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(54) **STEEL SHEET**
STAHLBLECH
TÔLE D'ACIER

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(73) Proprietor: **Nippon Steel Corporation**
Tokyo (JP)

(72) Inventors:
- **OKAMOTO, Riki**
  Tokyo 100-8071 (JP)
- **KAWATA, Hiroyuki**
  Tokyo 100-8071 (JP)
- **AZUMA, Masafumi**
  Tokyo 100-8071 (JP)
- **UENISHI, Akihiro**
  Tokyo 100-8071 (JP)
- **MARUYAMA, Naoki**
  Tokyo 100-8071 (JP)

(74) Representative: **Vossius & Partner**
Patentanwälte Rechtsanwälte mbB
Siebertstrasse 3
81675 München (DE)

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Description

TECHNICAL FIELD

[0001] The present invention relates to a steel sheet capable of obtaining an excellent crashworthiness suitable for an automobile member.

BACKGROUND ART

[0002] In the case of manufacturing an automotive vehicle body using a steel sheet, molding, welding, and paint baking of the steel sheet are performed generally. Thus, the steel sheet for automobile is required to have excellent formability, a high strength after paint baking, and an excellent crashworthiness. As a steel sheet used for an automobile, conventionally, a dual phase (DP) steel sheet having a dual phase structure of ferrite and martensite and a transformation induced plasticity (TRIP) steel sheet have been cited.

[0003] However, the DP steel sheet and the TRIP steel sheet have a problem that their mechanical properties after paint baking sometimes vary in a member. That is, in molding of the steel sheet, strain is applied according to the shape of a member to be obtained, and thus the molded steel sheet includes a portion with strain strongly applied thereto and a portion with less strain applied thereto. Then, as the applied strain is larger in the portion, the amount of strain age hardening by paint baking is larger and the hardness increases in the portion. As a result, the difference in yield strength after the paint baking is sometimes large between the portion with strain applied thereto and the portion with less strain applied thereto by molding. In this case, the portion with less strain applied thereto is soft and a break occurs in this portion, to thus fail to obtain a sufficient reaction force characteristic and crashworthiness. EP2757171 discloses a high-strength galvanized steel sheet having excellent formability and crashworthiness and a method for manufacturing the same. The galvanized steel sheet has a composition containing, by mass %, C: 0.05% or more and 0.5% or less, Si: 0.01% or more and 2.5% or less, Mn: 0.5% or more and 3.5% or less, P: 0.003% or more and 0.100% or less, S: 0.02% or less, Al: 0.010% or more and 0.5% or less, B: 0.0002% or more and 0.005% or less, Ti: 0.05% or less, a relationship of Ti >4N being satisfied, and the balance comprising Fe and inevitable impurities, and a microstructure containing 60% or more and 95% or less of tempered martensite in terms of area ratio and 5% or more and 20% or less of retained austenite in terms of area ratio, or further containing 10% or less of ferrite in terms of area ratio and/or 10% or less of martensite in terms of area ratio, the tempered martensite having an average grain diameter of 5 μm or less.

CITATION LIST

PATENT LITERATURE

[0004]

Patent Literature 1: Japanese Laid-open Patent Publication No. 2009-185355
Patent Literature 2: Japanese Laid-open Patent Publication No. 2011-111672
Patent Literature 3: Japanese Laid-open Patent Publication No. 2012-251239
Patent Literature 4: Japanese Laid-open Patent Publication No. 11-080878
Patent Literature 5: Japanese Laid-open Patent Publication No. 11-080879
Patent Literature 6: International Publication Pamphlet No. WO2013/047821 Japanese Laid-open Patent Publication No. 2011-132602
Patent Literature 7: Japanese Laid-open Patent Publication No. 2008-144233
Patent Literature 8: International Publication Pamphlet No. WO2012/070271

SUMMARY OF INVENTION

TECHNICAL PROBLEM

[0005] An object of the present invention is to provide a steel sheet capable of obtaining a stable yield strength after paint baking while obtaining good formability.

SOLUTION TO PROBLEM

[0006] The present inventors conducted earnest examinations in order to solve the above-described problems. As a result, they found out that in the case where a dislocation density in ferrite and a dislocation density in bainite are high, the yield strength improves by aging accompanying paint baking even in the portion with less strain applied thereto at the time of molding. They also found out that in the case of an average grain diameter of the ferrite and the bainite being small, the yield strength further improves by the aging.

[0007] As a result of further repeated earnest examinations based on such findings, the inventor of the present application devised various aspects of the following invention.

(1) A steel sheet, includes:

a chemical composition represented by,
in mass%,
C: 0.05% to 0.40%,
Si: 0.05% to 3.0%,
Mn: 1.5% to 4.0%,
Al: 1.5% or less,
N: 0.02% or less,
P: 0.2% or less,
S: 0.01% or less,
Nb and Ti: 0.005% to 0.2% in total,
V and Ta: 0.0% to 0.3% in total,
Cr, Mo, Ni, Cu, and Sn: 0.0% to 1.0% in total,
B: 0.00% to 0.01%,
Ca: 0.000% to 0.005%,
Ce: 0.000% to 0.005%,
La: 0.000% to 0.005%, and
the balance: Fe and impurities; and
a steel structure containing, in area fraction, 2% or more in total of ferrite and bainite, in which
an average dislocation density in the ferrite and an average dislocation density in the bainite are both 3×10^{12} m/m^3 to 1×10^{14} m/m^3, and
an average grain diameter of the ferrite and the bainite is 5 μm or less.

(2) The steel sheet according to (1), in which

the steel structure contains, in area fraction, ferrite and bainite: 2% to 60% in total and martensite: 10% to 90%,
an area fraction of retained austenite in the steel structure is 15% or less, and
a ratio of an area fraction of the ferrite to an area fraction of the martensite is 0.03 to 1.00.

(3) The steel sheet according to (1) or (2), in which in the chemical composition,
V and Ta: 0.01% to 0.3% in total is established.
(4) The steel sheet according to any one of (1) to (3), in which

in the chemical composition,
Cr, Mo, Ni, Cu, and Sn: 0.1% to 1.0% in total is established.

(5) The steel sheet according to any one of (1) to (4), in which

in the chemical composition,
B: 0.0003% to 0.01% is established.

(6) The steel sheet according to any one of (1) to (5), in which

in the chemical composition,
Ca: 0.001% to 0.005%,
Ce: 0.001% to 0.005%,
La: 0.001% to 0.005%, or
an arbitrary combination of these is established.

ADVANTAGEOUS EFFECTS OF INVENTION

[0008] According to the present invention, it is possible to obtain a stable yield strength even after paint baking because the average dislocation density in ferrite, the average dislocation density in bainite, and the like are appropriate.

DESCRIPTION OF EMBODIMENTS

[0009] Hereinafter, there will be explained an embodiment of the present invention.

[0010] First, there will be explained chemical compositions of the steel sheet according to the embodiment of the present invention and a steel to be used for its manufacture. Although its details will be described later, the steel sheet according to the embodiment of the present invention is manufactured by going through hot rolling, cold rolling, annealing, temper rolling, and so on of the steel. Thus, the chemical compositions of the steel sheet and the steel consider not only properties of the steel sheet, but also these treatments. In the following explanation, "%" being the unit of the content of each element contained in the steel sheet means "mass%" unless otherwise noted. The steel sheet according to this embodiment has a chemical composition represented by, in mass%, C: 0.05% to 0.40%, Si: 0.05% to 3.0%, Mn: 1.5% to 4.0%, Al: 1.5% or less, N: 0.02% or less, P: 0.2% or less, S: 0.01% or less, Nb and Ti: 0.005% to 0.2% in total, V and Ta: 0.0% to 0.3% in total, Cr, Mo, Ni, Cu, and Sn: 0.0% to 1.0% in total, B: 0.00% to 0.01%, Ca: 0.000% to 0.005%, Ce: 0.000% to 0.005%, La: 0.000% to 0.005%, and the balance: Fe and impurities. Examples of the impurities include ones contained in raw materials such as ore and scrap and ones contained in manufacturing steps.

(C: 0.05% to 0.40%)

[0011] C contributes to an improvement in tensile strength. When the C content is less than 0.05%, it is impossible to obtain a sufficient tensile strength, for example, a tensile strength of 980 MPa or more. Thus, the C content is 0.05% or more. The C content is preferably 0.08% or more so as to obtain a higher tensile strength. On the other hand, when the C content is greater than 0.40%, it is impossible to obtain a sufficient density dislocation in ferrite, and it is difficult to obtain a preferred steel structure. Thus, the C content is 0.40% or less. From the weldability viewpoint, the C content is preferably 0.35% or less.

(Si: 0.05% to 3.0%)

[0012] Si affects formation of iron carbides and age hardening accompanying this. When the Si content is less than 0.05%, it is impossible to obtain a sufficient content of solid-solution C, and the yield strength does not increase sufficiently even by aging accompanying paint baking. Thus, the Si content is 0.05% or more. The Si content is preferably 0.10% or more so as to further increase the yield strength. On the other hand, when the Si content is greater than 3.0%, it is impossible to obtain a sufficient density dislocation in ferrite, and it is difficult to obtain a preferred steel structure. Thus, the Si content is set to 3.0% or less. From the viewpoints of suppressing season cracking of a slab and suppressing edge cracking during hot rolling, the Si content is preferably 2.5% or less and more preferably 2.0% or less.

(Mn: 1.5% to 4.0%)

[0013] Mn suppresses transformation from austenite to ferrite, and contributes to an improvement in tensile strength. When the Mn content is less than 1.5%, it is impossible to obtain a sufficient tensile strength, for example, a tensile strength of 980 MPa or more. Thus, the Mn content is 1.5% or more. The Mn content is preferably 2.0% or more so as to obtain a higher tensile strength. On the other hand, when the Mn content is greater than 4.0%, it is impossible to obtain sufficient formability. Thus, the Mn content is 4.0% or less. The Mn content is preferably 3.5% or less so as to obtain more excellent formability.

(Al: 1.5% or less)

[0014] Al is not an essential element, but is used for deoxidation intended for reducing inclusions, for example, and is able to remain in the steel. When the Al content is greater than 1.5%, it is impossible to obtain ferrite or bainite having an average dislocation density in a later-described range. Thus, the Al content is 1.5% or less. Reducing the Al content is expensive, and thus, when the Al content is tried to be reduced down to less than 0.002%, its cost increases significantly. Therefore, the Al content may be set to 0.002% or more. After sufficient deoxidation is performed, Al, which is 0.01% or more, sometimes remains.

(N: 0.02% or less)

[0015] N is not an essential element, and is contained in the steel as an impurity, for example. When the N content is greater than 0.02%, nitrides in large amounts precipitate to fail to obtain sufficient formability. Thus, the N content is 0.02% or less. Reducing the N content is expensive, and thus, when the N content is tried to be reduced down to less than 0.001%, its cost increases significantly. Therefore, the N content may be set to 0.001% or more.

(P: 0.2% or less)

[0016] P is not an essential element, and is contained in the steel as an impurity, for example. When the P content is greater than 0.2%, P compounds in large amounts precipitate to fail to obtain sufficient formability. Thus, the P content is 0.2% or less. From the weldability viewpoint, the P content is preferably 0.07% or less. Reducing the P content is expensive, and thus, when the P content is tried to be reduced down to less than 0.001%, its cost increases significantly. Therefore, the P content may be set to 0.001% or more.

(S: 0.01% or less)

[0017] S is not an essential element, and is contained in the steel as an impurity, for example. When the S content is greater than 0.01%, sulfides in large amounts precipitate to fail to obtain sufficient formability. Thus, the S content is 0.01% or less. The S content is preferably 0.003% or less so as to more suppress the decrease in formability. Reducing the S content is expensive, and thus, when the S content is tried to be reduced down to less than 0.0002%, its cost increases significantly. Therefore, the S content may be set to 0.0002% or more.

(Nb and Ti: 0.005% to 0.2% in total)

[0018] Nb and Ti contribute to making crystal grains of ferrite or bainite fine and precipitation strengthening of ferrite or bainite. Nb and Ti form (Ti, Nb) carbonitrides, and thus, according to the contents of Nb and Ti, the content of solid-solution C and the content of solid-solution N after annealing change. When the total content of Nb and Ti is less than 0.005%, it is impossible to obtain ferrite or bainite having an average grain diameter in a later-described range, and the yield strength does not increase sufficiently even by aging accompanying paint baking. Thus, the total content of Nb and Ti is 0.005% or more. The total content of Nb and Ti is preferably 0.010% or more so as to sufficiently increase the yield strength by the aging. On the other hand, when the total content of Nb and Ti is greater than 0.2%, (Ti, Nb) carbonitrides in large amounts precipitate to fail to obtain sufficient formability. Thus, the total content of Nb and Ti is 0.2% or less. The total content of Nb and Ti is preferably 0.1% or less.

[0019] V, Ta, Cr, Mo, Ni, Cu, Sn, B, Ca, Ce, and La are not an essential element, but are an arbitrary element that may be appropriately contained, up to a predetermined amount as a limit, in the steel sheet and the steel.

(V and Ta: 0.0% to 0.3% in total)

[0020] V and Ta contribute to an improvement in strength by formation of carbides, nitrides, or carbonitrides and grain refining of ferrite and bainite. Thus, V or Ta, or the both of these may be contained. However, when the total content of V and Ta is greater than 0.3%, carbonitrides in large amounts precipitate and ductility decreases. Thus, the total content of V and Ta is 0.3% or less. From the viewpoints of suppressing season cracking of a slab and suppressing edge cracking during hot rolling, the total content of V and Ta is preferably 0.1% or less. The total content of V and Ta is preferably 0.01% or more so as to securely obtain an effect by the above-described functions.

(Cr, Mo, Ni, Cu, and Sn: 0.0% to 1.0% in total)

[0021] Cr, Mo, Ni, Cu, and Sn are used in order to suppress transformation from austenite to ferrite, similarly to Mn. Thus, Cr, Mo, Ni, Cu, or Sn, or an arbitrary combination of these may be contained. However, when the total content of Cr, Mo, Ni, Cu, and Sn is greater than 1.0%, workability deteriorates significantly and elongation decreases. Thus, the total content of Cr, Mo, Ni, Cu, and Sn is 1.0% or less. From the manufacturability viewpoint, the total content of Cr, Mo, Ni, Cu, and Sn is preferably 0.5% or less. The content of Cr, Mo, Ni, Cu, and Sn is preferably 0.1% or more so as to securely obtain an effect by the above-described functions.

(B: 0.00% to 0.01%)

[0022] B increases hardenability of the steel sheet, suppresses formation of ferrite, and promotes formation of martensite. Thus, B may be contained. However, when the B content is greater than 0.01% in total, boride in large amounts precipitates to fail to obtain sufficient formability. Thus, the B content is 0.01% or less. The B content is preferably 0.003% or less in total so as to more suppress the decrease in ductility. The B content is preferably 0.0003% or more so as to securely obtain an effect by the above-described functions.

(Ca: 0.000% to 0.005%, Ce: 0.000% to 0.005%, La: 0.000% to 0.005%)

[0023] Ca, Ce, and La make oxides and sulfides in the steel sheet fine and change properties of oxides and sulfides, to thereby suppress the decrease in workability, particularly, elongation. Thus, Ca, Ce, or La, or an arbitrary combination of these may be contained. However, when any one of the Ca content, the Ce content, and the La content is greater than 0.005%, an effect by the above-described functions is saturated and the cost increases needlessly, and at the same time, the formability decreases. Thus, the Ca content, the Ce content, and the La content each are 0.005% or less. The Ca content, the Ce content, and the La content each are preferably 0.003% or less so as to more suppress the decrease in formability. The Ca content, the Ce content, and the La content each are preferably 0.001% or more so as to securely obtain an effect by the above-described functions. That is, "Ca: 0.001% to 0.005%," "Ce: 0.001% to 0.005%," or "La: 0.001% to 0.005%," or an arbitrary combination of these is preferably satisfied.

[0024] Next, there will be explained a steel structure of the steel sheet according to the embodiment of the present invention. In the following explanation, "%" being the unit of a proportion of a phase or structure composing the steel structure means "area%" of an area fraction unless otherwise noted. The steel structure of the steel sheet according to the embodiment of the present invention contains, in area fraction, 2% or more in total of ferrite and bainite. The average dislocation density in the ferrite and the average dislocation density in the bainite are both 3×10^{12} m/m^3 to 1×10^{14} m/m^3, and the average grain diameter of the ferrite and the bainite is 5 μm or less.

[0025] As described above, the present inventors revealed that in the case of the dislocation density in the ferrite and the dislocation density in the bainite being high, the yield strength improves by the aging accompanying paint baking even in a portion with less strain applied thereto at the time of molding. When the average dislocation density in the ferrite, or the average dislocation density in the bainite, or the both of these are less than 3×10^{12} m/m^3, the yield strength in the portion with less strain applied thereto at the time of molding does not improve sufficiently by the aging to fail to obtain a sufficient crashworthiness. Thus, the average dislocation density in the ferrite and the average dislocation density in the bainite are both 3×10^{12} m/m^3 or more. The average dislocation density in the ferrite and the average dislocation density in the bainite are both preferably 6×10^{12} m/m^3 or more so as to obtain a more excellent crashworthiness. When the average dislocation density in the ferrite, or the average dislocation density in the bainite, or the both of these are greater than 1×10^{14} m/m^3, the formability decreases and the yield strength in the portion with less strain applied thereto at the time of molding does not improve sufficiently by the aging, to fail to obtain a sufficient crashworthiness in some cases. Thus, the average dislocation density in the ferrite and the average dislocation density in the bainite are both 1×10^{14} m/m^3 or less. The average dislocation density in the ferrite and the average dislocation density in the bainite are both preferably 8×10^{13} m/m^3 or less so as to obtain more excellent formability and crashworthiness.

[0026] The average dislocation density in the ferrite and the average dislocation density in the bainite can be obtained by using a transmission electron microscopy (TEM) photograph, for example. That is, a TEM photograph of a thin film sample is prepared, an arbitrary line is drawn on this TEM photograph, and in the case of trying to obtain the average dislocation density in the ferrite, the place where this line intersects with a dislocation line in the ferrite is counted. Then, when the length of the line in the ferrite is set to L, the number of places where the line and the dislocation line intersect in the ferrite is set to N, and the thickness of the sample is set to t, the dislocation density in the ferrite in the thin film sample is expressed as "2N/(Lt)." TEM photographs taken at plural places of the thin film sample are used, and an average value of dislocation densities obtained from these plural TEM photographs is obtained as the average dislocation density in the ferrite. As the thickness t of the sample, an actual measured value may be used, or 0.1 μm may be used simply. The average dislocation density in the bainite can be obtained by a method similar to the method of obtaining the average dislocation density in the ferrite as long as an intersecting place is counted in the bainite and the length of a line in the bainite is used.

[0027] As described above, the present inventors revealed that in the case of the grain diameter of the ferrite and the bainite being small, the yield strength further improves by the aging. When the average grain diameter of the ferrite and the bainite is greater than 5 μm, the yield strength of the portion with less strain applied thereto at the time of molding does not improve sufficiently by the aging to fail to obtain a sufficient crashworthiness. Thus, the average grain diameter of the ferrite and the bainite is 5 μm or more. The average grain diameter of the ferrite and the bainite is preferably 3 μm or less so as to obtain a more excellent crashworthiness.

[0028] If the total area fraction of the ferrite and the bainite is less than 2%, it is impossible to obtain sufficient formability and it is impossible to obtain sufficient collision performance even though the average dislocation density in the ferrite and the average dislocation density in the bainite are both 3×10^{12} m/m^3 to 1×10^{14} m/m^3 and the average grain diameter of the ferrite and the bainite is 5 μm or less. Thus, the total area fraction of the ferrite and the bainite is 2% or more. The total area fraction of the ferrite and the bainite is preferably 5% or more so as to obtain more excellent formability and collision performance.

[0029] In the present application, the ferrite includes polygonal ferrite (ap), quasi-polygonal ferrite (aq), and granular bainitic ferrite (aB), and the bainite includes lower bainite, upper bainite, and bainitic ferrite (α° B). The granular bainitic ferrite has a recovered dislocation substructure containing no laths, and the bainitic ferrite has a structure having no precipitation of carbides and containing bundles of laths, and prior γ grain boundaries remain as they are (see Reference: "Atlas for Bainitic Microstructures-1" The Iron and Steel Institute of Japan (1992) p. 4). This reference includes the description "Granular bainitic ferrite structure; dislocated substructure but fairly recovered like lath-less" and the description "sheaf-like with laths but no carbide; conserving the prior austenite grain boundary."

[0030] The ferrite and the bainite contribute also to the improvement in formability of the steel sheet. However, when the total area fraction of the ferrite and the bainite is greater than 60%, it is sometimes impossible to obtain a sufficient crashworthiness. Thus, the total area fraction of the ferrite and the bainite is preferably 60% or less. The total area fraction of the ferrite and the bainite is further preferably 40% or less so as to obtain a more excellent crashworthiness.

[0031] Martensite contributes to securing of the tensile strength. When an area fraction of the martensite is less than 10%, it is impossible to obtain a sufficient tensile strength, for example, a tensile strength of 980 MPa or more, and the average dislocation density in the ferrite is brought to less than 3×10^{12} m/m^3 in some cases. Thus, the area fraction of the martensite is preferably 10% or more. The area fraction of the martensite is further preferably 15% or more so as to obtain a more excellent tensile strength and crashworthiness. On the other hand, when the area fraction of the martensite is greater than 90%, the average dislocation density in the ferrite, or the average dislocation density in the bainite, or the both of these are brought to greater than 1×10^{14} m/m^3 and it becomes impossible to obtain sufficient ductility in some cases. Thus, the area fraction of the martensite is preferably 90% or less. The area fraction of the martensite is further preferably 85% or less so as to obtain more excellent collision performance and ductility. The martensite includes as-quenched martensite and tempered martensite, and 80 area% or more to the whole martensite is desired to be the tempered martensite.

[0032] When a ratio (f_F/f_M) of an area fraction f_F of the ferrite to an area fraction f_M of the martensite is less than 0.03, the average dislocation density in the ferrite is brought to greater than 1×10^{14} m/m^3 and it is impossible to obtain sufficient ductility in some cases. Thus, the ratio (f_F/f_M) is preferably 0.03 or more. The ratio (f_F/f_M) is further preferably 0.05 or more so as to obtain more excellent collision performance and ductility. On the other hand, when the ratio (f_F/f_M) is greater than 1.00, the average dislocation density in the ferrite is sometimes brought to less than 3×10^{12} m/m^3. Thus, the ratio (f_F/f_M) is preferably 1.00 or less. The ratio (f_F/f_M) is further preferably 0.80 or less so as to obtain more excellent collision performance.

[0033] Retained austenite is effective for an improvement in formability and an improvement in impact energy absorption characteristic. The retained austenite contributes also to an increase in amount of strain age hardening to occur at the time of paint baking. However, when an area fraction of the retained austenite is greater than 15%, the average dislocation density in the ferrite is brought to greater than 1×10^{14} m/m^3 and the steel sheet becomes brittle after molding in some cases. Thus, the area fraction of the retained austenite is preferably 15% or less. The area fraction of the retained austenite is further preferably 12% or less so as to obtain a more excellent crashworthiness and toughness. When the area fraction of the retained austenite is 2% or more, it is possible to expect an effect of the increase in amount of strain age hardening.

[0034] As an example to be contained in the steel structure other than the ferrite, the bainite, the martensite, and the retained austenite, pearlite can be cited. An area fraction of the pearlite is preferably 2% or less.

[0035] Area ratios of ferrite, bainite, martensite, and pearlite can be measured by a point counting method or an image analysis while using a steel structure photograph taken by an optical microscope or a scanning electron microscopy (SEM), for example. Distinction between the granular bainitic ferrite (a B) and the bainitic ferrite (α° B) can be performed based on the descriptions of the reference after a structure is observed by a SEM and a transmission electron microscope (TEM).

[0036] The area fraction of the retained austenite can be measured by an electron backscatter diffraction (EBSD) method or an X-ray diffractometry, for example. In the case of measurement by the X-ray diffractometry, it is possible to calculate the area fraction (f_A) of the retained austenite from the following expression after measuring a diffraction intensity (a (111)) of the (111) plane of ferrite, a diffraction intensity (γ(200)) of the (200) plane of retained austenite, a diffraction intensity (a (211)) of the (211) plane of ferrite, and a diffraction intensity (γ(311)) of the (311) plane of retained austenite by using a Mo-Kα line.

$$f_A = (2/3)\{100/(0.7 \times \alpha(111)/\gamma(200) + 1)\} + (1/3)\{100/(0.78 \times \alpha(211)/\gamma(311) + 1)\}$$

[0037] Next, there will be explained mechanical properties of the steel sheet according to the embodiment of the present invention.

[0038] The steel sheet according to this embodiment preferably has a tensile strength of 980 MPa or more. This is because in the case of the tensile strength being less than 980 MPa, it is difficult to obtain an advantage of a reduction in weight achieved by the strength of a member being increased.

[0039] The crashworthiness after molding and paint baking of the steel sheet can be evaluated by a parameter P_1 expressed by (Expression 1). "YS_{BH5}" is a yield strength (MPa) after aging in the case of a 5%-tensile prestrain being applied, "YS_{BH0}" is a yield strength (MPa) after aging in the case of no tensile prestrain being applied, and "TS" is the maximum tensile strength (MPa). The temperature of the aging is 170°C, and its time period is two hours. The parameter P_1 is equivalent to the ratio of the difference between the yield strength YS_{BH5} after paint baking in a portion with the prestrain applied thereto and the yield strength YS_{BH0} after paint baking in a portion with no prestrain applied thereto to the maximum tensile strength TS. The smaller value of the parameter P_1 means that the difference in yield strength in a member obtained through molding and paint baking is small. The reason why the magnitude of the tensile prestrain is set to 5% is because it is considered that a molding strain of 5% or more is generally introduced into a bending portion and a drawing portion in the manufacture of an automobile frame member. In the case of the value of the parameter P_1 being greater than 0.27, buckling or deformation occurs from a locally low hardness portion when the member manufactured through molding and paint baking receives collision to be subjected to deformation, and thus it is sometimes impossible to obtain an appropriate reaction force characteristic and energy absorption amount. Therefore, the value of the parameter P_1 is preferably 0.27 or less. The value of the parameter P_1 is further preferably 0.18 or less so as to obtain more excellent collision performance.

$$P_1 = (YS_{BH5} - YS_{BH0})/TS \ldots \text{(Expression 1)}$$

[0040] The formability of the steel sheet can be evaluated by a parameter P_2 expressed by (Expression 2). "uEl" is uniform elongation (%) obtained by a tensile test, and correlates with stretch formability (stretchability), stretch flangeability, and drawability. When the value of the parameter P_2 is less than 7000, cracking often occurs by molding or collision, which is difficult to contribute to a reduction in weight of an automobile member. Therefore, the value of the parameter P_2 is preferably 7000 or more. The value of the parameter P_2 is further preferably 8000 or more so as to obtain more excellent formability.

$$P_2 = TS \times uEL \ldots \text{(Expression 2)}$$

[0041] Next, there will be explained a method of manufacturing the steel sheet according to the embodiment of the present invention. When manufacturing the steel sheet according to the embodiment of the present invention, controls of particularly, the average grain diameter of the ferrite and the bainite, the average dislocation density in the ferrite, and the average dislocation density in the bainite are extremely important. As a result that the present inventors earnestly examined these controls, it became clear that it is possible to introduce dislocation into the ferrite and the bainite by using cubical expansion accompanying a martensite transformation, and the average dislocation density depends on the temperature at which the martensite is formed and the content of martensite. It also became clear that the average dislocation density in the bainite also depends on the temperature at which the bainite is formed. It also became clear that it is possible to control the average dislocation density in the ferrite and the average dislocation density in the bainite by adjusting an elongation ratio of temper rolling and a line load/tension ratio in the temper rolling. Thus, in this manufacturing method, there are performed hot rolling, cold rolling, annealing, temper rolling, and so on of the steel having the above-described chemical composition.

[0042] First, a slab having the above-described chemical composition is manufactured to be subjected to hot rolling. The slab to be subjected to hot rolling can be manufactured by a continuous casting method, a blooming method, a thin slab caster, or the like, for example. Such a process as continuous casting-direct rolling in which hot rolling is performed immediately after casting may be employed.

[0043] When the temperature of slab heating is less than 1100°C, remelting of carbonitrides precipitated during casing sometimes becomes insufficient. Thus, the slab heating temperature is set to 1100°C or more. After the slab heating, rough rolling and finish rolling are performed. The condition of the rough rolling is not limited in particular, and the rough rolling can be performed by a conventional method, for example. A reduction ratio, a time period between passes, and a rolling temperature in the finish rolling are not limited in particular, but the finish rolling temperature is preferably set to an Ar_3 point or more. The condition of descaling is also not limited in particular, and the descaling can be performed by a conventional method, for example.

[0044] After the finish rolling, the steel sheet is cooled to be coiled. When a coiling temperature is greater than 680°C, it is impossible to bring the average grain diameter of the ferrite and the bainite to 5 μm or less, and the yield strength does not increase sufficiently even by the aging accompanying paint baking in some cases. Thus, the coiling temperature is set to 680°C or less.

[0045] After the coiling, the steel sheet is cooled to be subjected to pickling and cold rolling. Annealing may be performed between the pickling and the cold rolling. When the temperature of this annealing is greater than 680°C, it is impossible to bring the average grain diameter of the ferrite and the bainite to 5 μm or less, and the yield strength does not increase sufficiently even by the aging accompanying paint baking in some cases. Thus, when the annealing is performed between the pickling and the cold rolling, the temperature is set to 680°C or less. For this annealing, for example, a continuous annealing furnace or a batch annealing furnace can be used.

[0046] The number of rolling passes of the cold rolling is not limited in particular, and is set to the same as that in a conventional method. When a reduction ratio of the cold rolling is less than 30%, it is impossible to bring the average grain diameter of the ferrite and the bainite to 5 μm or less, and the yield strength does not increase sufficiently even by the aging accompanying paint baking in some cases. Thus, the reduction ratio of the cold rolling is set to 30% or more.

[0047] After the cold rolling, annealing is performed. When the maximum temperature of this annealing is less than $(Ac_3 - 60)$°C, the contents of C and N solid-solutions become short, the yield strength does not increase sufficiently even by the aging accompanying paint baking, and it is difficult to obtain a preferred steel structure. Thus, the maximum temperature is set to $(Ac_3 - 60)$°C or more. The maximum temperature is preferably set to $(Ac_3 - 40)$°C or more in order to obtain a more excellent crashworthiness. On the other hand, when the maximum temperature is greater than 900°C, it is impossible to bring the average grain diameter of the ferrite and the bainite to 5 μm or less, and the yield strength does not increase sufficiently even by the aging accompanying paint baking in some cases. Thus, the maximum temperature is set to 900°C or less. The maximum temperature is preferably set to 870°C or less in order to obtain a more excellent crashworthiness. A holding time period at the maximum temperature is preferably set to three seconds to 200 seconds in order to bring the average grain diameter of the ferrite and the bainite to 5 μm or less. Particularly, the holding time period is preferably set to 10 seconds or more and 180 seconds or less.

[0048] In cooling after the annealing after the cold rolling, an average cooling rate between 700°C and 550°C is set to 4°C/s to 50°C/s. When this average cooling rate is less than 4°C/s, the average dislocation density in the bainite is brought to less than 3×10^{12} m/m^3. On the other hand, when this average cooling rate is greater than 50°C/s, the average dislocation density in the bainite is brought to greater than 1×10^{14} m/m^3. Thus, this average cooling rate is set to 4°C/s to 50°C/s.

[0049] Next, temper rolling of the steel sheet is performed. The temper rolling is performed under the condition that a parameter P_3 expressed by (Expression 3) is 2 or more and an elongation ratio is 0.10% to 0.8%. "A" is a line load (N/m) and "B" is a tension (N/m^2) to be applied to the steel sheet.

$$P_3 = B/A \quad \ldots \text{(Expression 3)}$$

[0050] The parameter P_3 affects the uniformity of dislocation densities in the steel sheet. When the parameter P_3 is less than 2, a sufficient dislocation is not introduced into the ferrite in a sheet thickness center portion of the steel sheet, and the yield strength does not increase sufficiently even by the aging accompanying paint baking in some cases. Thus, the parameter P_3 is set to 2 or more. The parameter P_3 is preferably set to 10 or more in order to obtain a more excellent crashworthiness.

[0051] When the elongation ratio of the temper rolling is less than 0.10%, a sufficient dislocation is not introduced into the ferrite, and the yield strength does not increase sufficiently even by the aging accompanying paint baking in some cases. Thus, the elongation ratio is set to 0.10% or more. The elongation ratio is preferably set to 0.20% or more in order to obtain a more excellent crashworthiness. On the other hand, when the elongation ratio is greater than 0.8%, it is sometimes impossible to obtain sufficient formability. Thus, the elongation ratio is set to 0.8% or less. The elongation ratio is preferably set to 0.6% or less in order to obtain more excellent formability.

[0052] In this manner, it is possible to manufacture the steel sheet according to the embodiment of the present invention.

[0053] Between the annealing after the cold rolling and the temper rolling, a plating treatment may be performed on the steel sheet. The plating treatment may be performed in a plating line provided in a continuous annealing line, or performed in a line exclusive to plating, which is different from the continuous annealing line, for example. The composition of plating is not limited in particular. As the plating treatment, for example, a hot-dip plating treatment, an alloying hot-dip plating treatment, or an electroplating treatment can be performed.

[0054] According to this embodiment, since the average dislocation density in the ferrite and the average dislocation density in the bainite, and the like are appropriate, it is possible to obtain a stable yield strength after paint baking.

[0055] It should be noted that the above-described embodiment merely illustrates concrete examples of implementing the present invention, and the technical scope of the present invention is not to be construed in a restrictive manner by these. That is, the present invention may be implemented in various forms without departing from the technical spirit or main features thereof.

EXAMPLE

[0056] Next, there will be explained examples of the present invention. Conditions of the examples are condition examples employed for confirming the applicability and effects of the present invention, and the present invention is not limited to these condition examples. The present invention can employ various conditions as long as the object of the present invention is achieved without departing from the spirit of the invention.

(First test)

[0057] In the first test, steels having chemical compositions illustrated in Table 1 were melted to manufacture steel billets, and these steel billets were heated to 1200°C to 1250°C to be subjected to hot rolling. In the hot rolling, rough rolling and finish rolling were performed. Each blank space in Table 1 indicates that the content of a corresponding element was less than a detection limit, and the balance is Fe and impurities. Each underline in Table 1 indicates that a corresponding numerical value is outside the range of the present invention.

[Table 1]

Table 1

STEEL SYMBOL	C	Si	Mn	Al	N	P	S	Ti	Nb	B	Cr	Ni	Cu	Mo	Ca	La	Ce	V	Ta	Sn
A	0.13	0.3	2.7	0.03	0.002	0.015	0.002	0.04	0.02											
B	0.11	0.1	2.4	0.3	0.002	0.015	0.002	0.03	0.05	0.001										
C	0.19	1.3	2.1	0.05	0.002	0.015	0.002	0.04		0.001	0.2									
D	0.22	1.4	2.0	0.04	0.002	0.015	0.002	0.02				0.4	0.5							
E	0.20	1.8	2.5	0.08	0.002	0.015	0.002	0.06	0.02					0.15	0.002					
F	0.30	1.7	2.4	0.03	0.002	0.015	0.002		0.03	0.001						0.001	0.002			
G	0.33	1.4	2.4	0.8	0.002	0.015	0.002	0.06	0.05									0.10	0.01	
H	0.18	1.3	2.3	0.1	0.002	0.015	0.002	0.06				0.1								0.1
I	0.04	1.3	2.3	0.1	0.002	0.015	0.002	0.04												
J	0.41	1.3	2.3	0.1	0.002	0.015	0.002	0.04												
K	0.18	0.01	2.3	0.1	0.002	0.015	0.002	0.04												
L	0.18	3.1	2.3	0.1	0.002	0.015	0.002	0.04												
M	0.18	1.3	1.2	0.1	0.002	0.015	0.002	0.04												
N	0.18	1.3	4.2	0.1	0.002	0.015	0.002	0.04												
O	0.18	1.3	2.3	1.7	0.002	0.015	0.002	0.04												
P	0.18	1.3	2.3	0.1	0.023	0.015	0.002	0.04												
Q	0.18	1.3	2.3	0.1	0.002	0.210	0.002	0.04												
R	0.18	1.3	2.3	0.1	0.002	0.015	0.011	0.04												
S	0.18	1.3	2.3	0.1	0.002	0.015	0.002	0.22												
T	0.18	1.3	2.3	0.1	0.002	0.015	0.002	0.04	0.18											
U	0.18	1.3	2.3	0.1	0.002	0.015	0.002	0.001												

[0058] Hot-rolled steel sheets obtained by the hot rolling were cooled to be coiled at 550°C to 700°C. Then, pickling of the hot-rolled steel sheets was performed to remove scales. Thereafter, cold rolling was performed at a reduction ratio of 25% to 70%, to thereby obtain cold-rolled steel sheets each having a thickness of 1.2 mm. Between the pickling and the cold rolling, annealing at 550°C was performed on some of the hot-rolled steel sheets.

[0059] After the cold rolling, annealing was performed. In this annealing, its temperature was set to 780°C to 900°C and its time period was set to 60 seconds, and cooling at an average cooling rate of 20°C/s between 700°C and 550°C was performed. Then, temper rolling was performed under the condition of the elongation ratio being 0.3% and the parameter P_3 being 80.

[0060] On some of the steel sheets, a hot-dip galvanizing treatment or an alloying hot-dip galvanizing treatment was performed during continuous annealing or after continuous annealing, and on another of the steel sheets, an electro-galvanizing treatment was performed after continuous annealing. Steel types corresponding to the plating treatments are illustrated in Table 2. In Table 2, "GI" indicates a hot-dip galvanized steel sheet obtained after the hot-dip galvanizing treatment was performed, "GA" indicates an alloyed hot-dip galvanized steel sheet obtained after the alloying hot-dip galvanizingtreatment was performed, "EG" indicates an electrogalvanized steel sheet obtained after the electrogalvanizing treatment was performed, and "CR" indicates the cold-rolled steel sheet that was not subjected to a plating treatment.

[0061] In this manner, steel sheet samples were fabricated. Then, each steel structure of the samples was observed to measure each average dislocation density in ferrite and each average dislocation density in bainite.

[0062] In the steel structure observation, there were measured area fractions of ferrite, bainite, martensite, and retained austenite and an average grain diameter of the ferrite and the bainite. In this observation, each 1/4 thickness portion of the steel sheets was analyzed by a point counting method or an image analysis using a structure photograph taken by a SEM or a TEM, or an X-ray diffractometry. At this time, as for the ferrite and the bainite, a region surrounded by a grain boundary with an inclination of 15° or more was set as one crystal grain and the average of nominal grain diameters of 50 or more crystal grains of each of the ferrite and the bainite was set as an average grain diameter d. A total area fraction f_{F+B} of the ferrite and the bainite, an area fraction f_F of the ferrite, an area fraction f_M of the martensite, an area fraction f_A of the retained austenite, and a ratio (f_F/f_M) of the area fractions are illustrated in Table 2. Each underline in Table 2 indicates that a corresponding numerical value is outside the range of the present invention.

[0063] The average dislocation density was obtained from (Expression 4) using a TEM photograph. Each thin film sample for a TEM observation was taken from a portion at the 1/4 thickness from the surface of the steel sheet. As a thickness t of the thin film sample, 0.1 μm was used simply. As for each of the ferrite and the bainite, a TEM photograph was taken at five or more places of each of the thin film samples and an average value of dislocation densities obtained from these TEM photographs was set as an average dislocation density of the thin film sample. An average dislocation density ρ_F in the ferrite and an average dislocation density ρ_B in the bainite are also illustrated in Table 2. Each underline in Table 2 indicates that a corresponding numerical value is outside the range of the present invention.

$$\rho = 2N/(Lt) \quad ...(\text{Expression } 4)$$

[Table 2]

[0064]

Table 2

SAMPLE No.	STEEL SYMBOL	STEEL TYPE	f_{F+B} (%)	f_F (%)	f_M (%)	f_A (%)	f_F/f_M	ρ_F (m/m³)	ρ_B (m/m³)	d (μm)	NOTE
1	A	CR	30	15	68	2	0.22	1×10^{13}	3×10^{13}	2.3	INVENTION EXAMPLE
2	A	CR	10	6	88	2	0.07	8×10^{13}	8×10^{13}	2.3	INVENTION EXAMPLE
3	A	CR	1	0	95	2	0.00	NO FERRITE	2×10^{14}	2.3	COMPARATIVE EXAMPLE
4	A	CR	70	40	28	2	1.43	2×10^{12}	8×10^{13}	2.3	COMPARATIVE EXAMPLE
5	A	CR	88	30	8	4	3.75	9×10^{11}	7×10^{12}	2.3	COMPARATIVE EXAMPLE
6	A	CR	8	1	90	2	0.01	2×10^{14}	8×10^{13}	2.3	COMPARATIVE EXAMPLE
7	A	CR	30	15	68	2	0.22	2×10^{12}	2×10^{13}	6.0	COMPARATIVE EXAMPLE
8	A	CR	33	15	65	2	0.23	1×10^{13}	3×10^{13}	5.8	COMPARATIVE EXAMPLE
9	A	CR	1	1	95	2	0.01	8×10^{13}	NO BAINITE	3.0	COMPARATIVE EXAMPLE
10	A	CR	70	25	28	2	0.89	8×10^{13}	8×10^{13}	2.3	INVENTION EXAMPLE
11	A	CR	88	7	8	4	0.88	8×10^{13}	7×10^{12}	2.3	INVENTION EXAMPLE
12	B	CR	12	3	88	0	0.03	5×10^{13}	7×10^{13}	2.0	INVENTION EXAMPLE
13	c	GA	10	5	82	8	0.06	2×10^{13}	7×10^{13}	3.0	INVENTION EXAMPLE
14	c	GA	1	0	91	8	0.00	NO FERRITE	2×10^{14}	3.0	COMPARATIVE EXAMPLE
15	c	GA	65	25	26	9	0.96	1×10^{12}	2×10^{12}	3.0	COMPARATIVE EXAMPLE
16	c	GA	85	12	8	7	1.50	9×10^{11}	1×10^{13}	3.0	COMPARATIVE EXAMPLE
17	c	GA	12	5	80	8	0.06	2×10^{12}	1×10^{13}	7.2	COMPARATIVE EXAMPLE
18	c	GA	12	3	85	3	0.04	2×10^{13}	7×10^{13}	6.0	COMPARATIVE EXAMPLE
19	c	GA	1	0	90	9	0.00	NO FERRITE	4×10^{13}	3.0	COMPARATIVE EXAMPLE
20	c	GA	4	4	91	5	0.04	1×10^{13}	NO BAINITE	3.0	INVENTION EXAMPLE
21	D	CR	30	3	59	11	0.05	7×10^{13}	8×10^{13}	3.4	INVENTION EXAMPLE
22	E	GI	40	20	51	9	0.39	6×10^{12}	5×10^{13}	2.1	INVENTION EXAMPLE
23	F	GA	25	3	61	14	0.05	1×10^{14}	9×10^{13}	3.0	INVENTION EXAMPLE
24	F	GA	25	3	57	18	0.05	3×10^{14}	2×10^{14}	3.2	COMPARATIVE EXAMPLE

(continued)

SAMPLE No.	STEEL SYMBOL	STEEL TYPE	f_{F+B} (%)	f_F (%)	f_M (%)	f_A (%)	f_F/f_M	ρ_F (m/m^3)	ρ_B (m/m^3)	d (μm)	NOTE
25	F	GA	25	1	61	14	0.02	1×10^{14}	9×10^{13}	3.0	INVENTION EXAMPLE
26	G	EG	15	5	72	13	0.07	8×10^{13}	8×10^{13}	1.5	INVENTION EXAMPLE
27	H	CR	38	5	54	8	0.09	5×10^{13}	7×10^{13}	3.0	INVENTION EXAMPLE
28	I	CR	15	10	85	0	0.12	2×10^{13}	7×10^{13}	3.3	COMPARATIVE EXAMPLE
29	J	CR	50	2	34	16	0.06	2×10^{14}	1×10^{14}	3.3	COMPARATIVE EXAMPLE
30	K	CR	10	4	88	2	0.05	6×10^{13}	8×10^{13}	3.3	COMPARATIVE EXAMPLE
31	L	CR	70	40	20	10	2.00	1×10^{12}	4×10^{12}	3.3	COMPARATIVE EXAMPLE
32	M	CR	50	30	42	8	0.71	6×10^{12}	5×10^{13}	3.3	COMPARATIVE EXAMPLE
33	N	CR	2	1	95	3	0.01	2×10^{14}	4×10^{14}	3.3	COMPARATIVE EXAMPLE
34	O	CR	60	40	30	10	1.33	9×10^{11}	2×10^{12}	3.3	COMPARATIVE EXAMPLE
35	P	CR	35	5	57	8	0.09	5×10^{12}	3×10^{13}	3.3	COMPARATIVE EXAMPLE
36	Q	CR	35	30	57	8	0.53	6×10^{12}	4×10^{13}	3.3	COMPARATIVE EXAMPLE
37	R	CR	35	5	57	8	0.09	8×10^{12}	1×10^{13}	3.3	COMPARATIVE EXAMPLE
38	S	CR	35	5	57	8	0.09	4×10^{13}	6×10^{13}	1.5	COMPARATIVE EXAMPLE
39	I	CR	35	5	57	8	0.09	6×10^{13}	5×10^{13}	1.5	COMPARATIVE EXAMPLE
40	U	CR	35	5	57	8	0.09	2×10^{12}	5×10^{12}	6.2	COMPARATIVE EXAMPLE

[0065] Thereafter, each of the samples was subjected to a tensile test in conformity with JIS Z 2241. In this tensile test, each tensile test piece in conformity with JIS Z 2201 with its sheet width direction (direction perpendicular to the rolling direction) set to a longitudinal direction was used. At this time, on each of the samples, the maximum tensile strength TS, a yield strength YS, a uniform elongation uEl, a yield strength YS_{BH5} after aging in the case of a 5%-tensile prestrain being applied, and a yield strength YS_{BH0} after aging in the case of no tensile prestrain being applied were measured. Then, the parameter P_1 regarding the yield strength expressed by (Expression 1) and the parameter P_2 regarding the formability expressed by (Expression 2) were calculated. These results are illustrated in Table 3. Each underline in Table 3 indicates that a corresponding numerical value is outside a target range.

[Table 3]

[0066]

Table 3

SAMPLE No.	YS (MPa)	TS (MPa)	uEL (%)	P_1	P_2	NOTE
1	850	1200	7	0.125	8400	INVENTION EXAMPLE
2	1050	1370	6	0.131	8220	INVENTION EXAMPLE
3	1130	1410	4	0.191	<u>5640</u>	COMPARATIVE EXAMPLE
4	550	1080	10	<u>0.287</u>	10800	COMPARATIVE EXAMPLE
5	490	<u>950</u>	12	<u>0.337</u>	11400	COMPARATIVE EXAMPLE
6	900	1310	4	<u>0.275</u>	<u>5240</u>	COMPARATIVE EXAMPLE
7	880	1360	6	<u>0.272</u>	8160	COMPARATIVE EXAMPLE
8	890	1355	4	0.150	<u>5420</u>	COMPARATIVE EXAMPLE
9	1100	1440	4	0.143	<u>5760</u>	COMPARATIVE EXAMPLE
10	900	1250	6	0.135	7500	INVENTION EXAMPLE
11	700	1220	6	0.130	7320	INVENTION EXAMPLE
12	970	1280	7	0.141	8960	INVENTION EXAMPLE
13	820	1090	13	0.119	14170	INVENTION EXAMPLE
14	990	1410	4	0.220	<u>5640</u>	COMPARATIVE EXAMPLE
15	510	<u>970</u>	15	<u>0.289</u>	14550	COMPARATIVE EXAMPLE
16	660	1050	13	<u>0.276</u>	13650	COMPARATIVE EXAMPLE
17	820	1080	13	<u>0.273</u>	14040	COMPARATIVE EXAMPLE
18	820	1180	5	0.122	<u>5900</u>	COMPARATIVE EXAMPLE
19	990	1370	5	0.130	<u>6850</u>	COMPARATIVE EXAMPLE
20	900	1300	6	0.165	7800	INVENTION EXAMPLE
21	850	1130	13	0.159	14690	INVENTION EXAMPLE
22	870	1270	11	0.157	13970	INVENTION EXAMPLE
23	1100	1510	12	0.166	18120	INVENTION EXAMPLE
24	1020	1520	10	<u>0.273</u>	15200	COMPARATIVE EXAMPLE
25	1100	1550	5	0.166	7750	INVENTION EXAMPLE
26	1120	1650	11	0.152	18150	INVENTION EXAMPLE
27	740	1020	16	0.167	16320	INVENTION EXAMPLE
28	490	<u>890</u>	10	0.247	8900	COMPARATIVE EXAMPLE
29	1120	1780	10	<u>0.272</u>	17800	COMPARATIVE EXAMPLE

(continued)

SAMPLE No.	YS (MPa)	TS (MPa)	uEL (%)	P_1	P_2	NOTE
30	780	1090	6	0.271	6540	COMPARATIVE EXAMPLE
31	870	1370	12	0.274	16440	COMPARATIVE EXAMPLE
32	570	950	12	0.232	11400	COMPARATIVE EXAMPLE
33	1160	1400	4	0.157	5600	COMPARATIVE EXAMPLE
34	870	1370	12	0.288	16440	COMPARATIVE EXAMPLE
35	730	1030	6	0.165	6180	COMPARATIVE EXAMPLE
36	780	1120	6	0.152	6720	COMPARATIVE EXAMPLE
37	720	1010	6	0.168	6060	COMPARATIVE EXAMPLE
38	810	1160	6	0.147	6960	COMPARATIVE EXAMPLE
39	910	1160	6	0.147	6960	COMPARATIVE EXAMPLE
40	540	990	10	0.278	9900	COMPARATIVE EXAMPLE

[0067] As illustrated in Table 3, Samples No. 1, No. 2, No. 10 to No. 13, No. 20 to No. 23, and No. 25 to No. 27 each being an invention example, exhibited an excellent crashworthiness and formability because of including the requirements of the present invention. In Samples No. 1, No. 2, No. 12, No. 13, No. 21 to No. 23, No. 26, and No. 27 in which the total area fraction of the ferrite and the bainite, the area fraction of the martensite, the area fraction of the retained austenite, and the ratio of the area fraction of the ferrite to the area fraction of the martensite each are within a preferred range, the parameter P_2 was 8000 or more and the formability was particularly excellent.

[0068] In Samples No. 3 and No. 14, the average dislocation density ρ_B was excessive, to thus fail to obtain sufficient formability. In Samples No. 4, No. 5, No. 7, No. 16, and No. 17, the average dislocation density ρ_F was too small, to thus fail to obtain a sufficient crashworthiness. In Sample No. 6, the average dislocation density ρ_F was excessive, to thus fail to obtain a sufficient crashworthiness. In Samples No. 8 and No. 18, the average grain diameter d was excessive, to thus fail to obtain sufficient formability. In Samples No. 9 and No. 19, the total area fraction f_{F+B} of the ferrite and the bainite was too small, to thus fail to obtain sufficient formability. In Sample No. 15, the average dislocation density ρ_F and the average dislocation density ρ_B were too small, to thus fail to obtain a sufficient crashworthiness. In Sample No. 24, the average dislocation density ρ_F and the average dislocation density ρ_B were excessive, to thus fail to obtain a sufficient crashworthiness.

[0069] In Sample No. 28, the C content was too small, to thus fail to obtain a sufficient tensile strength. In Sample No. 29, because of the C content being excessive, the average dislocation density ρ_F was excessive and it was impossible to obtain a sufficient crashworthiness. In Sample No. 30, the Si content was too small, to thus fail to obtain a sufficient crashworthiness. In Sample No. 31, because of the Si content being excessive, the average dislocation density ρ_F was too small and it was impossible to obtain a sufficient crashworthiness. In Sample No. 32, the Mn content was too small, to thus fail to obtain a sufficient tensile strength. In Sample No. 33, because of the Mn content being excessive, the average dislocation density ρ_F and the average dislocation density ρ_B were excessive and it was impossible to obtain sufficient formability. In Sample No. 34, because of the Al content being excessive, the average dislocation density ρ_F and the average dislocation density ρ_B were too small and it was impossible to obtain a sufficient crashworthiness. In Sample No. 35, the N content was excessive, to thus fail to obtain sufficient formability. In Sample No. 36, the P content was excessive, to thus fail to obtain sufficient formability. In Sample No. 37, the S content was excessive, to thus fail to obtain sufficient formability. In Samples No. 38 and No. 39, the total content of Ti and Nb was excessive, to thus fail to obtain sufficient formability. In Sample No. 40, because of the total content of Ti and Nb being too small, the average dislocation density ρ_F was too small and it was impossible to obtain a sufficient crashworthiness.

(Second test)

[0070] In the second test, Symbol A steel was used, the conditions of the treatments other than the temper rolling were set the same as those in Sample No. 1, and samples were fabricated while changing the elongation ratio of the temper rolling and the parameter P_3. Then, various measurements similar to those in the first test were performed. These results are illustrated in Table 4. Each underline in Table 4 indicates that a corresponding numerical value is outside a predetermined range of the temper rolling, the range of the present invention, or a target range.

[Table 4]

[0071]

Table 4

SAMPLE No.	STEEL SYMBOL	STEEL TYPE	ELONGATION RATIO (%)	P_3	ρ_F (m/m^3)	ρ_B (m/m^3)	YS (MPa)	TS (MPa)	uEI (%)	P_1	P_2	NOTE
41	A	CR	0.0	80	9×10^{11}	2×10^{12}	670	1180	8	0.297	9440	COMPARATIVE EXAMPLE
42	A	CR	0.05	80	1×10^{12}	2×10^{12}	690	1190	7.5	0.285	8925	COMPARATIVE EXAMPLE
43	A	CR	0.15	80	4×10^{12}	4×10^{12}	770	1195	7	0.220	8365	INVENTION EXAMPLE
44	A	CR	0.2	80	8×10^{12}	1×10^{13}	790	1190	7	0.210	8330	INVENTION EXAMPLE
45	A	CR	0.6	80	1×10^{13}	3×10^{13}	850	1200	7	0.125	8400	INVENTION EXAMPLE
46	A	CR	0.7	80	1.5×10^{13}	4×10^{13}	870	1200	7	0.120	8400	INVENTION EXAMPLE
47	A	CR	0.9	80	1.2×10^{14}	2×10^{14}	885	1200	5	0.115	6000	COMPARATIVE EXAMPLE
48	A	CR	1.0	80	2×10^{14}	3×10^{14}	900	1200	5	0.125	6000	COMPARATIVE EXAMPLE
49	A	CR	0.2	1	3×10^{12}	7×10^{12}	790	1190	7	0.277	8330	COMPARATIVE EXAMPLE
50	A	CR	0.2	10	6×10^{12}	9×10^{12}	770	1190	7	0.212	8330	INVENTION EXAMPLE

[0072] As illustrated in Table 4, in Samples No. 43 to No. 46, and No. 50, in which the temper rolling was performed in a preferred range, it was possible to manufacture a steel sheet satisfying the requirements of the present invention.

[0073] In Samples No. 41 and No. 42, because of the elongation ratio being too small, the average dislocation density ρ_F and the average dislocation density ρ_B became too small and it was impossible to obtain a sufficient crashworthiness. In Sample No. 47, because of the elongation ratio being excessive, the average dislocation density ρ_F and the average dislocation density ρ_B became excessive and it was impossible to obtain sufficient formability. In Sample No. 48, because of the elongation ratio being excessive, the average dislocation density ρ_F and the average dislocation density ρ_B became excessive and it was impossible to obtain sufficient formability. In Sample No. 49, the value of the parameter P_3 was too small, to thus fail to obtain a sufficient crashworthiness.

INDUSTRIAL APPLICABILITY

[0074] The present invention can be utilized for the industries relating to a steel sheet suitable for an automotive vehicle body, for example.

Claims

1. A steel sheet, comprising:

    a chemical composition represented by,
    in mass%,
    C: 0.05% to 0.40%,
    Si: 0.05% to 3.0%,
    Mn: 1.5% to 4.0%,
    Al: 1.5% or less,
    N: 0.02% or less,
    P: 0.2% or less,
    S: 0.01% or less,
    Nb and Ti: 0.005% to 0.2% in total,
    V and Ta: 0.0% to 0.3% in total,
    Cr, Mo, Ni, Cu, and Sn: 0.0% to 1.0% in total,
    B: 0.00% to 0.01%,
    Ca: 0.000% to 0.005%,
    Ce: 0.000% to 0.005%,
    La: 0.000% to 0.005%, and
    the balance: Fe and impurities; and
    a steel structure containing, in area fraction, 2% or more in total of ferrite and bainite, wherein
    an average dislocation density in the ferrite and an average dislocation density in the bainite are both 3×10^{12} m/m^3 to 1×10^{14} m/m^3,
    an average grain diameter of the ferrite and the bainite is 5 μm or less and a value of the parameter P_1 is 0.27 or less which is expressed by (Expression 1) wherein "YS_{BH5}" is a yield strength (MPa) after aging in the case of a 5%-tensile prestrain being applied, "YS_{BH0}" is a yield strength (MPa) after aging in the case of no tensile prestrain being applied, and "TS" is the maximum tensile strength (MPa) wherein the temperature of the aging is 170°C, and its time period is two hours

    $$P_1 = (YS_{BH5} - YS_{BH0})/TS \ldots (\text{Expression 1}).$$

2. The steel sheet according to claim 1, wherein the steel structure contains, in area fraction, ferrite and bainite: 2% to 60% in total and martensite: 10% to 90%,

    an area fraction of retained austenite in the steel structure is 15% or less, and
    a ratio of an area fraction of the ferrite to an area fraction of the martensite is 0.03 to 1.00.

3. The steel sheet according to claim 1 or 2, wherein

    in the chemical composition,

V and Ta: 0.01% to 0.3% in total is established.

4. The steel sheet according to any one of claims 1 to 3, wherein

in the chemical composition,
Cr, Mo, Ni, Cu, and Sn: 0.1% to 1.0% in total is established.

5. The steel sheet according to any one of claims 1 to 4, wherein

in the chemical composition,
B: 0.0003% to 0.01% is established.

6. The steel sheet according to any one of claims 1 to 5, wherein

in the chemical composition,
Ca: 0.001% to 0.005%,
Ce: 0.001% to 0.005%,
La: 0.001% to 0.005%, or
an arbitrary combination of these is established.

Patentansprüche

1. Ein Stahlblech, umfassend:

eine chemische Zusammensetzung, dargestellt durch,
in Massen-%,
C: 0,05% bis 0,40%,
Si: 0,05% bis 3,0%,
Mn: 1,5% bis 4,0%,
Al: 1,5% oder weniger,
N: 0,02% oder weniger,
P: 0,2% oder weniger,
S: 0,01% oder weniger,
Nb und Ti: insgesamt 0,005% bis 0,2%,
V und Ta: insgesamt 0,0% bis 0,3%,
Cr, Mo, Ni, Cu und Sn: insgesamt 0,0% bis 1,0%,
B: 0,00% bis 0,01%,
Ca: 0,000% bis 0,005%,
Ce: 0,000% bis 0,005%,
La: 0,000% bis 0,005% und
dem Rest: Fe und Verunreinigungen; und
eine Stahlstruktur, enthaltend, in Flächenanteilen, insgesamt 2% oder mehr an Ferrit und Bainit, wobei eine mittlere Versetzungsdichte in dem Ferrit und eine mittlere Versetzungsdichte in dem Bainit jeweils 3 x 10^{12} m/m^3 bis 1 x 10^{14} m/m^3 betragen, ein mittlerer Korndurchmesser des Ferrits und des Bainits 5 μm oder weniger beträgt und
ein Wert des Parameters P_1 0,27 oder weniger beträgt, welcher durch (Ausdruck 1) ausgedrückt ist, wobei "YS_{BH5}" eine Streckgrenze (MPa) nach Alterung in dem Fall, dass
eine 5% Vordehnung angewandt wird, "YS_{BH0}" eine Streckgrenze (MPa) nach Alterung in dem Fall, dass keine Vordehnung angewandt wird, und "TS" die maximale Zugfestigkeit (MPa) ist, wobei die Temperatur der Alterung 170°C beträgt und deren Zeitraum zwei Stunden beträgt

$$P_1 = (YS_{BH5} - YS_{BH0}) / TS \ldots \text{(Ausdruck 1)}.$$

2. Das Stahlblech nach Anspruch 1, wobei die Stahlstruktur, in Flächenanteilen, Ferrit und Bainit: insgesamt 2% bis 60% und

Martensit: 10% bis 90% enthält,
ein Flächenanteil an Restaustenit in der Stahlstruktur 15% oder weniger beträgt und ein Verhältnis eines Flächenanteils des Ferrits zu einem Flächenanteil des Martensits 0,03 bis 1,00 beträgt.

3. Das Stahlblech nach Anspruch 1 oder 2, wobei,

in der chemischen Zusammensetzung,
V und Ta: insgesamt 0,01% bis 0,3% etabliert ist.

4. Das Stahlblech nach einem der Ansprüche 1 bis 3, wobei,

in der chemischen Zusammensetzung,
Cr, Mo, Ni, Cu und Sn: insgesamt 0,1% bis 1,0% etabliert ist.

5. Das Stahlblech nach einem der Ansprüche 1 bis 4, wobei,

in der chemischen Zusammensetzung,
B: 0,0003% bis 0,01% etabliert ist.

6. Das Stahlblech nach einem der Ansprüche 1 bis 5, wobei,

in der chemischen Zusammensetzung,
Ca: 0,001% bis 0,005%,
Ce: 0,001% bis 0,005%,
La: 0,001% bis 0,005% oder
eine willkürliche Kombination derselben etabliert ist.

Revendications

1. Tôle d'acier comprenant :
une composition chimique représentée par, en % en masse :

C : 0,05 % à 0,40 %,
Si : 0,05 % à 3,0 %,
Mn : 1,5 % à 4,0 %,
Al : 1,5 % ou moins,
N : 0,02 % ou moins,
P : 0,2 % ou moins,
S : 0,01 % ou moins,
Nb et Ti : 0,005 % à 0,2 % au total,
V et Ta : 0,0 % à 0,3 % au total,
Cr, Mo, Ni, Cu et Sn : 0,0 % à 1,0 % au total,
B : 0,00 % à 0,01 %,
Ca : 0,000 % à 0,005 %,
Ce : 0,000 % à 0,005 %,
La : 0,000 % à 0,005 %, et
le reste : Fe et impuretés ; et
une structure d'acier contenant, en fraction surfacique, 2 % ou plus au total de ferrite et de bainite, dans laquelle la densité de dislocation moyenne dans la ferrite et la densité de dislocation moyenne dans la bainite sont toutes deux de 3 x 10^{12} m/m^3 à 1 x 10^{14} m/m^3,
le diamètre de grain moyen de la ferrite et de la bainite est de 5 μm ou moins, et
la valeur du paramètre P_1 est de 0,27 ou moins, lequel est exprimé par (l'expression 1) dans laquelle "YS_{BH5}" est la limite d'élasticité (MPa) après vieillissement dans le cas où une précontrainte de traction à 5 % a été appliquée, "YS_{BH0}" est la limite d'élasticité (MPa) après vieillissement dans le cas où aucune précontrainte de traction n'a été appliquée, et "TS" est la résistance à la traction maximale (MPa), où la température de vieillissement est de 170°C, et sa période de temps est de deux heures

$$P_1 = (YS_{BH5} - YS_{BH0}) / TS \quad \ldots \text{ expression 1.}$$

2. Tôle d'acier selon la revendication 1, dans laquelle la structure d'acier contient, en fraction surfacique,

ferrite et bainite : 2 % à 60 % au total, et
martensite : 10 % à 90 %,
la fraction surfacique de l'austénite résiduelle dans la structure d'acier est de 15 % ou moins, et
le rapport de la fraction surfacique de la ferrite à la fraction surfacique de la martensite est de 0,03 à 1,00.

3. Tôle d'acier selon la revendication 1 ou 2, dans laquelle, dans la composition chimique, V et Ta : 0,01 % à 0,3 % au total, sont établis.

4. Tôle d'acier selon l'une quelconque des revendications 1 à 3, dans laquelle, dans la composition chimique, Cr, Mo, Ni, Cu et Sn : 0,1 % à 1,0 % au total, sont établis.

5. Tôle d'acier selon l'une quelconque des revendications 1 à 4, dans laquelle, dans la composition chimique, B : 0,0003 % à 0,01 %, est établi.

6. Tôle d'acier selon l'une quelconque des revendications 1 à 5, dans laquelle, dans la composition chimique,

Ca : 0,001 % à 0,005 %,
Ce : 0,001 % à 0,005 %,
La : 0,001 % à 0,005 %, ou
une combinaison arbitraire de ceux-ci, sont établis.

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