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

(11) EP 2 103 697 A1

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

(43) Date of publication:
23.09.2009 Bulletin 2009/39

(21) Application number: **07860538.3**

(22) Date of filing: **21.12.2007**

(51) Int Cl.:
C21D 9/46 *(2006.01)* ***C21D 8/02*** *(2006.01)*
C22C 38/06 *(2006.01)* ***C22C 38/58*** *(2006.01)*

(86) International application number:
PCT/JP2007/075341

(87) International publication number:
WO 2008/081956 (10.07.2008 Gazette 2008/28)

(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HU IE IS IT LI LT LU LV MC MT NL PL PT RO SE SI SK TR

(30) Priority: **25.12.2006 JP 2006347539**

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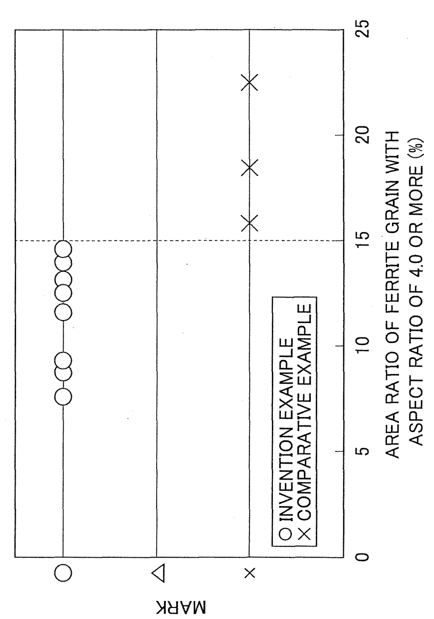
(54) HIGH CARBON HOT-ROLLED STEEL SHEET AND METHOD FOR PRODUCTION THEREOF

(57) The present invention provides a high-carbon hot-rolled steel sheet having excellent bending properties after stretching and a method of producing the same. A method of producing a high-carbon hot-rolled steel sheet includes a step of hot-rolling steel having a composition containing, in % by mass, 0.2 to 0.7% of C, 2% or less of Si, 2% or less of Mn, 0.03% or less of P, 0.03% or less of S, 0.01% or less of Sol. Al, and 0.01% or less of N at a finishing temperature of (Ar_3 transformation point - 20°C) or more to form a hot-rolled steel sheet, a step of cooling the hot-rolled steel sheet to a temperature of 650°C or less at a cooling rate of 60 °C/sec to less than 120 °C/sec, a step of coiling the hot-rolled steel sheet at a coiling temperature of 600°C or less after cooling, and a step of annealing the hot-rolled steel sheet at an annealing temperature of 640°C to Ac_1 transformation point.

FIG.1



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Description

Technical Field

[0001] The present invention relates to a high-carbon hot-rolled steel sheet, particularly a high-carbon hot-rolled steel sheet having excellent bending properties after processing, and a method of producing the same.

Background Art

[0002] High-carbon steel sheets used for tools or automobile parts (gear and transmission) are required by users to have excellent workability because they are worked into various complex shapes. On the other hand, in recent years, reduction in manufacturing cost of parts has been strongly required, resulting in the omission of a working process and a change in a working method. For example, as described in Non-Patent Document 1, a double-acting forming technique which permits thickness-additive forming process and realizes a significant reduction in the process is disclosed as a processing technique for automobile driving-system parts using high-carbon steel sheets and partially put into practical application. Accordingly, high-carbon steel sheets are required to be processable without a problem even when a plurality of processing types such as stretching, drawing, bulging, bending, and hole-expansion (burring) are combined. In particular, when bending is performed after tension, a crack frequently occurs in a bent portion, and thus excellent bending properties after stretching are required.

[0003] In order to improve workability of high-carbon steel sheets, several techniques have been investigated so far. For example, Patent Document 1 proposes a method in which high-carbon steel having predetermined chemical components is hot-rolled, descaled, annealed in an atmosphere containing 95% by volume or more of hydrogen at a heating rate for a soaking time which are specified according to the chemical components, and then cooled at a cooling rate of 100 ˚C/hr or less to produce a high-carbon workable steel strip having a uniform microstructure and excellent workability. Patent Document 2 proposes a method in which a steel sheet rolled at a finishing temperature of (Ac_1 transformation point + 30˚C) or more is cooled to a temperature of 20 to 500˚C at a cooling rate of 10 to 100 ˚C/sec, maintained for 1 to 10 seconds, reheated in a temperature range of 500˚C to (Ac_1 transformation point + 30˚C), and then coiled, and, if required, soaked at 650˚C to (Ac_1 transformation point + 30˚C) for 1 hour or more to produce a high-carbon thin steel sheet having good workability. Further, Patent Document 3 proposes a method in which steel containing 0.2 to 0.7% by mass of C is hot-rolled at a finishing temperature of (Ar_3 transformation point - 20˚C) or more, cooled at a cooling rate of over 120 ˚C/sec and a cooling stop temperature of 650˚C or less, coiled at a coiling temperature of 600˚C or less, and then annealed at an annealing temperature of 640˚C to Ac_1 transformation point to produce a high-carbon hot-rolled steel sheet having excellent stretch-flangeformability.

Non-patent Document 1: Journal of the JSTP, 44, 2003, p. 409-413
Patent Document 1: Japanese Unexamined Patent Application Publication No. 9-157758
Patent Document 2: Japanese Unexamined Patent Application Publication No. 5-9588
Patent Document 1: Japanese Unexamined Patent Application Publication No. 2003-13145

Disclosure of Invention

[0004] However, the high-carbon hot-rolled steel sheets described in these conventional techniques have excellent properties when processed by a single processing type such as stretching or hole-expansion, but has the problem of producing cracks when bending is performed after stretching, i.e., when a plurality of processing types are combined.

[0005] The present invention provides a high-carbon hot-rolled steel sheet having excellent bending properties after stretching and a method of producing the same.

[0006] As a result of intensive research on the bending properties of a high-carbon hot-rolled steel sheet after stretching, the inventors have found that it is very important to appropriately control a Sol. Al content in steel, cooling conditions after hot rolling, a coiling temperature, and an annealing temperature. Also the inventors have found that when a ferrite grain diameter measured by a measurement method, which will be described below, is controlled to 5.0 μm or less, and the area ratio of ferrite grains with an aspect ratio of 4.0 or more is controlled to 15% or less, excellent bending properties after stretching are achieved.

[0007] The present invention has been achieved on the basis of the above-mentioned findings and provides a method of producing a high-carbon hot-rolled steel sheet, the method including a step of hot-rolling steel having a composition containing, in % by mass, 0.2 to 0.7% of C, 2% or less of Si, 2% or less of Mn, 0.03% or less of P, 0.03% or less of S, 0.01% or less of Sol. Al, and 0.01% or less of N at a finishing temperature of (Ar_3 transformation point - 20˚C) or more to prepare a hot-rolled steel sheet, a step of cooling the hot-rolled steel sheet to a temperature of 650˚C or less at a cooling rate of 60 ˚C/sec to less than 120 ˚C/sec, a step of coiling the hot-rolled steel sheet at a coiling temperature of

600°C or less after cooling, and a step of annealing the hot-rolled steel sheet at an annealing temperature of 640°C to Ac_1 transformation point after coiling.

[0008] In the method of the present invention, the hot-rolled steel sheet is preferably cooled to a temperature of 600°C or less at a cooling rate of 80 °C/sec to less than 120 °C/sec in the cooling step, and coiled at a temperature of 550°C or less in the coiling step.

[0009] The present invention also provides a high-carbon hot-rolled steel sheet which is a hot-rolled spheroidizing annealed material, the steel sheet having a composition containing, in % by mass, 0.2 to 0.7% of C, 2% or less of Si, 2% or less of Mn, 0.03% or less of P, 0.03% or less of S, 0.01% or less of Sol. Al, and 0.01% or less of N, a ferrite grain diameter being 5.0 μm or less, and an area ratio of ferrite grains with an aspect ratio of 4.0 or more being 15% or less.

[0010] The ferrite grain diameter is an average grain diameter determined by approximating ferrite grains as circular grains in image analysis, and the aspect ratio is an average value of (major axis of ellipse)/(minor axis of ellipse) determined by approximating ferrite grains as elliptic grains in image analysis. Specifically, a section of the steel sheet in a direction parallel to the rolling direction is polished and etched a nital solution (nitric acid + ethanol) at a position of 1/4 thickness of the sheet, and then a microstructure is observed with a scanning electron microscope at a magnification of 1500× to determine a ferrite grain diameter and the aspect ratio of a ferrite grain by image analysis using an image analysis software "Image Pro Plus ver. 4.0" (TM) manufactured by Media Cybernetics Co., Ltd. The area ratio of ferrite grains with an aspect ratio of 4.0 or more is determined and then divided by the total area of the field of view to determine the area ratio of each field of view. The average of 50 fields of view is regarded as the area ratio of ferrite grains with an aspect ratio of 4.0 or more.

[0011] The area ratio of the ferrite grains with an aspect ratio of 4.0 or more is preferably 10% or less. In the present invention, the composition of the steel may further contain at least one selected from B, Cr, Ni, Mo, Cu, Ti, Nb, W, V, and Zr in the following content ranges: B: 0.005% by mass or less, Cr: 3.5% by mass or less, Ni: 3.5% by mass or less, Mo: 0.7% by mass or less, Cu: 0.1% by mass or less, Ti: 0.1% by mass or less, Nb: 0.1% by mass or less, W, V, Zr: 0.1% by mass or less in total.

[0012] According to the present invention, a high-carbon hot-rolled steel sheet exhibiting excellent bending properties even after processing such as stretching can be produced.

Brief Description of Drawings

[0013]

Fig. 1 is a graph showing a relation between the area ratio of ferrite grains with an aspect ratio of 4.0 or more and bending properties after stretching.

Best Mode for Carrying Out the Invention

[0014] A high-carbon hot-rolled steel sheet and a method of producing the same according to the present invention will be described in detail below. The unit "%" of the content of each component represents "% by mass" unless otherwise specified.

Composition of steel

[0015] C content: C is an important element which forms a carbide and provides hardness after quenching. When the C content is less than 0.2%, sufficient strength as machine structural parts cannot be obtained after quenching. On the other hand, when the C content exceeds 0.7%, a sufficient bending property after stretching cannot be obtained even when the ferrite grain diameter is 5.0 μm or less and the area ratio of ferrite grains with an aspect ratio is 15% or less. Also, the hardness after hot rolling is significantly increased, and the steel sheet becomes brittle to cause disadvantage in handling and saturate strength as machine structural parts after quenching. Therefore, the C content is specified to 0.2 to 0.7%. When hardness after quenching is regarded as more important, the C content preferably exceeds 0.5%, while when workability is regarded as important, the C content is preferably 0.5% or less.

[0016] Si content: Si graphitizes a carbide and tends to inhibit hardenability, and thus the content is 2% or less and preferably 1% or less.

[0017] Mn content: When Mn is excessively contained, ductility tends to be decreased. Therefore, the Mn content is specified to 2% or less and preferably 1% or less.

[0018] P content: When P is excessively contained, ductility such as stretch-flange properties is decreased, and cracks easily occur. Therefore, the P content is 0.03% or less and preferably 0.02% or less.

[0019] S content: When S is excessively contained, ductility such as stretch-flangeformability is decreased, and cracks easily occur. Therefore, the S content is 0.03% or less and preferably 0.07% or less.

[0020] Sol. Al content: Sol. Al is the most important element in the present invention. Namely, the inventors newly found that when the Sol. Al content exceeds 0.01%, AlN is formed on a surface layer of the steel sheet in annealing the hot-rolled steel sheet in a nitrogen atmosphere using nitrogen which is relatively inexpensive and frequently used as a non-oxidizing atmosphere, and the surface layer of the steel sheet is hardened to significantly decrease the bending properties after stretching. Therefore, the Sol. Al content is specified to 0.01% or less.

[0021] N content: When N is excessively contained, ductility is decreased. Therefore, the N content is 0.01% or less and preferably 0.005% or less.

[0022] Since the cost is increased by decreasing the content of each of the above elements to a predetermined amount, for example, less than 0.0001%, the content of each element is preferably about 0.0001% or more.

[0023] The balance is composed of Fe and inevitable impurities, but even when at least one element of B, Cr, Ni, Mo, Cu, Ti, Nb, W, V, and Zr may be added in a usual range in order to improve hardenability by quenching and resistance to temper softening, the advantage of the present invention is not impaired.

[0024] Specifically, these elements can be contained at the following contents: B: 0.005% by or less, Cr: 3.5% or less, Ni: 3.5% or less, Mo: 0.7% or less, Cu: 0.1% or less, Ti: 0.1% or less, Nb: 0.1% or less, W, V, Zr: 0.1% or less in total. For this purpose, the elements are preferably contained at the following contents: B: 0.0005% or more, Cr: 0.05% or more, Ni: 0.05% or more, Mo: 0.05% or more, Cu: 0.01% or more, Ti: 0.01% or more, Nb: 0.01% or more, W, V, Zr: 0.01% or more in total. Further, even when elements such as Sn, Pb, and the like are mixed as impurities in the production process, the advantage of the present invention is not affected.

Production condition

[0025] Finishing temperature of hot rolling: When the finishing temperature is lower than (Ar_3 transformation point - 20°C), the steel sheet is partially rolled in a ferrite transformation region, and thus the ferrite grain diameter after annealing exceeds 5.0 μm, thereby degrading the bending properties after stretching. Therefore, the finishing temperature of hot rolling is (Ar_3 transformation point - 20°C) or more. Although the Ar_3 transformation point can be calculated from the equation (1) below, an actually measured temperature may be used.

$$Ar_3 \text{ transformation point} = 910 - 203 \times [C]^{1/2} + 44.7 \times [Si] - 30 \times [Mn] \quad \ldots (1)$$

wherein [M] represents the content (%) of element M. Further, correction terms may be introduced according the elements contained. For example, when Cr, Mo, and Ni are contained, the correction terms, such as - 11 × [Cr], + 31.5 × [Mo], and - 15.2 × [Ni], may be added to the right side of the equation (1).

[0026] Cooling condition after hot rolling: In the present invention, grain refining of ferrite grains is achieved in spite of the low Sol. Al content and difficulty in inhibiting grain growth by AlN pinning. This is estimated to be due to the fact that strain applied to austenite grains during rolling is easily accumulated by rapid cooling after hot rolling, and the accumulated strain contributes as nucleation sites of ferrite grains during subsequent annealing. When the cooling rate after hot rolling is less than 60 °C/sec, the strain applied to the austenite grains during rolling is little accumulated, and thus the number of the nucleation sites of ferrite grains is decreased in subsequent annealing, thereby accelerate the growth of ferrite grains. As a result, the ferrite grain diameter exceeds 5.0 μm, and the bending properties after stretching are degraded. On the other hand, when the cooling rate is 120 °C/sec or more, the ferrite grain diameter after annealing is 5.0 μm or less, but the area ratio of ferrite grains with an aspect ratio of 4.0 or more exceeds 15%. Therefore, as described above, the bending properties after stretching are degraded. This is estimated to be due to the fact that when the cooling rate is 120 °C/sec or more, the strain applied to the austenite grains during rolling is excessively present after rolling, thereby causing difficulty in growth of equiaxial ferrite grains in subsequent annealing. Therefore, the cooling rate after hot rolling is 60 °C/sec to less than 120 °C/sec. The upper limit of the cooling rate is preferably 115 °C/sec.

[0027] When the end-point of cooling of the hot-rolled steel sheet at the above-described cooling rate, i.e., the cooling stop temperature, is higher than 650°C, the strain accumulated in austenite in cooling is released until the hot-rolled steel sheet is coiled. As a result, the ferrite grain diameter after annealing exceeds 5.0 μm, and thus the bending properties after stretching are degraded. Therefore, the cooling stop temperature is 650°C or less and preferably 600°C or less. In view of the problem with measurement accuracy of the temperature, the cooling stop temperature is preferably 500°C or more.

[0028] Cooling after the cooling stop temperature is attained is not particularly specified, and natural cooling or accelerated cooling with deceased cooling force may be continued. From the viewpoint of homogeneous mechanical properties of the steel sheet, accelerated cooling is preferably performed to an extent which suppresses regeneration of heat.

[0029] Coiling temperature: The hot-rolled steel sheet after cooling is coiled. When the coiling temperature exceeds 600°C, the strain accumulated in austenite during hot rolling is released. As a result, the ferrite grain diameter after annealing exceeds 5.0 μm, and thus the bending properties after stretching are degraded. Therefore, the coiling temperature is 600°C or less. In order to obtain the sufficient effect of cooling, the coiling stop is preferably lower than the cooling termination temperature. Since the shape of the hot-rolled steel sheet is degraded, the coiling temperature is preferably 200°C or more and more preferably 350°C or more.
[0030] When the area ratio of ferrite grains with an aspect ratio of 4.0 or more is 10% or less, the bending properties are further improved. In this case, it is necessary that the cooling rate is 80 °C/sec to less than 120 °C/sec, the cooling stop temperature is 600°C or less, and the coiling temperature is 550°C or less.
[0031] Descaling: The hot-rolled steel sheet after coiling is generally descaled before subsequent annealing. The descaling means is not particularly limited, but pickling by a usual method is preferred.
[0032] Annealing temperature of hot-rolled steel sheet: After descaling by pickling, the hot-rolled steel sheet is annealed by spheroidizing annealing for spheroidizing carbides. When the annealing temperature is less than 640°C, growth of ferrite grains is insufficient, and thus the area ratio of ferrite grains with an aspect ratio of 4.0 or more exceeds 15%, thereby deteriorating the bending properties after stretching. On the other hand, when the annealing temperature exceeds the Ac_1 transformation point, austenite formation partially proceeds to form pearlite during cooling, thereby deteriorating the bending properties after stretching. Therefore, the annealing temperature of the hot-rolled steel sheet is 640°C to the Ac_1 transformation point. In order to obtain more excellent stretch-flangeability, the annealing temperature of the hot-rolled steel sheet is preferably 680°C or above. Although the Ac_1 transformation point can be calculated from the equation (2) below, an actually measured temperature may be used.

$$Ac_1 \text{ transformation point} = 754.83 - 32.25 \times [C] + 23.32 \times [Si] - 17.76 \times [Mn] \quad \ldots (2)$$

wherein [M] represents the content (%) of element M. Further, correction terms may be introduced according the elements contained. For example, when Cr, Mo, and V are contained, the correction terms, such as + 17.3 × [Cr], + 4.51 × [Mo], and + 15.62 × [V], may be added to the right side of the equation (2).
[0033] The annealing time of the hot-rolled steel sheet is preferably about 8 to 80 hours. The carbide in the resultant steel sheet is spheroidized, and the average aspect ratio is about 5.0 or less (a value measured at a position of about 1/4 thickness of the sheet).
[0034] For steel making of the high-carbon steel according to the present invention either a converter or an electric furnace can be applied. Thus made high-carbon steel is formed into a slab by ingoting and blooming or continuous casting. The slab is generally heated, (reheated), and then treated by hot-rolled.
[0035] For the slab manufactured by continuous casting may be treated by hot direct rolling directly from the slab or after heat-holding to prevent temperature reduction. For the case of hot-rolling the slab after reheating, the slab heating temperature is preferably specified to 1280°C or below to avoid the deterioration of surface condition caused by scale. The hot-rolling can be given only by finishing rolling eliminating rough rolling. To assure the finishing temperature, the material being rolled may be heated during hot-rolling using a heating means such as sheet bar heater. To enhance spheroidization or to decrease hardness, the coiled sheet may be thermally insulated by a slow-cooling cover or other means.
Although the thickness of the hot-rolled sheet is not specifically limited if only the manufacturing conditions of the present invention are maintained, a particularly preferable range of the thickness thereof is from 1.0 to 10.0 mm from the point of operability.
The annealing of hot-rolled sheet can be done either by box annealing or by continuous annealing. After annealing or hot-rolled sheet, skin-pass rolling is applied, at need. Since the skin-pass rolling does not affect the hardenability by quenching, there is no specific limitation or the condition of skin-pass rolling.
[0036] The hot-rolled steel sheet produced by the above-described method of the present invention is a hot-rolled steel sheet subjected to hot-rolling spheroidizing annealing and containing carbides spheroidized to an average aspect ratio of about 5.0 or less.
[0037] The hot-rolled steel sheet of the present invention has a ferrite grain diameter of 5.0 μm or less. The ferrite grain diameter affects the bending properties after stretching. When the ferrite grain diameter exceeds 5.0 μm, many fine carbide grains are precipitated in ferrite grains, and voids produced by stretching at interfaces between carbides and ferrite are connected together during bending to cause cracks. When the ferrite grain diameter is 5.0 μm or less, the number of carbide in ferrite grains is decreased, and the fine voids produced by stretching are little connected by bending after stretching, thereby suppressing the occurrence of cracks.

[0038] Further, in the hot-rolled steel sheet of the present invention, the area ratio of ferrite grains with an aspect ratio of 4.0 or more is 15% or less. Like the ferrite grain diameter, the shape of ferrite grains affects the bending properties after stretching. When the aspect ratio of the ferrite grains is 4.0 or more, fine cracks easily occur by stretching at grain boundaries between ferrite grains with an aspect ratio of 4.0 or more and equiaxial ferrite grains with an aspect ratio less than 4.0. When the area ratio of such ferrite grains with an aspect ratio of 4.0 or more exceeds 15%, cracking starts in bending at fine cracks produced in stretching. When the area ratio of ferrite grains with an aspect ratio of 4.0 or more is 15% or less, the occurrence of cracks in bending after stretching can be suppressed. The area ratio of ferrite grains with an aspect ratio of 4.0 or more is more preferably 10% or less.

EXAMPLE 1

[0039] Continuously cast slabs of steels A to E and Z having the chemical compositions shown in Table 1 were heated to 1250˚C, hot-rolled under the conditions shown in Table 2, pickled, and then annealed under the conditions shown in Table 2 to produce steel sheet Nos. 1 to 20 having a thickness of 5. 0 mm. Annealing was performed in a nitriding atmosphere (N_2 atmosphere).

[0040] Steel sheets Nos. 1 to 10 are examples of the present invention, and steel sheet Nos. 11 to 20 are comparative examples. The ferrite grain diameter and the aspect ratio and area ratio of ferrite grains were measured by the following methods. The bending properties after stretching were also measured by the following method.

[0041] Ferrite grain diameter and aspect ratio and area ratio of ferrite grains: The ferrite grain diameter is an average grain diameter determined by approximating ferrite grains as circular grains in image analysis, and the aspect ratio is an average value of (major axis of ellipse)/(minor axis of ellipse) determined by approximating ferrite grains as elliptic grains in image analysis. Specifically, a thickness section of the steel sheet in a direction parallel to the rolling direction was polished and etched a nital solution (nitric acid + ethanol) at a position of 1/4 thickness of the sheet, and then a microstructure was observed with a scanning electron microscope at a magnification of 1500× to determine a ferrite grain diameter and the aspect ratio of a ferrite grain by image analysis using an image analysis software "Image Pro Plus ver. 4.0" (TM) manufactured by Media Cybernetics Co., Ltd. The area ratio of ferrite grains with an aspect ratio of 4.0 or more was determined and then divided by the total area of a field of view to determine the area ratio of each field of view. The average of 50 fields of view was regarded as the area ratio of ferrite grains with an aspect ratio of 4.0 or more.

[0042] Further, a thickness section of the steel sheet in a direction parallel to the rolling direction was polished and etched a picral solution (picric acid + ethanol) at a position of 1/4 thickness of the sheet, and then a microstructure was observed with a scanning electron microscope at a magnification of 3000× to determine the aspect ratio (maximum diameter)/(minimum diameter) of carbide using the image analysis software. The aspect ratios of carbides were averaged (number average) to determine the average aspect ratio. As a result, it was confirmed that the carbides were spheroidized and annealed.

[0043] Bending properties after stretching: A tensile test was performed by a method according to JIS Z 2241 using a JIS No. 5 test piece obtained in a direction perpendicular to the rolling direction and having a parallel portion of 30 mm in width to apply predistortion of 15%, and then a bending test was performed by a pressing bend method according to JIS Z 2249. The bending test was performed three times using a punch diameter D of 1 mm. When no crack occurred in the three tests, the bending property was decided as ○, when cracks occurred one time or two times, the bending property was decided as Δ, and when cracks occurred three times, the bending property was decided as ×. In the case of ○, the test piece was considered as an example of the present invention.

[0044] The results are shown in Table 3. In steel sheet Nos. 1 to 10 as examples of the present invention, the ferrite grain diameter is 5.0 μm or less, the area ratio of ferrite grains with an aspect ratio of 4.0 or more is 15% or less, and thus the bending property after stretching is excellent. In each of the examples of the present invention, it was confirmed that the average aspect ratio of carbides is 5.0 or less, and the carbides are spheroidized by spheroidizing annealing.

[0045] Fig. 1 shows a relation between the area ratio of ferrite grains with an aspect ratio of 4.0 or more and bending property after stretching when the ferrite grain diameter is 5.0 μm or less. As in steel sheet Nos. 1 to 10 as the examples of the present invention, when the ferrite grain diameter is 5.0 μm or less, and the area ratio of ferrite grains with an aspect ratio of 4.0 or more is 15% or less, the excellent bending property after stretching can be obtained.

Table 1 (% by mass)

Steel	C	Si	Mn	P	S	Sol. Al	N	Ar_3 transformation point determined from equation (1)	Ac_1 transformation point determined from equation (2)
A	0.26	0.22	0.83	0.010	0.0025	0.007	0.0031	791	737
B	0.34	0.20	0.74	0.015	0.0018	0.005	0.0033	778	735

(continued)

Steel	C	Si	Mn	P	S	Sol. Al	N	Ar_3 transformation point determined from equation (1)	Ac_1 transformation point determined from equation (2)
C	0.35	0.02	0.15	0.009	0.0030	0.006	0.0036	786	741
D	0.49	0.19	0.76	0.011	0.0027	0.010	0.0032	754	730
E	0.66	0.21	0.75	0.014	0.0045	0.003	0.0030	732	725
Z	0.36	0.21	0.73	0.013	0.0022	0.032	0.0032	776	735

Table 2

Steel sheet No.	Steel	Hot rolling condition				Annealing of hot-rolled steel sheet	Remarks
		Finishing temperature (˚C)	Cooling rate (˚C/sec)	Cooling stop temperature (˚C)	Coiling temperature (˚C)		
1	A	801	110	620	550	700˚C×40hr	Example of this invention
2	A	811	95	560	510	720˚C×40hr	Example of this invention
3	B	788	115	610	540	680˚C×40hr	Example of this invention
4	B	808	85	570	520	710˚C×40hr	Example of this invention
5	C	801	75	610	590	670˚C×40hr	Example of this invention
6	C	806	105	580	490	720˚C×40hr	Example of this invention
7	D	774	90	620	580	710˚C×40hr	Example of this invention
8	D	784	100	550	500	720˚C×40hr	Example of this invention
9	E	752	65	600	570	700˚C×40hr	Example of this invention
10	E	772	100	540	490	720˚C×40hr	Example of this invention
11	A	801	80	680	580	700˚C×40hr	Comp. Example
12	A	751	100	610	570	700˚C×40hr	Comp. Example

(continued)

Steel sheet No.	Steel	Hot rolling condition				Annealing of hot-rolled steel sheet	Remarks
		Finishing temperature (˚C)	Cooling rate (˚C/sec)	Cooling stop temperature (˚C)	Coiling temperature (˚C)		
13	B	798	110	620	560	600˚C×40hr	Comp. Example
14	B	793	90	600	<u>630</u>	690˚C×40hr	Comp. Example
15	C	816	<u>150</u>	580	520	720˚C×40hr	Comp. Example
16	C	806	<u>55</u>	630	550	710˚C×40hr	Comp. Example
17	D	794	115	<u>670</u>	590	720˚C×40hr	Comp. Example
18	D	<u>719</u>	95	610	580	680˚C×40hr	Comp. Example
19	E	752	<u>130</u>	590	550	710˚C×40hr	Comp. Example
20	Z	805	100	580	530	720˚C×40hr	Comp. Example

Table 3

Steel No.	Ferrite grain diameter (μm)	Area ratio of ferrite grain with aspect ratio of 4.0 or more (%)	Bending properties after stretching	Remarks
1	3.5	13.1	○	Example of this invention
2	3.2	8.8	○	Example of this invention
3	2.8	12.4	○	Example of this invention
4	2.6	9.2	○	Example of this invention
5	4.4	11.6	○	Example of this invention
6	3.3	7.5	○	Example of this invention
7	4.1	13.9	○	Example of this invention
8	3.7	8.7	○	Example of this invention
9	4.5	14.6	○	Example of this invention
10	3.1	9.2	○	Example of this invention
11	<u>6.4</u>	13.3	△	Comp. Example
12	<u>6.2</u>	14.4	△	Comp. Example
13	4.4	<u>15.8</u>	×	Comp. Example
14	5.6	14.1	△	Comp. Example
15	4.7	<u>18.4</u>	×	Comp. Example
16	<u>5.9</u>	14.6	△	Comp. Example
17	<u>5.4</u>	13.9	△	Comp. Example

(continued)

Steel No.	Ferrite grain diameter (μm)	Area ratio of ferrite grain with aspect ratio of 4.0 or more (%)	Bending properties after stretching	Remarks
18	5.5	14.2	△	Comp. Example
19	4.1	22.4	×	Comp. Example
20	4.0	13.5	×	Comp. Example

EXAMPLE 2

[0046] A slab was formed by continuous casting of each of steel E shown in Table 1 and the following steels:

Steel F (C: 0.31%, Si: 0.18%, Mn: 0.68%, P: 0.012%, S: 0.0033%, Sol. Al: 0.005%, N: 0.0040%, Ar_3 transformation point: 785˚C, Ac_1 transformation point: 737˚C),
Steel G (C: 0.23%, Si: 0.18%, Mn: 0.76%, P: 0.016%, S: 0.0040%, Sol. Al: 0.008%, N: 0.0028%, Cr: 1.2%, Ar_3 transformation point: 785˚C, Ac_1 transformation point: 759˚C),
Steel H (C: 0.32%, Si: 1.2%, Mn: 1.5%, P: 0.025%, S: 0.010%, Sol. Al: 0.006%, N: 0.0070%, Ar_3 transformation point: 804˚C, Ac_1 transformation point: 746˚C),
Steel I (C: 0.35%, Si: 0.20%, Mn: 0.68%, P: 0.012%, S: 0.0038%, Sol. Al: 0.005%, N: 0.0033%, Mo: 0.17%, Cr: 0.98%, Ar_3 transformation point: 773˚C, Ac_1 transformation point: 754˚C) .

[0047] Then the slabs were heated to 1230˚C and hot-rolled and annealed under the conditions shown in Table 4 to produce steel sheet Nos. 21 to 37 having a thickness of 4.5 m. Annealing was performed in a nitriding atmosphere (N_2 atmosphere). The ferrite grain diameter and the aspect ratio and area ratio of the ferrite grains of each of the resultant hot-rolled steel sheets were measured by the same methods as in Example 1, and the bending property after stretching was evaluated as in Example 1. Also, as in Example 1, it was confirmed that carbides were spheroidized.

[0048] The Ar_3 transformation point and the Ac_1 transformation point of each of steels F to I were determined from the equations (1) and (2), and the Ar_3 transformation point and the Ac_1 transformation point of each of steels G and I containing Cr or Mo were determined using the above-described correction terms.

[0049] The results are shown in Table 5. Table 5 indicates that in steel sheet Nos. 21 to 27 produced under the constant conditions except the cooling rate, steel sheet Nos. 22 to 26 produced at the cooling rates within the range of the present invention have excellent bending property after stretching. It is also found that in steel sheet Nos. 23 to 26, the area ratio of ferrite grains with an aspect ratio of 4.0 or more can be controlled to 10% or less. It is further found that in steel sheet Nos. 28 to 33 produced at a constant cooling rate, steel sheet Nos. 30 to 33 produced at a cooling termination temperature and a coiling temperature both of which are within the ranges of the present invention have excellent bending properties after stretching. It is further found that in steel sheet No. 33 produced at a cooling termination temperature of 600˚C or less and a coiling temperature of 550˚C or less, the area ratio of ferrite grains with an aspect ratio of 4.0 or more can be controlled to 10% or less. In the examples of the present invention, it was confirmed that the average aspect ratio of carbides is 5.0% or less, and the carbides are spheroidized by spheroidizing annealing.

[0050] Steels E to I each having the composition within the range of the present invention, including steels G and I containing an ally element other than the basic components, exhibit excellent bending properties after stretching.

Table 4

Steel sheet No.	Steel	Hot rolling condition				Annealing of hot-rolled steel sheet	Remarks
		Finishing temperature (˚C)	Cooling rate (˚C/sec)	Cooling termination temperature (˚C)	Coiling temperature (˚C)		
21	F	820	50	560	530	700˚C×30hr	Comp. Example
22	F	820	70	560	530	700˚C×30hr	Example of this invention

(continued)

Steel sheet No.	Steel	Hot rolling condition				Annealing of hot-rolled steel sheet	Remarks
		Finishing temperature (˚C)	Cooling rate (˚C/sec)	Cooling termination temperature (˚C)	Coiling temperature (˚C)		
23	F	820	85	560	530	700˚C×30hr	Example of this invention
24	F	820	95	560	530	700˚C×30hr	Example of this invention
25	F	820	105	560	530	700˚C×30hr	Example of this invention
26	F	820	115	560	530	700˚C×30hr	Example of this invention
27	F	820	140	560	530	700˚C×30hr	Comp. Example
28	F	820	105	660	530	700˚C×30hr	Comp. Example
29	F	820	105	630	610	700˚C×30hr	Comp. Example
30	F	820	105	630	560	700˚C×30hr	Example of this invention
31	F	820	105	630	530	700˚C×30hr	Example of this invention
32	F	820	105	580	560	700˚C×30hr	Example of this invention
33	F	820	105	580	530	700˚C×30hr	Example of this invention
34	E	790	105	560	530	715˚C×60hr	Example of this invention
35	G	800	105	560	530	720˚C×50hr	Example of this invention
36	H	810	105	560	530	700˚C×30hr	Example of this invention
37	I	820	105	560	530	700˚C×30hr	Example of this invention

Table 5

Steel No.	Ferrite grain diameter (μm)	Area ratio of ferrite grain with aspect ratio of 4.0 or more (%)	Bending property after stretching	Remarks
21	5.4	13.2	△	Comp. Example
22	4.7	11.3	○	Example of this invention
23	3.6	8.8	○	Example of this invention
24	3.1	7.9	○	Example of this invention
25	2.9	8.5	○	Example of this invention
26	3.2	7.6	○	Example of this invention
27	4.5	21.9	×	Comp. Example
28	6.4	14.2	△	Comp. Example
29	5.8	14.6	△	Comp. Example
30	4.3	12.1	○	Example of this invention
31	4.0	13.3	○	Example of this invention
32	4.5	10.7	○	Example of this invention
33	3.9	8.4	○	Example of this invention
34	3.8	9.5	○	Example of this invention
35	3.7	8.7	○	Example of this invention
36	4.8	9.6	○	Example of this invention
37	3.5	8.8	○	Example of this invention

Claims

1. A method of producing a high-carbon hot-rolled steel sheet, the method comprising:

a step of hot-rolling steel having a composition containing, in % by mass, 0.2 to 0.7% of C, 2% or less of Si, 2% or less of Mn, 0.03% or less of P, 0.03% or less of S, 0.01% or less of Sol. Al, and 0.01% or less of N at a finishing temperature of (Ar_3 transformation point - 20˚C) or more to form a hot-rolled steel sheet;
a step of cooling the hot-rolled steel sheet to a temperature of 650˚C or less at a cooling rate of 60 ˚C/sec to less than 120 ˚C/sec;
a step of coiling the hot-rolled steel sheet at a coiling temperature of 600˚C or less after cooling; and a step of annealing the hot-rolled steel sheet at an annealing temperature of 640˚C to Ac_1 transformation point after coiling.

2. The method of producing the high-carbon hot-rolled steel sheet according to claim 1, wherein the hot-rolled steel sheet is cooled to a temperature of 600˚C or less at a cooling rate of 80 ˚C/sec to less than 120 ˚C/sec in the cooling step and coiled at a temperature of 550˚C or less in the coiling step.

3. The method of producing the high-carbon hot-rolled steel sheet according to claim 1 or 2, wherein the composition of the steel further contains at least one selected from B, Cr, Ni, Mo, Cu, Ti, Nb, W, V, and Zr in the following content ranges in % by mass:

B: 0.005% or less, Cr: 3.5% or less, Ni: 3.5% or less, Mo: 0.7% or less, Cu: 0.1% or less, Ti: 0.1% or less, Nb: 0.1% or less, W, V, Zr: 0.1% or less in total.

4. A high-carbon hot-rolled steel sheet which is a hot-rolled spheroidized annealed material, the steel sheet comprising:

a composition containing, in % by mass, 0.2 to 0.7% of C, 2% or less of Si, 2% or less of Mn, 0.03% or less of

P, 0.03% or less of S, 0.01% or less of Sol. Al, and 0.01% or less of N;

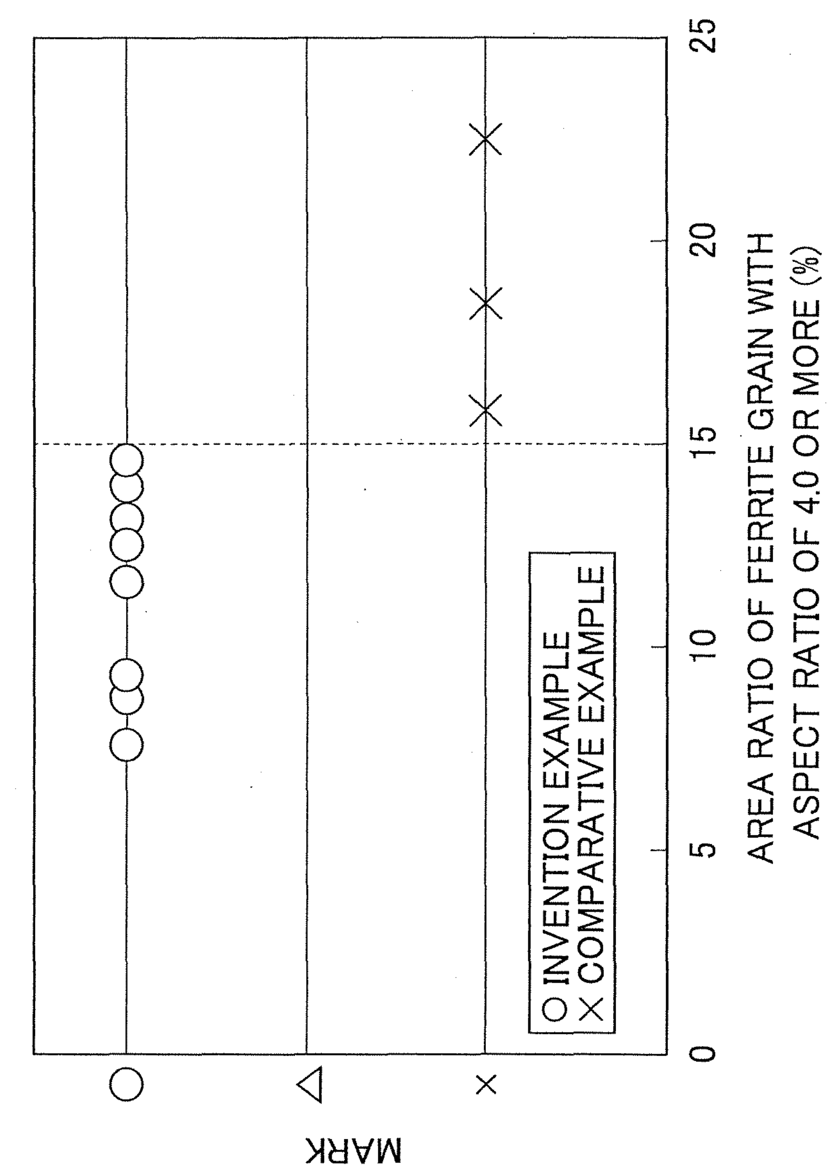
wherein a ferrite grain diameter is 5.0 μm or less, and an area ratio of ferrite grains with an aspect ratio of 4.0 or more is 15% or less;
wherein the ferrite grain diameter is an average grain diameter determined by approximating ferrite grains as circular grains in image analysis, and the aspect ratio is an average value of (major axis of ellipse)/(minor axis of ellipse) determined by approximating ferrite grains as elliptic grains in image analysis.

5. The high-carbon hot-rolled steel sheet according to claim 4, wherein the area ratio of ferrite grains with an aspect ratio of 4.0 or more is 10% or less.

6. The high-carbon hot-rolled steel sheet according to claim 4 or 5, wherein the composition of the steel further contains at least one selected from B, Cr, Ni, Mo, Cu, Ti, Nb, W, V, and Zr in the following content ranges in % by mass:

B: 0.005% or less, Cr: 3.5% or less, Ni: 3.5% or less, Mo: 0.7% or less, Cu: 0.1% or less, Ti: 0.1% or less, Nb: 0.1% or less, W, V, Zr: 0.1% or less in total.

FIG.1


MARK
INVENTION EXAMPLE
COMPARATIVE EXAMPLE
0
5
10
15
20
25
AREA RATIO OF FERRITE GRAIN WITH ASPECT RATIO OF 4.0 OR MORE (%)

INTERNATIONAL SEARCH REPORT

International application No. PCT/JP2007/075341

A. CLASSIFICATION OF SUBJECT MATTER
C21D9/46(2006.01)i, *C21D8/02*(2006.01)i, *C22C38/06*(2006.01)i, *C22C38/58* (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)
C21D9/46-9/48, C21D8/00-8/04, C22C38/00-38/60

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

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2008
Kokai Jitsuyo Shinan Koho	1971-2008	Toroku Jitsuyo Shinan Koho	1994-2008

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	JP 2005-290547 A (JFE Steel Corp.), 20 October, 2005 (20.10.05), Claims; tables 1 to 3 & US 2005/0199322 A1 & CN 1667151 A	1-6
A	JP 2005-97740 A (JFE Steel Corp.), 14 April, 2005 (14.04.05), Claims; tables 1 to 4 (Family: none)	1-6

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

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Date of the actual completion of the international search	Date of mailing of the international search report
25 March, 2008 (25.03.08)	08 April, 2008 (08.04.08)

Name and mailing address of the ISA/	Authorized officer
Japanese Patent Office	
Facsimile No.	Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2007/075341

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	JP 10-265845 A (Kawasaki Steel Corp.), 06 October, 1998 (06.10.98), Claims; Par. No. [0018]; tables 1, 2 (Family: none)	1-6
A	JP 5-239588 A (Sumitomo Metal Industries, Ltd.), 17 September, 1993 (17.09.93), Claims; tables 1(1) to 4(2) (Family: none)	1-6
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A	JP 55-50427 A (Kawasaki Steel Corp.), 12 April, 1980 (12.04.80), Claims (Family: none)	1-6
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P,A	JP 2007-277696 A (JFE Steel Corp.), 25 October, 2007 (25.10.07), Claims; tables 1 to 10 & WO 2007/043318 A1	1-6

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- JP 9157758 A **[0003]**
- JP 5009588 A **[0003]**
- JP 2003013145 A **[0003]**

Non-patent literature cited in the description

- *Journal of the JSTP,* 2003, vol. 44, 409-413 **[0003]**