energy at -20°C is 32J; Charpy V impact energy at -40°C is 17J.

Comparative example 2

[0073] The specification of the required finished form is Ø80mm, select 300×400mm sectional continuous casting billet; the chemical components and contents of the continuous casting billet are: C0.16, Si 0.30, Mn 0.8, Cr 0.15, V0.07, N0.012, Al 0.020, P≤0.020, S≤0.020, with the balance being Fe and inevitable impurities. The processing step and parameters of the alloy steel are shown in Fig. 7.

[0074] As shown in Table 6, because the content of manganese Mn in the chemical components of the continuous casting billet is 0.8, i.e., Mn<1.0, as shown in Table 8, the ductility of the rolled steel is 26%, Charpy V impact energy at -20°C is 54J; Charpy V impact energy at -40°C is 25J.

Comparative example 3

[0075] The specification of the required finished form is Ø100mm, select 300×400mm sectional continuous casting billet; the chemical components and contents of the continuous casting billet are: C0.16, Si 0.30, Mn 1.40, Cr 0.15, N0.011, Al 0.022, P≤0.020, S≤0.020, with the balance being Fe and inevitable impurities. The processing step and parameters of the alloy steel are shown in Fig. 7.

[0076] As shown in Table 6, because vanadium V is not added into the chemical components of the continuous casting billet, as shown in Table 8, the ductility of the rolled steel is 25%, Charpy V impact energy at -20°C is 35J; Charpy V impact energy at -40°C is 19J.

Comparative example 4

[0077] The specification of the required finished form is Ø90mm, select 300×400mm sectional continuous casting billet; the chemical components and contents of the continuous casting billet are: C0.16, Si 0.32, Mn 1.47, Cr 0.15, V0.06, N0.040, Al 0.020, P≤0.020, S≤0.020, with the balance being Fe and inevitable impurities. The processing step and parameters of the alloy steel are shown in Fig. 7.

[0078] As shown in Table 6, because the content of nitrogen N in the chemical components of the continuous casting billet is 0.040, i.e., N>0.025, as shown in Table 8, the ductility of the rolled steel is 27%, Charpy V impact energy at -20°C is 62J; Charpy V impact energy at -40°C is 37J.

[0079] As known from Table 8, through comparison the rolling method of the comparative examples 1-4 with that disclosed in the application, for the mechanical properties of the obtained steel, Charpy V impact energies at -20°C are all less than 100J, Charpy V impact energies at -40°C are less than 80J, the grain sizes of the alloy steel after rolling do not reach 9.0 or above.

Table 6 Chemical components of the continuous casting billet selected and used in comparative examples 1-4

Chemical components of the continuous casting billet in the invention (percentage by mass %)		Comparative example 1	Comparative example 2	Comparative example 3	Comparative example 4
C	C≤0.20	0.45	0.16	0.6	0.16
Si	Si≤0.60	0.28	0.30	0.30	0.32
Mn	Mn1.00~ 1.70	1.46	0.80	0.80	1.47
Cr	Cr≤0.30	0.16	0.15	0.07	0.15
V	V0.05~ 0.10	0.06	0.07	0	0.06
N	N≤0.025	0.010	0.012	0.008	0.040
Al	Al≤0.03	0.020	0.020	0.022	0.020
P	P≤0.020	P≤0.020	P≤0.020	P≤0.020	P≤0.020
S	S≤0.020	S≤0.020	S≤0.020	S≤0.020	S≤0.020
Fe	The balance being Fe				

[0080] The processing step and parameters of the alloy steel in comparative examples 1-4 are as shown in Table 7.

Table 7 the specific parameters of the processing step of the steel obtained in comparative examples 1-4

Processing parameters	Comparative example 1	Comparative example 2	Comparative example 3	Comparative example 4
Size of the steel (mm×mm)	300×400	300×400	300×400	300×400
Temperature of pre-heating (°C)	702	687	685	700
Temperature of heating one-section (°C)	980	1001	995	1005
Temperature of heating two-section (°C)	1068	1075	1098	1094
Temperature of soaking heating section (°C)	1170	1180	1182	1191
Time of soaking heating section (min)	53	47	56	62
Total time of heating (h)	4.2	3.9	4.6	4.8
Hydraulic pressure of descaling (MPa)	18.5	18.1	18.2	18.3
Entry temperature of rough rolling (°C)	1002	1003	1011	1006
Entry temperature of intermediate rolling (°C)	952	956	960	945
Temperature of pre-finish rolling (°C)	922	930	933	935
Temperature of first water cooling (°C)	785	/	780	782
Water cooling rate (°C/s) /Hydraulic pressure (MPa)	38/0.5	/	33/0.5	32/0.5
Entry temperature of finish rolling (°C)	835	880	820	821
Temperature of second water cooling (°C)	680	/	670	675
Water cooling rate (°C/s) / Hydraulic pressure (MPa)	72/0.6	/	65/0.5	62/0.5

[0081] Each property of the alloy steel obtained in comparative examples 1-4 are shown in Table 8.

Table 8 Parameters of mechanical properties of the steel obtained in comparative examples 1-4

Specification of the steel bar (mm)		∅65	∅80	Ø100	∅90
parameters of properties	Standard values	Comparative example 1	Comparative example 2	Comparative example 3	Comparative example 4
Yield strength (MPa)	≥ 420	460	330	330	340
Tensile strength (MPa)	≤ 520	657	445	445	498
Spread (%)	≥19	is	26	25	27

(continued)

Specification of the steel bar (mm)		∅65	∅80	Ø100	∅90
parameters of properties	Standard values	Comparative example 1	Comparative example 2	Comparative example 3	Comparative example 4
Charpy V impact energy at -20°C (J)	≥47	32	54	35	62
Charpy V impact energy at -40°C (J)	≥31	17	25	19	37

[0082] Although preferable examples of the invention are already described, the technical engineering person in the art may make other changes and modifications to those examples. Therefore, the attached claims should be interpreted as including preferable examples and all changes and modifications falling in the scope of the invention.
[0083] The above contents are only preferable examples of the invention, and not limited to the invention, for those skilled in the art, the invention may have various changes and varieties. Any changes, equivalent substitutions, improvements that are made within the spirit and principle of the invention should be included in the protection scope.

Claims

1. A rolling method for a high-toughness high-strength low-alloy steel, its characteristic is that, the rolling method sequentially comprises the following steps:

   Heating, descaling, rough rolling, continuous rolling, first water cooling, finish rolling, second water cooling, and cold hearth cooling;
   Using a converter continuous casting billet as a raw material, the continuous casting billet comprises the following chemical components and contents in percentage by mass: C≤0.20;Si≤0.60;Mn:1.37 ~ 1.70;Cr≤0.30;P≤.020;5≤0.020;V:0.07 ~ 0.10;Al≤0.03;N.0.008~0.025;with the balance being Fe and inevitable impurities;
   After the first water cooling, the temperature is 765~800°C;
   In the step of the finish rolling, entry temperature of initial rolling during the finish rolling is 832~850°C;
   During the second water cooling, the temperature under which the steel performs the second water cooling after the step of the finish rolling is 600°C~700°C, wherein, water cooling rate is 25~100°C/s, hydraulic pressure is 0.2~0.6MPa;
   The cold hearth cooling means the steel after the second water cooling is cooled on the cold hearth.

2. According to the rolling method for a high-toughness high-strength low-alloy steel in claim 1, its characteristic is that, the step of the heating is divided into four zones, which are sequentially as follows: pre-heating zone, heating first zone, heating second zone, and soaking zone,

   The temperature of the pre-heating zoneis less than or equal to 750°C;
   The temperature of the heating first zone is 900~1050°C;
   The temperature of the heating second zone is 1050~1150°C;
   The temperature of the soaking zone is 1150~1210°C.

3. According to the rolling method for a high-toughness high-strength low-alloy steel in claim 2, its characteristic is that, the total heating time of the step of the heating is 3~5h; the soaking time of the soaking zone is 30-80min.

4. According to the rolling method for a high-toughness high-strength low-alloy steel in claim 2, its characteristic is that, the step of the heating is performed in a four-section stepwise heating furnace.

5. According to the rolling method for a high-toughness high-strength low-alloy steel in claim 1 or 2, its characteristic is that, the entry temperature of the rough rolling is 950~1050°C, the pass of the rough rolling is 5~7.

6. According to the rolling method for a high-toughness high-strength low-alloy steel in claim 5, its characteristic is that, the number of rough-rolling mills provided in the step of the rough rolling is 6; the pass of the rough rolling is 6.

7. According to the rolling method for a high-toughness high-strength low-alloy steel in claim 6, its characteristic is that, the step of the continuous rolling includes intermediate rolling and pre-finish rolling,

   The entry temperature of the intermediate rolling is 900~1000°C, the pass of the intermediate rolling is 5~7;
   Outlet temperature of the pre-finish rolling is 850~950°C, the pass of the pre-finish rolling is 3~5.

8. According to the rolling method for a high-toughness high-strength low-alloy steel in claim 7, its characteristic is that, the number of intermediate-rolling mills provided in the step of the intermediate rolling is 6; the pass of the intermediate rolling is 6.

9. According to the rolling method for a high-toughness high-strength low-alloy steel in claim 7, its characteristic is that, the number of pre-finish-rolling mills provided in the step of the pre-finish rolling is 4; the pass of the pre-finish rolling is 4.

10. According to the rolling method for a high-toughness high-strength low-alloy steel in claim 5, its characteristic is that, during the first water cooling, the first water cooling is performed with incoming materials after the step of the continuous rolling, wherein, the water cooling rate is 25~50°C/s, the hydraulic pressure is 0.2~0.6MPa.

11. According to the rolling method for a high-toughness high-strength low-alloy steel in claim 5, its characteristic is that, a reducing and sizing mill set is used for the finish rolling.

12. According to the rolling method for a high-toughness high-strength low-alloy steel in claim 11, its characteristic is that, the reducing and sizing mill set is a three-roller reducing and sizing mill set.

13. According to the rolling method for a high-toughness high-strength low-alloy steel in claim 5, its characteristic is that, in the step of the descaling, high-pressure water descaling is used with the aim to descale an iron sheet, the hydraulic pressure of the high-pressure water is 15~20MPa.

14. According to the rolling method for a high-toughness high-strength low-alloy steel in claim 13, its characteristic is that, the hydraulic pressure of the high-pressure water is 17~20MPa.

15. According to the rolling method for a high-toughness high-strength low-alloy steel in any one of claims 1-2, its characteristic is that, a high-toughness high-strength low-alloy steel bar is obtained after the rolling method.

16. According to the rolling method for a high-toughness high-strength low-alloy steel in claim 15, its characteristic is that, the specification of the steel bar is Ø060~120mm.

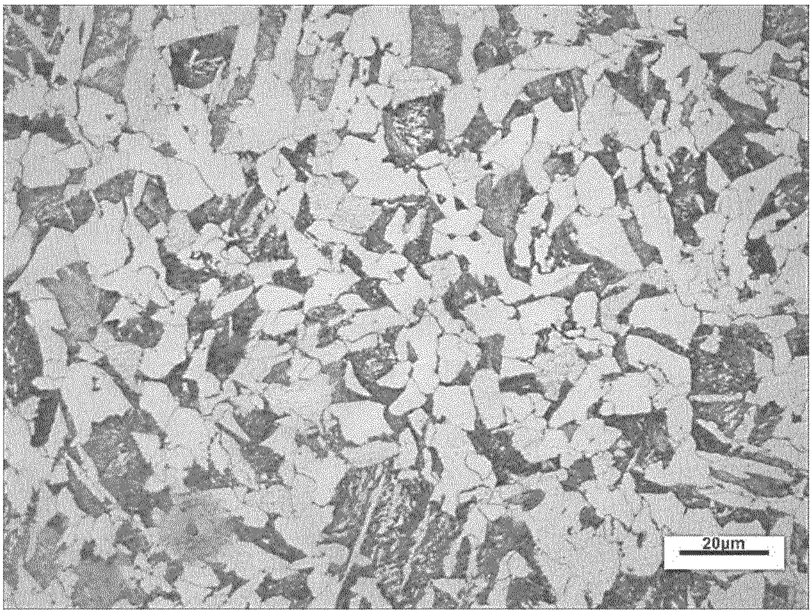

Fig 1

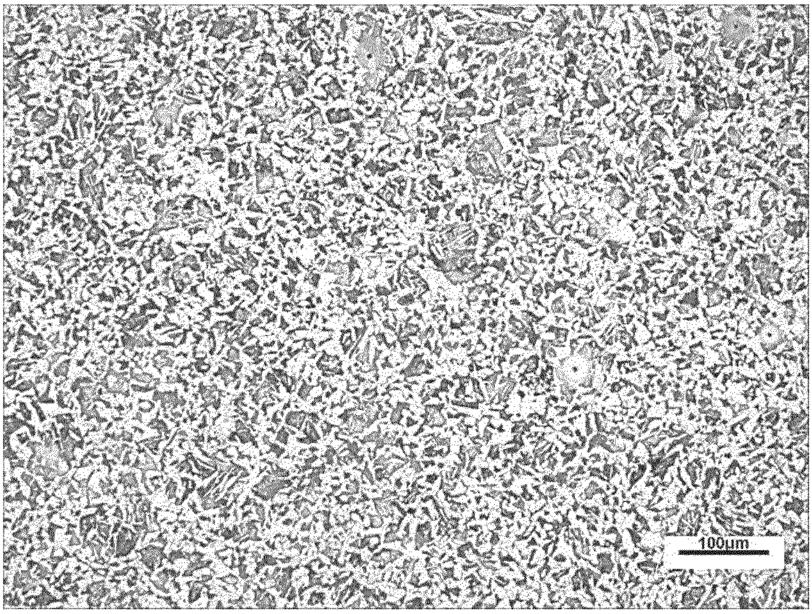

Fig 2

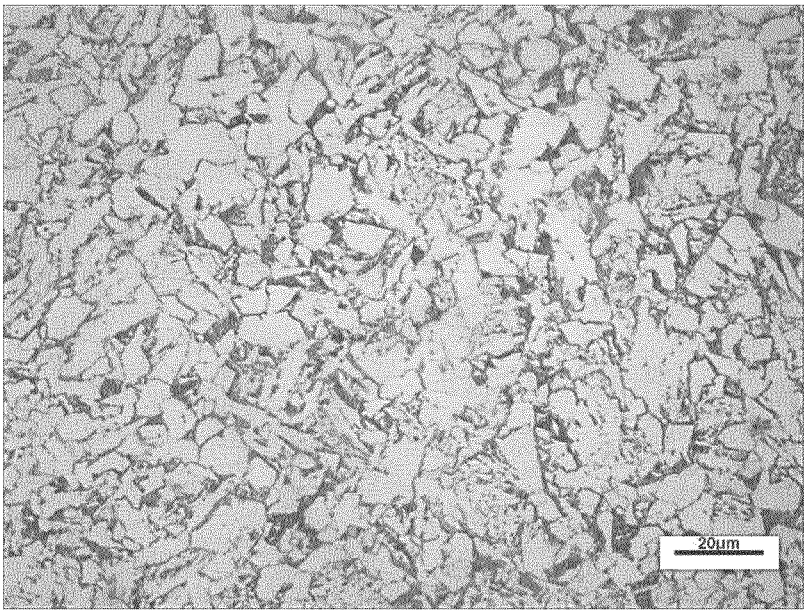

Fig 3

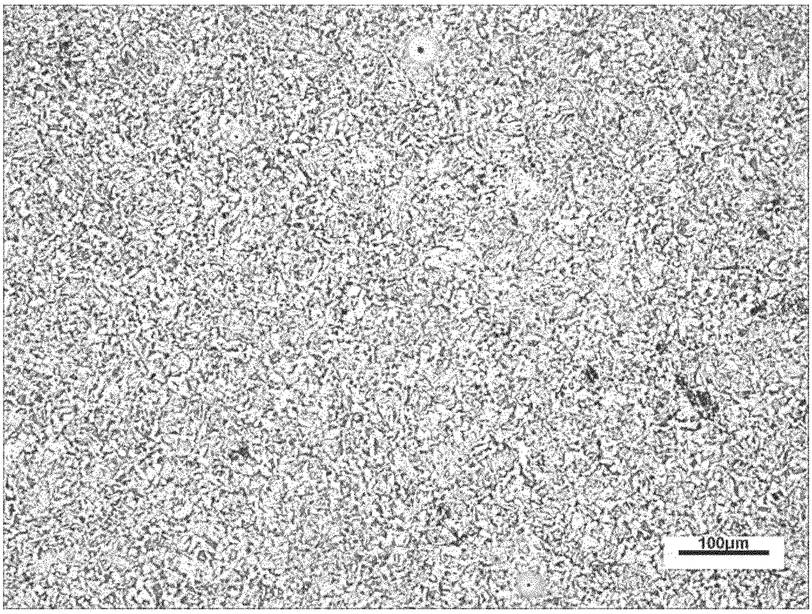

Fig 4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2022/092306

A. CLASSIFICATION OF SUBJECT MATTER

B21B 1/18(2006.01)i；C22C 38/02(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)

B21B C22C38

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

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

CNTXT, ENTXTC, ENTXT, CNKI: 大冶特殊钢有限公司, 粗轧, 精轧, 穿水, 冷却, 冷床, 铁素体, 珠光体, 加热, 均热, 水冷, 四段, 钒, 氮, 细晶, 细化, 韧性; roll+, pearlite, ferrite, heat+, temperature, toughness, cool+, "V", strength, refine+, "N"

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
PX	CN 113215492 A (DAYE SPECIAL STEEL CO., LTD.) 021)8.6. (021)-86) claims 1-10, and description, paragraphs 5-129	1-16
Y	JP 11158543 A (SUMITOMO METAL INDUSTRIES, LTD.) 15 June 1999 (1999-06-15) description, paragraphs 12-74, and tables 1-6	1-16
Y	CN 106086353 A (HUBEI XINYEGANG STEEL CO., LTD.) 09 November 2016 (2016-11-09) description, paragraphs 12-88	1-16
A	US 2015007913 A1 (BAOSHAN IRON & STEEL) 08 January 2015 (2015-01-08) entire document	1-16
A	CN 111570537 A (JIANGSU LIANFENG INDUSTRIAL CO., LTD.) 25 August 2020 (2020-08-25) entire document	1-16
A	CN 103911549 A (HEBEI UNITED UNIVERSITY) 09 July 2014 (2014-07-09) entire document	1-16
A	CN 112080687 A (DAYE SPECIAL STEEL CO., LTD.) 15 December 2020 (2020-12-15) entire document	1-16

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
01 August 2022	**18 August 2022**

Name and mailing address of the ISA/CN
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Facsimile No. **(86-10)62019451**

Authorized officer

Telephone No.

Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2022/092306

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	CN 108906884 A (DAYE SPECIAL STEEL CO., LTD.) 30 November 2018 (2018-11-30) entire document	1-16

Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2022/092306

Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)			Publication date (day/month/year)
CN	113215492	A	06 August 2021	None			
JP	11158543	A	15 June 1999	None			
CN	106086353	A	09 November 2016	None			
US	2015007913	A1	08 January 2015	JP	2015516504	A	11 June 2015
				DE	112013000747	T5	11 December 2014
				WO	2013135097	A1	19 September 2013
				CN	103305770	A	18 September 2013
				KR	20140119169	A	08 October 2014
CN	111570537	A	25 August 2020	None			
CN	103911549	A	09 July 2014	None			
CN	112080687	A	15 December 2020	None			
CN	108906884	A	30 November 2018	None			

Form PCT/ISA/210 (patent family annex) (January 2015)