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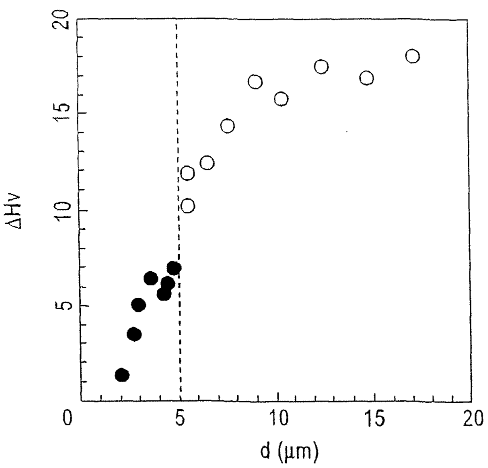
(54) STEEL SHEETS AND PROCESS FOR MANUFACTURING THE SAME

(57) This invention provides a steel sheet which is soft and has excellent formability and quench hardenability, and a method for manufacturing the same. Provided is a steel sheet, containing: a composition, containing, by mass %, C: 0.3 to 0.7%, Si: 0.1% or lower, Mn: 0.20% or lower, P: 0.01% or lower, S: 0.01% or lower, Al: 0.05% or lower, N: 0.0050% or lower, balance Fe, and inevitable impurities; and a microstructure containing ferrite, graphite, and cementite, in which the total volume ratio of ferrite, graphite, and cementite based on the whole microstructure is 95% or more, the volume ratio of graphite (ratio of graphite) based on the total of graphite and cementite is 5% or more, and the mean grain diameter of graphite and cementite is 5 μm or lower or a steel sheet in which the total volume ratio of graphite and cementite present in ferrite grains based on the total of graphite and cementite is 15% or lower.

FIG. 1



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Description

Technical Field

[0001] The present invention relates to a steel sheet suitable for automotive parts and the like, and particularly to a steel sheet with excellent formability and quench hardenability and a method for manufacturing the same.

Background Art

[0002] In many cases, a steel sheet for use in tools, automotive parts (gear, transmission), etc., is formed into a desired shape, and subjected to heat treatment, such as hardening annealing, for use. Such a steel sheet is processed into various complicated shapes, and thus is required to have excellent formability. In recent years, reduction in manufacturing cost has been strongly demanded in such parts. Thus, processing techniques in which omission of a processing process or alteration of a processing manner is intended, e.g., a double-acting processing technique which allows thickening of automobile driving parts using a high carbon steel sheet, and achieves sharp reduction in the number of processes, have been developed, and some of them have been put into practical use. In accordance therewith, the steel sheets for use in automotive parts have been strictly required to have high formability, and the steel sheets have been demanded to be softer and have high ductility. For example, when processed by cold forging, lower yield stress has been demanded. Furthermore, when hole expanding (burring) is performed after punching, excellent stretch-flangeability is desired.

[0003] In order to satisfy such demands, a technique has been examined which is intended to graphitize c in steel for improving formability. For example, Patent Document 1 discloses a steel sheet suitable as a tiller claw: containing, by mass %, C: 0.40 to 0.80%, Si: 0.20 to 2.00%, Mn: 0.20 to 1.50%, Al: 0.001 to 0.150%, P: 0.018% or lower, S: 0.010% or lower, N: 0.0050% or lower, balance Fe, and inevitable impurities; having a microstructure containing a ferrite phase and a graphite as a main body; has a soft material of TS ≤ 60kgf/mm^2; and having excellent formability, tenacity, and quench hardenability, and a method for manufacturing the same. Patent Document 2 discloses a method for manufacturing a medium carbon steel sheet with excellent formability, including: holding a hot rolled steel sheet containing, by mass%, C: 0.10 to 0.45%, Si: 0.05 to 1.00%, Mn: 0.05 to 0.50%, Nb: 0.005 to 0.1%, Al: 0.01 to 1.00%, N: 0.002 to 0.010%, B:3 to 50 ppm, Ca: 0.001 to 0.01%, Ni: 0 to 2.00%, the balance being Fe and inevitable impurities, P in the impurities of 0.012% or lower, and S in the impurities of 0.008% or lower within a temperature range of from Ac_1 to Ac_3 for 0.1 to 10 hr; cooling the resultant at a cooling rate of from 20 to 100°C/hr; and box annealing the resultant within the temperature range of from 650 to 750°C to thereby graphitize 50 area% or more of cementite in the steel.

[0004] Patent Document 3 discloses a high carbon steel sheet with excellent formability containing a chemical composition including, by mass %, C: 0.20 to 1.00%, Si: 0.20% or more and 1.20% or lower, Mn: 0.05 to 0.50%, N: 0.005 to 0.015%, B: 0.2 × N% to 0.8 × N%, and Al: lower than 0.05% and satisfying 1.0 × (N - B)% to 5.0 × (N - B)%, balance Fe, inevitable impurities, P in the impurities of 0.020% or lower, and S in the impurities being 0.010% or lower, and a microstructure containing ferrite, graphite, and cementite, and a method for manufacturing the same.

Patent-Document 1: Japanese Patent Application Laid-Open (JP-A) No. 1-025946
Patent Document 2: Japanese Patent Application Laid-Open (JP-A) No. 7-258743
Patent Document 3: Japanese Patent Application Laid-Open (JP-A) No. 4-202744

Disclosure of Invention

[0005] Conventionally, addition of a large amount of Si has been essential to graphitize c in steel for improving formability as described in, for example, Patent Documents 1 and 3. However, adding of Si hardens ferrite itself, which makes it difficult to obtain favorable formability. Moreover, as described in Patent Document 2, a technique has been developed which achieves graphitization and an increase in ductility by forming a component system containing B and Nb, and performing annealing twice under predetermined conditions, even when the addition amount of Si is not always large. However, performing annealing twice increases cost. Here, Patent Document 2 relates to a technique which is intended to graphitize 50% or more of cementite in steel. As a component composition of steel disclosed in Examples of Patent Document 2, the amount of Si is large and exceeds 0.20%. Although the steel sheets described in Patent Documents 1 to 3 are soft and excellent in bending properties and stretching properties in a tensile test, graphite and cementite may not fully dissolve at the time of hardening treatment of a steel sheet depending on heat conditions, resulting in poor hardening in some cases. Although the steel sheets described in Patent Documents 1 to 3 are soft, the steel sheets have had a problem that they are not always excellent in stretch-flangeability which is an index of hole expanding formability after punching.

[0006] The present invention aims to provide a steel sheet which is soft and has excellent formability and quench hardenability and a steel sheet with excellent formability having excellent stretch-flangeability, and a method for manufacturing the same.

[0007] The present inventors have conducted intensive studies on the above-described problems of the prior-art techniques. As a result, the present inventors found that, even in the case where the content of Si in a high carbon steel is very low, specifically 0.1% or lower, excellent formability can be achieved and excellent quench hardenability and stretch-flangeability can be secured by controlling the distributions of graphite and cementite even when a graphitization ratio is not always high. More specifically, the present inventors have conduced intensive studies on influences of the microstructure of a steel sheet containing C: 0.3 to 0.7 mass% on strength, quench hardenability, and stretch-flangeability thereof, and, as a result, found the following findings:

(1) For softening, it is effective to form a microstructure containing ferrite, graphite, and cementite and to adjust the total volume ratio of ferrite, graphite, and cementite to 95% or more based on the whole microstructure and adjust the volume ratio of graphite based on the total of graphite and cementite to 5% or more.

(2) It is necessary to adjust the mean grain diameter of graphite and cementite to 5 μm or lower for improvement in quench hardenability.

(3) For control of the grain diameters of graphite and cementite, cooling conditions after hot rolling are very important.

(4) For improvement in stretch-flangeability, it is necessary to adjust the total volume ratio of graphite and cementite present in ferrite grains to 15% or lower based on the total of graphite and cementite.

(5) For control of the volume ratios of graphite and cementite present in ferrite grains, cooling conditions after hot rolling are very important.

[0008] The present invention has been made based on such findings, and provides a steel sheet, containing: a composition containing, by mass%, C: 0.3 to 0.7%, Si: 0.1% or lower, Mn: 0.20% or lower, P: 0.01% or lower, S: 0.01% or lower, Al: 0.05% or lower, N: 0.0050% or lower, balance Fe, and inevitable impurities and a microstructure containing ferrite, graphite, and cementite, in which the total volume ratio of ferrite, graphite, and cementite based on the whole microstructure is 95% or more, the volume ratio of graphite (ratio of graphite) based on the total of graphite and cementite is 5% or more, and the mean grain diameter of graphite and cementite is 5 μm or lower.

[0009] It is preferable for the steel sheet of the present invention to contain at least one member selected from Ni: 3.0% or lower, B: 0.005% or lower, and Cu: 0.1% or lower (by mass%).

[0010] The steel sheet of the present invention can be obtained by a method, including: hot rolling the steel having the above-described composition at a finishing temperature of from 800 to 950°C to manufacture a hot rolled sheet, cooling the hot rolled sheet at a mean cooling rate of 50°C/s or more to a cooling temperature of 500°C or lower, winding the resultant at a winding temperature of 450°C or lower, and then annealing the wound hot rolled sheet at an annealing temperature of 720°C or lower.

[0011] The present invention provides a steel sheet, containing: a composition containing, by mass %, C: 0.3 to 0.7%, Si: 0.1% or lower, Mn: lower than 0.15%, P: 0.01% or lower, S: 0.01% or lower, Al: 0.05% or lower, N: 0.0050% or lower, balance Fe, and inevitable impurities; and a microstructure containing ferrite, graphite, and cementite, in which the total volume ratio of ferrite, graphite, and cementite based on the whole microstructure is 95% or more, the volume ratio of graphite (ratio of graphite) based on the total of graphite and cementite is 5% or more, and the total volume ratio of graphite and cementite present in ferrite grains based on the total of graphite and cementite is 15% or lower.

[0012] It is preferable for the steel sheet of the present invention to contain at least one member selected from Ni: 3.0% or lower, B: 0.005% or lower, and Cu: 0.1% or lower (by mass%).

[0013] The steel sheet of the present invention can be obtained by a method, including: hot rolling the steel having the above-described composition at a finishing temperature of from 800 to 950°C to manufacture a hot rolled sheet, cooling the hot rolled sheet at a mean cooling rate of 50°C/s or more to a cooling temperature of 600°C or lower, winding the resultant at a winding temperature of 550°C or lower, and then annealing the wound hot rolled sheet at an annealing temperature of 720°C or lower.

[0014] The present invention has made it possible to manufacture a steel sheet which is soft and has excellent formability and quench hardenability. In particular, the steel sheet of the present invention can be easily manufactured at low cost because components and cooling conditions after hot rolling may be merely controlled. Moreover, the steel sheet of the present invention is soft and excellent in formability, and thus is suitable for thickening of automobile driving parts. Even when applied to complicated-shaped parts, processing and welding of a plurality of parts become unnecessary, and thus an increase in productivity and cost reduction of automotive parts can be achieved. Furthermore, in the steel sheet of the present invention, poor hardening due to non-dissolution of graphite and cementite at the time of heating with high frequency does not occur.

[0015] The present invention has made it possible to manufacture a steel sheet which is soft and is excellent in formability, such as stretch-flangeability. In particular, the steel sheet of the present invention can be easily manufactured at low cost because components and cooling conditions after hot rolling may be merely controlled. Moreover, the steel sheet of the present invention is soft and excellent in formability, such as stretch-flangeability, and thus is suitable for thickening of automobile driving parts. Even when applied to complicated-shaped parts, processing and welding of a plurality of parts become unnecessary, and thus an increase in productivity and cost reduction of automotive parts can be achieved.

Brief Description of Drawings

[0016]

[Fig. 1] Fig. 1 is a diagram illustrating the relationship between the mean particle diameter d and ΔHv of cementite and graphite.
[Fig. 2] Fig. 2 is a diagram illustrating the relationship between the volume ratio S and the mean λ of cementite and graphite present in ferrite grains.

Best Modes for Carrying Out the Invention

[0017] Hereinafter, a steel sheet excellent in formability and a method for manufacturing the same of the present invention will be described in detail. It should be noted that "%" indicating the amount of a component is "mass%" unless otherwise specified.

1) Composition

C: 0.3 to 07%

[0018] C is an element forming graphite. When the amount of C is lower than 0.3%, hardness after quench hardening cannot be secured. When the amount of C exceeds 0.7%, a steel sheet is hardened, resulting in reduced formability, even when graphitized. Therefore, the amount of C is adjusted to 0.3 to 0.7%.

Si: 0.1% or lower

[0019] When the amount of Si exceeds 0.1%, ferrite is hardened, resulting in reduced formability. Therefore, the amount of Si is adjusted to 0.1% or lower, and preferably 0.05% or lower.

Mn: 0.20% or lower

[0020] When the amount of Mn exceeds 0.20%, graphite formation is impeded. Thus, Mn is adjusted to 0.20% or lower, and preferably 0.10% or lower.

P: 0.01% or lower

[0021] Since P is segregated on grain boundaries or the like to reduce formability and has an action of stabilizing cementite to impede graphite formation, the amount of P is preferably reduced as much as possible. Therefore, the amount of P is adjusted to 0.01% or lower, and preferably 0.008% or lower.

S: 0.01% or lower

[0022] Since S forms sulfide, such as MnS, to reduce formability and has an action of stabilizing cementite to impede graphite formation, the amount of S is preferably reduced as much as possible. Therefore, the amount of S is adjusted to 0.01% or lower, and preferably 0.007% or lower.

Al: 0.05% or lower

[0023] Al is an element which is combined with solid solution N to form AlN, thereby rendering the adverse effects of solid solution N, which has an action of impeding graphite formation, harmless and which promotes graphite formation with AlN as the nucleus.

[0024] Therefore, it is preferable to adjust the amount of Al to 0.003% or more. When the amount of Al exceeds 0.05%, cleanliness of steel decreases to deteriorate formability. Thus, the amount of Al is 0.05% or lower, and preferably 0.04% or lower.

N: 0.0050% or lower

[0025] When the amount of N exceeds 0.0050%, the action of solid solution N of stabilizing cementite becomes remarkable, and graphite formation is impeded. Therefore, the amount of N is adjusted to 0.0050%, and preferably 0.0040% or lower.

[0026] The balance contains Fe and inevitable impurities, and it is preferable that at least one member selected from Ni: 30% or lower, B: 0.005% or lower, and Cu: 0.1% or lower be contained for the following reasons.

Ni: 3.0% or lower

[0027] Ni is an element which promotes graphite formation and which is effective in improvement in quench hardenability. In order to obtain such effects, it is preferable to contain 0.1% or more of Ni. However, when the amount of Ni exceeds 3.0%, the effects are saturated. Therefore, the amount of Ni is adjusted to 3.0% or lower, preferably 0.1 to 3.0%, and more preferably 0.3 to 1.0%.

B: 0.005% or lower

[0028] B is a useful element which is combined with N to form BN, and acts as the nucleus of graphite formation and which effectively acts in improvement in quench hardenability. In order to obtain such effects, it is preferable to contain 0.0005% or more of B. When the amount of B exceeds 0.005%, the effects are saturated. Therefore, the amount of B is adjusted to 0.005% or lower, preferably 0.0005 to 0.005%, and more preferably 0.0010 to 0.0040%.

Cu: 0.1% or lower

[0029] Cu is an element which promotes graphite formation and which is effective in improvement in quench hardenability. In order to obtain such effects, Cu is contained in a proportion of 0.01% or more, and more preferably 0.02% or more. However, when the amount of Cu exceeds 0.1%, the effects are saturated. Therefore, the amount of Cu is adjusted to 0.1% or lower, and preferably 0.07% or lower.

2) Microstructure

[0030] In order to soften a steel sheet and to increase bending properties and stretch properties in a tensile test, it is necessary to form a microstructure containing ferrite, graphite, and cementite, to adjust the total volume ratio of ferrite, graphite, and cementite based on the whole microstructure to 95% or more, and to adjust the ratio of graphite based on the total of graphite and cementite to 5% or more. The present invention includes the case where the ratio of graphite is 100%, i.e., cementite being thoroughly graphitized, because the same effects are obtained. When the total volume ratio of ferrite, graphite, and cementite is lower than 95%, i.e., when the volume ratio of a phase other than ferrite, graphite, and cementite exceeds 5%, formability decreases. When the ratio of graphite is lower than 5%, formability decreases.

[0031] Here, the volume ratio of ferrite, graphite, and cementite is determined as follows. More specifically, a steel sheet is ground at 1/4 position of the sheet thickness of a through-thickness section in the rolling direction of the steel sheet, and subjected to nital corrosion. Then, the resultant is observed under an optical microscope (400x magnification) for 5 parts per visual field, i.e., 10 visual fields (Total: 50 parts). These images are subjected to image analysis with an image-analysis software "Image Pro Plus ver. 4.0" manufactured by Media Cybernetics. Then, areas of ferrite, graphite, and cementite are measured, and the proportions (area ratios) based on the whole observed area are defined as the volume ratio of each of ferrite, graphite, and cementite. Moreover, the proportion (area ratio) of the graphite area (Sgr) based on the sum of the graphite area (Sgr) and the cementite area (Scm) is defined as the volume ratio of graphite (ratio of graphite). More specifically, the ratio of graphite (%) can be represented by the following equation.

$$\text{Ratio of graphite} = \{Sgr/(Sgr + Scm)\} \times 100$$

[0032] Even when the total volume ratio of ferrite, graphite, and cementite and the ratio of graphite are merely controlled, excellent quench hardenability, especially quench hardenability at the time of performing induction quench hardening, is not always obtained. More specifically, in the present invention, in order to secure excellent quench hardenability, it is necessary to adjust the mean particle diameter of cementite and graphite to 5 μm or lower. More preferably, the mean particle diameter of cementite and graphite is adjusted to 3 μm or lower.

[0033] The present inventors have conducted various studies in order to obtain excellent quench hardenability. Hereinafter, an example of the studies will be described. More specifically, a steel slab containing C: 0.55%, Si: 0.01%, Mn: 0.10%, P: 0.003%, S: 0.0006%, Al: 0.005%, N: 0.0018%, Ni: 0.50%, B: 0.0013%, balance Fe, and inevitable impurities is heated to 1,150°C. Then, the resultant is subjected to rough rolling of 5 passes, and then subjected to finish rolling of 7 passes at a finishing temperature of 880°C to form a hot rolled sheet with a sheet thickness of 4.0 mm. Then, the hot rolled sheet is wound at a winding temperature of 430°C, washed with acid, and then subjected to batch annealing at 720°C for 40 hr. At this time, in order to change the grain diameters of cementite and graphite, cooling is performed after finish rolling while controlling the temperature range to the winding temperature at a mean cooling rate of from air-cooling (5°C/(s)) to 200 °C/s. Then, the microstructure and quench hardenability are examined as follows.

[0034] Similarly as described above, a steel sheet is ground at 1/4 position of the sheet thickness of a cross section parallel to the rolling direction of the steel sheet, and subjected to nital corrosion. Then, the cross section is observed under a scanning electron microscope (1,500x magnification) for 5 parts per visual field, i.e., 10 visual fields (Total: 50 parts). Using the above-mentioned image-analysis software, the diameter passing through two points on the outer circumference of cementite or graphite and the center of gravity of a substantially oval shape of cementite or graphite (ellipse having the same area as cementite and graphite and having the same primary and second moments as cementite and graphite) is measured twice, and then averaged to thereby determine each grain diameter. Then, grain diameters of cementite and graphite measured by observing 50 visual fields are averaged to be used as mean grain diameters of cementite and graphite.

[0035] Quench hardenability: A disc test sample having a diameter of 100 mm is extracted, the peripheral end of the disc test sample is heated to 1000°C using an induction heat treatment apparatus at a frequency of 100 kHz, and then the resultant is immediately water cooled. Then, the disc test sample after heat treatment is measured for Vickers hardness [Load: 49N (= 5 kgf)] of the front and rear surfaces 1.5 mm inside from the peripheral end at 8 places along the circumferential direction to obtain a difference ΔHv between the maximum Hv and the minimum Hv. When the ΔHv is 8 or lower, it can be said that the quench hardenability is excellent.

[0036] Fig. 1 shows the relationship between the mean grain diameter d and ΔHv of cementite and graphite. When the mean grain diameter d of cementite and graphite becomes 5 μm or lower, ΔHv becomes 8 or lower, which shows that excellent quench hardenability is obtained.

[0037] The present inventors have conducted various studies based on the above studies, and as a result, found that, in order to secure excellent quench hardenability, the mean grain diameter of cementite and graphite needs to be 5 μm or lower, and preferably 3 μm or lower. Thus, a reason why excellent quench hardenability is obtained by specifying a microstructure is considered as follows. More specifically, it is considered that, when the mean grain diameter of cementite and graphite become 5 μm or lower, cementite and graphite nearly thoroughly dissolve at the time of high frequency heating, and thus hardness after quench hardening is equalized.

3) Manufacturing conditions

[0038] Hereinafter, preferable manufacturing conditions of the steel sheet of the present invention will be described. It should be noted that the method for manufacturing a steel sheet of the present invention is not limited to the following methods.

Finishing temperature at the time of hot rolling: 800 to 950°C

[0039] When a finishing temperature at the time of hot rolling is lower than 800°C, a rolling load sharply increases. When the finishing temperature exceeds 950°C, a scale to be generated is thickened, pickling properties decrease, and a decarburized layer is manufactured on a steel sheet surface layer in some cases. Thus, the finishing temperature at the time of hot rolling is adjusted to 800 to 950°C.

Mean cooling rate after hot rolling: 50°C/s or higher

[0040] A steel sheet after hot rolling is immediately cooled to a cooling stop temperature mentioned later at a mean cooling rate of 50°C/s or more. When the mean cooling rate is lower than 50°C/s, ferrite grains easily grow during cooling to form large ferrite grains. It is considered that, at the time of annealing performed thereafter, graphite or cementite is formed with ferrite grain boundaries, inclusions, etc., as the nucleus. Thus, when ferrite grains are large, graphite or cementite which is formed with grain boundaries as the nucleus is coarsened, resulting in reduced quench hardenability. When the mean cooling rate is low, pearlites with coarse carbides are generated. Since graphite or cementite is formed through fragmentation, agglomeration, and coarsening of carbides in pearlites, graphite or cementite is coarsened, resulting in reduced quench hardenability. It should be noted that there are merits that, when the mean cooling rate is adjusted to 50°C/s or higher, rolling distortion introduced into austenite by hot rolling easily remains in a microstructure after modification to increase dislocation density, and graphite formation with such dislocation as the nucleus is promoted at the time of annealing. As described above, the mean cooling rate is 50°C/s or higher, and preferably 80°C/s or higher. The upper limit of the mean cooling rate is not necessary specified, and is preferably 200°C/s or lower so as to suppress deterioration of the shape of a steel sheet to secure the shape of the steel sheet.

Cooling stop temperature during cooling after hot rolling: 500°C or lower

[0041] When the lowest temperature which needs to be cooled at the above-mentioned cooling rate, i.e., cooling stop temperature, exceeds 500°C, pro-eutectoid ferrite generates during cooling until winding and a coarse pearlite generates. Thus, cementite or graphite is coarsened at the time of annealing after winding, reducing quench hardenability.

[0042] Thus, the cooling stop temperature is adjusted to 500°C or lower, and preferably 470°C or lower. The lower limit of the cooling stop temperature is not necessary specified, and is preferably 200°C or higher so as to secure the shape of a steel sheet.

Winding temperature = 450°C or lower

[0043] A hot rolled sheet after cooling is immediately wound. At the time of winding, when a winding temperature exceeds 450°C, a coarse pearlite generates, and thus cementite or graphite is coarsened at the time of annealing, resulting in reduced quench hardenability. Therefore, the winding temperature is adjusted to 450°C or lower. It should be noted that the winding temperature is preferably lower than the cooling stop temperature so as to sufficiently obtain the above-described cooling effects after hot rolling. Moreover, since the shape of a hot rolled sheet easily deteriorates, the winding temperature is preferably adjusted to 200°C or higher.

Annealing temperature: 720°C or lower

[0044] A hot rolled sheet after winding is washed with acid or the like to remove scales, and is annealed so as to promote spheroidizing or graphitization of cementite for softening. During the process, when the annealing temperature exceeds 720°C, a coarse pearlite generates during cooling, resulting in reduced quench hardenability. Thus, the annealing temperature is adjusted to 720°C or lower. When the annealing temperature is lower than 600°C, annealing time is excessively prolonged. Thus, the annealing temperature is preferably adjusted to 600°C or higher.

[0045] It should be noted that the annealing time is not necessary limited, and is preferably 8 hr or more so as to form graphite or 100 hr or lower because there is a possibility that ferrite grains may be excessively coarsened, resulting in reduced ductility.

[0046] For melting the steel of the present invention, both a converter and an electric furnace are usable. The steel thus melted is formed into a slab by ingot making-slabbing or continuous casting. A slab is generally hot rolled after heating (reheating). It should be noted that, in the case of a slab manufactured by continuous casting, the slab can be used as it is or may be subjected to direct rolling in which rolling is performed while maintaining heat so as to suppress reduction in temperature. When reheating a slab for hot rolling, it is preferable to adjust a slab heating temperature to 1,280°C or lower so as to avoid deterioration of the surface condition due to scales. The hot rolling can be carried out merely by finish rolling while omitting rough rolling. In order to secure a finishing temperature, a material to be rolled may be heated with a heating member, such as a sheet bar heater, during hot rolling. The sheet thickness of a hot rolled sheet is not limited insofar as the manufacturing conditions of the present invention can be maintained, and is preferably from 1.0 to 10.0 mm. The steel sheet after annealing can be subjected to temper rolling as required. A working example will be described in Example 1.

[0047] Simply by controlling the total volume ratio of ferrite, graphite, and cementite and the ratio of graphite, excellent stretch-flangeability is not always obtained. More specifically, in the present invention, the total volume ratio of cementite and graphite present in ferrite grains needs to be adjusted to 15% or lower in order to secure excellent stretch-flangeability. More preferably, the total volume ratio thereof is adjusted to 10% or lower.

[0048] The present inventors have conducted various studies in order to obtain excellent stretch-flangeability. An example of the studies will be described below. A steel slab containing C: 0.55%, Si: 0.01%, Mn: 0.10%, P: 0.003%, S: 0.0006%, Al: 0.005%, N: 0.0018%, Ni: 0.50%, B: 0.0013%, balance Fe, and inevitable impurities is heated to 1,150°C, subjected to rough rolling of 5 passes, subjected to finish rolling of 7 passes at a finishing temperature of 870°C to manufacture a hot rolled sheet having a sheet thickness of 4.0 mm. Then, the hot rolled sheet is wound at a winding temperature of 520°C, washed with acid, and subjected to batch annealing at 720°C for 40 hr. At this time, for the purpose of changing the amounts and distribution states of cementite and graphite, cooling is performed after finish rolling while changing the temperature range to the winding temperature at a mean cooling rate of from air-cooling (5°C/(s)) to 200°C/s. Then, the microstructure and stretch-flangeability are examined as follows.

[0049] Similarly as the above, a steel sheet is ground at 1/4 position of the sheet thickness of a cross section parallel to the rolling direction of the steel sheet, and subjected to nital corrosion. Then, the cross section is observed under an optical microscope (400x magnification) for 5 parts of the cross section, i.e., 10 visual fields (Total: 50 parts). Using the above-mentioned image-analysis software, cementite and graphite present on ferrite grain boundaries and cementite and graphite present in ferrite grains are distinguished. The occupation area S_{on} of cementite and graphite present on ferrite grain boundaries and the occupation area S_{in} of cementite and graphite present in ferrite grains are measured. The area ratio of cementite and graphite present in ferrite grains is measured according to the following equation to be used as a volume ratio S(%) of cementite and graphite present in ferrite grains based on the total of cementite and graphite. More specifically, S(%) can be represented by the following equation.

$$S = \{S_{in}/(S_{on} + S_{in}) \times 100$$

[0050] It should be noted that, with respect to cementite grains or graphite grains having a part present on ferrite grain boundaries, the whole area of each cementite grain or each graphite grain is measured as an occupation area of cementite grains or graphite grains present on ferrite grain boundaries. Moreover, the area of cementite grains or graphite grains not having a part present on ferrite grain boundaries is measured as an occupation area of cementite grains or graphite grains present in ferrite grains.

[0051] Stretch-flangeability: A test sample for a hole expanding test (100 × 100 mm) is extracted, and is punched using a punching tool having a punch diameter of 10 mm and a die diameter of 11.6 mm (clearance: sheet thickness of 20%) at the center of the test sample. Thereafter, the punched hole is pushed up using a cylindrical flat bottomed punch (diameter: 50 mmΦ, shoulder R: 8 mm) for hole expanding. Then, the hole diameter d (mm) at the time when through thickness cracks are formed at the hole edge is measured. Then, the hole expanding ratio λ(%) is calculated according to the equation. The same test is carried out 6 times to thereby obtain the mean ratio λ(%).

$$\lambda = 100 \times (d - 10)/10$$

[0052] Fig. 2 represents the relationship between the volume ratio S and the mean λ of cementite and graphite present in ferrite grains. It is revealed that when the volume ratio S of cementite and graphite present in ferrite grains becomes 15% or lower, the mean λ becomes 60% or more, and excellent stretch-flangeability is obtained.

[0053] The present inventors have conducted various studies based on the above studies, and, as a result, fount that, in order to secure excellent stretch-flangeability, the total volume ratio of cementite and graphite present in ferrite grains needs to be adjusted to 15% or lower, and preferably 10% or lower. The reason why excellent stretch-flangeability is obtained by specifying the microstructure as described above is considered as follows. More specifically, when a large amount of cementite or graphite is present in ferrite grains, fine cracks are likely to form at the interfaces between cementite or graphite and ferrite at the time of punching, and propagation and coalescence of cracks occur from the first stage of a hole expanding test, easily resulting in the formation of through thickness cracks. In contrast, the diffusion rate of carbon on ferrite grain boundaries is high, and thus an increase in agglomeration is promoted rather than inside ferrite grains. Thus, cementite or graphite on ferrite grain boundaries is likely to coarsen rather than cementite or graphite in ferrite grains, and the gap between each cementite grain and each graphite grain is likely to become broad. Therefore, cementite or graphite on ferrite grain boundaries slows down crack propagation compared with cementite or graphite in ferrite grains.

3) Manufacturing conditions

[0054] Hereinafter, preferable manufacturing conditions of the steel sheet of the present invention will be described. It should be noted that a method for manufacturing a steel sheet of the present invention is not limited to the following methods.

Finishing temperature at the time of hot rolling: 800 to 950°C

[0055] When the finishing temperature at the time of hot rolling is lower than 800°C, a rolling load sharply increases. When the finishing temperature at the time of hot rolling exceeds 950°C, a scale to be generated becomes thick, pickling properties decrease, and a decarburized layer may be formed on a steel sheet surface layer. Thus, the finishing temperature at the time of hot rolling is adjusted to 800 to 950°C.

Mean cooling rate after hot rolling: 50°C/s or more

[0056] When a steel sheet after hot rolling is immediately cooled to a cooling stop temperature mentioned later at a mean cooling rate of 50°C/s or more, formation of pro-eutectoid ferrite is suppressed and ferrite and cementite are finely precipitated. Therefore, c is likely to diffuse on ferrite grain boundaries at the time of annealing performed after winding, agglomeration and coarsening of cementite present on ferrite grain boundaries and graphitization thereof are promoted, cementite or graphite in ferrite grains decrease, and stretch-flangeability increases. Moreover, rolling distortion introduced into austenite with hot rolling is likely to remain in the microstructure after modification, resulting in an increase in dislocation density. As a result, the formation of graphite with dislocation as the nucleus becomes easy at the time of annealing and softening proceeds, resulting in increased formability. Considering the above, the mean cooling rate is adjusted to 50°C/s or more, and preferably 80°C/s or more. The upper limit of the mean cooling rate does not need to be specified, and is preferably adjusted to 200°C/s or lower in order to suppress deterioration of the shape of a steel sheet and secure the shape of a steel sheet.

Cooling stop temperature during cooling after hot rolling: 600°C or lower

[0057] The lowest temperature which needs to be cooled at the above-mentioned cooling rate, i.e., cooling stop temperature, exceeds 600°C, a pro-eutectoid ferrite generates during cooling to winding, a pearlite generates, cementite or graphite present in ferrite grains increases at the time of annealing after winding, and stretch-flangeability deceases. Thus, the cooling stop temperature is adjusted to 600°C or lower, and preferably 550°C or lower. The lower limit of the cooling stop temperature does not need to be specified, and is preferably adjusted to 200°C or higher in order to secure the shape of a steel sheet.

Winding temperature: 550°C or lower

[0058] A hot rolled sheet after cooling is immediately wound. When the winding temperature exceeds 550°C, a pearlite generates, cementite or graphite present in ferrite grains at the time of annealing increases, and stretch-flangeability decreases. Therefore, the winding temperature is adjusted to 550°C or lower. It should be noted that, in order to fully obtain the effects of cooling after hot rolling, it is preferable for the winding temperature to be lower than the cooling stop temperature. Since the shape of a hot rolled sheet is likely to deteriorate, in view of securing the shape of a steel sheet, the winding temperature is adjusted to preferably 200°C or higher, and more preferably exceeding 450°C.

Annealing temperature: 720°C or lower

[0059] A hot rolled sheet after winding is washed with acid to remove scales, and then is annealed in order to promote spheroidizing and graphitization of cementite for softening. When the annealing temperature exceeds 720°C, a pearlite generates during cooling and stretch-flangeability deceases. Thus, the annealing temperature is adjusted to 720°C or lower. When the annealing temperature is lower than 600°C, there is a tendency that cementite or graphite present in ferrite grains increases and stretch-flangeability deteriorates. Thus, the annealing temperature is adjusted to 600°C or higher.

[0060] It should be noted that the annealing time does not need to be specified, and is preferably 8 hr or more for forming graphite and reducing cementite or graphite present in ferrite grains. Moreover, there is a possibility that ferrite grains are excessively coarsened to reduce ductility, and thus the annealing time is preferably 100 hr or lower.

[0061] For melting the steel of the present invention, both a converter and an electric furnace are usable. The steel thus melted is formed into a slab by ingot making-slabbing or continuous casting. A slab is generally hot rolled after heating (reheating). It should be noted that, in the case of a slab manufactured by continuous casting, the slab can be used as it is, or may be subjected to direct rolling in which rolling is performed while maintaining heat so as to suppress reduction in temperature. When reheating a slab for hot rolling, it is preferable to adjust the slab heating temperature to 1,280°C or lower so as to avoid deterioration of the surface condition due to scales. The hot rolling can be carried out merely by finish rolling while omitting rough rolling. In order to secure a finishing temperature, a material to be rolled may be heated with a heating member, such as a sheet bar heater, during hot rolling. The sheet thickness of a hot rolled sheet is not limited insofar as the manufacturing conditions of the present invention can be maintained, and is preferably from 1.0 to 10.0 mm. The hot rolled sheet is washed with acid or subjected to shot blasting to remove scales on the surface, and then annealed. The steel sheet after annealing can be subjected to temper rolling as required. A working example will be described in Example 2.

EXAMPLES

EXAMPLE 1

[0062] Slabs of No. A to S steels having the compositions shown in Table 1 were heated to 1,250°C, hot rolled under the conditions shown in Table 2, washed with acid, and annealed under the conditions shown in Table 2 to manufacture No. 1 to 22 steel sheets having a sheet thickness of 4.0 mm. Then, a graphite ratio, a mean grain diameter of cementite and graphite, and ΔHv for evaluating quench hardenability were measured. Separately, a JIS No. 5 test piece for a tensile test was extracted along the rolling direction. Then, a tensile test was carried out, and a yield stress YP, a tensile strength Ts, and elongation El were measured.

[0063] The results are shown in Table 3. It is revealed that all the steel sheets of this example of the present invention have low YP, low TS, high El, and low ΔHv, are soft, and are excellent in formability and quench hardenability. It has been confirmed that the microstructure of each steel sheet of this example of the present invention basically contains ferrite, cementite, and graphite as shown in Table 3, and that the total volume ratio thereof needs to be 95% or more.

Table 1

											(mass%)
Steel No.	C	Si	Mn	P	S	Al	N	Ni	B	Cu	Remarks
A	0.35	0.08	0.06	0.010	0.0033	0.037	0.0031	-	-	-	Within the scope of the present invention
B	0.33	0.05	0.09	0.006	0.0032	0.023	0.0037	0.45	0.0023	-	Within the scope of the present invention
C	0.32	0.09	0.14	0.009	0.0040	0.026	0.0028	-	0.0017	-	Within the scope of the present invention
D	0.37	0.01	0.08	0.005	0.0037	0.025	0.0039	0.63	-	-	Within the scope of the present invention
E	0.36	0.02	0.15	0.007	0.0035	0.023	0.0042	0.47	0.0021	0.08	Within the scope of the present invention
F	0.33	0.07	0.11	0.009	0.0059	0.045	0.0035	-	-	0.07	Within the scope of the present invention
G	0.44	0.05	0.10	0.005	0.0041	0.029	0.0026	0.46	0.0033	0.06	Within the scope of the present invention
H	0.45	0.06	0.14	0.008	0.0044	0.036	0.0045	0.57	-	-	Within the scope of the present invention

(continued)

											(mass%)
Steel No.	C	Si	Mn	P	S	Al	N	Ni	B	Cu	Remarks
I	0.43	0.01	0.09	0.010	0.0025	0.010	0.0034	-	0.0029	-	Within the scope of the present invention the of the invention
J	0.46	0.05	0.08	0.005	0.0036	0.032	0.0033	-	-	0.06	Within scope present the of the invention
K	0.47	0.03	0.07	0.003	0.0028	0.005	0.0029	0.43	0.0024	-	Within scope present
L	0.44	0.08	0.10	0.032	0.0034	0.043	0.0041	-	-	-	Outside the scope of the present invention the invention
M	0.43	0.05	0.08	0.008	0.0044	0.035	0.0035	-	-	-	Within the scope of present the invention
N	0.54	0.03	0.07	0.007	0.0026	0.003	0.0017	0.52	0.0025	-	Within the scope of present
O	0.55	0.10	0.76	0.009	0.0037	0.023	0.0044	-	-	-	Outside the scope of the present invention
P	0.51	0.07	0.04	0.008	0.0021	0.025	0.0047	0.77	0.0015	0.03	Within the scope of the present invention
Q	0.58	0.07	0.09	0.007	0.0033	0.034	0.0029	-	-	-	Within the scope of the present invention
R	0.63	0.10	0.13	0.010	0.0046	0.028	0.0049	0.61	0.0026	-	Within the scope of the present invention
S	0.69	0.04	0.07	0.007	0.0040	0.031	0.0032	-	-	-	Within the scope of the present invention

Table 2

Steel sheet No.	Steel No.	Hot rolling conditions				Annealing conditions		Remarks
		Finishing temperature (°C)	Mean cooling rate (°C/s)	Cooling stop temperature (°C)	Winding temperature (°C)	Temperature (°C)	Time (hr)	
1	A	855	75	500	430	710	50	Example of the present invention
2	B	830	85	470	440	720	45	Example of the present invention
3	C	865	55	485	430	700	40	Example of the present invention
4	D	850	100	460	410	720	40	Example of the present invention
5	D	855	40	480	435	720	40	Comparative example
6	D	850	90	595	420	720	40	Comparative example
7	D	855	95	490	470	720	40	Comparative example
8	E	880	80	485	430	650	80	Example of the present invention
9	F	840	95	475	445	690	50	Example of the present invention
10	G	875	100	450	400	720	50	Example of the present invention
11	H	920	70	475	425	715	40	Example of the present invention
12	I	865	50	500	450	680	60	Example of the present invention
13	J	855	85	470	410	720	40	Example of the present invention
14	K	875	115	450	430	710	40	Example of the present invention
15	L	840	95	445	405	720	50	Comparative example

(continued)

Steel sheet No.	Steel No.	Hot rolling conditions				Annealing conditions		Remarks
		Finishing temperature (°C)	Mean cooling rate (°C/s)	Cooling stop temperature (°C)	Winding temperature (°C)	Temperature (°C)	Time (hr)	
16	M	855	85	460	430	720	40	Example of the present invention
17	N	850	90	460	400	720	40	Example of the present invention
18	O	845	95	440	415	720	50	Comparative example
19	P	865	55	465	435	700	60	Example of the present invention
20	Q	845	100	440	410	670	40	Example of the present invention
21	R	850	60	495	420	630	70	Example of the present invention
22	S	890	85	430	400	700	50	Example of the present invention

Table 3

Steel sheet No.	Steel No.	Microstructure			Tensile properties			ΔHv	Remarks
		Composition*	Ratio of graphite (%)	Mean grain diameter of cementite and graphite (μm)	YP (MPa)	TS (MPa)	El (%)		
1	A	F+G+C	16	4.5	152	330	53.8	6.6	Example of the present invention
2	B	F+G+C	25	3.0	138	314	53.7	4.7	Example of the present invention
3	C	F+G+C	19	4.2	153	333	51.0	7.1	Example of the present invention
4	D	F+G+C	16	2.1	137	311	54.5	1.4	Example of the present invention

(continued)

Steel sheet No.	Steel No.	Microstructure			Tensile properties			ΔHv	Remarks
		Composition*	Ratio of graphite (%)	Mean grain diameter of cementite and graphite (μm)	YP (MPa)	TS (MPa)	El (%)		
5	D	F+G+C	<u>3</u>	<u>7.8</u>	195	389	40.2	14.5	Comparative example
6	D	F+G+C	14	<u>8.3</u>	177	354	44.0	15.3	Comparative example
7	D	F+G+C	13	<u>10.4</u>	175	357	46.3	16.0	Comparative example
8	E	F+G+C	23	4.1	158	343	49.4	6.5	Example of the present invention
9	F	F+G+C	25	4.7	156	339	49.1	7.5	Example of the present invention
10	G	F+G+C	37	2.7	145	323	50.5	3.3	Example of the present invention
11	H	F+G+C	42	3.6	163	354	47.3	6.4	Example of the present invention
12	I	F+G+C	35	3.9	172	367	48.6	6.9	Example of the present invention
13	J	F+G+C	41	2.5	144	320	51.2	2.5	Example of the present invention
14	K	F+G+C	44	2.8	145	322	51.0	3.4	Example of the present invention
15	L	F+C	<u>3</u>	<u>8.4</u>	361	555	35.8	16.2	Comparative example
16	M	F+G+C	28	2.3	146	325	49.9	3.0	Example of the present invention
17	N	F+G+C	63	1.9	167	334	46.2	1.8	Example of the present invention
18	O	F+C	<u>2</u>	<u>9.1</u>	383	598	32.5	14.9	Comparative example
19	P	F+G+C	72	4.4	179	366	45.9	6.2	Example of the present invention

(continued)

Steel sheet No.	Steel No.	Microstructure			Tensile properties			ΔHv	Remarks
		Composition*	Ratio of graphite (%)	Mean grain diameter of cementite and graphite (μm)	YP (MPa)	TS (MPa)	El (%)		
20	Q	F+G+C	50	2.2	157	335	43.7	2.5	Example of the present invention
21	R	F+G+C	74	3.7	176	382	41.3	6.0	Example of the present invention
22	S	F+G+C	67	2.6	152	345	40.8	2.7	Example of the present invention
*: F: ferrite, G: graphite, C: cementite									

EXAMPLE 2

[0064] Slabs of No. AA to AS steels having the compositions shown in Table 4 were heated to 1,250°C, hot rolled under the conditions shown in Table 5, washed with acid, and annealed under the conditions shown in Table 5 to manufacture No. 101 to 122 steel sheets having a sheet thickness of 4.0 mm. Then, a ratio of graphite, the volume ratio S of cementite and graphite present in ferrite grains based on the total of cementite and graphite, and a mean λ which is an index of stretch-flangeability were measured by the above-mentioned method. Separately, a JIS No. 5 test piece for a tensile test was extracted along the rolling direction. Then, a tensile test was carried out, and a yield stress YP, a tensile strength Ts, and elongation El were measured. It should be noted that the same test was carried out twice for every test piece to obtain the mean value. Then, the mean value was defined as a property value of the steel sheet.

[0065] The results are shown in Table 6. It is revealed that all the steel sheets of this example of the present invention have low YP, low TS, high El, and high λ, are soft, and are excellent in formability including stretch-flangeability. It has been confirmed that the microstructure of each steel sheet of this example of the present invention basically contains ferrite, cementite, and graphite as shown in Table 6, and that the total volume ratio thereof needs to be 95% or more.

Table 4

Steel No.	C	Si	Mn	P	S	Al	N	Ni	B	Cu	Remarks
AA	0.36	0.01	0.01	0.008	0.0010	0.027	0.0023	-	-	-	Within the scope of the present invention
AB	0.32	0.08	0.08	0.007	0.0030	0.020	0.0034	0.46	0.0020	-	Within the scope of the present invention
AC	0.31	0.05	0.13	0.010	0.0033	0.028	0.0029	-	0.0015	-	Within the scope of the present invention

(continued)

Steel No.	C	Si	Mn	P	S	Al	N	Ni	B	Cu	Remarks
AD	0.36	0.01	0.10	0.006	0.0042	0.024	0.0037	0.59	-	-	Within the scope of the present invention
AE	0.35	0.03	0.14	0.008	0.0031	0.026	0.0039	0.51	0.0018	0.06	Within the scope of the present invention
AF	0.34	0.09	0.13	0.010	0.0067	0.042	0.0045	-	-	0.08	Within the scope of the present invention
AG	0.46	0.04	0.05	0.006	0.0038	0.025	0.0033	0.43	0.0024	0.05	Within the scope of the present invention
AH	0.44	0.09	0.12	0.010	0.0054	0.039	0.0042	0.55	-	-	Within the scope of the present invention
AI	0.47	0.03	0.10	0.009	0.0040	0.009	0.0035	-	0.0030	-	Within the scope of the present invention
AJ	0.45	0.05	0.07	0.007	0.0029	0.026	0.0028	-	-	0.07	Within the scope of the present invention
AK	0.46	0.01	0.07	0.002	0.0027	0.002	0.0035	0.40	0.0023	-	Within the scope of the present invention
AL	0.45	0.06	0.09	0.035	0.0030	0.034	0.0040	-	-	-	Outside the scope of the present invention
AM	0.45	0.04	0.10	0.008	0.0046	0.033	0.0039	-	-	-	Within the scope of the present invention
AN	0.55	0.01	0.10	0.001	0.0006	0.004	0.0016	0.50	0.0013	-	Within the scope of the present invention
AO	0.54	0.09	0.70	0.006	0.0039	0.025	0.0038	-	-	-	Outside the scope of the present invention

(continued)

Steel No.	C	Si	Mn	P	S	Al	N	Ni	B	Cu	Remarks
AP	0.53	0.08	0.03	0.007	0.0019	0.027	0.0044	0.67	0.0010	0.02	Within the scope of the present invention
AQ	0.57	0.10	0.10	0.006	0.0027	0.030	0.0039	-	-	-	Within the scope of the present invention
AR	0.62	0.09	0.14	0.010	0.0044	0.022	0.0047	0.60	0.0021	-	Within the scope of the present invention
AS	0.67	0.05	0.10	0.008	0.0037	0.029	0.0034	-	-	-	Within the scope of the present invention

Table 5

Steel sheet No.	Steel No.	Hot rolling conditions				Annealing		Remarks
		Finishing temperature (°C)	Mean cooling rate (°C/s)	Cooling stop temperature (°C)	Winding temperature (°C)	Temperature (°C)	Time (hr)	
101	AA	855	75	600	540	710	50	Example of the present invention
102	AB	830	85	540	520	720	45	Example of the present invention
103	AC	865	55	590	550	700	40	Example of the present invention
104	AD	850	100	550	530	720	40	Example of the present invention
105	AD	855	<u>40</u>	585	540	720	40	Comparative example
106	AD	850	90	<u>660</u>	535	720	40	Comparative example
107	AD	855	95	595	<u>580</u>	720	40	Comparative example
108	AE	880	80	580	525	650	80	Example of the present invention
109	AF	840	95	575	455	690	50	Example of the present invention

(continued)

Steel sheet No.	Steel No.	Hot rolling conditions				Annealing		Remarks
		Finishing temperature (°C)	Mean cooling rate (°C/s)	Cooling stop temperature (°C)	Winding temperature (°C)	Temperature (°C)	Time (hr)	
110	AG	875	100	530	500	720	50	Example of the present invention
111	AH	920	70	580	550	715	40	Example of the present invention
112	AI	865	50	595	530	680	60	Example of the present invention
113	AJ	855	85	545	510	720	40	Example of the present invention
114	AK	875	115	540	510	710	40	Example of the present invention
115	AL	840	95	530	510	720	50	Comparative example
116	AM	855	85	550	530	720	40	Example of the present invention
117	AN	850	90	530	520	720	40	Example of the present invention
118	AO	845	95	545	505	720	50	Comparative example
119	AP	865	55	585	545	700	60	Example of the present invention
120	AQ	845	100	550	525	670	40	Example of the present invention
121	AR	850	60	570	550	630	70	Example of the present invention
122	AS	890	85	540	515	700	50	Example of the present invention

Table 6

Steel sheet No.	Microstructure*	Ratio of graphite (%)	S (%)	Tensile properties			Average λ (%)	Remarks
				YP (MPa)	TS (MPa)	El (%)		
101	F+G+C	14	11	153	332	52.4	70	Example of the present invention
102	F+G+C	23	7	146	325	53.5	75	Example of the present invention
103	F+G+C	21	14	155	337	49.8	68	Example of the present invention
104	F+G+C	18	8	147	335	54.3	77	Example of the present invention
105	F+G+C	<u>3</u>	<u>30</u>	295	483	35.5	49	Comparative example
106	F+G+C	13	<u>35</u>	173	345	51.7	46	Comparative example
107	F+G+C	12	<u>25</u>	168	343	52.6	53	Comparative example
108	F+G+C	25	12	157	341	49.6	71	Example of the present invention
109	F+G+C	19	12	159	346	48.2	70	Example of the present invention
110	F + G + C.	46	9	157	348	49.9	69	Example of the present invention
111	F+G+C	39	13	164	356	45.3	62	Example of the present invention
112	F+G+C	43	13	165	350	47.4	61	Example of the present invention
113	F+G+C	37	10	156	347	50.7	65	Example of the present invention
114	F+G+C	48	8	155	344	51.5	67	Example of the present invention
115	F+C	<u>2</u>	<u>55</u>	359	553	33.9	36	Comparative example
116	F+G+C	35	9	157	349	49.6	66	Example of the present invention

(continued)

Steel sheet No.	Microstructure*	Ratio of graphite (%)	S (%)	Tensile properties YP (MPa)	TS (MPa)	El (%)	Average λ (%)	Remarks
117	F+G+C	67	8	193	385	45.1	64	Example of the present invention
118	F+C	1	40	364	568	31.2	32	Comparative example
119	F+G+C	77	14	179	365	43.5	60	Example of the present invention
120	F+G+C	52	7	178	379	42.7	63	Example of the present invention
121	F+G+C	76	13	175	381	40.6	55	Example of the present invention
122	F+G+C	69	10	167	380	41.3	57	Example of the present invention

*: F: ferrite, G: graphite, C: cementite

Claims

1. A steel sheet, comprising:

a composition containing, by mass %, C: 0.3 to 0.7%, Si: 0.1% or lower, Mn: 0.20% or lower, P: 0.01% or lower, S: 0.01% or lower, Al: 0.05% or lower, N: 0.0050% or lower, balance Fe, and inevitable impurities; and
a microstructure containing ferrite, graphite, and cementite,
the total volume ratio of ferrite, graphite, and cementite based on the whole microstructure being 95% or more, the volume ratio of graphite, i.e., ratio of graphite, based on the total of graphite and cementite being 5% or more, and the mean grain diameter of graphite and cementite being 5 μm or lower.

2. The steel sheet according to claim 1, comprising a composition further containing at least one member selected from Ni: 3.0 mass% or lower, B: 0.005 mass% or lower, and Cu: 0.1 mass% or lower.

3. A method for manufacturing a steel sheet, comprising:

hot rolling the steel having the composition according to claim 1 or 2 at a finishing temperature of from 800 to 950°C to manufacture a hot rolled sheet,
cooling the hot rolled sheet at a mean cooling rate of 50°C/s or more to a cooling temperature of 500°C or lower,
winding the resultant at a winding temperature of 450°C or lower, and
annealing the wound hot rolled sheet at an annealing temperature of 720°C or lower.

4. A steel sheet, comprising:

a composition containing, by mass %, C: 0.3 to 0.7%, Si: 0.1% or lower, Mn: lower than 0.15%, P: 0.01% or lower, S: 0.01% or lower, Al: 0.05% or lower, N: 0.0050% or lower, balance Fe, and inevitable impurities; and
a microstructure containing ferrite, graphite, and cementite,
the total volume ratio of ferrite, graphite, and cementite based on the whole microstructure being 95% or more, the volume ratio of graphite, i.e., ratio of graphite, based on the total of graphite and cementite being 5% or

more, and the total volume ratio of graphite and cementite present in ferrite grains based on the total of graphite and cementite being 15% or lower.

5. The steel sheet according to claim 4, comprising a composition further containing at least one member selected from Ni: 3.0 mass% or lower, B: 0.005 mass% or lower, and Cu: 0.1 mass% or lower.

6. A method for manufacturing a steel sheet, comprising:

hot rolling the steel having the composition according to claim 4 or 5 at a finishing temperature of from 800 to 950°C to manufacture a hot rolled sheet,
cooling the hot rolled sheet at a mean cooling rate of 50°C/s or more to a cooling temperature of 600°C or lower, winding the resultant at a winding temperature of 550°C or lower, and
annealing the wound hot rolled sheet at an annealing temperature of 720°C or lower.

FIG. 1

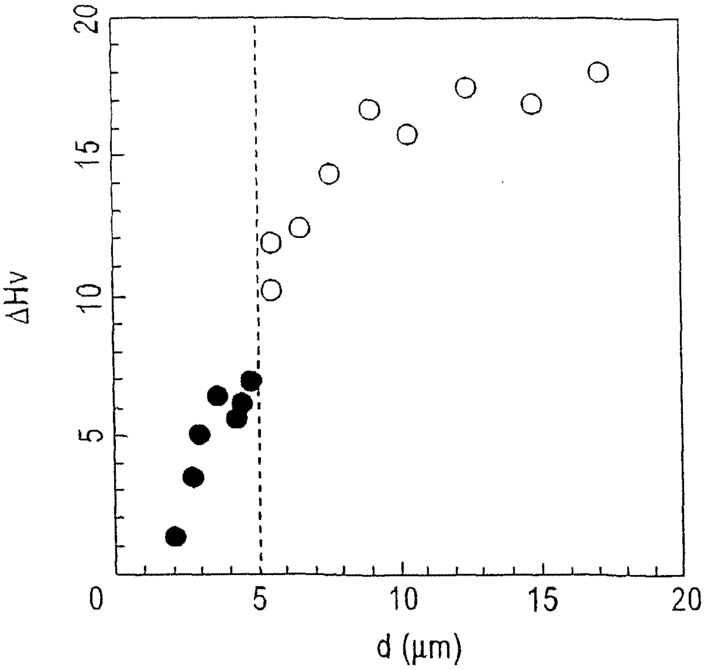
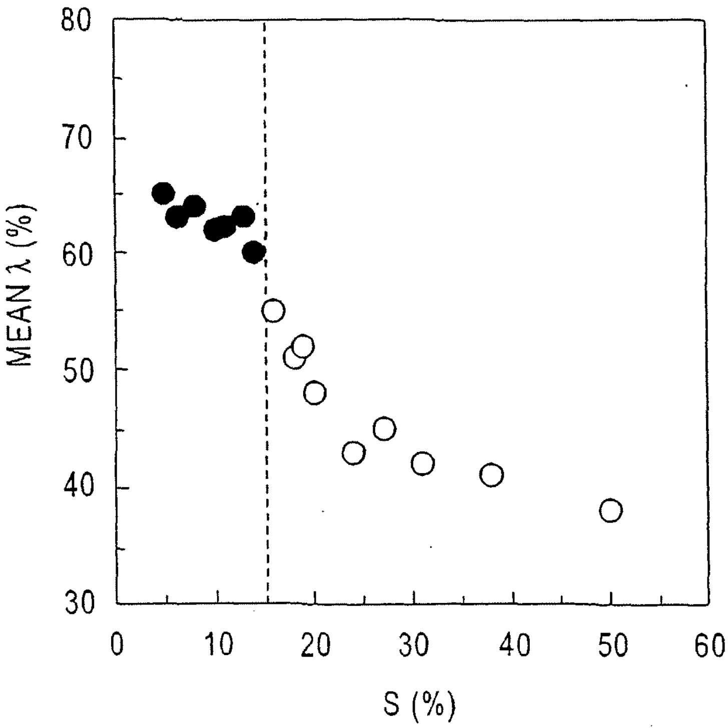

20
15
10
5
ΔHv
0
5
10
15
20
d (μm)

FIG. 2


80
70
60
50
40
30
MEAN λ (%)
0
10
20
30
40
50
60
S (%)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2008/071597

A. CLASSIFICATION OF SUBJECT MATTER
C22C38/00(2006.01)i, *B21B3/00*(2006.01)i, *C21D9/46*(2006.01)i, *C22C38/06*(2006.01)i, *C22C38/16*(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)
C22C1/00-49/14, B21B3/00, C21D9/46

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	1996-2009
Kokai Jitsuyo Shinan Koho	1971-2009	Toroku Jitsuyo Shinan Koho	1994-2009

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.
A	JP 4-311546 A (Kawasaki Steel Corp.), 04 November, 1992 (04.11.92), Full text (Family: none)	1-6
A	JP 9-13142 A (Kawasaki Steel Corp.), 14 January, 1997 (14.01.97), Full text (Family: none)	1-6
A	JP 2-107742 A (Kawasaki Steel Corp.), 19 April, 1990 (19.04.90), Full text (Family: none)	1-6

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
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"&" document member of the same patent family

Date of the actual completion of the international search 03 February, 2009 (03.02.09)	Date of mailing of the international search report 17 February, 2009 (17.02.09)
Name and mailing address of the ISA/ Japanese Patent Office Facsimile No.	Authorized officer Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No. PCT/JP2008/071597

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 4-124216 A (Sumitomo Metal Industries, Ltd.), 24 April, 1992 (24.04.92), Full text (Family: none)	1-6
A	JP 2007-39796 A (JFE Steel Corp.), 15 February, 2007 (15.02.07), Full text & WO 2007/000955 A1 & EP 1905851 A1	1-6

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REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- JP 1025946 A **[0004]**
- JP 7258743 A **[0004]**
- JP 4202744 A **[0004]**