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(54) **HIGH STRENGTH STEEL SHEET AND METHOD FOR MANUFACTURING THE SAME**

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(57) **ABSTRACT**

A high strength steel sheet includes a specific microstructure having a specific chemical composition and satisfying the formulas (1) and (2) defined below:

$$KAM(S)/KAM(C) < 1.00 \tag{1}$$

wherein KAM (S) is a KAM (Kernel average misorientation) value of a superficial portion of the steel sheet, and KAM (C) is a KAM value of a central portion of the steel sheet,

$$Hv(Q) - Hv(S) \geq 8 \tag{2}$$

wherein Hv (Q) indicates the hardness of a portion at ¼ sheet thickness and Hv (S) indicates the hardness of a superficial portion of the steel sheet.

HIGH STRENGTH STEEL SHEET AND METHOD FOR MANUFACTURING THE SAME

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This is the U.S. National Phase Application of PCT/JP2022/020892, filed May 19, 2022, which claims priority to Japanese Patent Application No. 2021-098034, filed Jun. 11, 2021, the disclosures of these applications being incorporated herein by reference in their entireties for all purposes.

FIELD OF THE INVENTION

[0002] The present invention relates to a high strength steel sheet excellent in tensile strength and delayed fracture resistance, and to a method for manufacturing the same. The high strength steel sheet according to aspects of the present invention may be suitably used as structural members, such as automobile parts.

BACKGROUND OF THE INVENTION

[0003] Steel sheets for automobiles are being increased in strength to reduce CO_2 emissions by weight reduction of vehicles and to enhance crashworthiness by weight reduction of automobile bodies at the same time, with introduction of new laws and regulations one after another. To increase the strength of automobile bodies, high strength steel sheets having a tensile strength (TS) of 1320 MPa or higher class are increasingly applied to principal structural parts of automobiles.

[0004] High strength steel sheets used for automobiles are required to have an excellent yield ratio (YR=yield strength YS/tensile strength TS) from the point of view of performance of parts. For example, automobile frame parts, such as bumpers, are required to exhibit excellent impact absorption at the time of collision. Thus, steel sheets that have excellent YR correlated with impact absorption are favorably used.

[0005] Automobile frame parts have many end faces formed by shearing. The morphology of a sheared end face depends on the shear clearance. The morphology of a sheared end face affects delayed fracture resistance. Here, delayed fracture is a phenomenon in which, when a formed part is placed in a hydrogen penetration environment, hydrogen penetrates into the steel sheet constituting the part to cause a decrease in interatomic bonding force or to cause local deformation, thus giving rise to microcracks that grow to fracture. High strength steel sheets used for automobiles are required to have a wide range of appropriate clearances not leading to delayed fracture.

[0006] To cope with these demands, for example, Patent Literature 1 provides a high strength steel sheet having a tensile strength of 980 MPa or more and excellent bending formability, and a method for manufacturing the same. However, the technique described in Patent Literature 1 does not consider YR or the range of appropriate clearances not leading to delayed fracture. Furthermore, the steel sheets described in Patent Literature 1 do not achieve $YR \geq 85\%$.

[0007] For example, Patent Literature 2 provides a high strength steel sheet having a tensile strength of 1320 MPa or more and excellent delayed fracture resistance at sheared end faces, and a method for manufacturing the same. However, the technique described in Patent Literature 2 does not consider the range of appropriate clearances not leading to delayed fracture.

[0008] For example, Patent Literature 3 provides a high strength steel sheet having a tensile strength of 1100 MPa or more and being excellent in YR, surface quality, and weldability, and a method for manufacturing the same. However, the technique described in Patent Literature 3 does not consider the range of appropriate clearances not leading to delayed fracture.

PATENT LITERATURE

[0009] PTL 1: Japanese Patent No. 6354909

[0010] PTL 2: Japanese Patent No. 6112261

[0011] PTL 3: Japanese Patent No. 6525114

SUMMARY OF THE INVENTION

[0012] Aspects of the present invention have been developed in view of the circumstances discussed above. Objects according to aspects of the present invention are therefore to provide a high strength steel sheet having a TS of 1320 MPa or more and a YR of 85% or more and having a wide range of appropriate clearances not leading to delayed fracture; and to provide a method for manufacturing the same.

[0013] The present inventors carried out extensive studies directed to solving the problems described above and have consequently found the following facts.

[0014] (1) 1320 MPa or higher TS can be achieved by limiting tempered martensite to 85% or more.

[0015] (2) 85% or higher YR can be achieved by limiting retained austenite to less than 58, KAM (S)/KAM (C) to less than 1.00, and further Hv (Q)-Hv (S) to 8 or more.

[0016] (3) A wide range of appropriate clearances not leading to delayed fracture can be achieved by limiting KAM (S)/KAM (C) to less than 1.00 and further Hv (Q)-Hv (S) to 8 or more.

[0017] Aspects of the present invention have been made based on the above findings. Specifically, a summary of configurations according to aspects of the present invention is as follows.

[1] A high strength steel sheet including a microstructure having a chemical composition including, by mass:

[0018] C: 0.15% or more and 0.45% or less,

[0019] Si: 0.10% or more and 2.00% or less,

[0020] Mn: 0.5% or more and 3.5% or less,

[0021] P: 0.100% or less,

[0022] S: 0.0200% or less,

[0023] Al: 0.010% or more and 1.000% or less,

[0024] N: 0.0100% or less, and

[0025] H: 0.0020% or less,

[0026] the balance being Fe and incidental impurities;

[0027] the microstructure being such that:

[0028] the area fraction of tempered martensite is 85% or more,

[0029] the volume fraction of retained austenite is less than 5%, and

[0030] the area fraction of the total of ferrite and bainitic ferrite is 10% or less;

[0031] the microstructure satisfying the formulas (1) and (2) defined below:

$$KAM(S)/KAM(C) < 1.00 \tag{1}$$

[0032] wherein KAM (S) is a KAM (Kernel average misorientation) value of a superficial portion of the steel sheet, and KAM (C) is a KAM value of a central portion of the steel sheet,

$$Hv(Q) - Hv(S) \geq 8 \tag{2}$$

[0033] wherein Hv (Q) indicates the hardness of a portion at ¼ sheet thickness and Hv (S) indicates the hardness of a superficial portion of the steel sheet.

[2] The high strength steel sheet described in [1], wherein the chemical composition further includes one, or two or more elements selected from, by mass %:

[0034] Ti: 0.100% or less,
[0035] B: 0.0100% or less,
[0036] Nb: 0.100% or less,
[0037] Cu: 1.00% or less,
[0038] Cr: 1.00% or less,
[0039] V: 0.100% or less,
[0040] Mo: 0.500% or less,
[0041] Ni: 0.50% or less,
[0042] Sb: 0.200% or less,
[0043] Sn: 0.200% or less,
[0044] As: 0.100% or less,
[0045] Ta: 0.100% or less,
[0046] Ca: 0.0200% or less,
[0047] Mg: 0.0200% or less,
[0048] Zn: 0.020% or less,
[0049] Co: 0.020% or less,
[0050] Zr: 0.020% or less, and
[0051] REM: 0.0200% or less.

[3] The high strength steel sheet described in [1] or [2], which has a coated layer on a surface of the steel sheet.

[4] A method for manufacturing a high strength steel sheet described in [1] or [2], the method including:

[0052] providing a cold rolled steel sheet produced by subjecting a steel slab to hot rolling, pickling, and cold rolling;

[0053] annealing the steel sheet under conditions where:

[0054] a temperature T1 is 850° C. or above and 1000° C. or below and a holding time t1 at T1 is 10 seconds or more and 1000 seconds or less;

[0055] cooling the steel sheet to 100° C. or below;

[0056] starting working at an elapsed time t2 of 1000 seconds or less from the time when the temperature reaches 100° C.,

[0057] the working being performed under conditions where:

[0058] a working start temperature T2 is 80° C. or below and an equivalent plastic strain is 0.10% or more and 5.00% or less;

[0059] tempering the steel sheet under conditions where:

[0060] a temperature T3 is 100° C. or above and 400° C. or below and a holding time t3 at T3 is 1.0 second or more and 1000.0 seconds or less; and

[0061] cooling the steel sheet under conditions where a cooling rate θ1 from T3 to 80° C. is 100° C./sec or less.

[5] The method for manufacturing a high strength steel sheet described in [4], wherein the working before the tempering is performed under conditions where strain is applied by two or more separate working operations, and the total of the equivalent plastic strains applied in the working operations is 0.10% or more.

[6] The method for manufacturing a high strength steel sheet described in [4] or [5], further including performing coating treatment during the annealing or after the annealing.

[0062] According to aspects of the present invention, a high strength steel sheet can be obtained that has a TS of 1320 MPa or more and a YR of 85% or more and has a wide range of appropriate clearances not leading to delayed fracture. Furthermore, for example, the high strength steel sheet according to aspects of the present invention may be applied to automobile structural members to reduce the weight of automobile bodies and thereby to enhance fuel efficiency. Thus, aspects of the present invention are highly valuable in industry.

DETAILED DESCRIPTION OF EMBODIMENTS OF THE INVENTION

[0063] Embodiments of the present invention will be described below.

[0064] First, appropriate ranges of the chemical composition of the high strength steel sheet and the reasons why the chemical composition is thus limited will be described. In the following description, "%" indicating the contents of constituent elements of steel means "mass %" unless otherwise specified.

C: 0.15% or More and 0.45% or Less

[0065] Carbon is one of the important basic components of steel, and, particularly in accordance with aspects of the present invention, is an important element that affects TS. If the C content is less than 0.15%, it is difficult to achieve 1320 MPa or higher TS. Thus, the C content is limited to 0.15% or more. The C content is preferably 0.16% or more. The C content is more preferably 0.17% or more. The C content is still more preferably 0.18% or more. The C content is most preferably 0.19% or more. However, if the C content is more than 0.45%, the ultimate deformability of the steel is lowered and the range of appropriate clearances not leading to delayed fracture is narrowed. Thus, the C content is limited to 0.45% or less. The C content is preferably 0.40% or less. The C content is more preferably 0.35% or less. The C content is still more preferably 0.30% or less. The C content is most preferably 0.26% or less.

Si: 0.10% or More and 2.00% or Less

[0066] Silicon is one of the important basic components of steel, and, particularly in accordance with aspects of the present invention, is an important element that affects TS and retained austenite. If the Si content is less than 0.10%, 1320 MPa or higher TS is hardly achieved. Thus, the Si content is limited to 0.10% or more. The Si content is preferably 0.15% or more. The Si content is more preferably 0.20% or more. The Si content is still more preferably 0.30%

or more. The Si content is most preferably 0.40% or more. However, if the Si content is more than 2.00%, the amount of retained austenite excessively increases to make it difficult to achieve 85% or higher YR. Thus, the Si content is limited to 2.00% or less. The Si content is preferably 1.80% or less. The Si content is more preferably 1.60% or less. The Si content is still more preferably 1.50% or less. The Si content is most preferably 1.20% or less.

Mn: 0.5% or More and 3.5% or Less

[0067] Manganese is one of the important basic components of steel, and, particularly in accordance with aspects of the present invention, is an important element that affects the fraction of ferrite and the fraction of bainite. If the Mn content is less than 0.5%, the fraction of ferrite and the fraction of bainite are increased to make it difficult to achieve 1320 MPa or higher TS and to achieve 85% or higher YR. Thus, the Mn content is limited to 0.5% or more. The Mn content is preferably 0.7% or more. The Mn content is more preferably 1.08 or more. The Mn content is still more preferably 1.1% or more. The Mn content is most preferably 1.5% or more. However, if the Mn content is more than 3.5%, manganese macro-segregation occurs to lower the ultimate deformability of the steel and thereby to narrow the range of appropriate clearances not leading to delayed fracture. Thus, the Mn content is limited to 3.5% or less. The Mn content is preferably 3.3% or less. The Mn content is more preferably 3.1% or less. The Mn content is still more preferably 3.0% or less. The Mn content is most preferably 2.8% or less.

P: 0.100% or Less

[0068] If the P content is more than 0.100%, phosphorus is segregated at grain boundaries to make the steel sheet brittle and to narrow the range of appropriate clearances not leading to delayed fracture. Thus, the P content is limited to 0.100% or less. The P content is preferably 0.080% or less. The P content is more preferably 0.060% or less. The lower limit of the P content is not particularly limited but is preferably 0.001% or more due to production technology limitations.

S: 0.0200% or Less

[0069] If the S content is more than 0.0200%, sulfides are formed making the ultimate deformability of the steel lower and thereby narrow the range of appropriate clearances not leading to delayed fracture. Thus, the S content is limited to 0.0200% or less. The S content is preferably 0.0100% or less. The S content is more preferably 0.0050% or less. The lower limit of the S content is not particularly limited but is preferably 0.0001% or more due to production technology limitations.

Al: 0.010% or More and 1.000% or Less

[0070] The addition of aluminum increases the strength of the steel sheet and facilitates achieving 1320 MPa or higher TS. To obtain these effects, the Al content needs to be 0.010% or more. Thus, the Al content is limited to 0.010% or more. The Al content is preferably 0.012% or more. The Al content is more preferably 0.015% or more. The Al content is still more preferably 0.020% or more. However, if the Al content is more than 1.000%, the fraction of ferrite and the fraction of bainite increase to make it difficult to achieve 1320 MPa or higher TS and to achieve 85% or higher YR. Thus, the Al content is limited to 1.000% or less. The Al content is preferably 0.500% or less. The Al content is more preferably 0.100% or less.

N: 0.0100% or Less

[0071] If the N content is more than 0.0100%, the cast slab becomes brittle and is easily cracked to cause a significant decrease in productivity. Thus, the N content is limited to 0.0100% or less. The N content is preferably 0.0080% or less. The N content is more preferably 0.0070% or less. The N content is still more preferably 0.0060% or less. The N content is most preferably 0.0050% or less. The lower limit of the N content is not particularly limited but is preferably 0.0010% or more due to production technology limitations.

H: 0.0020% or Less

[0072] If the H content exceeds not more than 0.0020%, the ultimate deformability of the steel is lowered and the range of appropriate clearances not leading to delayed fracture is narrowed. Thus, the H content is limited to 0.0020% or less. The H content is preferably 0.0015% or less. The H content is more preferably 0.0010% or less. The lower limit of the H content is not particularly limited. The H content may be 0% because the lower the H content, the wider the range of appropriate clearances not leading to delayed fracture.

[0073] In addition to the chemical composition described above, the high strength steel sheet according to aspects of the present invention preferably further contains one, or two or more elements selected from, by mass %, Ti: 0.100% or less, B: 0.0100% or less, Nb: 0.100% or less, Cu: 1.00% or less, Cr: 1.00% or less, V: 0.100% or less, Mo: 0.500% or less, Ni: 0.50% or less, Sb: 0.200% or less, Sn: 0.200% or less, As: 0.100% or less, Ta: 0.100% or less, Ca: 0.0200% or less, Mg: 0.0200% or less, Zn: 0.020% or less, Co: 0.020% or less, Zr: 0.020% or less, and REM: 0.0200% or less.

Ti: 0.100% or Less

[0074] If the Ti content is more than 0.100%, the cast slab becomes brittle and is easily cracked to cause a significant decrease in productivity. Thus, when titanium is added, the content thereof is limited to 0.100% or less. The Ti content is preferably 0.075% or less. The Ti content is more preferably 0.050% or less. The Ti content is still more preferably less than 0.050%. In contrast, the addition of titanium increases the strength of the steel sheet and facilitates achieving 1320 MPa or higher TS. To obtain these effects, the Ti content is preferably 0.001% or more. The Ti content is more preferably 0.005% or more. The Ti content is still more preferably 0.010% or more.

B: 0.0100% or Less

[0075] If the B content is more than 0.0100%, the cast slab becomes brittle and is easily cracked to cause a significant decrease in productivity. Thus, when boron is added, the content thereof is limited to 0.0100% or less. The B content is preferably 0.0080% or less. The B content is more preferably 0.0050% or less. In contrast, the addition of boron increases the strength of the steel sheet and facilitates achieving 1320 MPa or higher TS. To obtain these effects, the B content is preferably 0.0001% or more. The B content is more preferably 0.0002% or more.

Nb: 0.100% or Less

[0076] If the Nb content is more than 0.100%, the cast slab becomes brittle and is easily cracked to cause a significant decrease in productivity. Thus, when niobium is added, the content thereof is limited to 0.100% or less. The Nb content is preferably 0.090% or less. The Nb content is more preferably 0.050% or less. The Nb content is still more preferably 0.030% or less. In contrast, the addition of niobium increases the strength of the steel sheet and facilitates achieving 1320 MPa or higher TS. To obtain these effects, the Nb content is preferably 0.001% or more. The Nb content is more preferably 0.002% or more.

Cu: 1.00% or Less

[0077] If the Cu content is more than 1.00%, the cast slab becomes brittle and is easily cracked to cause a significant decrease in productivity. Thus, when copper is added, the Cu content is limited to 1.00% or less. The Cu content is preferably 0.50% or less. In contrast, copper suppresses the penetration of hydrogen into the steel sheet and improves the range of appropriate clearances not leading to delayed fracture. To obtain these effects, the Cu content is preferably 0.01% or more. The Cu content is preferably 0.03% or more. The Cu content is more preferably 0.10% or more.

Cr: 1.00% or Less

[0078] If the Cr content is more than 1.00%, large amounts of coarse precipitates and inclusions are formed to lower the ultimate deformability of the steel, thus narrowing the range of appropriate clearances for hole expanding deformation. Thus, when chromium is added, the content thereof is limited to 1.00% or less. The Cr content is preferably 0.70% or less. The Cr content is more preferably 0.50% or less. In contrast, chromium not only serves as a solid solution strengthening element but also can stabilize austenite and suppress ferrite formation in the cooling process during continuous annealing, thus increasing the strength of the steel sheet. To obtain these effects, the Cr content is preferably 0.01% or more. The Cr content is more preferably 0.02% or more.

V: 0.100% or Less

[0079] If the V content is more than 0.100%, large amounts of coarse precipitates and inclusions are formed to lower the ultimate deformability of the steel, thus narrowing the range of appropriate clearances for hole expanding deformation. Thus, when vanadium is added, the content thereof is limited to 0.100% or less. The V content is preferably 0.060% or less. In contrast, vanadium increases the strength of the steel sheet. To obtain this effect, the V content is preferably 0.001% or more. The V content is more preferably 0.005% or more. The V content is still more preferably 0.010% or more.

Mo: 0.500% or Less

[0080] If the Mo content is more than 0.500%, large amounts of coarse precipitates and inclusions are formed to lower the ultimate deformability of the steel, thus narrowing the range of appropriate clearances for hole expanding deformation. Thus, when molybdenum is added, the content thereof is limited to 0.500% or less. The Mo content is preferably 0.450% or less. The Mo content is more preferably 0.400% or less. In contrast, molybdenum not only serves as a solid solution strengthening element but also can stabilize austenite and suppress ferrite formation in the cooling process during continuous annealing, thus increasing the strength of the steel sheet. To obtain these effects, the Mo content is preferably 0.010% or more. The Mo content is more preferably 0.020% or more.

Ni: 0.50% or Less

[0081] If the Ni content is more than 0.50%, large amounts of coarse precipitates and inclusions are formed to lower the ultimate deformability of the steel, thus narrowing the range of appropriate clearances for hole expanding deformation. Thus, when nickel is added, the content thereof is limited to 0.50% or less. The Ni content is preferably 0.45% or less. The Ni content is more preferably 0.30% or less. In contrast, nickel can stabilize austenite and suppress ferrite formation in the cooling process during continuous annealing, thus increasing the strength of the steel sheet. To obtain these effects, the Ni content is preferably 0.01% or more. The Ni content is more preferably 0.02% or more.

Sb: 0.200% or Less

[0082] If the Sb content is more than 0.200%, large amounts of coarse precipitates and inclusions are formed to lower the ultimate deformability of the steel, thus narrowing the range of appropriate clearances for hole expanding deformation. Thus, when antimony is added, the content thereof is limited to 0.200% or less. The Sb content is preferably 0.100% or less. The Sb content is more preferably 0.050% or less. In contrast, antimony suppresses the formation of a soft superficial layer and increases the strength of the steel sheet. To obtain these effects, the Sb content is preferably 0.001% or more. The Sb content is more preferably 0.005% or more.

Sn: 0.200% or Less

[0083] If the Sn content is more than 0.200%, large amounts of coarse precipitates and inclusions are formed to lower the ultimate deformability of the steel, thus narrowing the range of appropriate clearances for hole expanding deformation. Thus, when tin is added, the content thereof is limited to 0.200% or less. The Sn content is preferably 0.100% or less. The Sn content is more preferably 0.050% or less. In contrast, tin suppresses the formation of a soft superficial layer and increases the strength of the steel sheet. To obtain these effects, the Sn content is preferably 0.001% or more. The Sn content is more preferably 0.005% or more.

As: 0.100% or Less

[0084] If the As content is more than 0.100%, large amounts of coarse precipitates and inclusions are formed to lower the ultimate deformability of the steel, thus narrowing the range of appropriate clearances for hole expanding deformation. Thus, when arsenic is added, the content thereof is limited to 0.100% or less. The As content is preferably 0.060% or less. The As content is more preferably 0.010% or less. Arsenic increases the strength of the steel sheet. To obtain this effect, the As content is preferably 0.001% or more. The As content is more preferably 0.005% or more.

Ta: 0.100% or Less

[0085] If the Ta content is more than 0.100%, large amounts of coarse precipitates and inclusions are formed to lower the ultimate deformability of the steel, thus narrowing the range of appropriate clearances for hole expanding deformation. Thus, when tantalum is added, the content thereof is limited to 0.100% or less. The Ta content is preferably 0.050% or less. The Ta content is more preferably 0.010% or less. On the other hand, tantalum increases the strength of the steel sheet. To obtain this effect, the Ta content is preferably 0.001% or more. The Ta content is more preferably 0.005% or more.

Ca: 0.0200% or Less

[0086] If the Ca content is more than 0.0200%, large amounts of coarse precipitates and inclusions are formed to lower the ultimate deformability of the steel, thus narrowing the range of appropriate clearances for hole expanding deformation. Thus, when calcium is added, the content thereof is limited to 0.0200% or less. The Ca content is preferably 0.0100% or less. In contrast, calcium is an element used for deoxidation, and furthermore this element is effective for controlling the shape of sulfides to spherical, enhancing the ultimate deformability of the steel sheet, and enhancing the range of appropriate clearances not leading to delayed fracture. To obtain these effects, the Ca content is preferably 0.0001% or more.

Mg: 0.0200% or Less

[0087] If the Mg content is more than 0.0200%, large amounts of coarse precipitates and inclusions are formed to lower the ultimate deformability of the steel, thus narrowing the range of appropriate clearances for hole expanding deformation. Thus, when magnesium is added, the content thereof is limited to 0.0200% or less. In contrast, magnesium is an element used for deoxidation, and furthermore this element is effective for controlling the shape of sulfides to spherical, enhancing the ultimate deformability of the steel sheet, and enhancing the range of appropriate clearances not leading to delayed fracture. To obtain these effects, the Mg content is preferably 0.0001% or more.

Zn: 0.020% or Less, Co: 0.020% or Less, Zr: 0.020% or Less

[0088] If the contents of zinc, cobalt, and zirconium are each more than 0.020%, large amounts of coarse precipitates and inclusions are formed to lower the ultimate deformability of the steel, thus narrowing the range of appropriate clearances for hole expanding deformation. Thus, when zinc, cobalt, and zirconium are added, the contents thereof are each limited to 0.020% or less. In contrast, zinc, cobalt, and zirconium are elements effective for controlling the shape of inclusions to spherical, enhancing the ultimate deformability of the steel sheet, and enhancing the range of appropriate clearances not leading to delayed fracture. To obtain these effects, the contents of zinc, cobalt, and zirconium are preferably each 0.0001% or more.

REM: 0.0200% or Less

[0089] If the REM content is more than 0.0200%, large amounts of coarse precipitates and inclusions are formed to lower the ultimate deformability of the steel, thus narrowing the range of appropriate clearances for hole expanding deformation. Thus, when rare earth metals are added, the content thereof is limited to 0.0200% or less. In contrast, rare earth metals are elements effective for controlling the shape of inclusions to spherical, enhancing the ultimate deformability of the steel sheet, and enhancing the range of appropriate clearances not leading to delayed fracture. To obtain these effects, the REM content is preferably 0.0001% or more.

[0090] The balance of the composition is Fe and incidental impurities. When the content of any of the above optional elements is below the lower limit, the element does not impair the advantageous effects according to aspects of the present invention. Thus, such an optional element below the lower limit content is regarded as an incidental impurity.

[0091] Next, the steel microstructure of the high strength steel sheet according to aspects of the present invention will be described.

Tempered Martensite: 85% or More in Terms of Area Fraction

[0092] This requirement is a highly important claim component in accordance with aspects of the present invention. 1320 MPa or higher TS may be achieved by making martensite as the main phase. To obtain this effect, the area fraction of tempered martensite needs to be 85% or more. Thus, the area fraction of tempered martensite is limited to 85% or more. The area fraction of tempered martensite is preferably 90% or more. The area fraction of tempered martensite is more preferably 92% or more and is further preferably 95% or more. On the other hand, the upper limit of the area fraction of tempered martensite is not particularly limited and may be 100%.

[0093] Here, tempered martensite is measured as follows. A longitudinal cross section of the steel sheet is polished and is subjected to etching in 3 vol % Nital solution. A portion at ¼ sheet thickness (a location corresponding to ¼ of the sheet thickness in the depth direction from the steel sheet surface) is observed using SEM in 10 fields of view at a magnification of ×2000. In the microstructure images, tempered martensite is structures that have fine irregularities inside the structures and contain carbides within the structures. The values thus obtained are averaged to determine the area fraction of tempered martensite.

Retained Austenite: Less than 5% in Terms of Volume Fraction

[0094] This requirement is a highly important claim component in accordance with aspects of the present invention. If the volume fraction of retained austenite is 5% or more, it is difficult to achieve 85% or higher YR. The lowering in YR is ascribed to the fact that the amount of retained austenite is so large that strain induced transformation of retained austenite results in low YS. Thus, retained austenite is limited to less than 5% and is preferably 4% or less. The lower limit of retained austenite is not particularly limited. A lower fraction of retained austenite is more preferable, and the fraction may be 0%.

[0095] Here, retained austenite is measured as follows. The steel sheet was polished to expose a face 0.1 mm below ¼ sheet thickness and was thereafter further chemically polished to expose a face 0.1 mm below the face exposed above. The face was analyzed with an X-ray diffractometer using CoKα radiation to determine the integral intensity ratios of the diffraction peaks of {200}, {220}, and {311} planes of fcc iron and {200}, {211}, and {220} planes of bcc iron. Nine integral intensity ratios thus obtained were averaged to determine retained austenite.

Total of Ferrite and Bainitic Ferrite: 10% or Less in Terms of Area Fraction

[0096] This requirement is a highly important claim component in accordance with aspects of the present invention. If the total of ferrite and bainitic ferrite is more than 10%, it is difficult to achieve 1320 MPa or higher TS and to achieve 85% or higher YR. The lowering in YR is ascribed to the fact that ferrite and bainitic ferrite are soft microstructures and hasten the occurrence of yielding. Thus, the total of ferrite and bainitic ferrite is limited to 10% or less. The total is preferably 8% or less and is more preferably 5% or less. The lower limit of the total of ferrite and bainitic ferrite is not particularly limited. A smaller fraction is more preferable. The lower limit of the total of ferrite and bainitic ferrite may be 0%.

[0097] Here, the total of ferrite and bainitic ferrite is measured as follows. A longitudinal cross section of the steel sheet is polished and is subjected to etching in 3 vol % Nital solution. A portion at ¼ sheet thickness (a location corresponding to ¼ of the sheet thickness in the depth direction from the steel sheet surface) is observed using SEM in 10 fields of view at a magnification of ×2000. In the microstructure images, ferrite and bainitic ferrite are recessed structures with a flat interior. The values thus obtained are averaged to determine the total of ferrite and bainitic ferrite.

[0098] Possible microstructures other than those described above include pearlite, fresh martensite, and acicular ferrite. These microstructures do not affect characteristics as long as their fractions do not exceed 58, and thus may be present within that range.

[0099] KAM (S)/KAM (C)<1.00

KAM (S): KAM (Kernel Average Misorientation) Value of a Superficial Portion of the Steel Sheet, KAM (C): KAM Value of a Central Portion of the Steel Sheet

[0100] This requirement is a highly important claim component in accordance with aspects of the present invention. The superficial portion of the steel sheet is located 100 μm below the steel sheet surface toward the center of the sheet thickness. The central portion of the steel sheet is located at ½ of the sheet thickness. Studies by the present inventors have revealed that varied distributions of dislocations from the superficial portion to the inside, specifically, KAM (S)/KAM (C) of less than 1.00 is effective for improving the YR and the range of appropriate clearances not leading to delayed fracture. Thus, KAM (S)/KAM (C) is limited to less than 1.00. The lower limit of KAM (S)/KAM (C) is not particularly limited but is preferably 0.80 or more due to production technology limitations.

[0101] Here, the KAM values are measured as follows. First, a test specimen for microstructure observation was sampled from the cold rolled steel sheet. Next, the sampled test specimen was polished by vibration polishing with colloidal silica to expose a cross section in the rolling direction (a longitudinal cross section) for use as observation surface. The observation surface was specular. Next, electron backscatter diffraction (EBSD) measurement was performed. Local crystal orientation data was thus obtained. Here, the SEM magnification was ×3000, the step size was 0.05 μm, the measured region was 20 μm square, and the WD was 15 mm. The local orientation data obtained was analyzed with analysis software: OIM Analysis 7. The analysis was performed with respect to 10 fields of view of the portion at the target sheet thickness, and the results were averaged.

[0102] Prior to the data analysis, cleanup was performed sequentially once using Grain Dilation function of the analysis software (Grain Tolerance Angle: 5, Minimum Grain Size: 2, Single Iteration: ON) and once with Grain CI Standardization function (Grain Tolerance Angle: 5, Minimum Grain Size: 5). Subsequently, measurement points with a CI value>0.1 were exclusively used for the analysis. The KAM values were displayed as a chart, and the average KAM value of the bcc phase was determined. The analysis here was performed under the following conditions:

[0103] Nearest neighbor: 1st,

[0104] Maximum misorientation: 5,

[0105] Perimeter only, and

[0106] Check Set 0-point kernels to maximum misorientation.

$$Hv(Q) - Hv(S) \geq 8$$

Hv (Q): Hardness of a Portion at ¼ Sheet Thickness, Hv (S): Hardness of a Superficial Portion of the Steel Sheet

[0107] This requirement is a highly important claim component in accordance with aspects of the present invention. The superficial portion of the steel sheet is located 100 μm below the steel sheet surface toward the center of the sheet thickness. Studies by the present inventors have revealed that variations in hardness from the superficial portion to the inside, specifically, Hv (Q)-Hv (S) of 8 or more is effective for improving the YR and the range of appropriate clearances not leading to delayed fracture. Thus, Hv (Q)-Hv (S) is limited to 8 or more. The upper limit of Hv (Q)-Hv (S) is not particularly limited but is preferably 30 or less due to production technology limitations. Preferred ranges of Hv (Q) and Hv (S) are 400 to 600 and 400 to 600, respectively. Here, the hardness is measured as follows. First, a test specimen for microstructure observation was sampled from the cold rolled steel sheet. Next, the sampled test specimen was polished to expose a cross section in the rolling direction (a longitudinal cross section) for use as observation surface. The observation surface was specular. Next, the hardness was determined using a Vickers tester with a load of 1 kg. The hardness was measured with respect to 10 points at 20 μm intervals at the target sheet thickness. The values of 8 points excluding the maximum hardness and the minimum hardness were averaged.

[0108] Next, a manufacturing method according to aspects of the present invention will be described.

[0109] In accordance with aspects of the present invention, a steel material (a steel slab) may be obtained by any known steelmaking method without limitation, such as a converter or an electric arc furnace. To prevent macrosegregation, the steel slab (the slab) is preferably produced by a continuous casting method.

[0110] In accordance with aspects of the present invention, the slab heating temperature, the slab soaking holding time, and the coiling temperature in hot rolling are not particularly limited. For example, the steel slab may be hot rolled in such a manner that the slab is heated and is then rolled, that the slab is subjected to hot direct rolling after continuous casting without being heated, or that the slab is subjected to a short heat treatment after continuous casting and is then rolled. The slab heating temperature, the slab soaking holding time, the finish rolling temperature, and the coiling temperature in hot rolling are not particularly limited. The slab heating temperature is preferably 1100° C. or above. The slab heating temperature is preferably 1300° C. or below. The slab soaking holding time is preferably 30 minutes or more. The slab soaking holding time is preferably 250 minutes or less. The finish rolling temperature is preferably Ar_3 transformation temperature or above. Furthermore, the coiling temperature is preferably 350° C. or above. The coiling temperature is preferably 650° C. or below.

[0111] The hot rolled steel sheet thus produced is pickled. Pickling can remove oxides on the steel sheet surface and is thus important to ensure good chemical convertibility and a high quality of coating in the final high strength steel sheet. Pickling may be performed at a time or several. The hot rolled sheet that has been pickled may be cold rolled directly or may be subjected to heat treatment before cold rolling.

[0112] The rolling reduction in cold rolling and the sheet thickness after rolling are not particularly limited. The rolling reduction in cold rolling is preferably 30% or more. The rolling reduction in cold rolling is preferably 80% or less. The advantageous effects according to aspects of the present invention may be obtained without limitations on the number of rolling passes and the rolling reduction in each pass.

[0113] The cold rolled steel sheet obtained as described above is annealed. Annealing conditions are as follows.

Annealing Temperature T1: 850° C. or Above and 1000° C. or Below

[0114] This requirement is a highly important claim component in accordance with aspects of the present invention. If the annealing temperature T1 is below 850° C., the area fraction of the total of ferrite and bainitic ferrite exceeds 10% to make it difficult to achieve 1320 MPa or higher TS and to achieve 85% or higher YR. Thus, the annealing temperature T1 is limited to 850° C. or above. T1 is preferably 860° C. or above. T1 is more preferably 870° C. or above. However, if the annealing temperature T1 is higher than 1000° C., the prior-austenite grain size excessively increases and the range of appropriate clearances not leading to delayed fracture is narrowed. Thus, the annealing temperature T1 is limited to 1000° C. or below. The annealing temperature T1 is preferably 970° C. or below. T1 is more preferably 950° C. or below.

Holding Time t1 at the Annealing Temperature T1: 10 Seconds or More and 1000 Seconds or Less

[0115] This requirement is a highly important claim component in accordance with aspects of the present invention. If the holding time t1 at the annealing temperature T1 is less than 10 seconds, austenitization is insufficient with the result that the area fraction of the total of ferrite and bainitic ferrite exceeds 10% to make it difficult to achieve 1320 MPa or higher TS and to achieve 85% or higher YR. Thus, the holding time t1 at the annealing temperature T1 is limited to 10 seconds or more. The holding time t1 at the annealing temperature T1 is preferably 30 seconds or more. t1 is more preferably 45 seconds or more. t1 is still more preferably 60 seconds or more. t1 is most preferably 100 seconds or more. However, if the holding time at the annealing temperature T1 is longer than 1000 seconds, the prior-austenite grain size excessively increases and the range of appropriate clearances not leading to delayed fracture is narrowed. Thus, the holding time t1 at the annealing temperature T1 is limited to 1000 seconds or less. The holding time t1 at the annealing temperature T1 is preferably 800 seconds or less. t1 is more preferably 500 seconds or less.

Cooling to 100° C. or Below after Annealing

[0116] In the step of cooling to 100° C. or below, austenite is transformed into martensite. To obtain 85% or more martensite, the annealed steel sheet needs to be cooled to 100° C. or below. Thus, cooling after annealing is effected to 100° C. or below. The lower limit of the cooling complete temperature is not particularly limited but is preferably 0° C. or above due to production technology limitations.

Elapsed Time t2 from the Time when the Temperature Reaches 100° C. Until the Start of Working: 1000 Seconds or Less

[0117] This requirement is a highly important claim component in accordance with aspects of the present invention. If the elapsed time t2 from the time when the temperature reaches 100° C. until the start of working is longer than 1000 seconds, aging of martensite microstructure proceeds and varied amounts of strains are introduced by working into the superficial portion of the steel sheet and the central portion of the steel sheet with the result that KAM (S)/KAM (C) becomes 1.00 or more. As a result, the YR is lowered and the range of appropriate clearances not leading to delayed fracture is narrowed. Thus, the elapsed time t2 from the time when the temperature reaches 100° C. until the start of working is limited to 1000 seconds or less. The elapsed time t2 from the time when the temperature reaches 100° C. until the start of working is preferably 900 seconds or less. t2 is more preferably 800 seconds or less. The lower limit of the elapsed time t2 from the time when the temperature reaches 100° C. until the start of working is not particularly limited but is preferably 5 seconds or more due to production technology limitations. Studies by the present inventors have shown that the elapsed time from the time when the temperature reaches 100° C. until the end of working does not affect the amounts of strains introduced by working into the superficial portion of the steel sheet and the central portion of the steel sheet.

Working Start Temperature T2: 80° C. or Below

[0118] This requirement is a highly important claim component in accordance with aspects of the present invention. If the working start temperature T2 is higher than 80° C., the steel sheet is soft and working introduces varied amounts of strains into the superficial portion of the steel sheet and the central portion of the steel sheet with the result that KAM (S)/KAM (C) becomes 1.00 or more. As a result, the YR is lowered and the range of appropriate clearances not leading to delayed fracture is narrowed. Thus, the working start temperature T2 is limited to 80° C. or below. The working start temperature T2 is preferably 60° C. or below. T2 is more preferably 50° C. or below. The lower limit of the working start temperature T2 is not particularly limited but is preferably 0° C. or above due to production technology limitations.

Equivalent Plastic Strain: 0.10% or More and 5.00% or Less

[0119] This requirement is a highly important claim component in accordance with aspects of the present invention. If the equivalent plastic strain is less than 0.10%, the amount of working is small and KAM (S)/KAM (C) becomes 1.00 or more. As a result, the YR is lowered and the range of appropriate clearances not leading to delayed fracture is narrowed. Thus, the equivalent plastic strain is limited to 0.10% or more. The equivalent plastic strain is preferably 0.15% or more. The equivalent plastic strain is more preferably 0.20% or more. If the equivalent plastic strain is more than 5.00%, the influences by working are equal between the superficial portion of the steel sheet and the central portion of the steel sheet with the result that KAM (S)/KAM (C) becomes 1.00 or more. As a result, the YR is lowered and the range of appropriate clearances not leading to delayed fracture is narrowed. The upper limit of the equivalent plastic strain is 5.00% or less due to production technology limitations. Thus, the equivalent plastic strain is limited to 5.00% or less. The equivalent plastic strain is preferably 4.00% or less. The equivalent plastic strain is more preferably 2.00% or less. The equivalent plastic strain is still more preferably 1.00% or less.

[0120] The working step before tempering is preferably performed under conditions where strain is applied by two or more separate working operations, and the total of the equivalent plastic strains applied in the working operations is 0.10% or more.

[0121] When the equivalent plastic strain in the first working operation is less than 0.108, the total of the equivalent plastic strains may be brought to 0.10% or more by the second and subsequent working operations. Even in this case, KAM (S)/KAM (C) becomes less than 1.00, and the YR and the range of appropriate clearances not leading to delayed fracture are enhanced. Thus, the working step before tempering may apply strain by two or more separate working operations as long as the total of the equivalent plastic strains applied in the working operations is 0.10% or more. Incidentally, there is no limitation on the elapsed time from when the temperature reaches 100° C. until the start of the second and subsequent working operations, because the mobility of dislocations in martensite has been lowered by the first working operation.

[0122] Here, the working process may be typically temper rolling or tension leveling. The equivalent plastic strain in temper rolling is the ratio by which the steel sheet is elongated and may be determined from the change in the length of the steel sheet before and after the working. The equivalent plastic strain of the steel sheet in leveler processing was calculated by the method of Reference 1 below. The data inputs described below were used in the calculation. Regarding the work hardening behavior, the material was assumed to be a linear hardening elastoplastic material. Bausinger hardening and the decrease in tension due to bend loss were ignored. Misaka's formula was used as the formula of bending curvature.

[0123] Sheet thickness breakdown: 31 divisions

[0124] Young's modulus: 21000 kgf/mm^2

[0125] Poisson's ratio: 0.3

[0126] Yield stress: 111 kgf/mm^2

[0127] Plastic coefficient: 1757 kgf/mm^2

[0128] [Reference 1] Yoshisuke Misaka, Takeshi Masui; Sosei to Kakou (Journal of JSTP), 17 (1976), 988.

[0129] Incidentally, the working may be any common strain imparting technique other than those described above. For example, the working may be performed with a continuous stretcher leveler or a roller leveler.

Tempering Temperature T3: 100° C. or Above and 400° C. or Below

[0130] This requirement is a highly important claim component in accordance with aspects of the present invention. If the tempering temperature T3 is lower than 100° C., the carbon diffusion distance is so short that the hardness of the steel sheet surface and the inside of the steel sheet is lowered and Hv (Q)-Hv (S) becomes less than 8. As a result, the YR is lowered and the range of appropriate clearances not leading to delayed fracture is narrowed. Thus, the tempering temperature T3 is limited to 100° C. or above. The tempering temperature T3 is preferably 150° C. or above. T3 is more preferably 170° C. or above. T3 is still more preferably 200° C. or above. However, if the tempering temperature T3 is higher than 400° C., tempering of martensite proceeds to make it difficult to achieve 1320 MPa or higher TS. Thus, the tempering temperature T3 is limited to 400° C. or below. The tempering temperature T3 is preferably 350° C. or below. T3 is more preferably 300° C. or below. T3 is still more preferably 280° C. or below.

Holding Time t3 at the Tempering Temperature T3: 1.0 Second or More and 1000.0 Seconds or Less

[0131] This requirement is a highly important claim component in accordance with aspects of the present invention. If the holding time t3 at the tempering temperature T3 is less than 1.0 second, the carbon diffusion distance is so short that the hardness of the steel sheet surface and the inside of the steel sheet is lowered and Hv (Q)-Hv (S) becomes less than 8 with the result that the YR is lowered and the range of appropriate clearances not leading to delayed fracture is narrowed. Thus, the holding time t3 at the tempering temperature T3 is limited to 1.0 second or more. The holding time t3 at the tempering temperature T3 is preferably 5.0 seconds or more. t3 is more preferably 50.0 seconds or more. t3 is still more preferably 100.0 seconds or more. However, if the holding time t3 at the tempering temperature T3 is longer than 1000.0 seconds, tempering of martensite proceeds to make it difficult to achieve 1320 MPa or higher TS. Thus, the holding time t3 at the tempering temperature T3 is limited to 1000.0 seconds or less. The holding time t3 at the tempering temperature T3 is preferably 800.0 seconds or less. t3 is more preferably 600.0 seconds or less. t3 is still more preferably 500.0 seconds or less.

Cooling Rate 01 from the Tempering Temperature T3 to 80° C.: 100° C./Sec or Less

[0132] This requirement is a highly important claim component in accordance with aspects of the present invention. If the cooling rate 01 from the tempering temperature T3 to 80° C. is higher than 100° C./sec, the carbon diffusion distance is so short that the hardness of the steel sheet surface and the inside of the steel sheet is lowered and Hv (Q)-Hv (S) becomes less than 8 with the result that the YR is lowered and the range of appropriate clearances not leading to delayed fracture is narrowed. Thus, the cooling rate 01 from the tempering temperature T3 to 80° C. is limited to 100° C./sec or less. The cooling rate 01 from the tempering temperature T3 to 80° C. is preferably 50° C./sec or less. The lower limit of the cooling rate 01 from the tempering temperature T3 to 80° C. is not particularly limited but is preferably 10° C./sec or more due to production technology limitations.

[0133] Below 80° C., cooling is not particularly limited and the steel sheet may be cooled to a desired temperature in an appropriate manner. Incidentally, the desired temperature is preferably about room temperature.

[0134] Furthermore, the high strength steel sheet described above may be worked again under conditions where the amount of equivalent plastic strain is 0.10% or more and 5.00% or less. Here, the target amount of equivalent plastic strain may be applied at a time or several.

[0135] When the high strength steel sheet is a product that is traded, the steel sheet is usually traded after being cooled to room temperature.

[0136] The high strength steel sheet may be subjected to coating treatment during annealing or after annealing. The phrase "during annealing" means a period from the end of the holding time t1 at the annealing temperature T1 until when the steel sheet that has been held for t3 at the tempering temperature T3 is cooled to room temperature. The phrase "after annealing" means a period after the steel sheet is cooled to room temperature.

[0137] For example, the coating treatment during annealing may be hot-dip galvanizing treatment and alloying treatment following the hot-dip galvanizing treatment which are performed when the steel sheet that has been held at the annealing temperature T1 is being cooled to 100° C. or below. For example, the coating treatment after annealing may be Zn—Ni electrical alloying coating treatment or pure Zn electroplated coating treatment performed after the steel sheet that has been held for t3 at the tempering temperature T3 is cooled to room temperature. A coated layer may be formed by electroplated coating, or hot-dip zinc-aluminum-magnesium alloy coating may be applied. In the above coating treatment, examples were described focusing on zinc coating, the types of coating metals, such as Zn coating and Al coating, are not particularly limited. Other conditions in the manufacturing method are not particularly limited. From the point of view of productivity, the series of treatments including annealing, hot-dip galvanizing, and alloying treatment of the coated zinc layer is preferably performed on hot-dip galvanizing line, that is CGL (continuous galvanizing line). To control the coating weight of the coated layer, the hot-dip galvanizing treatment may be followed by wiping. Conditions for operations, such as coating, other than those conditions described above may be determined in accordance with the usual hot-dip galvanizing technique.

[0138] After the coating treatment during annealing or after annealing, the steel sheet may be worked again under conditions where the amount of equivalent plastic strain is 0.10% or more and 5.00% or less. Here, the target amount of equivalent plastic strain may be applied at a time or several.

EXAMPLES

[0139] Steels having a chemical composition described in Table 1-1 or Table 1-2, with the balance being Fe and incidental impurities, were smelted in a converter and were continuously cast into slabs. Next, the slabs obtained were heated, hot rolled, pickled, cold rolled, and subjected to annealing treatment, working, and tempering treatment described in Table 2-1, Table 2-2, and Table 2-3. High strength cold rolled steel sheets having a sheet thickness of 0.6 to 2.2 mm were thus obtained. Incidentally, some of the steel sheets were subjected to coating treatment after annealing.

[0140] In EXAMPLES Nos. 77, 82, 85, 88, and 91, the slabs fractured in the casting step and thus the test was discontinued.

[0141] The high strength cold rolled steel sheets obtained as described above were used as test steels. Tensile characteristics and delayed fracture resistance were evaluated in accordance with the following test methods.

(Microstructure Observation)

[0142] The area fraction of tempered martensite, the volume fraction of retained austenite, and the total of the area fraction of ferrite and the area fraction of bainitic ferrite were determined in accordance with the methods described hereinabove.

(KAM Values)

[0143] The KAM value of a superficial portion of the steel sheet and the KAM value of a central portion of the steel sheet were determined in accordance with the method described hereinabove.

(Hardness Test)

[0144] The hardness of a portion at ¼ Sheet Thickness and the hardness of a superficial portion of the steel sheet were determined in accordance with the method described hereinabove.

(Tensile Test)

[0145] A JIS No. 5 test specimen (gauge length: 50 mm, width of parallel portion: 25 mm) was sampled so that the longitudinal direction of the test specimen would be perpendicular to the rolling direction. A tensile test was performed in accordance with JIS Z 2241 under conditions where the crosshead speed was 1.67×10^{-1} mm/sec. YS and TS were thus measured. In accordance with aspects of the present invention, 1320 MPa or higher TS was judged to be acceptable, and 85% or higher yield ratio (YR) was judged to be acceptable. The YR is determined from the following formula (3):

$$YR = 100 \times YS/TS \tag{3}$$

(Range of Appropriate Clearances not Leading to Delayed Fracture)

[0146] The range of appropriate clearances not leading to delayed fracture was determined by the following method. Test specimens having a size of 16 mm×75 mm were prepared by shearing in such a manner that the longitudinal direction would be perpendicular to the rolling direction. The rake angle in the shearing process was constant at 0°, and the shear clearance was changed from 5 to 10, 15, 20, 25, 30, and 35%. The test specimens were four-point loaded in accordance with ASTM (G39-99) so that 1000 MPa stress was applied to the bend apex. The loaded test specimens were immersed in pH 3 hydrochloric acid at 25° C. for 100 hours. The rating was “x” when the shear clearances that did not cause cracking ranged below 10%. The rating was “o” when the shear clearances ranged to 10% or above but below 158. The rating was “O” when the shear clearances that did not cause cracking ranged to 15% or above. The range of appropriate clearances not leading to delayed fracture was evaluated as excellent when the shear clearances that did not cause cracking ranged to 10% or above.

[0147] As described in Table 3-1, Table 3-2, and Table 3-3, INVENTIVE EXAMPLES achieved 1320 MPa or higher TS, 85% or higher YR, and an excellent range of appropriate clearances not leading to delayed fracture. In contrast, COMPARATIVE EXAMPLES were unsatisfactory in one or more of TS, YR, and the range of appropriate clearances not leading to delayed fracture.

TABLE 1-1

	Chemical composition (mass %)													
Steels	C	Si	Mn	P	S	Al	N	H	Ti	B	Nb	Cu	Others	Remarks
A	0.21	0.71	2.96	0.010	0.0015	0.037	0.0018	0.0000	0.015					Compliant steel
B	0.20	0.90	3.02	0.011	0.0007	0.032	0.0068	0.0000						Compliant steel
C	0.20	0.85	2.89	0.005	0.0009	0.054	0.0023	0.0000		0.0015				Compliant steel
D	0.18	0.28	1.01	0.015	0.0008	0.047	0.0033	0.0000			0.005			Compliant steel
E	0.19	0.14	1.11	0.005	0.0013	0.012	0.0025	0.0000						Compliant steel
F	0.19	0.11	1.01	0.006	0.0011	0.057	0.0010	0.0000					0.11	Compliant steel
G	0.16	0.91	2.95	0.006	0.0015	0.023	0.0010	0.0000	0.041					Compliant steel
H	0.14	0.78	3.05	0.012	0.0006	0.045	0.0028	0.0000						Comparative steel
I	0.44	0.67	2.77	0.005	0.0006	0.034	0.0039	0.0000			0.016			Compliant steel
J	0.46	0.69	3.12	0.012	0.0005	0.012	0.0041	0.0000						Comparative steel
K	0.18	0.11	2.73	0.008	0.0012	0.025	0.0063	0.0000						Compliant steel
L	0.21	1.91	2.96	0.011	0.0008	0.011	0.0070	0.0000						Compliant steel
M	0.18	2.11	3.03	0.006	0.0008	0.036	0.0033	0.0000						Comparative steel
N	0.20	0.78	1.12	0.011	0.0006	0.015	0.0060	0.0000						Compliant steel
O	0.19	0.75	0.41	0.011	0.0007	0.026	0.0050	0.0000						Comparative steel
P	0.21	0.94	3.45	0.013	0.0006	0.044	0.0056	0.0000						Compliant steel
Q	0.20	0.77	3.55	0.009	0.0007	0.021	0.0070	0.0000						Comparative steel
R	0.20	0.70	3.02	0.099	0.0013	0.018	0.0066	0.0000						Compliant steel
S	0.19	0.61	2.78	0.121	0.0006	0.045	0.0031	0.0000						Comparative steel
T	0.21	0.67	3.04	0.006	0.0182	0.021	0.0030	0.0000						Compliant steel
U	0.22	0.94	2.96	0.012	0.0222	0.028	0.0048	0.0000						Comparative steel
V	0.19	0.99	2.84	0.010	0.0011	0.976	0.0029	0.0000						Compliant steel
W	0.18	0.67	2.76	0.015	0.0010	1.135	0.0015	0.0000						Comparative steel
X	0.22	0.85	3.16	0.006	0.0011	0.014	0.0089	0.0000						Compliant steel
Y	0.20	0.87	2.85	0.005	0.0009	0.027	0.0112	0.0000						Comparative steel
Z	0.21	0.84	2.98	0.014	0.0014	0.040	0.0046	0.0012						Compliant steel

Underlines indicate being outside of the range of the present invention. Blanks indicate that the element was not added intentionally.

TABLE 1-2

	Chemical composition (mass %)													
Steels	C	Si	Mn	P	S	Al	N	H	Ti	B	Nb	Cu	Others	Remarks
AA	0.19	0.76	2.77	0.006	0.0007	0.056	0.0030	0.0035						Comparative steel
AB	0.21	0.91	2.96	0.005	0.0005	0.011	0.0033	0.0000		0.0028	0.019	0.15		Compliant steel
AC	0.21	0.64	3.01	0.006	0.0005	0.055	0.0038	0.0000	0.085	0.0022	0.029	0.18		Compliant steel
AD	0.20	0.81	2.82	0.010	0.0014	0.032	0.0062	0.0000	0.125	0.0017	0.028	0.12		Comparative steel
AE	0.19	0.89	3.15	0.010	0.0007	0.038	0.0032	0.0000	0.026		0.029	0.12		Compliant steel
AF	0.20	0.72	3.07	0.011	0.0013	0.010	0.0056	0.0000	0.021	0.0076	0.024	0.17		Compliant steel
AG	0.20	0.64	3.19	0.011	0.0012	0.016	0.0028	0.0000	0.045	0.0124	0.029	0.17		Comparative steel
AH	0.19	0.60	2.86	0.009	0.0007	0.015	0.0069	0.0000	0.019	0.0025		0.19		Compliant steel
AI	0.19	0.62	2.85	0.009	0.0011	0.034	0.0048	0.0000	0.030	0.0028	0.086	0.11		Compliant steel
AJ	0.19	0.89	3.16	0.009	0.0012	0.016	0.0047	0.0000	0.037	0.0014	0.135	0.12		Comparative steel
AK	0.22	0.68	3.11	0.007	0.0014	0.014	0.0018	0.0000	0.026	0.0018	0.025			Compliant steel
AL	0.18	0.62	2.83	0.007	0.0012	0.016	0.0022	0.0000	0.024	0.0026	0.026	0.96		Compliant steel
AM	0.21	0.79	2.99	0.015	0.0011	0.020	0.0042	0.0000	0.021	0.0026	0.012	1.02	—	Comparative steel
AN	0.19	0.22	1.33	0.010	0.0011	0.053	0.0047	0.0000					Cr: 0.340	Compliant steel
AO	0.21	0.83	2.86	0.013	0.0011	0.040	0.0011	0.0000					V: 0.056	Compliant steel
AP	0.21	0.18	1.00	0.014	0.0012	0.016	0.0035	0.0000					Mo: 0.330	Compliant steel
AQ	0.21	0.95	3.08	0.009	0.0008	0.011	0.0022	0.0000					Ni: 0.10	Compliant steel
AR	0.22	0.25	1.17	0.013	0.0013	0.056	0.0067	0.0000					As: 0.006	Compliant steel
AS	0.20	0.99	3.19	0.009	0.0006	0.047	0.0011	0.0000					Sb: 0.011	Compliant steel
AT	0.22	0.15	1.16	0.015	0.0006	0.031	0.0033	0.0000					Sn: 0.009	Compliant steel
AU	0.21	0.71	2.82	0.013	0.0009	0.022	0.0034	0.0000					Ta: 0.004	Compliant steel
AV	0.20	0.15	1.17	0.005	0.0008	0.017	0.0032	0.0000					Ca: 0.0014, Mg: 0.0150, Zn: 0.006, Co: 0.013	Compliant steel

TABLE 1-2-continued

	Chemical composition (mass %)													
Steels	C	Si	Mn	P	S	Al	N	H	Ti	B	Nb	Cu	Others	Remarks
AW	0.21	0.61	2.79	0.008	0.0012	0.016	0.0062	0.0000					Zr: 0.0022	Compliant steel
AX	0.22	0.26	1.04	0.013	0.0006	0.059	0.0055	0.0000	0.044	0.0030	0.006	0.12	REM: 0.0150	Compliant steel
AY	0.17	0.15	1.03	0.013	0.0008	0.039	0.0049	0.0000						Compliant steel
AZ	0.33	0.28	1.30	0.008	0.0014	0.049	0.0063	0.0000						Compliant steel

Underlines indicate being outside of the range of the present invention. Blanks indicate that the element was not added intentionally.

TABLE 2-1

No.	Steels	Sheet thickness (mm)	Annealing temp. T1 (° C.)	Holding time t1 (sec)	Elapsed time t2 from when the temp. reached 100° C. until start of working (sec)	Working start temp. T2 (° C.)	Equivalent plastic strain (%)	Working operations (times)	Tempering temp. T3 (° C.)	Holding time t3 (sec)	Cooling rate θ1 from tempering temp. T3 to 80° C. (° C./sec)	Type of product (*)	Remarks
1	A	1.4	875	105	729	44	0.44	1	237	160.5	29	CR	INV. EX.
2	B	1.4	870	151	653	25	0.55	1	250	62.0	34	CR	INV. EX.
3	B	1.4	855	119	710	47	0.42	1	177	121.1	50	CR	INV. EX.
4	B	1.4	842	168	763	27	0.53	1	239	236.5	26	CR	COMP. EX.
5	B	1.4	968	155	731	41	0.50	1	176	248.2	36	CR	INV. EX.
6	B	1.4	989	133	653	42	0.40	1	260	176.5	28	CR	INV. EX.
7	B	1.4	874	11	795	39	0.47	1	207	219.3	34	CR	INV. EX.
8	B	1.4	879	3	722	35	0.33	1	293	161.0	40	CR	COMP. EX.
9	B	1.4	878	956	777	47	0.35	1	266	236.0	49	CR	INV. EX.
10	B	1.4	868	992	711	47	0.32	1	198	263.7	34	CR	INV. EX.
11	B	1.4	875	106	22	30	0.54	1	292	185.9	45	CR	INV. EX.
12	B	1.4	879	71	723	27	0.37	2	215	294.1	50	CR	INV. EX.
13	B	1.4	874	179	986	48	0.39	1	211	276.5	34	CR	INV. EX.
14	B	1.4	860	146	1065	25	0.35	1	293	205.7	32	CR	COMP. EX.
15	B	1.4	862	72	758	12	0.54	1	218	138.9	28	CR	INV. EX.
16	B	1.4	862	158	792	37	0.52	3	224	283.1	26	CR	INV. EX.
17	B	1.4	861	56	730	77	0.44	1	150	217.0	41	CR	INV. EX.
18	B	1.4	877	98	614	95	0.42	1	279	245.1	26	CR	COMP. EX.
19	B	1.4	880	107	683	32	0.13	1	180	243.4	32	CR	INV. EX.
20	B	1.4	879	160	670	48	0.08	1	246	258.0	48	CR	COMP. EX.
21	B	1.4	866	112	695	28	4.20	1	269	170.2	31	CR	INV. EX.
22	B	1.4	871	170	629	29	0.40	4	197	224.4	32	CR	INV. EX.
23	B	1.4	879	83	652	35	0.54	1	106	200.6	30	CR	INV. EX.
24	B	1.4	865	151	612	33	0.39	1	90	228.7	31	CR	COMP. EX.
25	B	1.4	871	132	613	46	0.38	1	391	257.8	39	CR	INV. EX.
26	B	1.4	877	147	743	48	0.33	1	392	170.8	29	CR	INV. EX.
27	B	1.4	869	58	668	49	0.57	1	275	4.7	29	CR	INV. EX.
28	B	1.4	872	154	700	36	0.40	1	173	2.2	45	CR	INV. EX.
29	B	1.4	866	101	709	27	0.58	1	292	1.2	27	CR	INV. EX.
30	B	1.4	878	109	656	28	0.55	1	217	0.8	30	CR	COMP. EX.
31	B	1.4	879	180	690	48	0.34	1	232	988.0	38	CR	INV. EX.
32	B	1.4	872	175	725	28	0.54	1	200	998.5	49	CR	INV. EX.
33	B	1.4	879	151	610	45	0.58	1	218	146.7	5	CR	INV. EX.
34	B	1.4	870	85	792	39	0.58	4	191	280.5	26	CR	INV. EX.
35	B	1.4	877	161	682	46	0.49	1	228	256.5	98	CR	INV. EX.

Underlines indicate being outside of the range of the present invention.

(*) CR: Cold rolled steel sheet (without coating)

TABLE 2-2

No.	Steels	Sheet thickness (mm)	Annealing temp. T1 (° C.)	Holding time t1 (sec)	Elapsed time t2 from when the temp. reached 100° C. until start of working (sec)	Working start temp. T2 (° C.)	Equivalent plastic strain (%)	Working operations (times)	Tempering temp. T3 (° C.)	Holding time t3 (sec)	Cooling rate θ1 from tempering temp. T3 to 80° C. (° C./sec)	Type of product (*)	Remarks
36	B	1.4	872	58	706	29	0.52	1	204	228.1	125	CR	COMP. EX.
37	C	0.8	880	65	621	46	0.42	1	187	198.8	41	CR	INV. EX.
38	D	2.0	864	133	772	30	0.48	1	255	245.6	29	CR	INV. EX.
39	E	1.4	869	106	644	47	0.31	1	179	153.0	45	CR	INV. EX.
40	E	1.4	855	67	651	29	0.60	1	294	267.6	46	CR	INV. EX.
41	E	1.4	879	151	784	30	0.51	1	173	252.7	37	CR	INV. EX.

TABLE 2-2-continued

No.	Steels	Sheet thick-ness (mm)	An-nealing temp. T1 (° C.)	Holding time t1 (sec)	Elapsed time t2 from when the temp. reached 100° C. until start of working (sec)	Working start temp. T2 (° C.)	Equiv-alent plastic strain (%)	Working operations (times)	Tem-pering temp. T3 (° C.)	Holding time t3 (sec)	Cooling rate θ1 from tempering temp. T3 to 80° C. (° C./sec)	Type of prod-uct (*)	Remarks
42	E	1.4	880	12	654	31	0.47	1	286	117.4	46	CR	INV. EX.
43	E	1.4	876	946	759	27	0.57	1	288	270.3	25	CR	INV. EX.
44	E	1.4	865	182	20	28	0.44	1	269	195.9	30	CR	INV. EX.
45	E	1.4	865	185	996	28	0.37	1	277	164.1	38	CR	INV. EX.
46	E	1.4	877	54	720	11	0.53	1	171	140.1	37	CR	INV. EX.
47	E	1.4	864	86	663	79	0.33	1	287	161.4	43	CR	INV. EX.
48	E	1.4	860	190	635	43	0.13	1	228	114.9	28	CR	INV. EX.
49	E	1.4	867	70	651	47	4.22	1	172	169.5	33	CR	INV. EX.
50	E	1.4	877	117	755	49	0.51	1	105	245.2	28	CR	INV. EX.
51	E	1.4	866	58	650	50	0.38	1	381	158.2	38	CR	INV. EX.
52	E	1.4	870	84	641	50	0.40	1	228	4.6	50	CR	INV. EX.
53	E	1.4	872	191	693	46	0.55	1	245	2.1	31	CR	INV. EX.
54	F	1.4	869	158	769	46	0.42	1	170	1.1	30	CR	INV. EX.
55	E	1.4	880	117	787	37	0.46	1	225	991.0	28	CR	INV. EX.
56	E	1.4	862	85	712	33	0.35	1	186	163.9	4	CR	INV. EX.
57	E	1.4	877	157	748	30	0.49	1	296	240.2	88	CR	INV. EX.
58	F	1.2	861	132	602	44	0.42	1	274	198.2	40	CR	INV. EX.
59	G	1.2	874	149	697	32	0.43	1	253	135.5	29	GA	INV. EX.
60	H	1.2	874	116	722	49	0.36	1	222	231.8	44	GA	COMP. EX.
61	I	1.2	861	138	641	49	0.50	1	294	104.5	32	GA	INV. EX.
62	J	1.2	874	135	701	41	0.47	1	263	168.6	35	GA	COMP. EX.
63	K	1.2	865	125	757	28	0.56	1	221	147.9	41	GA	INV. EX.
64	L	1.2	867	103	774	38	0.31	1	253	185.8	45	CR	INV. EX.
65	M	1.2	864	126	651	36	0.56	1	152	121.6	37	CR	COMP. EX.
66	N	1.2	871	95	702	35	0.38	1	244	100.0	37	GA	INV. EX.
67	O	1.6	876	174	613	26	0.37	1	267	179.2	28	GA	COMP. EX.
68	P	1.6	861	52	621	35	0.51	1	196	202.4	47	G	INV. EX.
69	Q	1.6	873	158	672	48	0.50	1	278	181.0	27	GA	COMP. EX.
70	R	1.6	864	135	617	33	0.58	1	262	293.6	45	GA	INV. EX.

Underlines indicate being outside of the range of the present invention.

(*) CR: Cold rolled steel sheet (without coating), GI: Hot-dip galvanized steel sheet (without alloying treatment), GA: Galvannealed steel sheet

TABLE 2-3

No.	Steels	Sheet thick-ness (mm)	An-nealing temp. T1 (° C.)	Holding time t1 (sec)	Elapsed time t2 from when the temp. reached 100° C. until start of working (sec)	Working start temp. T2 (° C.)	Equiv-alent plastic strain (%)	Working operations (times)	Tem-pering temp. T3 (° C.)	Holding time t3 (sec)	Cooling rate θ1 from tempering temp. T3 to 80° C. (° C./sec)	Type of prod-uct (*)	Remarks
71	S	1.6	875	160	601	39	0.52	1	191	159.0	48	GA	COMP. EX.
72	T	1.6	878	72	623	41	0.33	1	233	169.5	37	GA	INV. EX.
73	U	1.6	878	182	742	28	0.55	1	222	156.0	29	GI	COMP. EX.
74	V	1.6	877	179	749	47	0.42	2	296	280.5	31	GA	INV. EX.
75	W	1.4	879	170	613	37	0.56	1	256	195.7	39	GA	COMP. EX.
76	X	1.4	870	51	759	36	0.37	1	159	156.5	28	GA	INV. EX.
77	Y				The slab fractured during casting and the test was discontinued.								COMP. EX.
78	Z	1.4	869	76	727	34	0.38	1	164	201.6	47	GA	INV. EX.
79	AA	1.4	864	63	756	43	0.32	1	161	169.5	44	GI	COMP. EX.
80	AB	1.4	876	52	644	47	0.38	1	166	280.4	44	GA	INV. EX.
81	AC	1.4	864	78	765	49	0.56	1	182	175.5	32	GA	INV. EX.
82	AD				The slab fractured during casting and the test was discontinued.								COMP. EX.
83	AE	1.4	871	123	757	37	0.58	1	276	233.2	29	GA	INV. EX.
84	AF	1.4	878	50	669	46	0.31	1	250	253.8	45	CR	INV. EX.
85	AG				The slab fractured during casting and the test was discontinued.								COMP. EX.
86	AH	1.4	870	161	682	47	0.52	3	218	228.3	48	GA	INV. EX.
87	AI	1.4	860	181	628	48	0.52	1	273	125.0	28	GA	INV. EX.
88	AJ				The slab fractured during casting and the test was discontinued.								COMP. EX.
89	AK	1.4	864	74	654	28	0.50	1	293	226.1	38	GA	INV. EX.
90	AL	1.4	860	173	730	50	0.46	1	223	289.8	41	GA	INV. EX.
91	AM				The slab fractured during casting and the test was discontinued.								COMP. EX.
92	AN	1.4	864	193	641	33	0.39	1	199	246.6	43	GA	INV. EX.
93	AO	1.4	877	99	669	42	0.51	1	211	195.4	44	CR	INV. EX.
94	AP	1.4	879	161	731	42	0.48	1	285	260.8	44	CR	INV. EX.
95	AQ	1.4	863	105	681	35	0.44	1	167	194.5	28	CR	INV. EX.
96	AR	1.4	872	145	794	46	0.41	4	172	189.4	32	CR	INV. EX.

TABLE 2-3-continued

No.	Steels	Sheet thickness (mm)	Annealing temp. T1 (° C.)	Holding time t1 (sec)	Elapsed time t2 from when the temp. reached 100° C. until start of working (sec)	Working start temp. T2 (° C.)	Equivalent plastic strain (%)	Working operations (times)	Tempering temp. T3 (° C.)	Holding time t3 (sec)	Cooling rate θ1 from tempering temp. T3 to 80° C. (° C./sec)	Type of product (*)	Remarks
97	AS	1.4	869	156	788	32	0.57	1	251	293.6	49	CR	INV. EX.
98	AT	1.4	877	200	767	47	0.55	1	160	299.8	34	CR	INV. EX.
99	AU	1.4	870	107	681	43	0.55	4	225	293.9	45	CR	INV. EX.
100	AV	1.4	864	136	670	41	0.52	1	285	104.4	28	CR	INV. EX.
101	AW	1.4	876	60	664	29	0.41	1	262	221.4	33	CR	INV. EX.
102	AX	1.4	864	85	750	32	0.33	1	243	295.8	43	CR	INV. EX.
103	AY	0.8	879	195	693	31	0.39	1	211	272.2	45	EG	INV. EX.
104	AZ	2.0	879	136	669	33	0.36	1	180	109.4	42	EG	INV. EX.

Underlines indicate being outside of the range of the present invention.

(*) CR: Cold rolled steel sheet (without coating), GI: Hot-dip galvanized steel sheet (without alloying treatment), GA: Galvannealed steel sheet, EG: Electrogalvanized steel sheet

TABLE 3-1

No.	Steels	Sheet thickness (mm)	Tempered martensite (%)	Retained austenite (%)	Total of ferrite and bainitic ferrite (%)	KAM(S) (°)	KAM(C) (°)	KAM(S)/KAM(C)	Hv(Q)
1	A	1.4	98	2	0	0.504	0.536	0.941	516
2	B	1.4	99	1	0	0.501	0.538	0.931	508
3	B	1.4	91	1	8	0.508	0.535	0.949	473
4	B	1.4	83	3	14	0.499	0.531	0.940	414
5	B	1.4	99	1	0	0.514	0.541	0.950	548
6	B	1.4	99	1	0	0.502	0.534	0.940	511
7	B	1.4	90	1	9	0.505	0.537	0.939	458
8	B	1.4	83	2	15	0.516	0.537	0.960	391
9	B	1.4	99	1	0	0.510	0.537	0.950	503
10	B	1.4	100	0	0	0.509	0.536	0.950	528
11	B	1.4	99	1	0	0.487	0.540	0.901	498
12	B	1.4	99	1	0	0.517	0.538	0.960	530
13	B	1.4	99	1	0	0.528	0.537	0.984	516
14	B	1.4	98	2	0	0.540	0.535	1.009	480
15	B	1.4	99	1	0	0.484	0.537	0.901	530
16	B	1.4	100	0	0	0.505	0.537	0.941	522
17	B	1.4	100	0	0	0.533	0.538	0.990	544
18	B	1.4	100	0	0	0.541	0.538	1.004	481
19	B	1.4	99	1	0	0.532	0.541	0.984	538
20	B	1.4	100	0	0	0.557	0.537	1.039	495
21	B	1.4	99	1	0	0.485	0.539	0.900	513
22	B	1.4	100	0	0	0.509	0.536	0.950	538
23	B	1.4	99	1	0	0.499	0.537	0.930	475
24	B	1.4	99	1	0	0.504	0.536	0.941	526
25	B	1.4	99	1	0	0.510	0.537	0.950	473
26	B	1.4	100	0	0	0.510	0.537	0.950	414
27	B	1.4	100	0	0	0.502	0.533	0.940	530
28	B	1.4	99	1	0	0.512	0.533	0.960	523
29	B	1.4	98	2	0	0.491	0.533	0.920	520
30	B	1.4	99	1	0	0.502	0.541	0.929	519
31	B	1.4	99	1	0	0.514	0.535	0.960	474
32	B	1.4	99	1	0	0.506	0.539	0.940	423
33	B	1.4	99	1	0	0.503	0.535	0.941	535
34	B	1.4	98	2	0	0.507	0.540	0.940	539
35	B	1.4	98	2	0	0.506	0.539	0.940	519

No.	Hv(S)	Hv(Q) − Hv(S)	YS (MPa)	TS (MPa)	YR (%)	Range of appropriate clearances not leading to delayed fracture	Remarks
1	498	18	1451	1560	93	◎	INV. EX.
2	491	17	1418	1538	92	◎	INV. EX.
3	460	13	1235	1440	86	◎	INV. EX.
4	395	19	1024	1240	83	◎	COMP. EX.
5	534	14	1503	1674	90	○	INV. EX.
6	491	20	1455	1538	95	○	INV. EX.
7	441	17	1206	1384	87	◎	INV. EX.
8	371	20	957	1159	83	◎	COMP. EX.
9	483	20	1431	1513	95	○	INV. EX.
10	512	16	1467	1605	91	○	INV. EX.
11	472	26	1469	1478	99	◎	INV. EX.

TABLE 3-1-continued

12	514	16	1471	1609	91	◎	INV. EX.
13	506	10	1408	1585	89	◎	INV. EX.
14	476	4	1218	1489	82	X	COMP. EX.
15	503	27	1561	1577	99	◎	INV. EX.
16	503	19	1479	1577	94	◎	INV. EX.
17	535	9	1437	1675	86	○	INV. EX.
18	481	0	1186	1509	79	X	COMP. EX.
19	529	9	1459	1659	88	○	INV. EX.
20	488	7	1290	1532	84	X	COMP. EX.
21	500	13	1350	1531	88	◎	INV. EX.
22	523	15	1486	1640	91	◎	INV. EX.
23	466	9	1249	1459	86	○	INV. EX.
24	525	1	1309	1648	79	X	COMP. EX.
25	460	13	1180	1334	88	◎	INV. EX.
26	395	19	1134	1331	85	◎	INV. EX.
27	521	9	1425	1633	87	○	INV. EX.
28	514	9	1422	1610	88	○	INV. EX.
29	511	9	1394	1601	87	○	INV. EX.
30	520	−1	1271	1634	78	X	COMP. EX.
31	449	25	1388	1408	99	◎	INV. EX.
32	397	26	1238	1334	93	◎	INV. EX.
33	511	24	1566	1601	98	◎	INV. EX.
34	522	17	1506	1633	92	◎	INV. EX.
35	509	10	1407	1596	88	○	INV. EX.

Underlines indicate being outside of the range of the present invention.

TABLE 3-2

No.	Steels	Sheet thickness (mm)	Tempered martensite (%)	Retained austenite (%)	Total of ferrite and bainitic ferrite (%)	KAM(S) (°)	KAM(C) (°)	KAM(S)/ KAM(C)	Hv(Q)
36	B	1.4	100	0	0	0.507	0.540	0.940	523
37	C	0.8	98	2	0	0.503	0.535	0.941	529
38	D	2.0	99	1	0	0.504	0.536	0.941	509
39	E	1.4	98	2	0	0.517	0.538	0.960	546
40	E	1.4	92	1	7	0.498	0.536	0.930	447
41	E	1.4	98	2	0	0.506	0.539	0.940	548
42	E	1.4	91	1	8	0.502	0.534	0.940	447
43	E	1.4	99	1	0	0.499	0.537	0.930	498
44	E	1.4	99	1	0	0.487	0.540	0.901	507
45	E	1.4	98	2	0	0.529	0.538	0.984	488
46	E	1.4	98	2	0	0.482	0.535	0.900	565
47	E	1.4	99	1	0	0.525	0.534	0.982	485
48	E	1.4	99	1	0	0.529	0.539	0.982	511
49	E	1.4	99	1	0	0.485	0.538	0.901	564
50	E	1.4	99	1	0	0.502	0.534	0.940	525
51	E	1.4	99	1	0	0.509	0.536	0.950	453
52	E	1.4	100	0	0	0.518	0.539	0.960	525
53	E	1.4	99	1	0	0.502	0.533	0.940	526
54	E	1.4	98	2	0	0.508	0.535	0.949	530
55	E	1.4	100	0	0	0.505	0.537	0.939	454
56	E	1.4	100	0	0	0.518	0.540	0.960	546
57	E	1.4	98	2	0	0.504	0.536	0.941	486
58	F	1.2	99	1	0	0.505	0.537	0.939	502
59	G	1.2	100	0	0	0.510	0.537	0.950	443
60	H	1.2	99	1	0	0.510	0.531	0.960	414
61	I	1.2	99	1	0	0.506	0.539	0.940	604
62	J	1.2	100	0	0	0.507	0.534	0.949	595
63	K	1.2	99	1	0	0.498	0.535	0.930	460
64	L	1.2	96	4	0	0.510	0.537	0.950	514
65	M	1.2	94	6	0	0.505	0.537	0.941	544
66	N	1.2	91	0	9	0.510	0.537	0.950	462
67	O	1.6	85	4	11	0.517	0.538	0.960	362
68	P	1.6	98	2	0	0.504	0.536	0.941	544
69	Q	1.6	98	2	0	0.502	0.534	0.940	504
70	R	1.6	99	1	0	0.506	0.538	0.939	503

TABLE 3-2-continued

No.	Hv(S)	Hv(Q) − Hv(S)	YS (MPa)	TS (MPa)	YR (%)	Range of appropriate clearances not leading to delayed fracture	Remarks
36	521	2	1309	1632	80	X	COMP. EX.
37	514	15	1457	1608	91	◎	INV. EX.
38	488	21	1460	1530	95	◎	INV. EX.
39	534	12	1473	1670	88	◎	INV. EX.
40	425	22	1137	1333	85	◎	INV. EX.
41	533	15	1516	1673	91	◎	INV. EX.
42	427	20	1141	1337	85	◎	INV. EX.
43	476	22	1438	1495	96	◎	INV. EX.
44	482	25	1489	1510	99	◎	INV. EX.
45	478	10	1291	1497	86	○	INV. EX.
46	538	27	1669	1686	99	◎	INV. EX.
47	477	8	1323	1498	88	○	INV. EX.
48	502	9	1383	1571	88	○	INV. EX.
49	538	26	1676	1686	99	◎	INV. EX.
50	516	9	1414	1614	88	○	INV. EX.
51	444	9	1192	1390	86	○	INV. EX.
52	516	9	1394	1616	86	○	INV. EX.
53	517	9	1425	1620	88	○	INV. EX.
54	520	10	1405	1633	86	○	INV. EX.
55	431	23	1311	1352	97	◎	INV. EX.
56	522	24	1601	1637	98	◎	INV. EX.
57	478	8	1304	1500	87	○	INV. EX.
58	481	21	1439	1508	95	◎	INV. EX.
59	425	18	1239	1332	93	◎	INV. EX.
60	398	16	1141	1248	91	◎	COMP. EX.
61	584	20	1731	1830	95	○	INV. EX.
62	576	19	1692	1804	94	X	COMP. EX.
63	442	18	1289	1386	93	◎	INV. EX.
64	495	19	1327	1551	86	◎	INV. EX.
65	532	12	1365	1665	82	◎	COMP. EX.
66	446	16	1216	1397	87	◎	INV. EX.
67	344	18	907	1077	84	◎	COMP. EX.
68	528	16	1511	1653	91	○	INV. EX.
69	483	21	1447	1517	95	X	COMP. EX.
70	481	22	1452	1509	96	○	INV. EX.

Underlines indicate being outside of the range of the present invention.

TABLE 3-3

No.	Steels	Sheet thickness (mm)	Tempered martensite (%)	Retained austenite (%)	Total of ferrite and bainitic ferrite (%)	KAM(S) (°)	KAM(C) (°)	KAM(S)/ KAM(C)	Hv(Q)
71	S	1.6	98	2	0	0.497	0.534	0.930	525
72	T	1.6	98	2	0	0.510	0.537	0.950	508
73	U	1.6	99	1	0	0.498	0.536	0.930	529
74	V	1.6	90	1	9	0.514	0.536	0.960	445
75	W	1.4	88	2	10	0.504	0.536	0.941	436
76	X	1.4	99	1	0	0.512	0.533	0.960	556
77	Y	The slab fractured during casting and the test was discontinued.							
78	Z	1.4	98	2	0	0.514	0.536	0.960	545
79	AA	1.4	98	2	0	0.514	0.536	0.960	535
80	AB	1.4	98	2	0	0.511	0.538	0.950	461
81	AC	1.4	99	1	0	0.502	0.534	0.940	597
82	AD	The slab fractured during casting and the test was discontinued.							
83	AE	1.4	99	1	0	0.495	0.533	0.930	471
84	AF	1.4	100	0	0	0.512	0.539	0.950	607
85	AG	The slab fractured during casting and the test was discontinued.							
86	AH	1.4	99	1	0	0.507	0.540	0.940	484
87	AI	1.4	99	1	0	0.514	0.541	0.950	606
88	AJ	The slab fractured during casting and the test was discontinued.							
89	AK	1.4	100	0	0	0.498	0.536	0.930	497
90	AL	1.4	100	0	0	0.502	0.533	0.940	503
91	AM	The slab fractured during casting and the test was discontinued.							
92	AN	1.4	99	1	0	0.502	0.533	0.940	540
93	AO	1.4	99	1	0	0.505	0.537	0.941	527
94	AP	1.4	98	2	0	0.506	0.539	0.940	506

TABLE 3-3-continued

95	AQ	1.4	98	2	0	0.511	0.538	0.950	553
96	AR	1.4	99	1	0	0.506	0.538	0.939	557
97	AS	1.4	99	1	0	0.497	0.534	0.930	524
98	AT	1.4	100	0	0	0.506	0.539	0.940	562
99	AU	1.4	98	2	0	0.503	0.535	0.941	521
100	AV	1.4	98	2	0	0.504	0.536	0.941	500
101	AW	1.4	99	1	0	0.504	0.536	0.941	505
102	AX	1.4	98	2	0	0.509	0.536	0.950	526
103	AY	0.8	100	0	0	0.506	0.533	0.949	470
104	AZ	2.0	98	2	0	0.515	0.537	0.960	592

No.	Hv(S)	Hv(Q) − Hv(S)	YS (MPa)	TS (MPa)	YR (%)	Range of appropriate clearances not leading to delayed fracture	Remarks
71	509	16	1460	1597	91	X	COMP. EX.
72	491	17	1420	1540	92	○	INV. EX.
73	511	18	1490	1602	93	X	COMP. EX.
74	423	22	1178	1324	89	◎	INV. EX.
75	416	20	1044	1305	80	◎	COMP. EX.
76	544	12	1502	1703	88	◎	INV. EX.
77	The slab fractured during casting and the test was discontinued.						COMP. EX.
78	533	12	1469	1666	88	○	INV. EX.
79	523	12	1448	1642	88	X	COMP. EX.
80	447	14	1259	1402	90	◎	INV. EX.
81	582	15	1651	1822	91	◎	INV. EX.
82	The slab fractured during casting and the test was discontinued.						COMP. EX.
83	449	22	1352	1405	96	◎	INV. EX.
84	588	19	1732	1846	94	◎	INV. EX.
85	The slab fractured during casting and the test was discontinued.						COMP. EX.
86	466	18	1357	1459	93	◎	INV. EX.
87	587	19	1727	1841	94	◎	INV. EX.
88	The slab fractured during casting and the test was discontinued.						COMP. EX.
89	475	22	1434	1491	96	○	INV. EX.
90	484	19	1424	1518	94	◎	INV. EX.
91	The slab fractured during casting and the test was discontinued.						COMP. EX.
92	523	17	1508	1636	92	◎	INV. EX.
93	510	17	1472	1597	92	◎	INV. EX.
94	484	22	1456	1513	96	◎	INV. EX.
95	540	13	1505	1691	89	◎	INV. EX.
96	543	14	1526	1699	90	◎	INV. EX.
97	502	22	1512	1572	96	◎	INV. EX.
98	548	14	1543	1718	90	◎	INV. EX.
99	502	19	1475	1573	94	◎	INV. EX.
100	480	20	1425	1506	95	◎	INV. EX.
101	484	21	1443	1513	95	◎	INV. EX.
102	507	19	1490	1589	94	◎	INV. EX.
103	453	17	1306	1416	92	◎	INV. EX.
104	580	12	1606	1821	88	◎	INV. EX.

Underlines indicate being outside of the range of the present invention.

1. A high strength steel sheet comprising a microstructure having a chemical composition comprising, by mass %:

C: 0.15% or more and 0.45% or less,

Si: 0.10% or more and 2.00% or less,

Mn: 0.5% or more and 3.5% or less,

P: 0.100% or less,

S: 0.0200% or less,

Al: 0.010% or more and 1.000% or less,

N: 0.0100% or less, and

H: 0.0020% or less,

the balance being Fe and incidental impurities;

the microstructure being such that:

the area fraction of tempered martensite is 85% or more,

the volume fraction of retained austenite is less than 5%, and

the area fraction of the total of ferrite and bainitic ferrite is 10% or less;

the microstructure satisfying formulas (1) and (2) defined below:

$$KAM(S)/KAM(C) < 1.00 \tag{1}$$

wherein KAM (S) is a KAM (Kernel average misorientation) value of a superficial portion of the steel sheet, and KAM (C) is a KAM value of a central portion of the steel sheet,

$$Hv(Q) - Hv(S) \geq 8 \tag{2}$$

wherein Hv (Q) indicates the hardness of a portion at ¼ sheet thickness and Hv (S) indicates the hardness of a superficial portion of the steel sheet.

2. The high strength steel sheet according to claim **1**, wherein the chemical composition further comprises one, or two or more elements selected from, by mass %:

Ti: 0.100% or less,
B: 0.0100% or less,
Nb: 0.100% or less,
Cu: 1.00% or less,
Cr: 1.00% or less,
V: 0.100% or less,
Mo: 0.500% or less,
Ni: 0.50% or less,
Sb: 0.200% or less,
Sn: 0.200% or less,
As: 0.100% or less,
Ta: 0.100% or less,
Ca: 0.0200% or less,
Mg: 0.0200% or less,
Zn: 0.020% or less,
Co: 0.020% or less,
Zr: 0.020% or less, and
REM: 0.0200% or less.

3. The high strength steel sheet according to claim **1**, which has a coated layer on a surface of the steel sheet.

4. The high strength steel sheet according to claim **2**, which has a coated layer on a surface of the steel sheet.

5. A method for manufacturing a high strength steel sheet described in claim **1**, the method comprising:

providing a cold rolled steel sheet produced by subjecting a steel slab to hot rolling, pickling, and cold rolling;
annealing the steel sheet under conditions where:
a temperature T1 is 850° C. or above and 1000° C. or below and
a holding time t1 at T1 is 10 seconds or more and 1000 seconds or less;
cooling the steel sheet to 100° C. or below;
starting working at an elapsed time t2 of 1000 seconds or less from the time when the temperature reaches 100° C.,
the working being performed under conditions where:
a working start temperature T2 is 80° C. or below and
an equivalent plastic strain is 0.10% or more and 5.00% or less;
tempering the steel sheet under conditions where:
a temperature T3 is 100° C. or above and 400° C. or below and
a holding time t3 at T3 is 1.0 second or more and 1000.0 seconds or less; and
cooling the steel sheet under conditions where a cooling rate θ1 from T3 to 80° C. is 100° C./sec or less.

6. A method for manufacturing a high strength steel sheet described in claim **2**, the method comprising:

providing a cold rolled steel sheet produced by subjecting a steel slab to hot rolling, pickling, and cold rolling;
annealing the steel sheet under conditions where:
a temperature T1 is 850° C. or above and 1000° C. or below and
a holding time t1 at T1 is 10 seconds or more and 1000 seconds or less;
cooling the steel sheet to 100° C. or below;
starting working at an elapsed time t2 of 1000 seconds or less from the time when the temperature reaches 100° C.,
the working being performed under conditions where:
a working start temperature T2 is 80° C. or below and
an equivalent plastic strain is 0.10% or more and 5.00% or less;
tempering the steel sheet under conditions where:
a temperature T3 is 100° C. or above and 400° C. or below and
a holding time t3 at T3 is 1.0 second or more and 1000.0 seconds or less; and
cooling the steel sheet under conditions where a cooling rate θ1 from T3 to 80° C. is 100° C./sec or less.

7. The method for manufacturing a high strength steel sheet according to claim **5**, wherein the working before the tempering is performed under conditions where strain is applied by two or more separate working operations, and the total of the equivalent plastic strains applied in the working operations is 0.10% or more.

8. The method for manufacturing a high strength steel sheet according to claim **6**, wherein the working before the tempering is performed under conditions where strain is applied by two or more separate working operations, and the total of the equivalent plastic strains applied in the working operations is 0.10% or more.

9. The method for manufacturing a high strength steel sheet according to claim **5**, further comprising performing coating treatment during the annealing or after the annealing.

10. The method for manufacturing a high strength steel sheet according to claim **6**, further comprising performing coating treatment during the annealing or after the annealing.

11. The method for manufacturing a high strength steel sheet according to claim **7**, further comprising performing coating treatment during the annealing or after the annealing.

12. The method for manufacturing a high strength steel sheet according to claim **8**, further comprising performing coating treatment during the annealing or after the annealing.

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