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(54) **HIGH-STRENGTH COLD-ROLLED STEEL SHEET, HIGH-STRENGTH HOT-DIP GALVANIZED STEEL SHEET, AND HIGH-STRENGTH HOT-DIP GALVANNEALED STEEL SHEET EXCELLENT IN FORMABILITY AND SHAPE FIXABILITY, AND METHODS FOR MANUFACTURING THEM**

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C22C 38/06	(2006.01)
C21D 6/00	(2006.01)
C22C 38/08	(2006.01)
C22C 38/12	(2006.01)
C22C 38/16	(2006.01)
C22C 38/28	(2006.01)
C22C 38/32	(2006.01)
C22C 38/34	(2006.01)
C22C 38/38	(2006.01)
C23C 2/02	(2006.01)
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C21D 8/04	(2006.01)
C21D 1/20	(2006.01)
C21D 1/22	(2006.01)

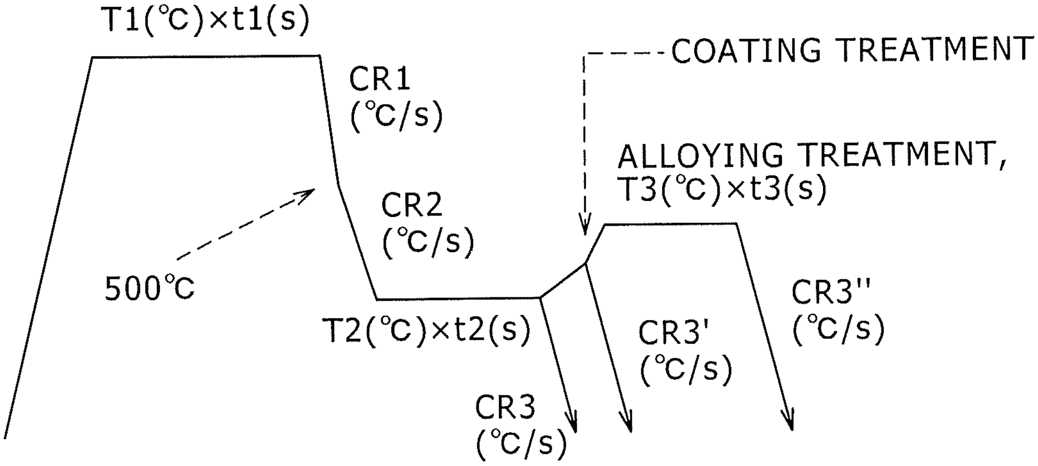
(52) **U.S. Cl.**

CPC ***C21D 9/46*** (2013.01); *C21D 2211/005* (2013.01); ***C22C 38/002*** (2013.01); ***C22C 38/02*** (2013.01); ***C22C 38/04*** (2013.01); ***C22C 38/14*** (2013.01); ***C23C 2/06*** (2013.01); ***C22C 38/06*** (2013.01); ***C21D 6/001*** (2013.01); ***C21D 6/002*** (2013.01); ***C21D 6/005*** (2013.01); ***C21D 6/008*** (2013.01); ***C22C 38/08*** (2013.01); ***C22C 38/12*** (2013.01); ***C22C 38/16*** (2013.01); ***C22C 38/28*** (2013.01); ***C22C 38/32*** (2013.01); ***C22C 38/34*** (2013.01); ***C22C 38/38*** (2013.01); ***C23C 2/02*** (2013.01); ***C23C 2/28*** (2013.01); ***C21D 8/0447*** (2013.01); ***C21D 1/20*** (2013.01); ***C21D 1/22*** (2013.01); *Y10T 428/12799* (2015.01); *C21D 2211/008* (2013.01); *C21D 2211/002* (2013.01); *C21D 2211/001* (2013.01); ***C22C 38/001*** (2013.01)

(57) **ABSTRACT**

A high-strength cold-rolled steel sheet has a specific chemical composition and has a steel microstructure meeting conditions: a total content of bainitic ferrite (BF) and tempered martensite (TM) is 65% (in area percent, hereinafter the same for steel microstructure) or more; a fresh martensite (M) content is 3% to 18%; a retained austenite content is 5% or more; and a polygonal ferrite (F) content is 5% or less. The steel sheet has a specific average $\mathrm{KAM}_{<1.00^\circ}$ of 0.50° or more and has a tensile strength of 980 MPa or more. The high-strength cold-rolled steel sheet excels in formability and shape fixability.

FIG. 1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CR1 (℃/s)
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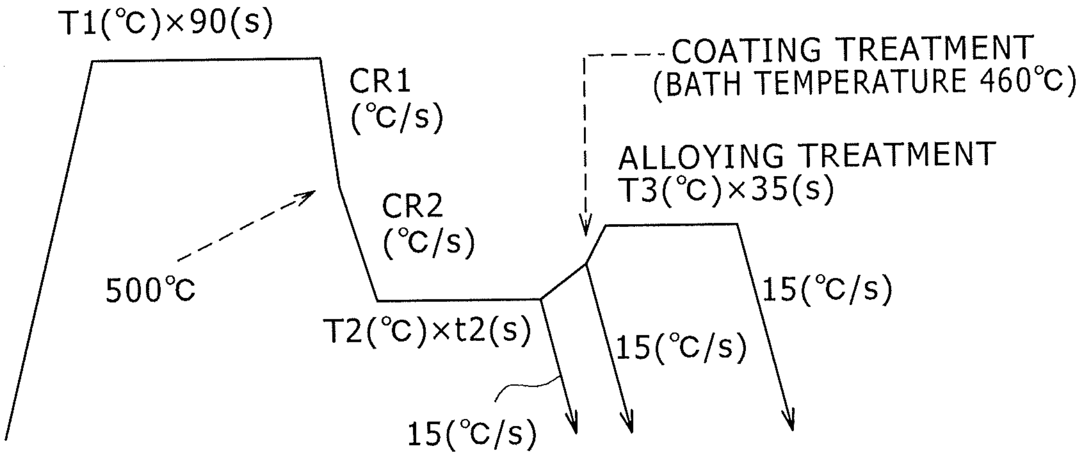
CR2 (℃/s)
T2(℃)×t2(s)
CR3 (℃/s)
COATING TREATMENT
ALLOYING TREATMENT, T3(℃)×t3(s)
CR3' (℃/s)
CR3'' (℃/s)

FIG. 2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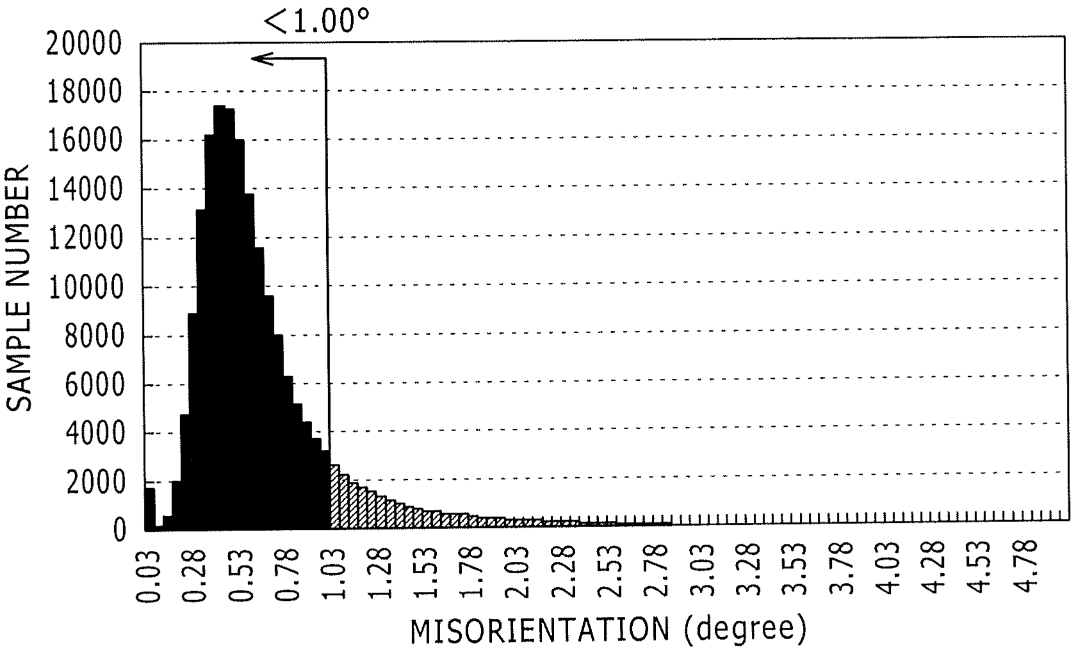
CR1 (℃/s)
500℃
CR2 (℃/s)
T2(℃)×t2(s)
15(℃/s)
COATING TREATMENT (BATH TEMPERATURE 460℃)
ALLOYING TREATMENT T3(℃)×35(s)
15(℃/s)
15(℃/s)

FIG. 3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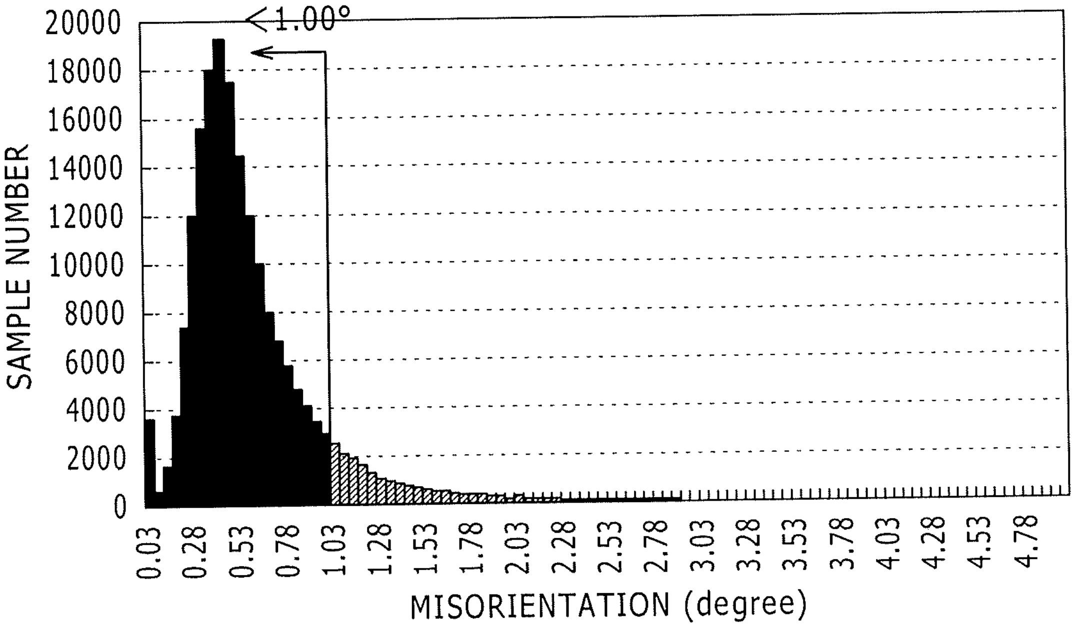
MISORIENTATION (degree)

FIG. 4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MISORIENTATION (degree)

HIGH-STRENGTH COLD-ROLLED STEEL SHEET, HIGH-STRENGTH HOT-DIP GALVANIZED STEEL SHEET, AND HIGH-STRENGTH HOT-DIP GALVANNEALED STEEL SHEET EXCELLENT IN FORMABILITY AND SHAPE FIXABILITY, AND METHODS FOR MANUFACTURING THEM

TECHNICAL FIELD

[0001] The present invention relates to: a high-strength cold-rolled steel sheet, a high-strength hot-dip galvanized steel sheet, and a high-strength hot-dip galvannealed steel sheet each excellent in formability and shape fixability, and methods for manufacturing them.

BACKGROUND ART

[0002] In automobiles, a demand has been made to improve fuel efficiency in consideration of environments, and this accelerates body weight reduction more and more. In addition, a demand has been increasingly made to provide steel sheets having a strength (in terms of tensile strength of 980 MPa or more) higher than those of conventional equivalents. Such high-strength steel sheets are for use in various steel members forming automobile bodies so as to maintain safety even when the body weights are reduced. Steels having such high strengths, however, are liable to suffer from deterioration in formability and shape fixability (spring-back control). To prevent this, a demand has been made to provide a steel sheet having a high strength and still offering good shape fixability and formability (ductility and bore expandability).

[0003] Various proposals to improve the properties have been made. Typically, Patent Literature (PTI) 1 describes that better TS×EL balance and shape fixability can be obtained by controlling microstructure fractions, carbon content in retained austenite, distance between second-phase grains, and grain size of the second-phase grains. The technology disclosed in PTL 1, however, is not aimed at ensuring the properties of a steel sheet having a strength at a still higher level.

[0004] PTL 2 discloses a technology of controlling chemical compositions within appropriate ranges (particularly controlling the total content of Cr and Mn within a specific range) and thereby controlling the shapes of its microstructure and precipitates. This technology is intended to improve bending workability and shape fixability. A steel sheet according to the technology is designed to contain a large amount of Cr for controlling the microstructure and precipitates. Further investigations on the chemical compositional design, however, are probably required so as to ensure still better formability.

[0005] PTL 3 discloses a technology of controlling the microstructure and particularly controlling the peak width at half height of an X-ray diffraction peak on a (200) plane of alpha iron to 0.220° or less. The technology is intended to provide a high-strength cold-rolled steel sheet and a coated steel sheet each excellent in balance between strength and workability. The microstructure control herein means reduction of a dislocation density in the microstructure (bainitic ferrite). However, a study of another means is probably required so as to improve both ductility and bore expandability in a high strength region.

[0006] PTL 4 discloses a technology of allowing a steel sheet to contain tempered martensite and upper bainite in predetermined contents so as to provide a high-strength steel sheet offering excellent ductility and stretch flangeability and still having a tensile strength of 980 MPa or more. The upper bainite probably has a low KAM value mentioned later. PTL 5 discloses a technology of allowing a steel sheet to contain upper bainite in a predetermined content so as to ensure formability, as with the technology in PTL 4.

[0007] PTL 6 discloses a technology of allowing a steel sheet to mainly contain martensite (fresh martensite and tempered martensite) so as to give a high-strength steel sheet offering excellent workability and having a tensile strength of 980 MPa or more. PTL 7 discloses a technology of allowing a steel sheet to include bainitic ferrite and martensite as a microstructure and controlling shapes of retained austenite grains so as to give an ultrahigh-strength thin steel sheet having excellent hydrogen embrittlement resistance.

CITATION LIST

Patent Literature

[0008] PTL 1: Japanese Unexamined Patent Application Publication (JP-A) No. 2010-236066

[0009] PTL 2: JP-A No. 2010-222688

[0010] PTL 3: JP-A No. 2006-274417

[0011] PTL 4: JP-A No. 2010-090475

[0012] PTL 5: JP-A No. 2010-065273

[0013] PTL 6: JP-A No. 2011-047034

[0014] PTL 7: JP-A No. 2011-190474

SUMMARY OF INVENTION

Technical Problem

[0015] The present invention has been made also to provide a high-strength cold-rolled steel sheet, a hot-dip galvanized steel sheet, and a hot-dip galvannealed steel sheet, each of which is excellent in formability and shape fixability even having a tensile strength of 980 MPa or more. An object of the present invention is to manufacture the novel steel sheets having a predetermined microstructure by performing an austempering treatment in annealing at a lower temperature for a shorter time in a manufacturing process than those of the conventional technologies.

Solution to Problem

[0016] The present invention achieves the object and provides, in an embodiment, a high-strength cold-rolled steel sheet excellent in formability and shape fixability which contains:

[0017] C in a content of 0.1% to 0.3% (in mass percent, hereinafter the same for chemical composition);

[0018] Si in a content of 1.0% to 3.0%;

[0019] Mn in a content of 0.5% to 3.0%;

[0020] P in a content of 0.1% or less;

[0021] S in a content of 0.03% or less;

[0022] Al in a content of 0.01% to 1.0%; and

[0023] N in a content of 0.01% or less,

[0024] with the remainder being iron and inevitable impurities, in which:

[0025] the steel sheet has a steel microstructure meeting conditions given as follows:

- **[0026]** a total content of bainitic ferrite (BF) and tempered martensite (TM) is 65% (in area percent, hereinafter the same for steel microstructure) or more;
- **[0027]** a content of flesh martensite (M) is 3% to 18%;
- **[0028]** a content of retained austenite is 5% or more; and
- **[0029]** a content of polygonal ferrite (F) is 5% or less,

[0030] the steel microstructure further meets a condition given as follows: an average $KAM_{<1.00°}$ is 0.50° or more, where the "average $KAM_{<1.00°}$" denotes an average of kernel average misorientation (KAM) values (misorientation values, in "degree (°)") in a region of less than 1.00° as measured at two or more points; and

[0031] the steel sheet has a tensile strength of 980 MPa or more.

[0032] The high-strength cold-rolled steel sheet may further contain any of:

(a) at least one element selected from the group consisting of: Ti in a content of 0.01% to 0.1%, Nb in a content of 0.01% to 0.1%, and V in a content of 0.01% to 0.1%;

(b) at least one element selected from the group consisting of Cr in a content of 0.01% to 1%, Mo in a content of 0.01% to 1%, and B in a content of 0.0001% to 0.005%;

(c) at least one element selected from the group consisting of Cu in a content of 0.01% to 1% and Ni in a content of 0.01% to 1%; and

(d) at least one element selected firm the group consisting of Ca in a content of 0.0005% to 0.005% and Mg in a content of 0.0005% to 0.005%.

[0033] The present invention includes, in another embodiment, a high-strength hot-dip galvanized steel sheet excellent in formability and shape fixability, which includes the high-strength cold-rolled steel sheet and a hot-dip galvanized layer formed on or over a surface of the steel sheet.

[0034] The present invention includes, in yet another embodiment, a high-strength hot-dip galvannealed steel sheet excellent in formability and shape fixability, which includes the high-strength cold-rolled steel sheet and a hot-dip galvannealed layer formed on or over a surface of the steel sheet.

[0035] The present invention includes, in still another embodiment, a method for manufacturing the high-strength cold-rolled steel sheet excellent in formability and shape fixability. The method includes, in an order as follows, the steps of heating a cold-rolled steel sheet having the chemical composition to a temperature range (T**1**) of Ac_3 to 960° C.; cooling the cold-rolled steel sheet from the temperature range (T**1**) down to 500° C. at an average cooling rate (CR**1**) of 5° C./s or more; further cooling the cold-rolled steel sheet from 500° C. down to a temperature range (T**2**) of (Ms-200)° C. to 420° C. at an average cooling rate (CR**2**) of 10° C./s or more; and holding the cold-rolled steel sheet in the temperature range (T**2**) for a time period (t**2**) of 10 to 70 seconds.

[0036] The present invention further includes, in another embodiment, a method for manufacturing the high-strength hot-dip galvanized steel sheet excellent in formability and shape fixability. The method includes, in an order as follows, the steps of heating a cold-rolled steel sheet having the chemical composition to a temperature range (T**1**) of Ac_3 to 960° C.; cooling the cold-rolled steel sheet from the temperature range (T**1**) down to 500° C. at an average cooling rate (CR**1**) of 5° C./s or more; further cooling the cold-rolled steel sheet from 500° C. down to a temperature range (T**2**) of (Ms-200)° C. to 420° C. at an average cooling rate (CR**2**) of 10° C./s or more; holding the cold-rolled steel sheet in the temperature range (T**2**) for a time period (t**2**) of 10 to 70 seconds; and immersing the cold-rolled steel sheet in a zinc bath.

[0037] In addition and advantageously, the present invention includes, in yet another embodiment, a method for manufacturing the high-strength hot-dip galvannealed steel sheet excellent in formability and shape fixability. The method includes, in an order as follows, the steps of heating a cold-rolled steel sheet having the chemical composition to a temperature range (T**1**) of Ac_3 to 960° C.; cooling the cold-rolled steel sheet from the temperature range (T**1**) down to 500° C. at an average cooling rate (CR**1**) of 5° C./s or more; further cooling the cold-rolled steel sheet from 500° C. down to a temperature range (T**2**) of (Ms-200°)° C. to 420° C. at an average cooling rate (CR**2**) of 10° C./s or more; holding the cold-rolled steel sheet in the temperature range (T**2**) for a time period (t**2**) of 10 to 70 seconds; immersing the cold-rolled steel sheet in a zinc bath; and subjecting the cold-rolled steel sheet to an alloying treatment at an alloying treatment temperature (T**3**) of 450° C. to 560° C.

Advantageous Effects of Invention

[0038] The present invention can provide a high-strength (980 MPa or more) cold-rolled steel sheet, a high-strength hot-dip galvanized steel sheet, and a high-strength hot-dip galvannealed steel sheet each of which is adapted to have a specific microstructure, is excellent in formability and shape fixability, and is suitable for automobile parts. These steel sheets are hereinafter also generically referred to as "steel sheet(s)". As used herein the term "excellent in formability (outstanding formability)" refers to "excellent in balance between tensile strength and elongation (TS×EL balance) and balance between tensile strength and bore expandability (TS×λ balance) at a tensile strength of 980 MPa or more". Also as used herein the term "excellent in shape fixability" refers to "a low yield ratio (YR)".

BRIEF DESCRIPTION OF DRAWINGS

[0039] FIG. **1** is a schematic diagram illustrating a heat pattern for the explanation of an annealing process in a manufacturing method according to the embodiment of the present invention.

[0040] FIG. **2** is a schematic diagram of a heat pattern of an annealing process in Experimental Example.

[0041] FIG. **3** depicts an exemplary distribution (Example) of KAM values measured in Experimental Example.

[0042] FIG. **4** depicts an exemplary distribution (Comparative Example) of KAM values measured in Experimental Example.

DESCRIPTION OF EMBODIMENTS

[0043] After intensive investigations to achieve the object, the present inventors have found as follows. A steel sheet, when having a specific steel microstructure, can effectively achieve improvements in TS×EL balance and TS×λ balance (better formability) and reduction in YR (better shape fixability) concurrently, where the steel microstructure contains bainitic ferrite and tempered martensite as a matrix and contains retained austenite and fresh martensite in predetermined contents, but polygonal ferrite is minimized in the microstructure. In addition, to form the microstructure, the steel sheet should be adapted to have a Si content of 1.0% or more; and annealing in a manufacturing process of the steel sheet should be performed such that the work is soaked in an austenite single-phase region (austenite single-phase region), cooled down to a relatively low temperature range at a predetermined cooling rate, and held in the low temperature range for a short time. The present invention has been achieved based on these findings.

[0044] Reasons why the microstructure may be specified herein will be initially described.

[0045] Steel Microstructure

[0046] The steel sheet according to the embodiment of the present invention is adapted to include bainitic ferrite (BF) and tempered martensite (TM) (hereinafter these phases are together referred to as "BF+TM" (phases)) as a matrix microstructure. The BF+TM phases effectively help the steel to have a high strength without impairing elongation (EL) and bore expandability (λ). The BF+TM phases are adapted to occupy 65% (in area percent) or more of the microstructure. The content (total content) of BF+TM is preferably 70% or more and more preferably 75% or more. There is no need to distinguish BF and TM from each other, because these phases affect the material steel properties similarly. Specifically, there is no need to specify percentages of individual phases, i.e., BF and TM in the BF+TM phases, whereas the total content of BF+TM may be specified herein.

[0047] The BF+TM phases include lathy phases. The present inventors have also found that the steel sheet can have a still higher strength without impairing bore expandability by reducing the lath size and increasing a dislocation density in grains.

[0048] The lath size of BF+TM and the dislocation density in grains can be evaluated by a KAM (kernel average misorientation) value.

[0049] The KAM value is an average value of quantity of crystal rotation (crystal misorientation) between a target measuring point and measuring points around the target measuring point, and a high KAM value means that strain exists in the crystal. A measuring method for the KAM value will be illustrated in detail in Experimental Example. The present inventors made investigations on relationship between the KAM value and the steel microstructure and verified that a region at a KAM value less than 1.00° corresponds to the BF+TM phases, whereas a region at a KAM value of 1.00° or more mainly corresponds to fresh martensite (M) and grain boundaries.

[0050] Based on this finding, the present inventors made further studies for the region at a KAM value less than 1.00° on a process or unit for reducing the lath size and increasing the dislocation density in grains so as to provide a still higher strength without impairing bore expandability (namely, to provide a process or unit that offers good TS×λ balance). As a result, the present inventors have found that good TS×λ balance is obtained when an average of KAM values in a region at a KAM value less than 1.00° is 0.50° or more. Specifically, KAM values in the region of less than 1.00° are distributed in a higher KAM value region in the distribution of KAM values measured at two or more measuring points. Hereinafter the average is also referred to as "average $\text{KAM}_{<1.00^\circ}$".

[0051] The region at a KAM value less than 1.00° also includes a polygonal ferrite (F) region, but the polygonal ferrite (F) region is negligible because the steel sheet herein has a low polygonal ferrite (F) content (5% or less). Accordingly, it can be said that the "average $\text{KAM}_{<1.00^\circ}$" refers to an average KAM value in the BF+TM region.

[0052] The average $\text{KAM}_{<1.00^\circ}$ is preferably 0.52° or more, and more preferably 0.54° or more. The upper limit of this value may be about 0.7° from the viewpoint of TS×EL balance.

[0053] In the KAM value analysis, data of measuring points with a confidence index (CI) of 0.1 or less are considered to lack reliability and are excluded firm the analysis. The CI is an index indicating how much an electron backscattering diffraction pattern detected at each measuring point meets a database value of a specified crystal system (bcc or fcc in the case of iron). This index indicates confidence (reliability) of the data.

[0054] A steel sheet can have a high strength by being adapted to have a microstructure including BF+TM in a content of 65% or more and to have an average $\text{KAM}_{<1.00^\circ}$ of 0.50° or more, as described above. However, a steel sheet, if adapted to have a high strength by these factors alone, may have a high YR and inferior shape fixability. To prevent this, fresh martensite (MI) is allowed to exist in the microstructure herein. The fresh martensite is also effective for a higher strength, and moving dislocation in the fresh martensite is effective for a lower YR. The present invention can achieve a high strength, a low YR, and good formability concurrently by allowing fresh martensite to be present in a content of 3% or more in the matrix BF+TM having an average $\text{KAM}_{<1.00^\circ}$ of 0.50° or more. The flesh martensite content is preferably 5% or more, and more preferably 6% or more. However, fresh martensite, if present in an excessively high content, may cause the steel sheet to suffer from deterioration in formability (TS×EL balance and TS×λ balance). To prevent this, the fresh martensite content may be 18% or less. The fresh martensite content is preferably 14% or less, and more preferably 10% or less.

[0055] The present invention improves the TS×EL balance by the presence of retained austenite in the microstructure. To this end, the retained austenite content may be specified to 5% or more. The retained austenite content is preferably 6% or more, and more preferably 7% or more. The upper limit of the retained austenite content may be about 20%.

[0056] In contrast, the presence of polygonal ferrite (F) in the microstructure herein may invite inferior TS×λ balance. To prevent this, polygonal ferrite is preferably minimized, and the polygonal ferrite content herein may be specified to 5% or less. The polygonal ferrite content is preferably 3% or less, and most preferably 0%.

[0057] Next, a chemical composition and manufacturing conditions for the steel sheet to ensure the microstructure and to provide still improvements in properties such as formability.

[0058] Initially, the chemical composition will be illustrated.

[0059] Chemical Composition

[0060] C in a Content of 0.1% to 0.3%

[0061] Carbon (C) element is highly capable of strengthening the steel and is important in stabilizing austenite and for ensuring retained austenite. In addition, carbon effectively suppresses polygonal ferrite formation during cooling from a high temperature. To exhibit such actions, carbon may be contained in a content of 0.1% or more, preferably 0.15% or more, and more preferably 0.17% or more. However, carbon, if contained in a content greater than 0.3%, may cause the steel to have inferior weldability. To prevent this, the upper limit of the carbon content may be specified to 0.3%. The carbon content is preferably 0.25% or less, and more preferably 0.2% or less.

[0062] Si in a Content of 1.0% to 3.0%

[0063] Silicon (Si) element acts as a solute strengthening element and helps the steel to have a high strength. This element also effectively suppresses the formation of carbides, stabilizes austenite by allowing carbon to be enriched in austenite, and is important in ensuring retained austenite. To exhibit such actions, Si may be contained in a content of 1.0% or more, preferably 1.2% or more, and more preferably 1.4% or more. However, Si, if contained in a content greater than 3.0%, may cause significant scale formation during hot rolling and thereby cause the steel sheet to have scale marks (scale defects) on its surface and to offer inferior surface quality. To prevent this, the upper limit of the Si content may be specified to 3.0%. The Si content is preferably 2.5% or less, and more preferably 2.0% or less.

[0064] Mn in a Content of 0.5% to 3.0%

[0065] Manganese (Mn) element is important not only in helping the steel to have a higher strength, but also in directly acting on the stabilization of austenite. This element also helps the steel to have better hardenability and effectively suppresses the polygonal ferrite formation. To exhibit such actions, Mn may be contained in a content of 0.5% or more, preferably 1.0% or more, and more preferably 2.0% or more. However, Mn, if contained in a content greater than 3.0%, may cause adverse effects such as the generation of slab cracking. To prevent this, the upper limit of the content may be specified to 3.0%. The Mn content is preferably 2.8% or less, and more preferably 2.5% or less.

[0066] P in a Content of 0.1% or Less

[0067] Phosphorus (P) element accelerates intergranular embrittlement due to grain boundary segregation and causes the steel to have inferior formability. To prevent this, the phosphorus content is preferably minimized, and the upper limit of the phosphorus content herein may be specified to 0.1%. The phosphorus content is preferably 0.08% or less, and more preferably 0.05% or less.

[0068] S in a Content of 0.03% or Less

[0069] Sulfur (S) element forms MnS and other sulfide inclusions acting as cracking origins and causes the steel to have inferior formability. To prevent this, the sulfur content is preferably minimized, and the upper limit of the sulfur content herein may be specified to 0.03%. The sulfur content is preferably 0.02% or less, and more preferably 0.01% or less.

[0070] Al in a Content of 0.01% to 1.0%

[0071] Aluminum (Al) element acts as a deoxidizer. To exhibit such actions, Al may be contained in a content of 0.01% or more, preferably 0.02% or more, and more preferably 0.03% or more. However, Al, if contained in a content greater than 1.0%, may cause the steel sheet to have inferior formability because alumina and other inclusions are formed in large amounts in the steel sheet. To prevent this, the upper limit of the Al content may be specified to 1.0%. The Al content is preferably 0.5% or less, and more preferably 0.1% or less.

[0072] N in a Content of 0.01% or Less

[0073] Nitrogen (N) element forms nitrides acting as cracking origins and thereby causes the steel to have inferior formability. To prevent this, the nitrogen content is preferably minimized, and the upper limit of the nitrogen content herein may be specified to 0.01%. The nitrogen content is preferably 0.008% or less, and more preferably 0.006% or less.

[0074] The chemical composition of the steel sheet according to the embodiment of the present invention is as mentioned above, with the remainder being iron and inevitable impurities. In addition to the elements, the steel sheet may further contain any of following elements in an appropriate amount so as to offer a still higher strength and better properties such as toughness and corrosion resistance. These elements will be described in detail below.

[0075] At least one element selected from the group consisting of Ti in a content of 0.01% to 0.1%; Nb in a content of 0.01% to 0.1%; and V in a content of 0.01% to 0.1%

[0076] Titanium (Ti), niobium (Nb), and vanadium (V) elements each contribute to microstructure refinement, helps the steel sheet to have a higher strength and better toughness, and may be added according to necessity. To exhibit such actions, any of the elements is preferably contained in a content of 0.01% or more, more preferably 0.015% or more, and furthermore preferably 0.02% or more. However, each element, if contained in a content greater than 0.1%, may exhibit saturated effects and may cause the steel sheet to have a higher yield ratio YR and inferior shape fixability. To prevent this, the upper limit of the content of each element may be specified to 0.1%. The contents of the elements are each preferably 0.08% or less, and more preferably 0.06% or less. Each of Ti, Nb, and V may be contained alone or in an arbitrary combination of two or more.

[0077] At least one element selected from the group consisting of Cr in a content of 0.01% to 1%; Mo in a content of 0.01% to 1%; and B in a content of 0.0001% to 0.005%

[0078] Chromium (Cr), molybdenum (Mo), and boron (B) elements each suppress polygonal ferrite formation during cooling from a high temperature and may be added according to necessity. To exhibit such actions, each of Cr and Mo may be contained in a content of preferably 0.01% or more, more preferably 0.05% or more, and furthermore preferably 0.1% or more. Boron may be contained in a content of preferably 0.0001% or more, more preferably 0.0005% or more, and furthermore preferably 0.001% or more. However, each element, if contained in an excessively high content, may exhibit saturated effects and may cause the steel sheet to have inferior formability. To prevent this, the upper limits of Cr and Mo contents may be specified preferably to 1%. The contents are each more preferably 0.8% or less, and furthermore preferably 0.6% or less. Likewise, the upper limit of the boron content may be preferably 0.005%. The boron content is more preferably 0.004% or less, and furthermore preferably 0.003% or less. Each of Cr, Mo, and B may be contained alone or in an arbitrary combination of two or more.

[0079] At least one element selected from the group consisting of Cu in a content of 0.01% to 1%; and Ni in a content of 0.01% to 1%

[0080] Copper (Cu) and nickel (Ni) elements each effectively help the steel sheet to have better corrosion resistance and may be added according to necessity. To exhibit such actions, each of the elements may be contained in a content of preferably 0.01% or more, more preferably 0.05% or more, and furthermore preferably 0.1% or more. However, each element, if contained in a content greater than 1%, may exhibit saturated effects and may cause the steel sheet to have inferior formability. To prevent this, the upper limit of each content may be specified to 1%. The contents are each more preferably 0.8% or less, and furthermore preferably 0.6% or less. Each of Cu and Ni may be contained alone or in combination.

[0081] At least one element selected from the group consisting of Ca in a content of 0.0005% to 0.005%; and Mg in a content of 0.0005% to 0.005%

[0082] Calcium (Ca) and magnesium (Mg) elements help the steel sheet to have better corrosion resistance as with Cu and Ni and may be added according to necessity. To exhibit such actions, each of the elements may be contained in a content of preferably 0.0005% or more, more preferably 0.001% or more, and furthermore preferably 0.003% or more. However, each element, if contained in excess, may cause the steel sheet to have inferior formability. To prevent this, the upper limit of each of the contents may be specified to 0.005%. The contents are each more preferably 0.0045% or less, and further more preferably 0.0040% or less.

[0083] Manufacturing Methods

[0084] A cold-rolled steel sheet having the chemical composition is obtained by sequentially subjecting a material steel to hot rolling, acid wash, and cold rolling as manufacturing processes. The obtained cold-rolled steel sheet is subjected to annealing and, where necessary, further subjected to a coating treatment, an alloying treatment. To obtain the specific microstructure, the annealing is performed under after-mentioned conditions; and the alloying treatment is performed under after-mentioned conditions in the case of the high-strength hot-dip galvannealed steel sheet. Other processes may employ generally performed conditions. In the present invention, a steel sheet immediately before annealing is refers to as a "cold-rolled steel sheet"; and a cold-rolled steel sheet after subjected to the specific annealing is referred to as a "high-strength cold-rolled steel sheet", thus distinguishing them from each other.

[0085] The annealing (heat treatment) process will be illustrated below with reference to FIG. **1**. FIG. **1** is a schematic explanatory drawing explanatively illustrating an annealing process in the manufacturing method according to the embodiment of the present invention. T**1**, t**1**, CR**1**, CR**2**, T**2**, t**2**, T**3**, t**3**, CR**3**, CR**3**', and CR**3**" as described below correspond to reference signs in FIG. **1**.

[0086] Heating temperature (T**1**) in annealing process: Ac_3 to 960° C.

[0087] In the annealing process, the work should be heated to an austenite single-phase region. This is because heating, if performed to a low temperature in a two-phase region, may cause polygonal ferrite formation and cause the steel sheet to have inferior TS×λ balance. The presence of the polygonal ferrite may cause carbon to be enriched in untransformed austenite and thereby suppress transformation to bainitic ferrite during austempering. The resulting steel sheet may fail to ensure BF+TM in a desired amount and may have inferior TS×EL balance and TS×λ balance due to the formation of excessive fresh martensite. The heating temperature (T**1**) in the annealing process herein may be specified to the Ac_3 point or higher. T**1** is preferably Ac_3+30° C. or higher, and more preferably Ac_3+50° C. or higher.

[0088] In contrast, heating, if performed to an excessively high temperature T**1**, may cause the microstructure to coarsen and cause the steel sheet to have a low tensile strength. To prevent this, the temperature T**1** may be specified to 960° C. or lower. T**1** is preferably 940° C. or lower, and more preferably 920° C. or lower.

[0089] Heating is preferably performed by holding the work at T**1** for a holding time (t**1**) of 10 to 1000 seconds. Holding, if performed for a time shorter than 10 seconds, may fail to heat the work sufficiently to the austenite single-phase region. Holding, if performed for a time longer than 1000 seconds, may often cause the microstructure to coarsen and readily cause the steel sheet to have inferior formability.

[0090] Average cooling rate (CR**1**) from the heating temperature (T**1**) down to 500° C.: 5° C./s or more

[0091] Average cooling rate (CR**2**) from 500° C. down to a temperature range (T**2**) of (Ms-200)° C. to 420° C.: 10° C./s or more Cooling from the heating temperature (T**1**) down to 500° C., if performed at an excessively low average cooling rate (CR**1**), may cause polygonal ferrite formation and cause the steel sheet to have inferior TS×λ balance. To prevent this, the average cooling rate CR**1** herein may be specified to 5° C./s or more. The average cooling rate CR**1** is preferably 10° C./s or more, and more preferably 15° C./s or more. The upper limit of CR**1** may be about 500° C./s.

[0092] Cooling from 500° C. down to a temperature range (austempering temperature range) (T**2**) of (Ms-200)° C. to 420° C., if performed at an excessively low average cooling rate (CR**2**), may cause the formation of bainitic ferrite with a low KAM value (with a low dislocation density) (namely with an average $KAM_{<1.00°}$ of less than 0.50°) and cause the steel sheet to have inferior TS×λ balance. To prevent this, the average cooling rate CR**2** herein may be specified to 10° C./s or more and is preferably 15° C./s or more. The upper limit of CR**2** may be about 500° C./s in a real operation.

[0093] In the heat pattern in FIG. **1**, the cooling rate in cooling from T**1** is changed at 500° C. The heat pattern, however, is not limited thereto. Typically, cooling from the heating temperature (T**1**) down to the temperature range (T**2**) of (Ms-200)° C. to 420° C. may be performed at a constant average cooling rate without change, namely, CR**1** may be equal to CR**2**, as long as meeting the conditions for CR**1** and CR**2**.

[0094] As used herein the term "average cooling rate" refers to a value as given by [(Cooling start temperature)−(Cooling stop temperature)]/(Time required for cooling). The same is true for CR**3**, CR**3**', and CR**3**" mentioned later.

[0095] When cooling from 500° C. at an average cooling rate (CR**2**) of 10° C./s or more is stopped at a temperature (cooling stop temperature) of equal to or lower than the martensite start temperature (Ms), fresh martensite may be formed partially. The fresh martensite is converted into tempered martensite (TM) by holding in a temperature range T**2** mentioned below.

[0096] Holding in a temperature range (austempering temperature; T**2**) of (Ms-200)° C. to 420° C. for a time period (t**2**) of 10 to 70 seconds

[0097] This process is important for forming BF+TM and retained austenite. Specifically, fresh martensite is converted into tempered martensite (TM); and untransformed austenite forms bainitic ferrite (BF) in the process. The process is also necessary for ensuring desired retained austenite by accelerating carbon to be enriched in untransformed austenite.

[0098] Holding, if performed in a temperature range T2 lower than (Ms-200)° C., may cause untransformed austenite to remain in an excessively small amount at the time when the cooling is stopped, thereby cause the steel sheet to fail to ensure sufficient retained austenite and to have inferior TS×EL balance. In addition, the steel sheet may include fresh martensite in an excessively low content and thereby have a high YR, thus being undesirable. The temperature range T2 is preferably (Ms-150)° C. or higher, and more preferably (Ms-100)° C. or higher.

[0099] In contrast, holding, if performed in a temperature range T2 higher than 420° C., may cause the steel sheet to have an excessively low dislocation density in BF+TM, to have a low average $\text{KAM}_{<1.00^\circ}$, and to offer inferior TS×λ balance. In addition, the steel sheet may often have a final microstructure including flesh martensite in a higher content. To prevent this, the temperature range T2 may be specified to 420° C. or lower. T2 is preferably 400° C. or lower, and more preferably 380° C. or lower.

[0100] The holding temperature does not have to be constant, as long as being within the temperature range, and may be varied within the predetermined temperature range. This is not deviated from the spirit and scope of the present invention.

[0101] Holding in the temperature range T2, if performed for a holding time (t2) shorter than 10 seconds, may fail to accelerate carbon enrichment in austenite, thereby fail to ensure sufficient retained austenite, and cause the steel sheet to have inferior TS×EL balance. In addition, the steel sheet may contain fresh martensite in an excessively high content because of insufficient transformation to bainitic ferrite and thereby have inferior TS×EL balance and TS×λ balance. To prevent these, the holding time t2 may be specified to 10 seconds or longer and is preferably 20 seconds or longer, and more preferably 30 seconds or longer.

[0102] In contrast, holding, if performed for a holding time t2 longer than 70 seconds, may cause the steel sheet to have an excessively low average $\text{KAM}_{<1.00^\circ}$ and to offer inferior TS×λ balance. Holding performed for such a long time t2 may also cause excessive transformation to bainitic ferrite, and this may cause the steel sheet to have a final microstructure including fresh martensite in an excessively low content and to thereby have a high YR, thus being undesirable. In addition, such long-time holding may impair productivity. To prevent these, the holding time t2 may be specified to 70 seconds or shorter and is preferably 60 seconds or shorter.

[0103] The present invention differs from the technologies in PTL 3 to 7 in that holding is performed in a relatively low temperature range T2 for a short time. Specifically, PTL 3 describes that a work is cooled down to a temperature range of 480° C. to 350° C., and then held in the temperature range for 100 to 400 seconds or slowly cooled. The holding time is longer than that in the present invention. The technology in PTL 4 employs other processes than those in the present invention. Specifically, the technology employs processes of heating a work in the austenite single phase region, once cooling down to a low temperature range (50° C. to 300° C.), and heating from the temperature range up to a temperature in the range of 350° C. to 490° C. The technology in PTL 5 employs holding in a first temperature range and a second temperature range for a long total time of 220 seconds or longer. The technology in PTL 6 employs holding in a temperature range of 100° C. to (Ms-10° C.) for a long time of 80 seconds or longer. The technology in PTL 7 performs holding in a temperature range of (Ms-20° C.) to Bs for a long time of 240 seconds. This may probably impede ensuring of sufficient martensite and a high average $\text{KAM}_{<1.00^\circ}$. As is described above, these technologies, as employing a long holding time, probably give a low average $\text{KAM}_{<1.00^\circ}$ as specified in the present invention and fail to attain an average $\text{KAM}_{<1.00^\circ}$ of 0.50° or more.

[0104] To obtain the high-strength cold-rolled steel sheet, cooling after the annealing down to room temperature is performed at an average cooling rate (CR3) of 1° C./s or more. The cooling helps untransformed austenite to be partially transformed to fresh martensite and to partially remain as retained austenite. Cooling at an average cooling rate (CR3) of 1° C./s or more suppresses the decomposition of untransformed austenite during cooling and ensures a sufficient amount of retained austenite. The upper limit of the average cooling rate (CR3) may be about 500° C./s.

[0105] Coating Treatment

[0106] The steel sheet may be subjected to coating after the heat treatment (annealing). Immersion in a bath does not affect the material properties. The coating treatment itself may employ a generally performed procedure. Typically, a generally employed hot-dip galvanizing bath may be used while controlling the bath temperature at 400° C. to about 500° C. A mass of coating (per one side) is not critical, but may be set within a range typically of 20 to 100 g/m^2.

[0107] To obtain a high-strength hot-dip galvanized steel sheet, cooling after the coating treatment down to room temperature may be performed at an average cooling rate (CR3') of 1 to 500° C./s. This range is specified for the same reason as with the average cooling rate CR3.

[0108] Alloying treatment temperature (T3): 450° C. to 560° C.

[0109] An alloying treatment, if performed at a temperature (T3) higher than 560° C., may cause decomposition of untransformed austenite, thereby cause the steel sheet to fail to ensure sufficient retained austenite and to have inferior TS×EL balance. The resulting steel sheet may have an excessively low average $\text{KAM}_{<1.00^\circ}$ and offer inferior TS×λ balance. In addition, the steel sheet may suffer from precipitation of carbides, thereby have a high YR, and offer inferior TS×EL balance and TS×λ balance. To prevent these, the alloying treatment temperature T3 may be herein specified to 560° C. or lower. T3 is preferably 540° C. or lower, and more preferably 520° C. or lower. In contrast, an alloying treatment, if performed at a temperature lower than 450° C., may fail to proceed alloying. To prevent this, the temperature T3 may be specified to 450° C. or higher and is preferably 480° C. or higher.

[0110] The alloying treatment may be performed under a common condition for the alloying treatment time (t3), such as about 5 to about 60 seconds.

[0111] To obtain the high-strength hot-dip galvannealed steel sheet, cooling after the alloying treatment down to mom temperature may be performed at an average cooling rate (CR3") of 1 to 500° C./s. This range is specified for the same reason as with the average cooling rate CR3.

EXAMPLES

[0112] The present invention will be illustrated in further detail with reference to several examples (experimental examples) below. It should be noted, however, that the examples are by no means intended to limit the scope of the invention; that various changes and modifications can naturally be made therein without deviating from the spirit and scope of the invention as described above and below; and all such changes and modifications should be considered to be within the scope of the invention.

[0113] While simulating an actual machine, steel ingots having chemical compositions given in Table 1 were made by vacuum ingot-making, heated to 1250° C., subjected to hot rolling which was completed at a finish rolling temperature of 880° C., cooled down to a coiling temperature of 600° C., held at that temperature for 30 minutes, cooled by furnace cooling, and thereby yielded hot-rolled steel sheets. The hot-rolled steel sheets were subjected to acid wash to remove surface scales, subjected to cold rolling to a cold rolling reduction of 46% to 62%, and thereby yielded 1.4-mm thick cold-rolled steel sheets. The cold-rolled steel sheets were subjected to annealing (heat treatment) as follows.

[0114] Specifically, as indicated in FIG. **2** and Table 2 below, each cold-rolled steel sheet was held at a soaking temperature T**1** (° C.) for 90 seconds, cooled from T**1** down to 500° C. at an average cooling rate CR**1** (° C./s), further cooled from 500° C. to a temperature T**2** (° C.) at an average cooling rate CR**2** (° C./s), and held in the temperature range (T**2**) for a time period t**2** (second).

[0115] High-strength cold-rolled steel sheets (CR) were obtained by, after the annealing, cooling down to room temperature at an average cooling rate (CR**3**) of 15° C./s. High-strength hot-dip galvanized steel sheets (GI) were obtained by, after the heat treatment, immersing in a galvanizing bath at 460° C. to perform a coating treatment; and cooling down to room temperature at an average cooling rate (CR**3'**) of 15° C./s. High-strength hot-dip galvannealed steel sheets (GA) were obtained by, after the immersion in the galvanizing bath, performing an alloying treatment at an alloying treatment temperature T**3** (° C.) given in Table 2 for 35 seconds and cooling down to mom temperature at an average cooling rate (CR**3''**) of 15° C./s.

[0116] The mass of coating per one side was 40 g/m^2.

[0117] Ac$_3$ and Ms were calculated according to expressions below, as described in "The Physical Metallurgy of Steels", William C. Leslie (Maruzen Co., Ltd., published on May 31, 1985, pp. 273 and 231). In the expressions, the term "[element]" denotes a content (in mass percent) of each element contained in the steel sheet. In the expressions, the calculation was performed while setting the content of an element not contained in the steel sheet as 0%.

$$\mathrm{Ac}_3(^\circ\ \mathrm{C.})=910-203\times[\mathrm{C}]^{1/2}-15.2\times[\mathrm{N}]+44.7\times[\mathrm{Si}]+104\times[\mathrm{V}]+31.5\times[\mathrm{Mo}]+13.1\times[\mathrm{W}]-30\times[\mathrm{Mn}]-11\times[\mathrm{Cr}]-20\times[\mathrm{Cu}]+700\times[\mathrm{P}]+400\times[\mathrm{Al}]+120\times[\mathrm{As}]+400\times[\mathrm{Ti}] \quad \text{[Math. 1]}$$

$$\mathrm{Ms}(^\circ\ \mathrm{C.})=561-474\times[\mathrm{C}]-33\times[\mathrm{Mn}]-17\times[\mathrm{Cr}]-21\times[\mathrm{Mo}] \quad \text{[Math. 2]}$$

TABLE 1

Test	Steel	Chemical composition (in mass percent) with the remainder being iron and inevitable impurities											
No.	type	C	Si	Mn	P	S	Al	N	Ti	Nb	V	Cr	Mo
1	A	0.19	1.7	2.4	0.008	0.003	0.04	0.004	—	—	—	—	—
2	A	0.19	1.7	2.4	0.008	0.003	0.04	0.004	—	—	—	—	—
3	A	0.19	1.7	2.4	0.008	0.003	0.04	0.004	—	—	—	—	—
4	A	0.19	1.7	2.4	0.008	0.003	0.04	0.004	—	—	—	—	—
5	A	0.19	1.7	2.4	0.008	0.003	0.04	0.004	—	—	—	—	—
6	A	0.19	1.7	2.4	0.008	0.003	0.04	0.004	—	—	—	—	—
7	A	0.19	1.7	2.4	0.008	0.003	0.04	0.004	—	—	—	—	—
8	A	0.19	1.7	2.4	0.008	0.003	0.04	0.004	—	—	—	—	—
9	A	0.19	1.7	2.4	0.008	0.003	0.04	0.004	—	—	—	—	—
10	A	0.19	1.7	2.4	0.008	0.003	0.04	0.004	—	—	—	—	—
11	A	0.19	1.7	2.4	0.008	0.003	0.04	0.004	—	—	—	—	—
12	A	0.19	1.7	2.4	0.008	0.003	0.04	0.004	—	—	—	—	—
13	A	0.19	1.7	2.4	0.008	0.003	0.04	0.004	—	—	—	—	—
14	B	0.13	1.3	2.8	0.008	0.003	0.04	0.004	—	—	—	—	—
15	C	0.30	1.3	1.7	0.008	0.003	0.04	0.004	—	—	—	—	—
16	D	0.19	1.2	2.4	0.008	0.003	0.04	0.004	—	—	—	—	—
17	E	0.19	0.8	2.4	0.008	0.003	0.04	0.004	—	—	—	—	—
18	F	0.19	2.7	2.4	0.008	0.003	0.04	0.004	—	—	—	—	—
19	G	0.18	2.0	2.0	0.007	0.002	0.03	0.004	0.02	—	—	—	—
20	G	0.18	2.0	2.0	0.007	0.002	0.03	0.004	0.02	—	—	—	—
21	G	0.18	2.0	2.0	0.007	0.002	0.03	0.004	0.02	—	—	—	—
22	H	0.18	2.0	2.2	0.008	0.002	0.03	0.004	0.02	—	—	—	—
23	H	0.18	2.0	2.2	0.008	0.002	0.03	0.004	0.02	—	—	—	—
24	H	0.18	2.0	2.2	0.008	0.002	0.03	0.004	0.02	—	—	—	—
25	I	0.19	1.7	2.4	0.008	0.003	0.04	0.004	—	0.03	—	—	—
26	J	0.19	1.7	2.4	0.008	0.003	0.04	0.004	—	—	0.03	—	—
27	K	0.19	1.7	2.5	0.008	0.003	0.04	0.004	—	—	—	0.50	—
28	L	0.19	1.7	2.4	0.008	0.003	0.04	0.004	—	—	—	—	0.20
29	M	0.19	1.7	2.4	0.008	0.003	0.04	0.004	—	—	—	—	—
30	N	0.20	1.7	1.0	0.008	0.003	0.04	0.004	—	—	—	—	—
31	O	0.18	2.0	2.6	0.006	0.001	0.04	0.004	0.03	—	—	0.02	—
32	P	0.19	1.7	2.4	0.008	0.003	0.04	0.004	—	—	—	—	—
33	Q	0.19	1.7	2.4	0.008	0.003	0.04	0.004	—	—	—	—	—
34	R	0.22	1.2	2.4	0.005	0.001	0.03	0.005	—	—	—	—	—

TABLE 1-continued

35	R	0.22	1.2	2.4	0.005	0.001	0.03	0.005	—	—	—	—	—
36	S	0.25	1.2	2.4	0.005	0.001	0.03	0.005	—	—	—	—	—
37	T	0.22	1.0	2.4	0.005	0.001	0.03	0.005	—	—	—	—	—
38	U	0.22	1.5	2.4	0.005	0.001	0.03	0.005	—	—	—	—	—
39	V	0.23	1.2	1.8	0.005	0.001	0.03	0.005	—	—	—	—	—
40	W	0.23	1.2	1.5	0.005	0.001	0.03	0.005	—	—	—	—	—

Test	Chemical composition (in mass percent) with the remainder being iron and inevitable impurities					Ac_3	Ms	Ms-200
No.	B	Cu	Ni	Ca	Mg	(° C.)	(° C.)	(° C.)
1	—	—	—	—	—	846	392	192
2	—	—	—	—	—	846	392	192
3	—	—	—	—	—	846	392	192
4	—	—	—	—	—	846	392	192
5	—	—	—	—	—	846	392	192
6	—	—	—	—	—	846	392	192
7	—	—	—	—	—	846	392	192
8	—	—	—	—	—	846	392	192
9	—	—	—	—	—	846	392	192
10	—	—	—	—	—	846	392	192
11	—	—	—	—	—	846	392	192
12	—	—	—	—	—	846	392	192
13	—	—	—	—	—	846	392	192
14	—	—	—	—	—	832	407	207
15	—	—	—	—	—	827	363	163
16	—	—	—	—	—	824	392	192
17	—	—	—	—	—	806	392	192
18	—	—	—	—	—	891	392	192
19	—	—	—	—	—	879	410	210
20	—	—	—	—	—	879	410	210
21	—	—	—	—	—	879	410	210
22	—	—	—	—	—	871	401	201
23	—	—	—	—	—	871	401	201
24	—	—	—	—	—	871	401	201
25	—	—	—	—	—	846	392	192
26	—	—	—	—	—	849	392	192
27	—	—	—	—	—	838	380	180
28	—	—	—	—	—	853	388	188
29	0.0020	—	—	—	—	846	392	192
30	0.0020	—	—	—	—	886	433	233
31	0.0005	—	—	—	—	865	390	190
32	—	0.30	0.20	—	—	837	388	188
33	—	—	—	0.0040	0.0040	846	392	192
34	—	—	—	—	—	812	378	178
35	—	—	—	—	—	812	378	178
36	—	—	—	—	—	806	363	163
37	—	—	—	—	—	803	378	178
38	—	—	—	—	—	825	378	178
39	—	—	—	—	—	828	393	193
40	—	—	—	—	—	837	402	202

TABLE 2

			Heat treatment process					
Test No.	Steel type	Product type	T1 (° C.)	CR1 (° C./s)	CR2 (° C./s)	T2 (° C.)	t2 (s)	T3 (° C.)
1	A	GA	900	15	15	300	30	500
2	A	GA	900	15	15	340	60	500
3	A	CR	900	15	15	340	60	—
4	A	GA	830	15	15	340	60	500
5	A	GA	900	3	15	310	60	500
6	A	GA	900	15	5	310	60	500
7	A	GA	900	15	15	180	60	500
8	A	GA	900	15	15	440	60	500
9	A	GA	900	15	15	400	5	500
10	A	GA	900	15	15	400	90	500
11	A	GA	900	15	15	340	240	500
12	A	GA	900	15	15	370	60	575
13	A	GI	900	15	15	410	60	—
14	B	GA	950	30	30	340	60	500

TABLE 2-continued

			Heat treatment process					
Test No.	Steel type	Product type	T1 (° C.)	CR1 (° C./s)	CR2 (° C./s)	T2 (° C.)	t2 (s)	T3 (° C.)
15	C	GA	950	30	30	300	60	500
16	D	GA	900	30	30	340	60	500
17	E	GA	900	30	30	340	60	500
18	F	GA	950	30	30	340	60	500
19	G	GA	950	50	50	310	60	500
20	G	GA	950	50	50	340	60	500
21	G	GA	950	50	50	400	60	500
22	H	GA	950	50	50	310	60	500
23	H	GA	950	50	50	340	60	500
24	H	GA	950	50	50	400	60	500
25	I	GA	900	15	15	340	60	500
26	J	GA	900	15	15	340	60	500
27	K	GA	900	15	15	340	60	500
28	L	GA	900	15	15	340	60	500

TABLE 2-continued

			Heat treatment process					
Test No.	Steel type	Product type	T1 (° C.)	CR1 (° C./s)	CR2 (° C./s)	T2 (° C.)	t2 (s)	T3 (° C.)
29	M	GA	900	15	15	340	70	500
30	N	GA	950	30	30	340	70	500
31	O	GA	950	18	18	340	60	540
32	P	GA	900	15	15	340	60	500
33	Q	GA	900	15	15	340	60	500
34	R	GA	860	15	20	300	45	500
35	R	GI	860	15	20	300	45	—
36	S	GI	860	15	20	300	45	—
37	T	GA	860	15	20	300	45	500
38	U	GA	860	15	20	300	45	500
39	V	GA	860	30	30	300	45	500
40	W	GA	860	30	30	300	45	500

[0118] Each of the obtained steel sheets was subjected to microstructure fraction measurement, average $\mathrm{KAM}_{<1.00^\circ}$ measurement, and mechanical properties evaluation in the following manner.

[0119] Microstructure Fraction Measurement

[0120] Retained Austenite

[0121] Retained austenite frequently exists typically between laths in bainitic ferrite, and it is difficult to measure the amount thereof by microstructure observation. The amount (content) of retained austenite was therefore measured by X-ray diffraction analysis.

[0122] Specifically, a sample steel sheet was ground to one-fourth the thickness (t/4), chemically polished, and subjected to an X-ray diffracted intensity measurement to determine a retained austenite content. Using Co—Kα ray as an incident X-ray, the retained austenite content was calculated by an intensity ratio of each of austenite (200), (220), and (311) planes to each of ferrite (ferrite in a broad sense, including polygonal ferrite and bainitic ferrite) (200), (211), and (220) planes. The resulting retained austenite content determined by the X-ray diffraction measurement was calculated as a volume fraction. The volume fraction can be read as "area percentage" without conversion. The unit of the retained austenite content is therefore regarded and treated as "area percentage" herein.

[0123] Polygonal Ferrite, Bainitic Ferrite+Tempered Martensite, and Fresh Martensite

[0124] A test specimen was sampled firm each steel sheet so as to enable observation at a one-fourth the thickness (t/4) position in a cross section perpendicular to the sheet width direction. The test specimen was mechanically polished, etched with a Nital solution, and subjected to observation with a scanning electron microscope (SEM) at 3000-fold magnification. Area percentages of polygonal ferrite (F) and fresh martensite (M) were measured by image analysis. The measurement was performed in three fields of view, and an average of measured values in the three fields of view was determined.

[0125] The area percentage of BF+TM is measurable by microstructure observation. However, the steel sheets manufactured under conditions within the ranges specified in the experimental example each had a microstructure including polygonal ferrite (F), BF+TM, fresh martensite (M), and retained austenite alone. Accordingly the BF+TM content (in area percent) was determined by the expression: [100 (in area percent)−F (in area percent)−M (in area percent)-retained γ (in area percent)].

[0126] Average $\mathrm{KAM}_{<1.00^\circ}$ Measurement

[0127] A steel sheet was ground to one-fourth the thickness (t/4), mechanically polished, and yielded a sample. While the sample was inclined 70°, an electron backscattering diffraction pattern was measured in an area of 50 μm by 50 μm at a scan step of 0.125 μm using an SEM. KAM values at respective measuring points were determined based on the measurement result using an analysis software (OIM System supplied by TexSEM Laboratories, Inc. (TS)).

[0128] Exemplary results (distributions) of the KAM value measurements at respective measuring points are illustrated in FIGS. **3** and **4**. FIG. **3** is a graph illustrating a KAM value distribution of Test No. 26 (Example); whereas FIG. **4** is a graph illustrating a KAM value distribution of Test No. 12 (Comparative Example). KAM values of less than 1.00° are subjects herein, and blackened areas in FIGS. **3** and **4** correspond to this. An average of the KAM values in the blackened area is defined as an average $\mathrm{KAM}_{<1.00^\circ}$. In a comparison between FIG. **3** and FIG. **4**, it seems that there is little difference in distribution between the two as a result of visual observation. However, the analysis results demonstrate that the sample of Test No. 26 (FIG. **3**) had an average $\mathrm{KAM}_{<1.00^\circ}$ of 0.52, whereas the sample of Test No. 12 (FIG. **4**) had an average $\mathrm{KAM}_{<1.00^\circ}$ of 0.49, differing from each other. Such a small difference in the average $\mathrm{KAM}_{<1.00^\circ}$ herein significantly affects properties, as mentioned later.

[0129] The average $\mathrm{KAM}_{<1.00^\circ}$ of the other samples in the experimental example were determined by a measurement by the procedure as in FIG. **3** and FIG. **4**.

[0130] Mechanical Properties Evaluation

[0131] Tensile Test

[0132] A Japanese Industrial Standard (JIS) No. 5 test specimen (having a gauge length of 50 mm and a parallel width of 25 mm) was sampled from each steel sheet so as to have a longitudinal direction as a direction perpendicular to the steel sheet rolling direction, and yield strength YS, tensile strength TS, and total elongation EL were measured according to JIS Z2241. A strain rate in the test was 10 mm/min.

[0133] Bore Expanding Test

[0134] Evaluation was performed according to The Japan Iron and Steel Federation Standard (JFS) T1001. Specifically, a hole with a diameter of 10 mm was formed in a sample steel sheet with a punch, bore expanding in the hole was performed using a 60° conical punch so that burr faced upward, and a bore expansion ratio 2 upon crack penetration was measured.

[0135] Samples having a tensile strength TS of 980 MPa or more were evaluated as having a high strength. Of the samples having a tensile strength TS of 980 MPa or more, samples meeting conditions: $TS \times EL \geq 16$ (GPa·%) and $TS \times \lambda \geq 30$ (GPa·%) were evaluated as having excellent formability; and samples meeting a condition: YR ($=100 \times YS/TS$)≤ 80(%) were evaluated as having excellent shape fixability.

[0136] The results are indicated in Table 3.

TABLE 3

		Microstructure fraction					Mechanical properties						
Test No.	Steel type	F in area percent	BF + TM in area percent	Retained austenite in area percent	M in area percent	Average KAM < 1.00° (°)	YS (MPa)	TS (MPa)	YR (%)	EL (%)	λ (%)	T$ × EL (GPa · %)	T$ × λ (GPa · %)
1	A	0	77	8	15	0.59	731	1243	59	13	25	16	31
2	A	0	82	10	8	0.55	876	1226	71	14	28	17	34
3	A	0	80	9	11	0.58	706	1268	56	14	24	18	30
4	A	13	69	6	25	0.48	768	1473	54	10	9	14	13
5	A	24	87	9	4	0.43	612	993	62	19	25	19	25
6	A	0	84	10	6	0.45	771	1109	70	16	26	18	29
7	A	0	96	4	0	0.65	1143	1328	86	12	34	15	46
8	A	0	76	7	17	0.46	803	1340	60	12	13	16	17
9	A	0	60	4	36	0.52	843	1400	60	10	12	14	17
10	A	0	86	9	5	0.47	891	1198	74	15	24	17	29
11	A	0	91	9	0	0.49	1002	1146	87	14	25	16	29
12	A	0	82	4	14	0.49	759	1077	70	13	25	14	27
13	A	0	87	10	3	0.62	999	1277	78	14	42	18	54
14	B	0	89	6	5	0.57	763	1178	65	16	34	19	40
15	C	0	72	15	13	0.52	715	1293	55	12	24	16	31
16	D	0	86	7	7	0.54	866	1235	70	15	29	19	36
17	E	0	92	3	5	0.54	889	1210	73	12	39	14	47
18	F	0	76	13	11	0.56	703	1250	56	13	28	17	35
19	G	0	90	7	3	0.54	912	1148	79	15	43	17	50
20	G	0	86	11	3	0.54	875	1160	75	15	45	18	52
21	G	0	81	14	5	0.51	798	1096	73	16	34	18	37
22	H	0	87	9	4	0.53	916	1192	77	15	41	18	49
23	H	0	81	13	6	0.53	859	1194	72	14	38	17	45
24	H	0	79	12	9	0.50	747	1157	65	15	31	18	36
25	I	0	82	10	8	0.55	788	1235	64	14	27	17	33
26	J	0	85	8	7	0.52	830	1220	68	16	30	19	37
27	K	0	76	7	17	0.52	729	1270	57	14	23	18	30
20	L	0	80	8	12	0.54	709	1238	57	14	25	18	31
29	M	0	76	10	14	0.51	711	1244	57	15	28	18	35
30	N	0	86	11	3	0.55	885	1128	78	16	42	18	47
31	O	0	84	12	4	0.55	884	1226	72	15	31	18	37
32	P	0	81	9	10	0.53	743	1218	61	15	25	18	31
33	Q	0	83	9	8	0.53	798	1215	66	15	26	18	32
34	R	0	86	6	8	0.54	829	1255	66	14	30	17	38
35	R	0	84	8	8	0.58	733	1240	59	14	37	17	46
36	S	0	85	5	10	0.55	730	1272	57	13	24	17	31
37	T	0	88	5	7	0.55	834	1250	67	13	29	16	36
38	U	0	85	9	6	0.56	831	1208	69	15	32	18	39
39	V	0	85	6	9	0.58	751	1247	60	14	26	17	32
40	W	5	84	6	10	0.55	749	1250	60	13	29	16	36

[0137] Tables 1 to 3 give considerations as follows. Hereinafter "No." refer to "Test No." Specifically, Nos. 1 to 3, 13 to 16, and 18 to 40 were each manufactured by methods specified in the present invention, had a chemical composition and a microstructure within the specific ranges, and each gave a cold-relied steel sheet, a hot-dip galvanized steel sheet, or a hot-dip galvannealed steel sheet each of which had a tensile strength of 980 MPa or more and still offered excellent in formability and shape fixability.

[0138] In contrast, Nos. 4 to 12 and 17 had a chemical composition and a manufacturing conditions, either one of which did not meet the specific condition, thereby failed to have a desired microstructure, and were inferior in any of the properties.

[0139] Specifically, No. 4 underwent heating at an excessively low T**1** in the two-phase region, thereby included a large amount of polygonal ferrite, and had inferior TS×λ balance. In addition, the presence of polygonal ferrite caused carbon enrichment in untransformed austenite, this retarded the transformation to bainitic ferrite during austempering to cause a larger amount of fresh martensite. This sample thereby had inferior TS×EL balance and TS×λ balance.

[0140] No. 5 underwent cooling at an excessively low average cooling rate CR**1**, thereby suffered from polygonal ferrite formation during the cooling, and had inferior TS×λ balance.

[0141] No. 6 underwent cooling at an excessively low average cooling rate CR**2**, thereby suffered from the formation of bainitic ferrite having a low KAM value during the cooling, had a low average $\text{KAM}_{<1.00^\circ}$, and offered inferior TS×λ balance.

[0142] No. 7 underwent cooling to and holding in an excessively low temperature range T**2**, thereby failed to ensure sufficient retained austenite, and had inferior TS×EL balance. This sample also suffered from an excessively low fresh martensite content and thereby had a high YR.

[0143] No. 8 underwent cooling to and holding in an excessively high temperature range T**2**, thereby had an excessively low average $\text{KAM}_{<1.00^\circ}$, and offered inferior TS×λ balance.

[0144] No. 9 underwent holding in the temperature range T**2** for an excessively short time period t**2**, thereby failed to ensure desired amounts of BF+TM and retained austenite, included flesh martensite in an excessively high content, and thereby offered inferior TS×EL balance and TS×λ balance.

[0145] No. 10 underwent holding in the temperature range T**2** for an excessively long time period t**2**, thereby had a low average $\text{KAM}_{<1.00°}$, and offered inferior TS×λ balance.

[0146] No. 11 underwent holding for a still long t**2**, failed to ensure fresh martensite in a sufficient amount, and had a high YR. This sample also had an excessively low average $\text{KAM}_{<1.00°}$ and offered inferior TS×λ balance.

[0147] No. 12 underwent an alloying treatment at an excessively high temperature T**3**, thereby failed to ensure a desired amount of retained austenite, had an excessively low average $\text{KAM}_{<1.00°}$, suffered from carbides precipitation, and offered inferior TS×λ balance and TS×EL balance.

[0148] No. 17 had an excessively low Si content, thereby failed to ensure a sufficient amount of retained austenite, and offered inferior TS×EL balance.

1-10. (canceled)

11. A cold-rolled steel sheet, comprising, in mass percent, based on the chemical composition:
C in a content of 0.1% to 0.3%;
Si in a content of 1.0% to 3.0%;
Mn in a content of 0.5% to 3.0%;
P in a content of 0.1% or less;
S in a content of 0.03% or less;
Al in a content of 0.01% to 1.0%;
N in a content of 0.01% or less; and
iron and inevitable impurities,
the steel sheet having a steel microstructure meeting conditions given as follows:
a total content of bainitic ferrite (BF) and tempered martensite (TM) is 65% in area percent or more;
a content of fresh martensite (M) is from 3% to 18%;
a content of retained austenite is 5% or more; and
a content of polygonal ferrite (F) is 5% or less,
the steel microstructure further meeting a condition given as follows:
an average $\text{KAM}_{<1.00°}$ is from 0.50° to 0.7°,
wherein the "average $\text{KAM}_{<1.00°}$" is an average of kernel average misorientation (KAM) values (misorientation values, in "degree (°)") in a region of less than 1.00° as measured at two or more points; and
the steel sheet having a tensile strength of 980 MPa or more.

12. The cold-rolled steel sheet according to claim **11**, further comprising at least one element selected from the group consisting of:
Ti in a content of 0.01% to 0.1%;
Nb in a content of 0.01% to 0.1%; and
V in a content of 0.01% to 0.1%.

13. The cold-rolled steel sheet according to claim **11**, further comprising at least one element selected from the group consisting of:
Cr in a content of 0.01% to 1%;
Mo in a content of 0.01% to 1%; and
B in a content of 0.0001% to 0.005%.

14. The cold-rolled steel sheet according to claim **11**, further comprising at least one element selected from the group consisting of:
Cu in a content of 0.01% to 1%; and
Ni in a content of 0.01% to 1%.

15. The cold-rolled steel sheet according to claim **11**, further comprising at least one element selected from the group consisting of:
Ca in a content of 0.0005% to 0.005%; and
Mg in a content of 0.0005% to 0.005%.

16. A hot-dip galvanized steel sheet, comprising:
the cold-rolled steel sheet of claim **11**; and
a hot-dip galvanized layer formed on or over a surface of the cold-rolled steel sheet.

17. A hot-dip galvannealed steel sheet, comprising:
the cold-rolled steel sheet of claim **11**; and
a hot-dip galvannealed layer formed on or over a surface of the cold-rolled steel sheet.

18. A method for manufacturing the cold-rolled steel sheet of claim **11**, the method comprising, in an order as follows:
heating a cold-rolled steel sheet having, in mass percent, the chemical composition:
C in a content of 0.1% to 0.3%;
Si in a content of 1.0% to 3.0%;
Mn in a content of 0.5% to 3.0%;
P in a content of 0.1% or less;
S in a content of 0.03% or less;
Al in a content of 0.01% to 1.0%;
N in a content of 0.01% or less; and
iron and inevitable impurities,
to a temperature range (T**1**) of Ac_3 to 960° C.;
cooling the cold-rolled steel sheet from the temperature range (T**1**) down to 500° C. at an average cooling rate (CR**1**) of 5° C./s or more;
further cooling the cold-rolled steel sheet from 500° C. down to a temperature range (T**2**) of (Ms-200°)° C. to 420° C. at an average cooling rate (CR**2**) of 10° C./s or more; and
holding the cold-rolled steel sheet in the temperature range (T**2**) for a time period (t**2**) of 10 to 70 seconds.

19. A method for manufacturing the hot-dip galvanized steel sheet of claim **16**, the method comprising, in an order as follows:
heating a cold-rolled steel sheet having, in mass percent, the chemical composition:
C in a content of 0.1% to 0.3%;
Si in a content of 1.0% to 3.0%;
Mn in a content of 0.5% to 3.0%;
P in a content of 0.1% or less;
S in a content of 0.03% or less;
Al in a content of 0.01% to 1.0%;
N in a content of 0.01% or less; and
iron and inevitable impurities,
to a temperature range (T**1**) of Ac_3 to 960° C.;
cooling the cold-rolled steel sheet from the temperature range (T**1**) down to 500° C. at an average cooling rate (CR**1**) of 5° C./s or more;
further cooling the cold-rolled steel sheet from 500° C. down to a temperature range (T**2**) of (Ms-200°)° C. to 420° C. at an average cooling rate (CR**2**) of 10° C./s or more;
holding the cold-rolled steel sheet in the temperature range (T**2**) for a time period (t**2**) of 10 to 70 seconds; and
immersing the cold-rolled steel sheet in a zinc bath.

20. A method for manufacturing the hot-dip galvannealed steel sheet of claim **17**, the method comprising, in an order as follows:
heating a cold-rolled steel sheet having, in mass percent, the chemical composition:
C in a content of 0.1% to 0.3%;
Si in a content of 1.0% to 3.0%;

Mn in a content of 0.5% to 3.0%;
P in a content of 0.1% or less;
S in a content of 0.03% or less;
Al in a content of 0.01% to 1.0%;
N in a content of 0.01% or less; and
iron and inevitable impurities,

to a temperature range (T**1**) of Ac_3 to 960° C.;

cooling the cold-rolled steel sheet from the temperature range (T**1**) down to 500° C. at an average cooling rate (CR**1**) of 5° C./s or more;

further cooling the cold-rolled steel sheet from 500° C. down to a temperature range (T**2**) of (Ms-200°)° C. to 420° C. at an average cooling rate (CR**2**) of 10° C./s or more;

holding the cold-rolled steel sheet in the temperature range (T**2**) for a time period (t**2**) of 10 to 70 seconds;

immersing the cold-rolled steel sheet in a zinc bath; and

subjecting the cold-rolled steel sheet to an alloying treatment at an alloying treatment temperature (T**3**) of 450° C. to 560° C.

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