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(54) **High-tensile strength hot-rolled steel sheet excellent in elongation properties and stretch flangeability, and producing method thereof**

(57) A high-tensile strength hot-rolled steel sheet that satisfies, in addition to TS of 780 MPa or more or furthermore 980 MPa or more, TS X EL $\geq$ 20000 MPa% and TS $\times$ $\lambda \geq$ 82000 MPa%, and a method of producing the same are provided. Specific resolution means are as follows. That is, a high-tensile strength hot-rolled steel sheet including a composition that includes C of 0.04% by mass or more and 0.25% by mass or less; Si of 0.4% by mass or more and 2.0% by mass or less; Mn of 3.0% by mass or less; Al of 0.2% by mass or less; S of 0.007% by mass or less; Ti of 0.08% by mass or more and 0.3% by mass or less; and the balance of Fe and inevitable impurities, in the above, the contents of the C, the Si and the Ti satisfing ([%C]/12 - [%Ti]/48)/([%Si]/28) $\leq$ 0.4; and a microstructure that includes ferrite; bainite; and retained austenite; in the above a fraction of the ferrite in an entire microstructure is 40% or more and an average grain size of the ferrite is 5 μm or less; a fraction of the bainite is in the range of 20% to 48% with respect to an entire microstructure; and a fraction of the retained austenite is in the range of 2% to 7% with respect to an entire microstructure is produced.

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Description

BACKGROUND OF THE INVENTION

1. FIELD OF THE INVENTION

[0001] The present invention relates to a high-tensile strength hot-rolled steel sheet having excellent elongation properties and excellent stretch flangeability and a method of producing the same.

2. DESCRIPTION OF THE RELATED ART

[0002] Of hot-rolled steel sheets for use in automobiles, for structural members of a vehicle body, suspension members (for instance, wheels, rims, chassis and so on) and strengthening members (for instance, bumpers, door guard covers and so on), high-tensile strength hot-rolled steel sheets that have the tensile strength of 780 MPa class to 980 MPa class are used. Among these, the hot-rolled steel sheets that are used for vehicle bodies, in order to attain lower fuel consumption and an improvement in collision safety of automobiles, are demanded to satisfy the high mechanical strength and high workability.

[0003] As a hot-rolled steel sheet developed from such view points, a composite structure steel (so-called DP steel) having a microstructure primarily made of ferrite and martensite, and a retained austenitic steel that has a microstructure made of ferrite, bainite and retained austenite are known.

[0004] As a result of a recent trend to equip with safety- and environment-oriented devices, a weight of a vehicle body tends to increase. In this connection, by making active use of the high-tensile strength hot-rolled steel sheet that is thin and has the tensile strength of 780 MPa or more, it has been tried to make the vehicle body lighter.

[0005] For instance, patent reference No.1 discloses a method of producing a hot-rolled steel sheet in which steel whose essential components are C, Si and Mn is subjected to hot finish rolling under a rolling reduction of 80% or more and at a rolling temperature from 780 to 900°C, after the rolling has come to completion, cooling is started at a cooling rate of less than 40°C/sec and finished at a predetermined temperature, subsequently cooling is applied at a cooling rate of 40°C/sec or more further followed by coiling temperature in the range of 350 to 500°C, and thereby a hot-rolled steel sheet that has a microstructure that has a space factor of polygonal ferrite of 61% or more, a ratio of the space factor of the polygonal ferrite to a grain size of 18 or more, a second phase made of bainite and retained austenite, and 5% or more of retained austenite in the second phase is obtained.

[0006] According to the technology, a TS x EL value calculated from the tensile strength TS (MPa) and the elongation EL (%) can attain 20000 MPa%, that is, a hot-rolled steel sheet excellent in the elongation properties can be obtained. However, in the technology, the stretch flangeability that is important characteristics demanded for automobile high-tensile strength steel sheets is not at all considered. The stretch flangeability is an indicator that is generally expressed by use of a hole expansion rate obtained by hole expansion test and evaluates workability of the steel sheet. There is no correlation between the stretch flangeability and the elongation properties. Accordingly, even with the technology disclosed in patent reference No.1, it is difficult to produce a high-tensile strength hot-rolled steel sheet that combines the excellent stretch flangeability and the excellent elongation properties.

[0007] Furthermore, in patent reference No.2, a high-tensile strength steel sheet excellent in the stretch flangeability is disclosed. The high-tensile strength steel sheet is characterized in that C, Si, Mn and B are contained as essential constituents, an S content is restricted to 0.02% or less, and a microstructure is made of three phases of polygonal ferrite, bainite and martensite.

[0008] According to the technology, with a hot-rolled steel sheet having the tensile strength of 66 kgf/mm^2 (= 647 MPa), the hole expansion ratio λ of 150% (that is, TS $\times$ λ = 97050 MPa%) is attained. However, since the elongation properties are only 24% (that is, TS $\times$ EL = 15528 MPa%), there is a problem in that its applications to the suspension parts that are frequently demanded to be excellent in the elongation properties are restricted. Moreover, in the patent reference No.2, there is no description of a high-tensile strength hot-rolled steel sheet that has the tensile strength of 780 MPa or more (so-called TS780 MPa class hot-rolled steel sheet) , accordingly, the technology can be applied to the high-tensile strength hot-rolled steel sheet having the tensile strength of 780 MPa class with difficulty.

[0009] Furthermore, in patent reference No.3, a high-tensile strength hot-rolled steel sheet excellent in the stretch flangeability is disclosed. The steel sheet is characterized in that it includes C, Si, Mn, Ti and Nb as essential components, the area rate of ferrite having an average grain size of 25 μm or less is 70 to 95%, and the balance is made of a microstructure that comprises martensite or retained austenite.

[0010] According to the technology, since the microstructure contains martensite, the tensile strength of 99 kgf/mm^2 (=970 MPa) is achieved. However, according to the technology, even at TS 80 kgf/mm^2 (= 784 MPa), the hole expansion ratio λ is only 48%, the stretch flangeability is not sufficient.

[0011] Furthermore, in patent reference No.4, a high-tensile strength steel sheet excellent in the burring properties is disclosed. The steel sheet is characterized in that it contains C, Si, Mn and Ti as essential components and has a microstructure made of a primary phase (that is, ferrite) having an average grain size of 5 μm or less and a secondary phase having an average grain size of 3.5 μm or less.

[0012] The technology intends to produce a high-tensile strength steel sheet excellent in the TS-EL balance and the TS-λ balance, particularly excellent in the burring properties (that is, hole expansion workability). However, since the secondary phase contains pearlite, the disclosed tensile strength is at most 740 MPa, that is, 780 MPa is not achieved.

[0013] Patent reference No.1: JP-A-3-10049 gazette.

[0014] Patent reference No.2: JP-A-58-167750 gazette.

[0015] Patent reference No.3: JP-A-9-125194 gazette.

[0016] Patent reference No.4: JP-A-2000-192191 gazette.

[0017] In order to realize a lighter weight vehicle body, a steel sheet that is a high-tensile strength hot-rolled steel sheet having the tensile strength TS of 780 MPa or more or furthermore of 980 MPa or more, and has the elongation properties capable of attaining $TS \times EL \geq 20000$ MPa% and the stretch flangeability capable of attaining $TS \times \lambda \geq 82000$ MPa% is in demand. That is, in the case of, for instance, TS 780MPa, the high-tensile strength hot-rolled steel sheet capable of satisfying $EL \geq 25.5\%$ and $\lambda \geq 105\%$ is demanded. However, as mentioned above, there has been no technology that can attain the target.

[0018] The present invention has been carried out to overcome these problems and intends to provide a high-tensile strength hot-rolled steel sheet in which the TS is 780 MPa or more or 980 MPa or more, the elongation properties are excellent, that is, $TS \times EL \geq 20000$ MPa% is satisfied, and the stretch flangeability is excellent, that is, $TS \times \lambda \geq 82000$ MPa% is satisfied, and a method of producing the same.

[0019] The present inventors, after intensively studying in order to attain the above object, have found that when, with Ti as an indispensable component, ferrite generated after the hot rolling is made finer in its grain size, and fractions of bainite and retained austenite generated from non-transformed austenite are controlled in predetermined ranges, the high-tensile strength hot-rolled steel sheet having the tensile strength of 780 MPa or more or furthermore 980 MPa or more can be remarkably improved in the elongation properties and the stretch flangeability.

[0020] Furthermore, it is found that, when C and Si are added within predetermined ranges, such high-tensile strength hot-rolled steel sheet can be stably produced.

SUMMARY OF THE INVENTION

[0021] In the present invention, a high-tensile strength hot-rolled steel sheet comprises a composition that includes C of 0.04% by mass or more and 0.25% by mass or less, Si of 0.4% by mass or more and 2.0% by mass or less, Mn of 3.0% by mass or less, Al of 0.2% by mass or less, S of 0.007% by mass or less, Ti of 0.08% by mass or more and 0.3% by mass or less, and the balance of Fe and inevitable impurities, wherein contents of the C, the Si and the Ti satisfy the following equation (1); and a microstructure that contains ferrite, bainite and retained austenite, wherein a fraction of the ferrite in an entire microstructure is 40% or more, an average grain size of the ferrite is 5 μm or less, a fraction of the bainite is in the range of 20% to 48% with respect to an entire microstructure, and a fraction of the retained austenite is in the range of 2% to 7% with respect to an entire microstructure.

[0022] Furthermore, in the present invention, a method of producing a high-tensile strength hot-rolled steel sheet comprises, after a steel slab having a composition that includes C of 0.04% by mass or more and 0.25% by mass or less, Si of 0.4% by mass or more and 2.0% by mass or less, Mn of 3.0% by mass or less, Al of 0.2% by mass or less, S of 0.007% by mass or less, Ti of 0.08% by mass or more and 0.3% by mass or less, and the balance of Fe and inevitable impurities, wherein contents of the C, the Si and the Ti satisfy the following equation (1), is heated to 1150°C or less, hot rolling at a finish rolling temperature of (Ar_3 transformation temperature + 20°C) or more and (Ar_3 transformation temperature + 100°C) or less; cooling the obtained hot-rolled steel sheet at a cooling rate of 30°C/sec or more followed by holding for 2 to 20 seconds in a temperature range of 600 to 750°C; subsequently cooling at a cooling rate of 15°C/sec or more followed by coiling the hot-rolled steel sheet in a temperature range of 380 to 520°C.

$$([\%C]/12 - [\%Ti]/48)/([\%Si]/28) \leq 0.4 \qquad (1)$$

[%C]: C content (% by mass),
[%Ti]: Ti content (% by mass) and
[%Si] : Si content (% by mass).

DETAILED DESCRIPTION OF THE INVENTION

[0023] Firstly, a composition of the high-tensile strength hot-rolled steel sheet according to the invention will be explained.

C: 0.04% by mass or more and 0.25% by mass or less

C is an element necessary in improving the mechanical strength of a hot-rolled steel sheet; combining with Ti later described to generate TiC and thereby making a microstructure of the hot-rolled steel sheet finer; and generating bainite and retained austenite within ranges of fractions described later. In order to obtain the tensile strength of 780 MPa or more, C is necessary to be contained 0.04% by mass or more. On the other hand, in the case of exceeding 0.25% by mass, the weldability of the hot-rolled steel sheet remarkably deteriorates. Accordingly, C has to satisfy a range of 0.04% by mass or more and 0.25% by mass or less. In order to further inhibit the weldability from deteriorating, it is preferable for the C content to be 0.20% by mass or less. Furthermore, the more preferable range is 0.08% by mass or more and 0.16% by mass or less.

Si: 0.4% by mass or more and 2.0% by mass or less

Si is an element acting as a deoxidation element in a steel making process. Furthermore, Si contained in the hot-rolled steel sheet, owing to solid solution strengthening, without damaging a yield ratio and a strength-elongation balance (elongation properties), can improve the strength of the hot-rolled steel sheet, and activates a transformation from austenite to ferrite and thereby promotes C thickening to a non-transformed austenite phase. Furthermore, the Si is indispensable element in suppressing carbides such as FeC_3 from generating and thereby forming a microstructure made of ferrite, bainite and retained austenite. In order to attain these effects, Si has to be contained 0.4% by mass or more. On the other hand, in the case of exceeding 2.0% by mass, these effects saturate, and moreover since scales difficult to peel are generated on a surface of the hot-rolled steel sheet to result in generating scale defects, the hot-rolled steel sheet is difficult to apply to appearance-oriented usage. Accordingly, Si is necessary to satisfy a range of 0.4% by mass or more and 2.0% by mass or less. Furthermore, it is further preferable for Si to be contained in a range of 0.7% by mass or more and 1.5% by mass or less.

Mn: 3.0% by mass or less

Mn is an element capable of improving the strength and the hardenability of the hot-rolled steel sheet. Furthermore, by precipitating S later described as MnS, it is effective also in suppressing various characteristics from deteriorating owing to S. When the content of Mn exceeds 3.0% by mass, the bainite transformation after coiling of the hot-rolled steel sheet is suppressed from occurring, and the retained austenite is remarkably reduced. Accordingly, the content of Mn is set at 3.0% by mass or less. In order to obtain the above effects, Mn is preferably contained by 0.5% by mass or more. Furthermore, Mn is more preferably contained 1.0% by mass or more and 2.5% by mass or less.

Al: 0.2% by mass or less

Al works as a deoxidation agent in the steel making process. When Al is contained exceeding 2.0% by mass, the deoxidation effect saturates, and moreover the toughness and the stretch flangeability of the hot-rolled steel sheet deteriorate. Accordingly, the content of Al is set 0.2% by mass or less. In order to obtain the above effect, Al is preferably contained 0.01% by mass or more. Furthermore, it is more preferable for Al to be contained 0.02% by mass or more and 0.05% by mass or less.

S: 0.007% by mass or less

S, being an element that deteriorates the toughness and the stretch flangeability of the hot-rolled steel sheet, is necessary to be reduced to as low as possible. When the content of S exceeds 0.007% by mass, the toughness and stretch flangeability of the hot-rolled steel sheet markedly deteriorate. Accordingly, the content of S is set 0.007% by mass or less. It is more preferable to be 0.005% by mass or less, being further more preferable to be 0.0025% by mass or less. According to the present smelting technology, in order to reduce S to less than 0.001% by mass, much smelting time and various kinds of additives are required, resulting in cost increase. Accordingly, the lower limit of the S content according to the present smelting technology is substantially 0.001% by mass.

Ti: 0.08% by mass or more and 0.3% by mass or less

Ti, during heat-treatment of the steel slab prior to the hot rolling, combines with C to generate TiC. As a result, grain sizes of the austenite during the heat treatment become substantially 50 μm or less, resulting in inhibiting ferrite grains of the hot-rolled steel sheet from becoming coarser. That is, by hot-rolling the steel slab having austenite grains having grain sizes of substantially 50 μm or less, the austenite grains are forwarded in recrystallization, resulting in generating furthermore finer austenite grains. Furthermore, during the cooling of the hot-rolled steel sheet, since the ferrite transformation is promoted, finer ferrite grains result and non-transformed austenite is also made finer. In the cooling step after that, the bainite and austenite generated in a low temperature region are also made finer, resulting in obtaining a hot-rolled steel sheet having a uniform and fine microstructure.

[0024] The hot-rolled steel sheet thus obtained has excellent elongation properties and stretch flangeability. In order to obtain the effect like this, Ti is necessary to be contained 0.08% by mass or more. On the other hand, when Ti is contained exceeding 0.3% by mass, the austenite is very much disturbed in recrystallization, accordingly, not only the microstructure of the hot-rolled steel sheet is made coarser but also the elongation properties and stretch flangeability are deteriorated. Accordingly, Ti has to satisfy a range of 0.08% by mass or more and 0.3% by mass or less. Ti is preferably contained in the range of 0.12% by mass or more and 0.25% by mass or less.

[0025] Still furthermore, the C content, the Ti content and the Si content, in order to form a mixed microstructure of ferrite, bainite and retained austenite as mentioned later, have to satisfy the following equation (1).

$$([\%C]/12 - [\%Ti]/48)/([\%Si]/28) \leq 0.4 \qquad (1)$$

[%C]: C content (% by mass),
[%Ti]: Ti content (% by mass) and
[%Si]: Si content (% by mass).

[0026] The bainite and retained austenite, during the cooling process after the hot rolling, are generated from the non-transformed austenite. When the hot-rolled steel sheet is cooled, in a high temperature region, C is accelerated in diffusing, and in a low temperature region, C is suppressed from diffusing. As C is accelerated in diffusing like this, ferrite increases and the fractions of bainite and retained austenite decrease. That is, the diffusion behavior of C affects a great influence on the generation of ferrite, bainite and retained austenite.

[0027] Furthermore, Si suppresses cementite from being generated in the hot-rolled steel sheet and promotes C to diffuse from the ferrite to the non-transformed austenite. As a result, the C contents in the ferrite, bainite and retained austenite reach saturation states in a very short time, accordingly, even when the cooling conditions (for instance, the cooling rate and so on) fluctuate, an influence on the generation of the ferrite, bainite and retained austenite can be suppressed. That is, Si affects a great influence upon the diffusion behavior of C.

[0028] Still furthermore, Ti, fixing C as TiC, affects largely the diffusion behavior of C.

[0029] Accordingly, the diffusion behavior of C varies according to interactions of C, Si and Ti. The interactions of these elements can be evaluated according to an index calculated from the respective numbers of atoms. That is, when the index is in the range satisfying equation (1), the diffusion of C is promoted, and a hot-rolled steel sheet that has a mixed microstructure containing ferrite, bainite and retained austenite as described later can be stably obtained. Moreover, without being affected by the fluctuation of the cooling conditions after the hot rolling, the hot-rolled steel sheet made of ferrite, bainite and retained austenite can be obtained.

[0030] In the next place, a microstructure of a high-tensile strength hot-rolled steel sheet according to the invention will be explained.

[0031] In the high-tensile strength hot-rolled steel sheet according to the invention, a ferrite fraction is set at 40% or more with respect to an entire microstructure. The reason for this is that when the ferrite fraction is 40% or more, the elongation properties can be improved. When the elongation properties are improved with the tensile strength maintained at 780 MPa class, it is preferable for the ferrite to be rendered a primary phase (that is, the ferrite fraction is made 50% or more with respect to an entire microstructure).

[0032] Furthermore, an average grain size of the ferrite grains is necessary to be 5 μm or less. When the average grain size exceeds 5 μm, the stretch flangeability deteriorates remarkably. When the ferrite grains having an average grain size of 5 μm or less are generated, an addition amount of an alloying element can be reduced. Accordingly, without causing the deterioration of the mechanical properties such as the elongation properties and the stretch flangeability of the hot-rolled steel sheet, the tensile strength of 780 MPa class or furthermore 980 MPa class can be obtained. The average grain size of the ferrite grains is preferable to be 4 μm or less.

[0033] The other phase than the ferrite phase is rendered a mixed phase that contains bainite and retained austenite. The bainite is softer in comparison with the retained austenite and martensite, accordingly, hardness difference with ferrite is small. In general, cracks in the stretch flanging occur in an interface with hardness greatly different between phases difference (for instance, an interface between the ferrite and martensite). Accordingly, as the soft bainite is contained much, the stretch flangeability is improved.

[0034] Such effect can. be obtained when the bainite fraction is 20% or more with respect to an entire microstructure. On the other hand, when the bainite fraction exceeds 48%, the ferrite fraction decreases, resulting in deterioration of the elongation properties. Furthermore, the C content in the non-transformed austenite is largely lowered and the retained austenite decreases. This also causes the deterioration of the elongation properties. Accordingly, the bainite fraction is necessary to be from 20% to 48% with respect to an entire microstructure. When the elongation properties are improved with the tensile strength maintained at 780 MPa class, the bainite fraction is preferable to be 40% or less, being more preferable to be in the range of 25% to 35%.

[0035] The retained austenite, owing to the generation of stress-induced martensite, exhibits uniform and high elongation properties. Such effects can be obtained when the retained austenite fraction is 2% or more in an entire microstructure. On the other hand, when the retained austenite fraction is over 7%, owing to being subjected to the stretch flanging, the retained austenite becomes harder, resulting in a large hardness difference with the ferrite. As a result, by stretch flanging, in an interface between the ferrite and the retained austenite, cracks tend to be generated. Accordingly, the retained austenite fraction is necessary to be 2 to 7% with respect to an entire microstructure. It is preferable to be 4 to 6%.

[0036] In production processes of the hot-rolled steel sheet, other than the ferrite, bainite and the retained austenite, in some cases, martensite is'generated. The martensite is the hardest phase in the microstructure of the hot-rolled steel sheet. Accordingly, by stretch flanging, in an interface between the ferrite and the martensite, cracks tend to be generated. Accordingly, the smaller the martensite fraction is, the better, it is preferable to be 5% or less relative to an entire microstructure.

[0037] Thus, when the ferrite and retained austenite that improve the elongation properties and the bainite that improves the stretch flangeability are generated with proper fractions, respectively, a high-tensile strength hot-rolled steel sheet with excellent elongation properties and the excellent stretch flangeability can be obtained.

[0038] In the next place, a method of producing a high-tensile strength hot-rolled steel sheet according to the invention will be explained.

[0039] Molten steel with the above composition is prepared, and therefrom according to a so far known method such as a continuous casting method or ingot making method, a steel slab is produced. Subsequently, the steel slab is set in a heating furnace and heated to a temperature of 1150°C or less. When the steel slab is heated to a temperature exceeding 1150°C, since TiC is dissolved, finer austenite grains cannot be obtained. As a result, the ferrite becomes coarser, resulting in deterioration of the elongation properties and stretch flangeability.

[0040] The lower limit of the heating temperature of the steel slab, in order to secure a finish rolling temperature described later, is preferable to be 1050°C or more. A more preferable range of the heating temperature of the steel slab is from 1050 to 1100°C.

[0041] Thus heated steel slab is subjected to the hot rolling. The finish rolling temperature of the hot rolling is set, above the Ar_3 transformation point, in a range of (Ar_3 transformation point + 20°C) or more and (Ar_3 transformation point + 100°C) or less. When the hot rolling is applied at a finish rolling temperature in the range, the bainite fraction can be maintained within the range of 20 to 48% in an entire microstructure. When the finish rolling temperature is lower than (Ar_3 transformation point + 20°C), the bainite fraction cannot attain 20%, resulting in an increase in the ferrite fraction and the retained austenite fraction. On the other hand, when the finish rolling temperature is higher than (Ar_3 transformation point + 100°C), the austenite grains grow and the microstructure becomes coarser, resulting in deterioration in the elongation properties and the stretch flangeability.

[0042] The hot-rolled steel sheet obtained through the hot rolling is, according to a first step cooling, cooled at a cooling rate of 30°C/sec or more to 600 to 750°C. When the cooling rate is set at 30°C/sec or more, the microstructure can be hindered from becoming coarser. Furthermore, when a temperature where the first step cooling is stopped is outside of the range of 600 to 750°C, ferrite transformation in the second cooling described later is delayed. As a result, the ferrite, bainite and retained austenite fractions cannot be properly maintained. The temperature where the first cooling is stopped is preferably 650 to 700°C.

[0043] The hot-rolled steel sheet thus obtained by stopping the first step cooling at 600 to 750°C is retained for 2 to 20 seconds in a temperature range of 600 to 750°C. When the hot-rolled steel sheet is held at 600 to 750°C, the thickening of C into the bainite and retained austenite can be promoted. When the retention time is less than 2 seconds, since the thickening of C into the austenite is insufficient, proper fractions of the ferrite, bainite and retained austenite cannot be maintained. On the other hand, when the retention time exceeds 20 seconds, the ferrite transformation excessively proceeds and pearlite is generated, resulting in deterioration of the elongation properties and stretch flangeability. The preferable retention time is 4 to 10 seconds. In order to hold in the above temperature range for 2 to 20 seconds, atmospheric cooling (radiational cooling) is only necessary after the first step cooling is stopped, or a heating device may be used to keep hot.

[0044] Subsequently, the hot-rolled steel sheet is cooled at a cooling rate of 15°C/sec or more to 380 to 520°C according to the second cooling step, thereafter the hot-rolled steel sheet is wound. By setting the cooling rate at 15°C/sec or more, the microstructure can be inhibited from becoming coarser. Furthermore, when the second cooling is stopped at 380 to 520°C and the hot-rolled steel sheet is wound, the martensite is inhibited from being generated and thereby the bainite is generated, and at the same time owing to the bainite transformation the retained austenite can be generated. When the stopping temperature of the second cooling step (that is, coiling temperature) is less than 380°C, because of lowering of the coiling temperature, the hot-rolled steel sheet becomes undulating. Moreover, since the martensite is excessively generated, the stretch flangeability deteriorates. On the other hand, when the stopping temperature exceeds 520°C, since the pearlite is generated, the bainite and retained austenite are suppressed from being generated, resulting in deterioration of the elongation properties and stretch flangeability. The preferable stopping temperature of the second cooling step (that is, coiling temperature) is preferable to be 400 to 500°C.

EMBODIMENTS

[0045] Steel slabs having compositions shown in Table 1 are produced and a test piece is sampled from each of the steel slabs followed by measuring an Ar_3 transformation point (°C) . That is, the test piece is held at 1250°C for 30 min followed by cooling at a cooling rate of 1°C/sec, and the Ar_3 transformation point is measured by use of a differential dilatometer. Measurements of the Ar_3 transformation point are shown together in table 1.

[0046] Steel slabs A through D are examples that satisfy component ranges according to the invention. On the other hand, steel slab E is an example whose S content is deviated from the range of the invention, steel slab F is an example in which the equation (1) is not satisfied and contents of Si and Ti are outside of the ranges of the invention, steel slab G is an example whose contents of C and Mn are outside of the range of the invention, steel slab H is an example in which contents of Si and Al are outside of the ranges of the invention, steel slab I is an example in which the equation (1) is not satisfied and C content is deviated from the range of the invention, and steel slab J is an example in which the equation (1) is not satisfied.

[0047] The steel slabs are hot-rolled under various conditions, and thereby hot-rolled steel sheets having thickness of 2.9 mm are produced. Conditions of the hot rolling are as shown in Tables 2 and 3.

[0048] A test piece is sampled from each of thus obtained hot-rolled steel sheets, and grain size and fraction of ferrite are measured. The grain size measurement is performed as follows. That is, after an electron microgram is taken of a section in a rolling direction, according to an intercept method in a method for estimating ferrite grain size defined in JIS G0552, the grain size is measured. An area rate of ferrite is obtained according to an image analysis of the electron microgram, and the area rate is regarded as a fraction thereof. Results are shown in Tables 2 and 3.

[0049] Furthermore, with the test piece sampled from the hot-rolled steel sheet, kinds of microstructures of phases other than the ferrite, the bainite fraction, the retained austenite fraction and the martensite fraction are estimated. The microstructure of the second phase is estimated with an electron microscope. The bainite fraction is estimated by applying image analysis to an electron microgram. The retained austenite fraction is calculated from integrated intensities of (200) and (220) planes of the austenite phase and (200) and (211) planes of the ferrite phase obtained with K alpha line of Co by use of an X-ray diffractometer. The martensite fraction is estimated by image analyzing the electron microgram. Results thereof are shown in Tables 2 and 3.

[0050] Subsequently, a JIS No. 5 test piece is sampled in a rolling width direction (that is, a direction orthogonal to a rolling direction) of the hot-rolled steel sheet and tensile test is carried out therewith. Results thereof are shown in Tables 2 and 3.

[0051] The hole-expansion test is carried out according to Japan Iron and Steel Federation standard JFS-T1001-1996. That is, an initial hole having a diameter d_0 = 10 mm is punched through the hot-rolled steel sheet with a clearance of 12.5% and, with burring of the initial hole as a die side (that is, a side opposite to a conical punch), the hole is enlarged by inserting a conical punch (apical angle: 60°) into the initial hole, and a hole diameter d when crack penetrates through the hot-rolled steel sheet is obtained. With these do and d values, a hole expansion ratio λ (%) is calculated from the following equation (2). Results are shown in Tables 2 and 3.

$$\lambda = 100 \times (d - d_0)/d_0 \qquad (2)$$

[0052] Furthermore, by visually observing a surface of the hot-rolled steel sheet, scale defects and cracks are investigated. When there is observed no scale defect and crack, it is evaluated as good (O), and when the scale defect or the crack is observed, it is evaluated as bad (×). Results thereof are shown in Tables 2 and 3.

[0053] As obvious from Tables 2 and 3, all of the hot-rolled steel sheets according to the invention, in addition to satisfying the tensile strength of 780 MPa or more, satisfy TS × EL ≥ 20000 MPa% and TS × λ ≥ 82000 MPa%. Furthermore, results of appearance evaluation are good.

[0054] According to the invention, a hot-rolled steel sheet that satisfies, in addition to the tensile strength TS of 780 MPa class or furthermore 980 MPa class, TS × EL ≥ 20000 MPa% and TS × λ ≥ 82000 MPa%, that is, a high-tensile strength hot-rolled steel sheet excellent in the elongation properties and the stretch flangeability can be obtained.

Table 1

Steel Slab	Components (% by mass)						([%C]/12-[%Ti]/48)/ ([%Si]/28)	Ar_3 Transformation point (°C)	Remark
	C	Si	Mn	S	Ti	Al			
A	0.16	1.5	1.6	0.005	0.25	0.031	0.15	860	Inventive Example
B	0.10	1.0	2.0	0.003	0.18	0.032	0.13	840	
C	0.08	0.7	2.6	0.002	0.20	0.050	0.10	820	
D	0.12	0.6	1.8	0.003	0.08	0.032	0.39	830	
E	0.10	1.0	1.3	0.010	0.20	0.032	0.12	856	Comparative Example
F	0.18	0.2	2.0	0.007	0.35	0.035	1.08	810	
G	0.02	0.4	3.5	0.005	0.08	0.035	0	792	
H	0.12	2.3	0.7	0.007	0.10	0.300	0.10	910	
I	0.35	1.6	0.5	0.006	0.08	0.030	0.48	850	
J	0.18	0.7	2.0	0.006	0.12	0.033	0.50	810	
K	0.21	1.0	1.8	0.003	0.18	0.033	0.39	820	Inventive Example

Table 2

Sample number	Steel slab symbol	Rolling conditions								Microstructure						Tensile characteristics				Hole expansion		Appearance	Remark
		SRT	FDT	CR_1	T_1	t_1	T_2	CR_2	CT	Average grain size of ferrite	Fraction of ferrite	Microstructures other than ferrite	Fraction of B	Fraction of R	Fraction of M	Yield stress	Tensile strength TS	Elongation EL	TS × EL	Hole expansion ratio, λ	TS × λ		
		(°C)	(°C)	(°C/s)	(°C)	(s)	(°C)	(°C/s)	(°C)	(μm)	(%)		(%)	(%)	(%)	(MPa)	(MPa)	(%)	(MPa%)	(%)	(MPa%)		
1	A	1100	890	50	720	4	680	30	500	2.4	56	B+R	40	4	0	662	827	27	22329	103	85181	O	Inventive example
2	A	1050	920	35	680	12	600	35	420	3.2	60	B+R	33	7	0	670	812	30	24360	105	85260	O	
3	A	1100	900	15	740	6	680	20	380	7.0	65	B+R+M	25	5	5	596	755	23	17365	80	60400	O	Comparative example
4	A	1080	820	30	630	5	600	32	400	3.0	75	B+R+M	10	12	3	638	790	32	25280	50	39500	O	
5	A	1100	900	40	750	7	680	25	600	4.6	55	P+B	15	0	0	688	834	19	15846	58	48372	O	
6	A	1150	920	40	780	4	740	35	480	9.6	65	B	35	0	0	622	782	20	15640	76	59432	O	
7	B	1080	870	40	650	4	620	32	400	3.8	55	B+R+M	35	6	4	654	814	29	23606	102	83028	O	Inventive example
8	B	1030	900	35	750	30	560	35	380	10.0	48	P+B	8	0	0	732	855	18	15390	45	38475	O	Comparative example
9	B	1120	880	30	620	2	600	8	350	8.9	52	B+M	36	0	12	574	833	22	18326	68	56644	O	
10	B	1100	910	50	550	5	520	36	380	4.2	10	B	90	0	0	803	869	14	12166	100	86900	O	
11	B	1200	960	40	730	4	690	28	490	12.2	32	B	68	0	0	761	847	14	11858	98	83006	O	

SRT : heating temperature of slab
FDT : finish rolling temperature
CR_1 : cooling rate of the first step (average cooling rate from FDT to T_1)
T_1 : stop temperature of the first cooling step
t_1 : Retention time period (retention (atmospheric cooling) time from T_1 to T_2)
T_2 : start temperature of the second cooling step
CR_2 : cooling rate of the second cooling step (average cooling rate from T_2 to CT)
CT : coiling temperature

B : Bainite phase
R : Retained austenite phase
P : Pearlite phase
M : Martensite phase

Table 3

Sample number	Steel slab symbol	Rolling conditions SRT (°C)	FDT (°C)	CR_1 (°C/s)	T_1 (°C)	t_1 (s)	T_2 (°C)	CR_2 (°C/s)	CT (°C)	Microstructure Average grain size of ferrite (μm)	Fraction of ferrite (%)	Microstructures other than ferrite	Fraction of B (%)	Fraction of R (%)	Fraction of M (%)	Tensile characteristics Yield stress (MPa)	Tensile strength TS (MPa)	Elongation EL (%)	TS × EL (MPa%)	Hole expansion Hole expansion ratio, λ (%)	TS × λ (MPa%)	Appearance	Remark
12	C	1080	880	40	700	6	650	35	450	2.8	60	B+R+M	28	7	5	637	809	28	22652	105	84945	O	Inventive example
13	C	1250	920	35	680	8	620	30	390	7.5	57	B+R+M	36	4	3	609	760	25	19000	100	76000	O	
14	C	1050	850	40	720	<1	710	42	500	8.0	81	B+R	12	3	4	611	762	26	19812	44	33528	O	Comparative example
15	D	1150	890	40	630	3	610	20	380	3.5	67	B+R+M	22	6	5	644	826	27	22302	100	82600	O	
16	D	1050	860	10	750	5	700	10	520	9.8	50	B	50	0	0	793	882	15	13230	96	84672	O	Inventive example
17	D	1100	900	30	720	6	670	28	280	3.3	72	M	5	0	23	487	897	18	16146	36	32292	O	Comparative example
18	E	1100	930	35	730	4	690	32	480	3.0	57	B+R+M	34	5	4	637	781	22	17182	25	19525	O	
19	F	1080	870	40	680	5	640	28	400	6.6	50	P+B	20	0	0	752	849	19	16131	55	46695	O	
20	G	1150	840	50	620	2	600	30	380	10.6	95	B	5	0	0	436	680	25	17000	88	59840	O	
21	H	1100	930	30	740	15	620	33	500	4.2	60	B+R+M	35	2	3	689	800	28	22400	104	83200	×	
22	I	1100	900	40	700	7	640	40	450	2.9	55	P+B	45	0	0	677	836	17	14212	85	71060	O	
23	J	1050	850	35	660	3	630	28	380	3.2	77	B+R+M	15	3	5	655	803	26	20878	70	56210	O	
24	K	1100	910	35	680	4	640	20	420	4.2	43	B+R+M	48	6	3	759	1006	23	23138	85	85510	O	Inventive example
25	K	1100	880	40	520	2	510	15	380	10.5	20	B	70	0	10	964	1103	10	11030	90	99270	O	Comparative example
26	K	1050	850	30	700	5	660	30	300	3.0	50	B+M	15	0	35	681	1022	17	17374	25	25550	O	

SRT : heating temperature of slab
FDT : finish rolling temperature
CR_1 : cooling rate of the first step (average cooling rate from FDT to T_1)
T_1 : stop temperature of the first cooling step
t_1 : Retention time period (retention (atmospheric cooling) time from T_1 to T_2)
T_2 : start temperature of the second cooling step
CR_2 : cooling rate of the second cooling step (average cooling rate from T_2 to CT)
CT : coiling temperature

B : Bainite phase
R : Retained austenite phase
P : Pearlite phase
M : Martensite phase

Claims

1. A high-tensile strength hot-rolled steel sheet, comprising:

a composition that includes C of 0.04% by mass or more and 0.25% by mass or less; Si of 0.4% by mass or more and 2.0% by mass or less; Mn of 3.0% by mass or less; Al of 0.2% by mass or less; S of 0.007% by mass or less; Ti of 0.08% by mass or more and 0.3% by mass or less ; and a balance of Fe and inevitable impurities;

wherein contents of the C, the Si and the Ti satisfy the following equation (1); and
a microstructure that includes ferrite; bainite; and retained austenite;
wherein a fraction of the ferrite in an entire microstructure is 40% or more and an average grain size of the ferrite is 5 μm or less; a fraction of the bainite is in the range of 20% to 48% with respect to an entire microstructure; and a fraction of the retained austenite is in the range of 2% to 7% with respect to an entire microstructure.

$$([\%C]/12 - [\%Ti]/48)/([\%Si]/28) \leq 0.4 \qquad (1)$$

[%C]: C content (% by mass),
[%Ti]: Ti content (% by mass), and
[%Si]: Si content (% by mass).

2. A method of producing a high-tensile strength hot-rolled steel sheet, comprising:

after a steel slab having a composition that includes C of 0.04% by mass or more and 0.25% by mass or less; Si of 0.4% by mass or more and 2.0% by mass or less; Mn of 3.0% by mass or less; Al of 0.2% by mass or less; S of 0.007% by mass or less; Ti of 0.08% by mass or more and 0.3% by mass or less; and a balance of Fe and inevitable impurities; wherein contents of the C, the Si and the Ti satisfy the following equation (1) is heated to 1150°C or less;
hot rolling at a finish rolling temperature of (Ar_3 transformation temperature + 20°C) or more and (Ar_3 transformation temperature + 100°C) or less;
cooling the hot-rolled steel sheet at a cooling rate of 30°C/sec or more followed by holding for 2 to 20 seconds in a temperature range of 600 to 750°C followed by further cooling at a cooling rate of 15°C/sec or more; and coiling the hot-rolled steel sheet in a temperature range of 380 to 520°C.

$$([\%C]/12 - [\%Ti]/48)/([\%Si]/28) \leq 0.4 \qquad (1)$$

[%C]: C content (% by mass),
[%Ti]: Ti content (% by mass) and
[%Si]: Si content (% by mass).

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EUROPEAN SEARCH REPORT

Application Number
EP 03 00 6195

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The present search report has been drawn up for all claims

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