A steel plate for linepipes having ultra-high strength and excellent low temperature toughness, and a method for manufacturing the same are disclosed. The steel plate has a strength of 930 MPa or more and excellent toughness even with much smaller amounts of alloying elements than that of conventional steel plates, and a method for manufacturing the same. The steel includes by weight %: 0.03-0.10% C; 0-0.6% Si; 1.6-2.1% Mn; 0-1.0% Cr; 0-1.0% Ni; 0.02-0.06% Nb; 0-0.1% V; 0-0.5% Mo; 0-1.0% Cr; 0.005-0.03% Ti; 0.01-0.06% Al; 0.0005-0.0025% B; 0.001-0.005% N; 0-0.006% Ca; 0.02% or less P; 0.005% or less S; and the balance Fe and unavoidable impurities. The microstructure includes at least about 75 area percent of a mixture of bainitic ferrite and acicular ferrite.
[Fig. 1]

Lower Bainite  Tempering

Temperature

\( \gamma \)
\( \alpha + \gamma \)
\( A_{C3} \)
\( A_{C1} \)

RT

Time
[Fig. 6]
STEEL PLATE FOR LINEPIPE HAVING ULTRA-HIGH STRENGTH AND EXCELLENT LOW TEMPERATURE TOUGHNESS AND MANUFACTURING METHOD OF THE SAME

TECHNICAL FIELD

[0001] The present invention relates to a steel plate for linepipes having ultra-high strength and excellent low temperature toughness, and a method for manufacturing the same. More particularly, the present invention relates to a steel plate for linepipes that has strength of 930 MPa or more and excellent toughness even with much smaller amounts of alloying elements than that of conventional steel plates, and a method for manufacturing the same.

BACKGROUND ART

[0002] Linepipes refer to a steel pipe buried in the ground for a long-distance transportation of crude oil and natural gas, and generally experience high pressure caused by a fluid of high pressure gas or crude oil flowing therein.

[0003] For increasing transportation efficiency of the linepipes, it is necessary to increase a transportable amount of crude oil or gas (hereinafter, simply referred to as “crude oil and the like”) per hour. For this purpose, the outer diameter of linepipe must be increased to a large size.

[0004] When the outer diameter of linepipe is increased, the amount of crude oil and the like flowing therein can also be increased, which in turn increases the pressure of crude oil and the like applied to the linepipe. In this regard, despite of a need for high strength steel for linepipes, steel plates having X70 grade in view of strength standard of linepipes are generally used in the related art. The X70 grade steel plate has strength of 70 ksi, that is, about 480 MPa. Thus, when manufacturing a linepipe of a large outer diameter with the steel plate having such a grade of strength, it becomes necessary to increase the thickness of steel plate, which increases an economic burden.

[0005] Accordingly, although there is an increasing demand for a steel plate that has noticeably improved strength compared to a conventional steel plate for linepipes, such a steel plate capable of sufficiently fulfilling requirement for high strength has not been developed in the art.

[0006] This is attributable not only to a technical barrier in increasing the strength of the steel plate, but also to other technical problems concomitant to the increase in strength of the steel plate.

[0007] Specifically, in the case of increasing the strength of the steel plate, although alloying elements effective for strength increase are generally added to the steel, not only does addition of the alloying elements ensure a sufficient increase of the strength, but an increase in added amount of alloying elements also leads to deterioration in low temperature toughness of a welded zone and a matrix. Therefore, when increasing the strength of the steel plate, it is also necessary to improve the low temperature toughness.

[0008] Additionally, when increasing the strength of the steel plate in the conventional technique, the steel plate is generally quenched to generate low temperature microstructure, such as lower bainite or martensite in the steel plate, for improving the hardness and strength of the steel plate at the same time. However, when the microstructure such as martensite and the like is formed in the steel plate, the steel plate has insufficient strength or can suffer from significant deterioration in toughness due to residual stress in the steel plate.

[0009] As described above, the strength and the toughness have been generally considered as incompatible mechanical properties, by which an increase in strength leads to a decrease in toughness.

[0010] As such, it has been continuously attempted to ensure both strength and toughness of the steel plate to thereby provide the high strength-high toughness steel plate. One of such attempts is a thermo mechanical controlling process (TMCP). The TMCP is a generic term indicating a process of changing the properties of a steel plate into desired properties by a thermal and mechanical control during rolling and cooling process. Although the TMCP is widely used through various modifications, it generally comprises a controlled rolling process where rolling is performed at a specific temperature in strictly controlled conditions, and an accelerated cooling process where the steel plate is cooled at a suitable cooling rate.

[0011] The TMCP has merits in that fine grains and desired microstructure are formed in the steel plate through this process, thereby, in theory, making it possible to effectively control the mechanical properties of the steel plate to desired degrees.

[0012] However, in order to manufacture a steel plate having desired strength through the accelerated cooling process of the TMCP, it is necessary to form hard structure as in the conventional technique. As a result, even for the steel plate prepared through the TMCP, the increase in strength inevitably leads to the decrease in toughness.

[0013] Accordingly, it has been continuously investigated in the field of high strength steel products to develop a method for improving the low temperature toughness along with the strength.

[0014] In particular, tempering is most widely adopted to solve such a problem.

[0015] For example, U.S. Pat. Nos. 5,545,269, 5,755,895, 5,798,004, 5,900,075, 6,045,630, 6,183,573, 6,245,290, and 6532995 disclose a method for manufacturing a steel plate, which comprises performing TMCP for rolling and cooling the steel plate as shown in FIG. 1, followed by tempering the steel plate at lower than A₃ transformation temperature (at which ferrite is transformed to austenite). Since the steel plate must be reheated to perform tempering after cooling the steel plate, however, this method requires high consumption of energy. Further, addition of the tempering process leads to an increase in manufacturing costs.

[0016] Further, various kinds of alloying elements are added to the steel to increase the strength of steel, and in particular, Mo is generally added as one of the most effective elements. For example, U.S. Pat. Nos. 6,224,689, 6,228,183, 6,248,191, and 6264760 disclose steel that comprises a great amount of Mo, in particular, 0.2 wt % or more Mo, to have lower bainite and lath martensite as microstructure of the steel. Similarly, referring to Korean Patent No. 2000-0053380, steel comprising 0.35 wt % or more Mo is disclosed as an inventive example, whereas a comparative example with 0.14 wt % Mo has a low tensile strength less than 930 MPa.

[0017] However, since Mo is an expensive element, the Mo content more than 0.15 wt % or 0.2 wt % becomes a cause of increasing the manufacturing costs. Additionally, since lower bainite shown in FIG. 3 has a very narrow temperature range for phase transformation as can be seen from FIG. 2, the steel
requires very strict cooling conditions and a very high cooling rate, which leads to requirement for very specific capability of equipment. Further, since such a high cooling rate can cause defects such as plate deformation, an additional process for shape control must be performed after manufacturing the steel plate, which makes the manufacturing conditions further complicated and troublesome.

DISCLOSURE OF INVENTION

Technical Problem

The present invention has been made to solve the foregoing problems of the prior art and therefore an aspect of the present invention is to provide a steel plate that has high tensile strength and excellent low temperature toughness without containing a great amount of Mo, and a method of manufacturing the same.

Technical Solution

According to an aspect of the present invention, the present invention provides a steel plate, comprising, by weight %: 0.03–0.10% C; 0–0.6% Si; 1.6–2.1% Mn; 0–1.0% Cu; 0–1.0% Ni; 0.02–0.06% Nb; 0–0.1 V; 0.1–0.5% Mo; 0–1.0 Cr; 0.005–0.03% Ti; 0.01–0.06% Al; 0.0005–0.0025% B; 0.001–0.005% N; 0–0.006% Ca; 0.02% or less P; 0.005% or less S; and the balance of Fe and unavoidable impurities, wherein the microstructure comprises at least about 75 area percent of a mixture of bainitic ferrite and acicular ferrite. The steel slab comprises preferably 0.015 wt % or less Mo.

Preferably, the steel slab comprises 0.015 wt % or less Mo.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other aspects, features and other advantages of the present invention will be more clearly understood from the following detailed description taken in conjunction with the accompanying drawings, in which:

Fig. 1 is a schematic diagram comparing manufacturing method based on tempering a steel plate, prepared by rolling and cooling, for ensuring mechanical properties with another manufacturing method that can ensure the mechanical properties without tempering;

Fig. 2 is a TTT diagram showing cooling conditions for steel containing lower bainite and lath martensite as main microstructure, and cooling conditions for steel containing bainitic ferrite and acicular ferrite as main microstructure;

Fig. 3 is a transmission electron microphotograph of lower bainite;

Fig. 4 is a transmission electron microphotograph of bainitic ferrite;

Fig. 5 is a transmission electron microphotograph of acicular ferrite; and

Fig. 6 is a transmission electron microphotograph of granular bainite.

BEST MODE FOR CARRYING OUT THE INVENTION

Exemplary embodiments of the present invention will now be described in detail with reference to the accompanying drawings.

Through the extensive and intensive investigation for the problems of the conventional techniques, inventors of the present invention have found the following facts: with adding smaller Mo than existing invent, which has been added to steel for increasing the strength of a steel plate, the steel plate can exhibit sufficient strength even without forming lower bainite or lath martensite as is formed in the existing invent for ultra-high strength steel, and at the same time, the steel plate can also have good toughness by making the fine austenite grain size with controlling the rolling condition and with other kinds of microstructure instead of very hard microstructure, such as lower bainite or lath martensite. The present invention is made based on these findings.

Specifically, in a steel plate according to the invention, the content of Mo is lowered along with an adjustment in added amount of other alloying elements, and the microstructure is regulated to comprise bainitic ferrite and acicular ferrite, both of which have fine grains, to ensure the same or higher strength than that of the existing invented steel plate having hard microstructure, lower bainite or lath martensite. Further, in the steel plate of the invention, these microstructures are formed to have a fine grain size, thereby providing excellent low temperature toughness compared to the conventional steel plate that includes lower bainite or lath martensite. The present invention also provides a method for manufacturing such a steel plate.

Hereinafter, the steel plate of the present invention will be described in detail in view of composition, microstructure and manufacturing process.
To obtain sufficient strength and toughness including welded zone toughness, the composition of the steel plate according to the present invention is provided as follows.

- C: 0.03–0.10 wt %
- Nb: 0.02–0.06 wt %
- Ni: 0.1–1.0 wt %
- Cu: 0–1.0 wt %
- Mo: 0.5–1.5 wt %
- Mn: 1.6–2.1 wt %

Carbon (C) is the most effective element that serves to strengthen a welded zone and a matrix thereof through solid solution strengthening. Further, carbon provides strengthening effect through precipitation hardening by forming fine cementite, V and Nb carbonitrides [NbC, Nb(N)], and Mo carbide [Mo2C] in steel. Additionally, Nb carbonitride serves to retard austenite recrystallization and to inhibit grain growth during hot rolling, thereby simultaneously improving the strength and the low temperature toughness through grain refinement. Carbon also increases hardenability, which is an ability to form strong fine structure in a steel plate during cooling. Generally, if the content of C is less than 0.03 wt %, these strengthening effects are not obtained. If the content of C exceeds 0.1 wt %, the steel plate is generally susceptible to cold cracking after field welding and to lowering of toughness in the steel plate and in its weld HAZ.

Silicon (Si) assists Al in deoxidation of molten steel and acts as a solid solution strengthening element. However, the upper limit is set at 0.6 wt % to avoid the significant deterioration of field weldability and the toughness of the welding heat affected zone, that can result from excessive silicon content. Since Al or Ti can perform the same function, Si is not necessarily added to the steel for deoxidation.

Manganese (Mn) is an effective element in solid solution strengthening of the steel. To improve the hardenability and strength, it is desirable that Mn be added in an amount of 1.6 wt % or more. However, the Mn content in excess of 2.1 wt % tends to promote centerline segregation in continuously cast steels and can also lead to a deterioration of the steel toughness. Additionally, an excessively high content of Mn leads to deterioration in field weldability and toughness of the heat affected zone of weld through an excessive increase of the hardenability.

Copper (Cu) is an element that strengthens the matrix metal and the heat affected zone of weld. However, an excessive content of Cu leads to deterioration in field weldability and toughness of the heat affected zone of weld.

Nickel (Ni) is an element that can improve the mechanical properties without deteriorating the field weldability and low temperature toughness in low-carbon steel. In contrast to Mn and Mo, Ni forms a smaller amount of martensite-austenite constituents deteriorating the low temperature toughness, and improves the toughness of the heat affected zone of weld. Additionally, Ni is effective for the prevention of copper-induced surface cracking during continuous casting and hot rolling. However, Ni is an expensive element, and an excessive addition of Ni deteriorates the toughness of the heat affected zone of weld.

Molybdenum (Mo) improves the hardenability, and this effect is very noticeable when added along with B. Further, when added along with Nb, Mo contributes to grain refinement by suppressing austenite recrystallization. However, since an excessive addition of Mo leads to deterioration in toughness of the heat affected zone of weld during field welding, the content of Mo is 0.5 wt % or less. More preferably, 0.01 wt % to 0.15 wt % Mo is added.

Chromium (Cr) serves to improve the hardenability. However, since an excessive addition of Cr leads to deterioration in toughness of the heat affected zone of weld and the matrix by generating low temperature cracks after field welding, the content of Cr has an upper limit of 1.0 wt %.

Titanium (Ti) combines with nitrogen to form fine Ti nitride (TiN), and suppresses austenite grains from being coarsened when heating the slab, thereby contributing to grain refinement. Additionally, not only does TiN prevent coarse grains of the heat affected zone of weld, but it also fixes the free nitrogen from molten steel, thereby improving the toughness. In order to sufficiently fix the free nitrogen, the quantity of titanium added is preferably at least 3.4 times the quantity of nitrogen (by weight). Therefore, Ti is an effective element for high strength and grain refinement of the base metal and the heat affected zone of weld, and exists as TiN to suppress grain growth during heating for rolling. Further, Ti remaining after reaction with N is dissolved as a solid solution in the steel and combines with C to form very fine TiC precipitates, which significantly improve the strength of the steel, when aluminum content is low (less than 0.005 wt %), titanium forms an oxide which serves as the nucleation site for intergranular acicular ferrite in the heat affected zone. Accordingly, for obtaining the effect of suppressing austenite grain growth by TiN precipitation and the effect of strength increase by TiC formation, it is necessary to add Ti in an amount of 0.005 wt % or more. On the other hand, if the content of Ti exceeds 0.03 wt %, excessive titanium content leads to coarsening of the titanium nitride and to titanium-carbide-induced precipitation hardening, thereby significantly lowering the low temperature toughness. Moreover, when the steel plate is welded to produce a steel pipe by heating the steel plate to melting point, TiN is dissolved again in the steel plate, thereby deteriorating the toughness of the heat affected zone of weld. Therefore, the content of Ti has an upper limit of 0.03 wt %.
Aluminum (Al) is an element that is generally added for deoxidation of the steel. Further, not only does Al help refine microstructure, but it also improves the toughness of the heat affected zone by elimination of free nitrogen in the coarse grain heat affected zone region where the heat of welding allows the TiN to partially dissolve, thereby liberating nitrogen. However, if the content of Al exceeds 0.06 wt %, Al forms Al oxide (Al₂O₃), type inclusions, which can be detrimental to the toughness of the base metal and heat affected zone. Since deoxidation can be achieved by addition of Ti and Si, Al is not an essential element in the present invention.

Boron (B) significantly improves the hardenability and increases the weldability and low temperature crack resistance in low carbon steel. In particular, B serves to improve the hardenability improving effect of Mo and Nb, and to suppress intergranular cracks caused by hydrogen by increasing the strength of grain boundaries. However, an excessive addition of B can promote the formation of embritting particle of Fe₂₅(C,B)₃. Therefore, the content of B must be determined considering the content of other elements added for improving the hardenability, and is preferably in the range of 0.0005–0.0025 wt %.

Nitrogen (N) is an element that suppresses growth of austenite grains and forms 1GN precipitates during slab heating, thereby suppressing the austenite grain growth in the heat affected zone of weld. However, an excessive content of N promotes surface defects on the slab and reduces the effective hardenability of boron. Further, solute N deteriorates the toughness of the matrix and the heat affected zone of weld.

Ca is an element for controlling the shape of MnS inclusions and improving the low temperature toughness. However, when an excessive amount of Ca is added to the steel, a great amount of CaO—CaS is formed and converted to large clusters and large inclusions, which deteriorate cleanliness and field weldability of the steel.

Phosphorus (P) is an element to forming nonmetallic inclusions with combining with Mn and the like to cause brittleness of the steel. Thus, it is necessary to lower the content of P in the steel. However, excessively controlling P to have a very low content thereof leads to a severe load in steel manufacturing process, and the above problem is not severe when the content of P is 0.02 wt % or less in the steel. Thus, the content of P has an upper limit of 0.02 wt %.

Sulfur (S) is an element that combines with Mn and the like to cause brittleness of the steel, such as red brittleness. According to this invention, the content of S has an upper limit of 0.005 wt %, considering the load of the steel manufacturing process as in the control of P.

Specifically, according to the present invention, the microstructure of the steel plate comprises bainitic ferrite as shown in FIG. 4 and acicular ferrite as shown in FIG. 5 and the area fraction of mixture of bainitic ferrite and acicular ferrite is 75% or more.

In addition to the microstructure phases as described above, the steel plate may further comprise a small fraction of granular bainite. However, since granular bainite causes deterioration of the low temperature toughness, the upper limit of granular bainite is 5% in terms of area fraction.

Further, the steel plate of the invention has very fine microstructure. As the steel plate has finer microstructure, it is more effective in obstructing propagation of cracks, thereby preventing brittle fracture. The inventors of the present invention suggest that the most preferable grain size be 15 μm or less in view of austenite grain size.

With the composition and microstructure as described above, the steel plate of the present invention has a yield strength of 930 MPa or more, and an impact toughness of 230 joules or more at −40°C, thereby satisfying the desired properties of the present invention.

Hereinafter, the method of manufacturing the steel plate according to the invention will be described in detail. The method is conceived by the inventors of the present invention to provide the steel plate that satisfies the objects of the present invention.

The method of the invention generally comprises reheating a steel slab, reducing the reheated steel slab in one or more hot rolling passes in an austenite recrystallization temperature region, further reducing the plate in one or more hot rolling passes in a temperature region below the Ar₃ temperature and above the Ar₃ transformation point, and cooling the rolled steel plate at a cooling rate of 20–50°C/sec, followed by stopping the cooling of the steel plate at a temperature of 200–400°C. The cooled steel plate is preferably air-cooled or cooled at room temperature.

Hereinafter, respective conditions of the method will be described in detail.

Slab reheating: 1,050–1,150°C.

Since slab heating is performed for the purpose of enabling effective subsequent rolling and providing desired mechanical properties to the steel, it must be performed in a suitable temperature range according to the purpose. In heating the slab, it is important to uniformly heat the slab so as to allow precipitation elements to be sufficiently dissolved in the slab, while preventing excessive grain growth as much as possible. If the heating is performed less than 1,050°C, Nb or V cannot be dissolved again in the slab, making it difficult to obtain a high strength steel plate. Additionally, since austenite grains are non-uniformly formed due to partial recrystallization, it becomes difficult to obtain high toughness. Conversely, if the heating is performed above 1,150°C, the austenite grains become excessively coarsened to cause an increase in grain size of the steel plate, thereby severely deteriorating the toughness of the steel plate. Therefore, the reheating temperature preferably is in the range of 1,050–1,150°C.

Rolling Conditions

In order to have low temperature toughness, it is necessary for the steel plate to have fine austenite grains, which can be obtained by controlling rolling temperature and reduction ratio. According to the present invention, rolling is preferably performed in two different temperature regions. Since these two temperature regions provide different recrystallization behaviors, it is desirable that rolling conditions be differently set for the respective rolling temperatures. First, in the austenite recrystallization temperature region, the slab is rolled with a total reduction ratio of 20–80% with respect to
an initial slab thickness by one or more hot rolling passes. The rolling in the austenite recrystallization temperature region provides an effect of reducing the size of grains through austenite recrystallization. At this time, when performing the multi-pass rolling, it is necessary to suitably control the reduction ratio and time for each pass in order to prevent grain growth after the austenite recrystallization. Fine austenite grains formed by the above process serve to improve the low temperature toughness of a final steel plate. Then, in the austenite non-recrystallization temperature region which is between $T_m$ (at which austenite recrystallization does not occur) and $A_r$ (austenite-to-ferrite transformation temperature), the rolled slab is rolled again by one or more rolling passes to provide a steel plate. At this time, the rolling is performed with a total reduction ratio of 40~80% with respect to the thickness of the slab rolled in the austenite recrystallization temperature region. The rolling in the temperature region between $T_m$ (at which austenite recrystallization does not occur) and $A_r$ (austenite-to-ferrite transformation temperature) crushes the grains and develops strain-induced disruptions in the grains, thereby providing nucleation sites for a low temperature transformation phase during cooling after the rolling.

**MODE FOR THE INVENTION**

[0091] Each of slabs having compositions shown in Table 1 was subjected to reheating, rolling and cooling to prepare a steel plate having a thickness of 16 mm. i.e., each steel plate is manufactured according to the same conditions. Irrespective of steel kinds, the slab was reheated at 1,120°C., followed by multi-pass rolling of 9~11 passes with respect to the reheated slab with a total reduction ratio of 73% at 1,050−1, 100°C. (austenite recrystallization temperature) and secondary multi-pass rolling of 9~11 passes with respect to the rolled slab with a total reduction ratio of 76% at 750−950°C. (austenite non-recrystallization temperature) to prepare a steel plate. Immediately after rolling, cooling of the steel plate was performed at a cooling rate of 25~35°C./sec, and was finished at 250~350°C. Then, the steel plate was left in atmosphere for air cooling.

**TABLE 1**

<table>
<thead>
<tr>
<th>No.</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>Mo</th>
<th>Cr</th>
<th>Ni</th>
<th>Ti</th>
<th>Nb</th>
<th>Al</th>
<th>Cu</th>
<th>Ca*</th>
<th>B*</th>
<th>N*</th>
<th>P*</th>
<th>S*</th>
</tr>
</thead>
<tbody>
<tr>
<td>IS 1</td>
<td>0.049</td>
<td>0.15</td>
<td>1.89</td>
<td>0.14</td>
<td>0.47</td>
<td>0.47</td>
<td>0.014</td>
<td>0.037</td>
<td>0.037</td>
<td>0.025</td>
<td>0.2</td>
<td>14</td>
<td>16</td>
<td>43</td>
<td>54</td>
</tr>
<tr>
<td>IS 2</td>
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<td>0.15</td>
<td>1.89</td>
<td>0.13</td>
<td>0.50</td>
<td>0.50</td>
<td>0.015</td>
<td>0.040</td>
<td>0.040</td>
<td>0.023</td>
<td>0.2</td>
<td>10</td>
<td>10</td>
<td>39</td>
<td>70</td>
</tr>
<tr>
<td>IS 3</td>
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<td>1.89</td>
<td>0.15</td>
<td>0.49</td>
<td>0.50</td>
<td>0.015</td>
<td>0.038</td>
<td>0.039</td>
<td>0.022</td>
<td>0.2</td>
<td>11</td>
<td>20</td>
<td>36</td>
<td>70</td>
</tr>
<tr>
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<td>0.15</td>
<td>1.90</td>
<td>0.30</td>
<td>0.30</td>
<td>0.49</td>
<td>0.15</td>
<td>0.040</td>
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<td>0.2</td>
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<tr>
<td>CS 1</td>
<td>0.024</td>
<td>0.16</td>
<td>1.91</td>
<td>0.25</td>
<td>0.38</td>
<td>0.51</td>
<td>0.016</td>
<td>0.041</td>
<td>0.042</td>
<td>0.020</td>
<td>0.2</td>
<td>13</td>
<td>18</td>
<td>39</td>
<td>65</td>
</tr>
<tr>
<td>CS 2</td>
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<td>0.15</td>
<td>1.88</td>
<td>0.16</td>
<td>0.45</td>
<td>0.51</td>
<td>0.016</td>
<td>0.043</td>
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<td>0.021</td>
<td>0.2</td>
<td>10</td>
<td>15</td>
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<td>56</td>
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<td>CS 3</td>
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<td>0.16</td>
<td>2.32</td>
<td>0.18</td>
<td>0.46</td>
<td>0.48</td>
<td>0.015</td>
<td>0.041</td>
<td>0.042</td>
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<td>0.2</td>
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<td>13</td>
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<td>1.88</td>
<td>0.20</td>
<td>0.46</td>
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<td>0.040</td>
<td>0.020</td>
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<tr>
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<td>0.15</td>
<td>0.50</td>
<td>0.50</td>
<td>0.015</td>
<td>0.041</td>
<td>0.039</td>
<td>0.020</td>
<td>0.2</td>
<td>12</td>
<td>31</td>
<td>35</td>
<td>70</td>
</tr>
<tr>
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<td>1.91</td>
<td>0.25</td>
<td>0.53</td>
<td>0.51</td>
<td>0.017</td>
<td>0.043</td>
<td>0.037</td>
<td>0.021</td>
<td>0.2</td>
<td>12</td>
<td>43</td>
<td>37</td>
<td>60</td>
</tr>
</tbody>
</table>

IS: Inventive Steel,
CS: Comparative Steel

In Table 1, the content of elements marked by "*" has unit of ppm, and the content of the other elements has unit of % by weight (wt.%).

[0087] Cooling rate: 20~50°C./sec

[0088] The cooling rate is one of important factors that improve the toughness and strength of the steel plate. The above cooling condition is set to form bainitic ferrite or acicular ferrite as described above. If the steel plate is cooled at a low cooling rate, unfavorable microstructure such as polygonal ferrite or granular bainite as shown in FIG. 6 can be formed with a coarsened grain size, thereby significantly lowering the strength and toughness of the steel plate. Conversely, if the steel plate is cooled at a high cooling rate of 50°C./sec or more, the steel plate is formed with hard phases such as martensite or suffers from shape defects such as distortion due to an excessive amount of cooling water.

[0089] Cooling Finish Temperature: 200~400°C.

[0090] For controlling the microstructure of the steel plate, it is necessary to cool the steel plate to the temperature where the effect of cooling rate can be sufficiently realized. If the cooling finish temperature is 400°C. or more, it becomes difficult to form a sufficient amount of bainitic ferrite and acicular ferrite having fine grains in the steel plate, which leads to an insufficient improvement of yield strength. According to the invention, the cooling finish temperature has an upper limit of 400°C. Conversely, if cooling finish temper-
TABLE 2-continued

<table>
<thead>
<tr>
<th>No.</th>
<th>Fraction of BF + AF (%)</th>
<th>Grain size of initial austenite (μm)</th>
<th>Tensile Strength (MPa)</th>
<th>VE-40 (Joule)</th>
<th>VTrs (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS 2</td>
<td>86</td>
<td>13</td>
<td>1053</td>
<td>102</td>
<td>-48</td>
</tr>
<tr>
<td>CS 3</td>
<td>88</td>
<td>12</td>
<td>1012</td>
<td>175</td>
<td>-64</td>
</tr>
<tr>
<td>CS 4</td>
<td>84</td>
<td>11</td>
<td>983</td>
<td>187</td>
<td>-58</td>
</tr>
<tr>
<td>CS 5</td>
<td>62</td>
<td>13</td>
<td>1034</td>
<td>192</td>
<td>-52</td>
</tr>
<tr>
<td>CS 6</td>
<td>57</td>
<td>13</td>
<td>1038</td>
<td>136</td>
<td>-43</td>
</tr>
</tbody>
</table>

Is: Inventive Steel, CS: Comparative Steel

In Table 2, VE-40 means impact toughness at -40°C, VTrs means ductile-brittle transition temperature, BF means bainitic ferrite, and AF means acicular ferrite.

[0094] As can be seen from Table 2, all the inventive steels having the compositions of the invention had a tensile strength of 930 MPa or more, an impact toughness of 230 joules or more at -40°C, and a ductile-brittle transition temperature of -70°C, thereby exhibiting good mechanical properties. For Comparative Steel 1 having the too low content of C, although the impact toughness was good, a significantly low tensile strength of about half that of the inventive steels was obtained. For Comparative Steel 2 having the too high content of C, although an ultra-high tensile strength of 1,000 MPa or more was obtained, the impact toughness was 102 joules at -40°C, and the ductile-brittle transition temperature was -48°C. As such, Comparative Steel 2 showed the incompatibility between strength and toughness as in the conventional steel. Further, Comparative Steel 3 having the excessively high content of Mn exhibited similar behaviors to the Comparative Steel 2. For Comparative Steel 4 having the excessively high content of Ti, the -40°C impact toughness and the ductile-brittle transition temperature were insufficient. For Comparative Steels 5 and 6 having the excessively high content of B, although the strength was good, the impact toughness and the ductile-brittle transition temperature were not satisfactory.

[0095] As such, influence depending on the composition of the steel plate according to the invention could be found.

[0096] For a slab having the composition of Inventive Steel 1, rolling was performed in the conditions shown in Table 3.

TABLE 3

<table>
<thead>
<tr>
<th>No.</th>
<th>Slab reheating Temp. (°C)</th>
<th>Reduction ratio in recrystallization region (%)</th>
<th>Reduction ratio in non-recrystallization region (%)</th>
<th>Cooling rate (°C/min)</th>
<th>Cooling finish Temp. (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IE 1</td>
<td>1110</td>
<td>73</td>
<td>76</td>
<td>22</td>
<td>225</td>
</tr>
<tr>
<td>IE 2</td>
<td>1122</td>
<td>74</td>
<td>75</td>
<td>25</td>
<td>350</td>
</tr>
<tr>
<td>IE 3</td>
<td>1134</td>
<td>70</td>
<td>78</td>
<td>29</td>
<td>372</td>
</tr>
<tr>
<td>IE 4</td>
<td>1145</td>
<td>77</td>
<td>72</td>
<td>33</td>
<td>296</td>
</tr>
<tr>
<td>CE 1</td>
<td>1112</td>
<td>75</td>
<td>74</td>
<td>24</td>
<td>425</td>
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<tr>
<td>CE 2</td>
<td>1165</td>
<td>75</td>
<td>74</td>
<td>32</td>
<td>250</td>
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<tr>
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<td>1185</td>
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<td>472</td>
</tr>
<tr>
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<td>76</td>
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<td>289</td>
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<tr>
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<td>78</td>
<td>17</td>
<td>466</td>
</tr>
<tr>
<td>CE 6</td>
<td>1130</td>
<td>90</td>
<td>35</td>
<td>25</td>
<td>244</td>
</tr>
</tbody>
</table>

Is: Inventive Example, CS: Comparative Example

[0097] As can be seen from Table 3, Inventive Examples 1 to 4 satisfied all of the conditions of the present invention. However, Comparative Example 1 was cooled at a too high temperature toughness due to the excessively high slab reheating temperature. For Comparative Steel 3 having the excessively high slab reheating temperature and the excessively high cooling rate. Comparative Examples 2 and 3 were reheated at too high reheating temperatures. In particular, for Comparative Example 3, not only was the reheating temperature excessively high, but the cooling finish temperature was also excessively high. For Comparative Examples 4 and 5, the cooling rate was too low. In particular, for Comparative Example 5, not only was the cooling rate too low, but the cooling finish temperature was also excessively high. For Comparative Example 6 the reduction rate in the non-recrystallization region was too low.

[0098] With samples of steel plates prepared by the conditions shown in Table 3, tensile test, impact test, and ductile-brittle transition temperature were measured, and results thereof are shown in Table 4.
cooling finish temperature, the low temperature toughness was low due to the same reason as that of Comparative Example 2, and the tensile strength was also low due to the same reason as that of Comparative Example 1. For Comparative Steel 4 having the too low cooling rate, a mixture of polygonal ferrite and granular bainite was formed instead of desired microstructure, thereby lowering the tensile strength and low temperature toughness. For Comparative Steels 5, the too low cooling rate and the excessively high cooling finish temperature resulted in low tensile strength and low temperature toughness due to the same reason as the above. For Comparative Example 6 rolled with the too low reduction rate in the non-recrystallization region, not only were the ausfreenite grains sufficiently elongated, but also dislocations were not piled up in the grains, which led to insufficient formation of low temperature phases. As a result, Comparative Example 6 had very low temperature toughness.

[0100] From the results as described above, it is possible to find the effect of the manufacturing method according to the present invention.

[0101] As apparent from the above description, the present invention can provide the steel plate that has high strength and excellent low temperature toughness without containing a great amount of Mo.

9. A steel plate having ultra-high strength and excellent low temperature toughness, comprising, by weight %: 0.03–0.10% C; 0–0.6% Si; 1.6–2.1% Mn; 0–1.0% Cu; 0–1.0% Ni; 0.02–0.06% Nb; 0–0.1% V; 0–10.5% Mo; 0–1.0% Cr; 0.005–0.03% Ti; 0.01–0.06% Al; 0.005–0.025% B; 0.001–0.006% N; 0–0.006% Ca; 0.02% or less P; 0.005% or less S; and the balance of Fe and unavoidable impurities, wherein the microstructure comprises at least about 75 area percent of a mixture of bainitic ferrite and acicular ferrite.

10. The steel plate according to claim 9, wherein the steel plate comprises 0.015 wt % or less Mo.

11. The steel plate according to claim 9, wherein the microstructure of the steel plate includes 5% or less granular bainite in terms of area fraction.

12. The steel plate according to claim 9, wherein the through thickness dimension of austenite grains should less than 15 μm.

13. A steel plate having ultra-high strength and excellent low temperature toughness, comprising, by weight %: 0.03–0.10% C; 0–0.6% Si; 1.6–2.1% Mn; 0–1.0% Cu; 0–1.0% Ni; 0.20–0.06% Nb; 0–0.1 V; 0.1–0.5% Mo; 0–1.0 Cr; 0.005–0.03% Ti; 0.01–0.06% Al; 0.005–0.0025% B; 0.001–0.006% N; 0–0.006% Ca; 0.02% or less P; 0.005% or less S; and the balance of Fe and unavoidable impurities, wherein the microstructure comprises at least about 75 area percent of a mixture of bainitic ferrite and acicular ferrite.

14. The steel plate according to claim 13, wherein the steel plate comprises 0.015 wt % or less Mo.

15. The steel plate according to claim 13, wherein the microstructure of the steel plate includes 5% or less granular bainite in terms of area fraction.

16. The steel plate according to claim 13, wherein the through thickness dimension of austenite grains should less than 15 μm.

17. A method of manufacturing a steel plate having ultra-high strength and excellent low temperature toughness, the method comprising:

- reheating a slab to 1.050–1.150°C, the slab comprising, by weight %, 0.03–0.10% C, 0–0.6% Si, 1.6–2.1% Mn, 0–1.0% Cu, 0–1.0% Ni, 0.02–0.06% Nb, 0–0.1% V, 0.1–0.5% Mo, 0–1.0 Cr, 0.005–0.03% Ti, 0.01–0.06% Al, 0.005–0.0025% B, 0.001–0.006% N, 0–0.006% Ca, 0.02% or less P, 0.005% or less S, and the balance of Fe and unavoidable impurities;
- rolling the reheated slab by one or more hot rolling passes in an austenite recrystallization temperature region or more with a reduction ratio of 20–80%;
- rolling the rolled steel slab by one or more hot rolling passes in the range from the austenite recrystallization temperature or less to Ar3 temperature or more with a reduction ratio of 40–80% to provide a steel plate;
- cooling the rolled steel plate at a cooling rate of 20–50°C/sec; and
- stopping the cooling of the steel plate at a temperature of 200–400°C.

18. The method according to claim 17, wherein the steel slab comprises 0.015 wt % or less Mo.

19. The method according to claim 17, further comprising: air cooling or room temperature-cooling the steel plate after the cooling finish step.

20. The method according to claim 18, further comprising: air cooling or room temperature-cooling the steel plate after the cooling finish step.

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