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(54) **STEEL SHEET**

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(57) **ABSTRACT**

Provided is a steel sheet having a chemical composition comprising C: 0.020 to 0.100%, Mn: 1.00 to 2.50%, P: 0.100% or less, S: 0.0200% or less, Al: 0.005 to 0.700%, N: 0.0150% or less, O: 0.0100% or less, etc., and a balance of Fe and impurities, and a microstructure comprising, by area %, ferrite: 70 to 97% and a hard phase: 3 to 30%, wherein an Str of the surface is 0.35 to 0.75, and a difference ΔStr of the Str and the Str after imparting 5% tensile strain is 0.15 or less.

STEEL SHEET

FIELD

[0001] The present invention relates to a steel sheet.

BACKGROUND

[0002] In the auto industry, lighter weight of vehicle bodies is being sought from the viewpoint of improvement of fuel economy. To achieve both lighter weight of vehicle bodies and collision safety, increasing the strength of the steel sheet used would be one effective method.

[0003] Development of a high strength steel sheet is underway from such a background.

[0004] In relation to this, PTL 1 describes a high strength hot dip galvanized steel sheet comprised of a base sheet of steel sheet having a hot dip galvanized plating layer on its surface, wherein the base sheet contains, by mass %, C: 0.02 to 0.20%, Si: 0.7% or less, Mn: 1.5 to 3.5%, P: 0.10% or less, S: 0.01% or less, Al: 0.1 to 1.0%, N: 0.010% or less, and Cr: 0.03 to 0.5%, wherein an annealing surface oxidation index A, defined by the numerical formula: A=400 Al/(4 Cr+3 Si+6 Mn) having the contents of Al, Cr, Si, and Mn as terms, is 2.3 or more, and a balance of Fe and unavoidable impurities, and, further, a microstructure of the base sheet comprised of ferrite and a second phase, wherein the second phase is mainly comprised of martensite. Further, PTL 1 describes that the high strength hot dip galvanized steel sheet has an excellent surface quality and a tensile strength of 590 MPa or more suitable for application as mainly structural members, rocker panels, and other structural parts of automobiles.

CITATIONS LIST

Patent Literature

[0005] [PTL 1] Japanese Unexamined Patent Publication No. 2005-220430

SUMMARY

Technical Problem

[0006] In recent years, in response to demands for further improvement of fuel economy, the need for lighter weight has been rising not only in the structural members and other structural parts described in PTL 1, but also roofs, hoods, fenders, doors, and other outer panels. These outer panels differ from such structural parts. They are visible to the human eye, therefore not only strength and other properties, but also design freedom and surface quality are important. Therefore, excellent appearance after forming is sought. On the other hand, in response to such demands for lighter weight, even further higher strength and thinness are being sought in a steel sheet used for such outer panels. In addition, along with the increasing complexity of shapes in these outer panels, irregularities tend to easily form on the surface of the steel sheet after forming. If such irregularities form, there is the problem that the appearance deteriorates.

[0007] More specifically, for example, in the case of DP steel (dual phase steel) comprised of soft ferrite and a hard second phase mainly comprised of martensite such as described in PTL 1, at the time of press-forming and other working, uneven shaping where the soft phase comprised of ferrite and its surroundings are preferentially changed in shape easily occurs. For this reason, if utilizing such dual phase steel comprised of a soft phase and hard phase, fine irregularities form on the surface of the steel sheet after forming, whereby defects in appearance called "ghost lines" sometimes appear.

[0008] Therefore, the present invention has as its object the provision of a high strength steel sheet having an improved appearance after forming by a novel constitution.

Solution to Problem

[0009] The inventors conducted studies focusing on in particular the surface properties of a steel sheet so as to achieve the above object. As a result, the inventors discovered that in a steel sheet made of DP steel comprised of a composite structure of a soft phase made of ferrite and a hard phase mainly made of martensite, the aspect ratio of the surface properties (Str) has a great effect on the formation of ghost lines and, in relation to this, by controlling the initial Str to within a specific range while keeping the fluctuations in the Str when imparting tensile strain to within a predetermined range, it is possible to maintain the high strength due to the hard phase mainly made of martensite while remarkably inhibiting the formation of ghost lines at the steel sheet surface even at the time of press-forming or other forming and thereby completed the present invention.

[0010] The present invention able to achieve the above object is as follows:

[0011] (1) A steel sheet having a chemical composition comprising, by mass %,

[0012] C: 0.020 to 0.100%,
[0013] Mn: 1.00 to 2.50%,
[0014] P: 0.100% or less,
[0015] S: 0.0200% or less,
[0016] Al: 0.005 to 0.700%,
[0017] N: 0.0150% or less,
[0018] O: 0.0100% or less,
[0019] Si: 0 to 1.500%,
[0020] Cr: 0 to 0.80%,
[0021] Mo: 0 to 0.50%,
[0022] B: 0 to 0.0100%,
[0023] Ti: 0 to 0.100%,
[0024] Nb: 0 to 0.060%,
[0025] V: 0 to 0.50%,
[0026] Ni: 0 to 1.00%,
[0027] Cu: 0 to 1.00%,
[0028] W: 0 to 1.00%,
[0029] Sn: 0 to 1.00%,
[0030] Sb: 0 to 0.200%,
[0031] Ca: 0 to 0.0100%,
[0032] Mg: 0 to 0.0100%,
[0033] Zr: 0 to 0.0100%,
[0034] REM: 0 to 0.0100%, and
[0035] balance: Fe and impurities, and
[0036] a microstructure comprising, by area %,
[0037] ferrite: 70 to 97%, and
[0038] a hard phase: 3 to 30%, wherein
[0039] an Str of the surface is 0.35 to 0.75, and
[0040] a difference ΔStr of the Str and the Str after imparting a 5% tensile strain is 0.15 or less.

[0041] (2) The steel sheet according to (1), wherein the chemical composition contains, by mass %, one or more selected from the group consisting of

[0042] Si: 0.005 to 1.500%,
[0043] Cr: 0.001 to 0.80%,

[0044] Mo: 0.001 to 0.50%,
[0045] B: 0.0001 to 0.0100%,
[0046] Ti: 0.001 to 0.100%,
[0047] Nb: 0.001 to 0.060%,
[0048] V: 0.001 to 0.50%,
[0049] Ni: 0.001 to 1.00%,
[0050] Cu: 0.001 to 1.00%,
[0051] W: 0.001 to 1.00%,
[0052] Sn: 0.001 to 1.00%,
[0053] Sb: 0.001 to 0.200%,
[0054] Ca: 0.0001 to 0.0100%,
[0055] Mg: 0.0001 to 0.0100%,
[0056] Zr: 0.0001 to 0.0100%, and
[0057] REM: 0.0001 to 0.0100%.
[0058] (3) The steel sheet according to (1) or (2), wherein the hard phase is comprised of at least one of martensite, bainite, tempered martensite, and pearlite.

Advantageous Effects of Invention

[0059] According to the present invention, it is possible to provide a high strength steel sheet having an improved appearance after forming in addition to excellent appearance before forming.

EMBODIMENTS OF INVENTION

<Steel Sheet>

[0060] The steel sheet according to an embodiment of the present invention has
[0061] a chemical composition comprising, by mass %,
[0062] C: 0.020 to 0.100%,
[0063] Mn: 1.00 to 2.50%,
[0064] P: 0.100% or less,
[0065] S: 0.0200% or less,
[0066] Al: 0.005 to 0.700%,
[0067] N: 0.0150% or less,
[0068] O: 0.0100% or less,
[0069] Si: 0 to 1.500%,
[0070] Cr: 0 to 0.80%,
[0071] Mo: 0 to 0.50%,
[0072] B: 0 to 0.0100%,
[0073] Ti: 0 to 0.100%,
[0074] Nb: 0 to 0.060%,
[0075] V: 0 to 0.50%,
[0076] Ni: 0 to 1.00%,
[0077] Cu: 0 to 1.00%,
[0078] W: 0 to 1.00%,
[0079] Sn: 0 to 1.00%,
[0080] Sb: 0 to 0.200%,
[0081] Ca: 0 to 0.0100%,
[0082] Mg: 0 to 0.0100%,
[0083] Zr: 0 to 0.0100%,
[0084] REM: 0 to 0.0100%, and
[0085] balance: Fe and impurities, and
[0086] a microstructure comprising, by area %,
[0087] ferrite: 70 to 97%, and
[0088] hard phase: 3 to 30%, wherein
[0089] an Str of the surface is 0.35 to 0.75, and
[0090] a difference ΔStr of the Str and the Str after imparting a 5% tensile strain is 0.15 or less.

[0091] In a roof or door or other outer panel, from the viewpoint of avoiding surface defects called "surface strain" occurring at the time of press-forming, etc., in many cases use is made of DP steel which has a relatively low yield strength. However, as explained previously, in the case of DP steel, which is made of a mixture of a soft phase comprised of ferrite and a hard phase mainly comprised of martensite, etc., uneven changes in shape where the soft phase and its surroundings change in shape preferentially easily occur at the time of press-forming or other working and fine irregularities are formed at the surface of the steel sheet after forming, whereby sometimes defects in appearance called "ghost lines" are formed. Explained in more detail, at the time of press-forming and other working, the shape is changed so that the soft phase comprised of ferrite becomes pushed down, while the hard phase mainly comprised of martensite, etc., does not become pushed down or rather is built up so as to project out, whereby ghost lines are formed in band shapes (striations). To deal with this, in the prior art, for example, attempts have been made to reduce the defects in appearance after forming from the viewpoint of making the internal structure of the steel sheet including the soft phase and hard phase a more suitable one. On the other hand, ghost lines are defects in appearance, therefore the surface properties of steel sheet may also conceivably greatly contribute to the formation of ghost lines. Therefore, the inventors next conducted studies particularly focusing on the surface properties of steel sheet rather than the internal structure of steel sheet. As a result, the inventors discovered that in steel sheet comprised of DP steel comprised of a composite structure of a soft phase made of ferrite and a hard phase mainly made of martensite, the aspect ratio of the surface properties (Str) greatly affects the formation of ghost lines.

[0092] The aspect ratio Str of the texture in the surface properties (texture aspect ratio) is one of the spatial parameters of the surface properties defined in JIS B0681-2:2018 and shows the strength of the anisotropy of the surface. It is known to take a value in the range of 0 to 1. In general, if the value of the Str approaches 0, the anisotropy becomes stronger and striations, etc., are formed at the surface. On the other hand, if the value of the Str approaches 1, the surface becomes isotropic without regard as to the direction. The inventors, as a result of their studies, discovered that controlling the initial Str of the surface of the steel sheet (i.e., before forming by press-forming, etc.) (if there is a plating layer present on the surface of the steel sheet, the surface of the plating layer) to within 0.35 to 0.75 in range is extremely effective in suppressing the formation of ghost lines at the steel sheet surface if strain is imparted due to press-forming or other forming. Ghost lines are related to striated patterns of the steel sheet surface, therefore from the viewpoint of suppressing the formation of these ghost lines, the value of the Str is preferably more isotropic. Therefore, it is generally expected that it is preferably closer to 1. For example, if the Str is a lower value, i.e., if the Str is closer to 0 (zero), therefore the anisotropy of the surface is stronger and striation of the steel sheet surface becomes more noticeable, only naturally, the appearance after forming by press-forming, etc., deteriorates. Therefore, to improve the appearance after forming, the value of the Str is preferably not too low. It is preferably a value of a specific value or more. From such a viewpoint, the inventors discovered that the initial Str of the steel sheet surface has to be 0.35 or more. On the other hand, according to the results of experiments by the inventors, if the Str becomes closer to 1, ghost lines remarkably form after press-forming and therefore, it was learned the appearance after forming deteriorated. Therefore, from the viewpoint of suppressing the formation of ghost lines, the initial Str has to be controlled to a suitable range. Specifically, it has to be controlled to within 0.35 to 0.75 in range. By controlling the initial Str to within such a suitable range, it is possible to maintain the appearances of both before forming and after forming at excellent states.

[0093] While not intending to be bound to any specific theory, for example if the value of the Str is closer to 1, in relative relationship with the first more isotropic surface properties, the presence of fine irregularities formed on the steel sheet surface after forming overly stands out and, it is believed, the appearance deteriorates. On the other hand, if the Str is a suitable value, i.e., if striations of an extent not noticeable to the naked eye, etc., are present, the fine irregularities formed at the steel sheet surface after forming due to the effects of the striations present from the start become unnoticeable or the fine irregularities formed at the steel sheet surface after forming cancel each other out, etc., and as a result, it is believed, formation of ghost lines is suppressed or reduced. Whatever the case, it is generally expected that to suppress the formation of ghost lines, the value of the Str is preferably closer to 1, therefore the fact that, contrary to such a general expectation, by controlling the initial Str to 0.35 to 0.75 in range, the formation of ghost lines after forming is suppressed or reduced is extremely unexpected and should be surprising.

[0094] While explained in detail later in relation to the method of production of the steel sheet, the inventors discovered that to control the initial Str to within the desired range, it is effective to make the decarburization of the steel sheet surface at the annealing step a suitable one and to realize such suitable decarburization, it is preferable to reduce as much as possible the internal oxides of Si, Mn, etc., formed on the surface layer of the steel sheet at the time of the hot rolling step. More specifically, the inventors discovered that by suppressing the upper limit values of the Si and Mn contents in the steel sheet to respectively 1.500% and 2.50% or less while controlling in particular the coiling temperature in the hot rolling step and the atmosphere, temperature, and time of the annealing step to within predetermined ranges, it is possible to sufficiently suppress or reduce the formation of internal oxides in the hot rolling step and, in relation to this, possible to realize suitable decarburization treatment in the annealing step and in turn realize the desired initial Str at the steel sheet surface.

[0095] The inventors, by further studies, discovered that just controlling the initial Str of the steel sheet surface to 0.35 to 0.75 in range is not necessarily sufficient from the viewpoint of suppressing or reducing the formation of ghost lines and that in addition to control of the initial Str, suppressing fluctuations of the Str when imparting tensile strain, i.e., keeping the difference ΔStr between the initial Str and the Str after imparting 5% tensile strain, to within a predetermined range is important. More specifically, the inventors discovered that in addition to controlling the initial Str to within 0.35 to 0.75 in range, controlling the ΔStr obtained by subtracting the Str after imparting 5% tensile strain from that initial Str (i.e., ΔStr-initial Str-Str after imparting 5% tensile strain) to 0.15 or less is important.

[0096] While not intending to be bound to any specific theory, in addition to the value of the initial Str, the ΔStr is believed to be closely related to segregation of Mn in the steel. It is believed that it is possible to make the value of the ΔStr smaller by reducing segregation of Mn in the steel in addition to controlling the initial Str to within 0.35 to 0.75 in range. Ghost lines are believed to become more remarkable in extent due to the presence of the hard phase connected in striations in the microstructure. On the other hand, to suppress the formation of such a banded hard phase, it is believed effective to reduce the segregation of Mn in the steel. Mn segregation is affected by the various alloying elements contained in the steel sheet. In particular, if the C and Mn contents in the steel sheet become high, that degree becomes particularly remarkable. This is due to the fact that if the C and Mn contents become high, the diffusion speed of Mn at the time of solidification at the slab casting falls. Therefore, by controlling the initial Str of the steel sheet surface to within 0.35 to 0.75 in range while making the chemical composition of the steel sheet related to segregation of Mn a suitable one, in particular by making the C and Mn contents in the steel sheet suitable ones, it is possible to keep the ΔStr within the desired range, i.e., to 0.15 or less. Conversely speaking, if the ΔStr is controlled to 0.15 or less, it is believed that segregation of Mn in the steel is sufficiently suppressed or reduced. In relation to this, in the microstructure of the steel sheet, formation of a banded hard phase is sufficiently suppressed, therefore even at the time of press-forming or other work, formation of ghost lines at the steel sheet surface can be remarkably suppressed or reduced.

[0097] Therefore, according to the steel sheet according to the embodiment of the present invention, by sufficiently maintaining the high strength due to the hard phase contained in the steel sheet while controlling the initial Str to 0.35 to 0.75 in range and additionally keeping the ΔStr when imparting 5% tensile strain to 0.15 or less, it is possible to maintain a good appearance before forming of course and, even when strain is imparted by press-forming or other forming, remarkably suppress the formation of ghost lines and other defects in appearance at the steel sheet surface. For this reason, according to the embodiment of the present invention, it is possible to provide a high strength steel sheet having excellent appearance before forming and also improved appearance after forming.

[0098] Below, the steel sheet according to an embodiment of the present invention will be explained in more detail. In the following explanation, the units "%" of contents of the elements mean "mass %" unless otherwise indicated. Further, in this Description, the "to" showing a numerical range, unless otherwise indicated, is used in the sense including the numerical values before and after it as the lower limit value and upper limit value.

[C: 0.020 to 0.100%]

[0099] C is an element increasing the strength of a steel sheet. To sufficiently obtain such an effect, the C content is 0.020% or more. The C content may also be 0.025% or more, 0.030% or more, 0.035% or more, 0.040% or more, or 0.050% or more. On the other hand, if excessively including C, sometimes the diffusion of Mn at the time of solidification is inhibited, the segregation of Mn cannot be sufficiently suppressed, and the ΔStr cannot be controlled to within the desired range. Therefore, the C content is 0.100% or less. The C content may also be 0.095% or less, 0.090% or less, 0.085% or less, 0.080% or less, or 0.070% or less.

[Mn: 1.00 to 2.50%]

[0100] Mn is an element raising the hardenability of steel to contribute to improvement of the strength. To sufficiently obtain such an effect, the Mn content is 1.00% or more. The Mn content may also be 1.20% or more, 1.30% or more, 1.40% or more, or 1.50% or more. On the other hand, if excessively including Mn, the diffusion of Mn at the time of solidification is inhibited, segregation of Mn cannot be sufficiently suppressed, and sometimes the ΔStr cannot be controlled to within the desired range. In addition, if excessively including Mn, internal oxides are excessively formed at the time of hot rolling and therefore it is not possible to suitably control the decarburization of the steel sheet surface layer at the time of the later annealing step and sometimes the initial Str cannot be controlled to within the desired range. Therefore, the Mn content is 2.50% or less. The Mn content may also be 2.25% or less, 2.10% or less, 2.00% or less, 1.85% or less, or 1.75% or less.

[P: 0.100% or Less]

[0101] P is an element entering in the production process. The P content may also be 0%. However, reduction of the P content to less than 0.0001% requires time for refining and a drop in productivity is invited. Therefore, the P content may also be 0.0001% or more, 0.0005% or more, 0.001% or more, or 0.005% or more. On the other hand, if excessively including P, sometimes the toughness of the steel sheet falls. Therefore, the P content is 0.100% or less. The P content may also be 0.070% or less, 0.060% or less, 0.040% or less, or 0.020% or less.

[S: 0.0200% or Less]

[0102] S is an element entering in the production process. The S content may also be 0%. However, reduction of the S content to less than 0.0001% requires time for refining and a drop in productivity is invited. Therefore, the S content may also be 0.0001% or more, 0.0005% or more, or 0.0010% or more. On the other hand, if excessively including S, Mn sulfides are formed and the steel sheet is sometimes made to decline in ductility, hole expandability, stretch flangeability, and/or bendability or other formability. Therefore, the S content is 0.0200% or less. The S content may also be 0.0100% or less, 0.0060% or less, or 0.0040% or less.

[Al: 0.005 to 0.700%]

[0103] Al is an element functioning as a deoxidizer and an element effective for raising the strength of steel. Further, Al is an element effective for promoting the diffusion of Mn at the time of solidification to reduce the segregation of Mn. To obtain these effects, the Al content is 0.005% or more. The Al content may also be 0.010% or more, 0.020% or more, or 0.025% or more. On the other hand, if excessively including Al, sometimes the castability deteriorates and the productivity falls. Therefore, the Al content is 0.700% or less. The Al content may also be 0.600% or less, 0.400% or less, 0.300% or less, 0.150% or less, 0.100% or less, or 0.070% or less.

[N: 0.0150% or Less]

[0104] N is an element entering in the production process. The N content may also be 0%. However, reduction of the N content to less than 0.0001% requires time for refining and a drop in productivity is invited. Therefore, the N content may also be 0.0001% or more, 0.0005% or more, or 0.0010% or more. On the other hand, if excessively including N, nitrides are formed and sometimes the steel sheet falls in ductility, hole expandability, stretch flangeability, and/or bendability and other formability. Therefore, the N content is 0.0150% or less. The N content may also be 0.0100% or less, 0.0080% or less, or 0.0050% or less.

[O: 0.0100% or Less]

[0105] O is an element entering in the production process. The O content may also be 0%. However, reduction of the O content to less than 0.0001% requires time for refining and a drop in productivity is invited. Therefore, the O content may also be 0.0001% or more, 0.0005% or more, or 0.0010% or more. On the other hand, if excessively including O, coarse oxides are formed and sometimes the steel sheet falls in ductility, hole expandability, stretch flangeability, and/or bendability and other formability. Therefore, the O content is 0.0100% or less. The O content may also be 0.0070% or less, 0.0040% or less, 0.0030% or less, or 0.0020% or less.

[0106] The basic chemical composition of the steel sheet according to this embodiment of the present invention is as explained above. Furthermore, the steel sheet may, according to need, contain one or more of the following optional elements in place of part of the Fe of the balance. Below, these optional elements will be explained in detail. The lower limits of the contents of these optional elements are all 0%.

[Si: 0 to 1.500%]

[0107] Si is a deoxidizing element of steel and an element effective for raising the strength without detracting from the ductility of the steel sheet. Further, Si is an element effective for promoting the diffusion of Mn at the time of solidification to reduce the segregation of Mn. The Si content may be 0%, but to sufficiently obtain these effects, the Si content is preferably 0.001% or more or 0.005% or more. The Si content may also be 0.010% or more, 0.050% or more, 0.100% or more, or 0.150% or more. On the other hand, if excessively including Si, internal oxides excessively form at the time of hot rolling therefore the decarburization treatment of the steel sheet surface layer at the time of the subsequent annealing step cannot be suitably controlled and sometimes the initial Str cannot be controlled to inside the desired range. Therefore, the Si content is 1.500% or less. The Si content may also be 1.400% or less, 1.200% or less, 1.000% or less, 0.800% or less, 0.600% or less, 0.500% or less, or 0.300% or less.

[Cr: 0 to 0.80%]

[0108] Cr is an element raising the hardenability of steel and contributing to improvement of the strength of steel sheet. Further, Cr is an element effective for promoting the diffusion of Mn at the time of solidification to reduce the segregation of Mn. The Cr content may also be 0%, but to sufficiently obtain these effects, the Cr content is preferably 0.001% or more. The Cr content may also be 0.01% or more, 0.10% or more, 0.20% or more, or 0.30% or more. On the other hand, if excessively including Cr, sometimes coarse Cr carbides becoming starting points of fracture are formed. Therefore, the Cr content is preferably 0.80% or less. The Cr content may also be 0.70% or less, 0.60% or less, or 0.50% or less.

[Mo: 0 to 0.50%]

[0109] Mo is an element suppressing phase transformation at a high temperature and contributing to improvement of the strength of steel sheet. Further, Mo is an element effective for promoting the diffusion of Mn at the time of solidification to reduce the microsegregation of Mn. The Mo content may also be 0%, but to sufficiently obtain these effects, the Mo content is preferably 0.001% or more. The Mo content may also be 0.01% or more, 0.05% or more, or 0.07% or more. On the other hand, if excessively including Mo, sometimes the hot workability falls and the productivity falls. Therefore, the Mo content is preferably 0.50% or less. The Mo content may also be 0.40% or less, 0.30% or less, or 0.20% or less.

[B: 0 to 0.0100%]

[0110] B is an element suppressing phase transformation at a high temperature and contributing to improvement of the strength of steel sheet. The B content may also be 0%, but to sufficiently obtain these effects, the B content is preferably 0.0001% or more. The B content may also be 0.0005% or more, 0.0010% or more, or 0.0015% or more. On the other hand, if excessively including B, sometimes B precipitates are formed and the strength of the steel sheet falls.

[0111] Therefore, the B content is preferably 0.0100% or less. The B content may also be 0.0080% or less, 0.0060% or less, or 0.0030% or less.

[Ti: 0 to 0.100%]

[0112] Ti is an element having the effect of reducing the amounts of S, N, and O causing the formation of coarse inclusions acting as starting points of fracture. Further, Ti has the effect of making the microstructure finer and improving the strength-formability balance of steel sheet. The Ti content may also be 0%, but to obtain these effects, the Ti content is preferably 0.001% or more. The Ti content may also be 0.005% or more, 0.007% or more, or 0.010% or more. On the other hand, if excessively including Ti, sometimes coarse Ti sulfides, Ti nitrides, and/or Ti oxides are formed and the steel sheet falls in formability. Therefore, the Ti content is preferably 0.100% or less. The Ti content may also be 0.080% or less, 0.070% or less, 0.060% or less, or 0.030% or less.

[Nb: 0 to 0.060%]

[0113] Nb is an element contributing to improvement of strength of steel sheet due to strengthening by precipitates, grain refinement strengthening by suppression of growth of ferrite crystal grains, and/or dislocation strengthening by suppression of recrystallization. The Nb content may also be 0%, but to obtain these effects, the Nb content is preferably 0.001% or more. The Nb content may also be 0.005% or more, 0.007% or more, or 0.010% or more. On the other hand, if excessively including Nb, sometimes the nonrecrystallized ferrite increases and the steel sheet falls in formability. Therefore, the Nb content is preferably 0.060% or less. The Nb content may also be 0.050% or less, 0.040% or less, or 0.030% or less.

[V: 0 to 0.50%]

[0114] V is an element contributing to improvement of strength of steel sheet due to strengthening by precipitates, grain refinement strengthening by suppression of growth of ferrite crystal grains, and/or dislocation strengthening by suppression of recrystallization. The V content may also be 0%, but to obtain these effects, the V content is preferably 0.001% or more. The V content may also be 0.005% or more, 0.01% or more, or 0.02% or more. On the other hand, if excessively including V, sometimes carbonitrides precipitate in large amounts and the steel sheet falls in formability. Therefore, the V content is preferably 0.50% or less. The V content may also be 0.40% or less, 0.20% or less, or 0.10% or less.

[Ni: 0 to 1.00%]

[0115] Ni is an element suppressing phase transformation at a high temperature and contributing to improvement of the strength of steel sheet. The Ni content may also be 0%, but to sufficiently obtain these effects, the Ni content is preferably 0.001% or more. The Ni content may also be 0.01% or more, 0.03% or more, or 0.05% or more. On the other hand, if excessively including Ni, sometimes the steel sheet falls in weldability. Therefore, the Ni content is preferably 1.00% or less. The Ni content may also be 0.60% or less, 0.40% or less, or 0.20% or less.

[Cu: 0 to 1.00%]

[0116] Cu is an element present in steel in the form of fine grains and contributing to improvement of strength of steel sheet. The Cu content may also be 0%, but to sufficiently obtain these effects, the Cu content is preferably 0.001% or more. The Cu content may also be 0.01% or more, 0.03% or more, or 0.05% or more. On the other hand, if excessively including Cu, sometimes the steel sheet falls in weldability. Therefore, the Cu content is preferably 1.00% or less. The Cu content may also be 0.60% or less, 0.40% or less, or 0.20% or less.

[W: 0 to 1.00%]

[0117] W is an element suppressing phase transformation at a high temperature and contributing to improvement of the strength of steel sheet. The W content may also be 0%, but to sufficiently obtain these effects, the W content is preferably 0.001% or more. The W content may also be 0.01% or more, 0.02% or more, or 0.10% or more. On the other hand, if excessively including W, sometimes the hot workability falls and the productivity falls. Therefore, the W content is preferably 1.00% or less. The W content may also be 0.80% or less, 0.50% or less, 0.20% or less, or 0.15% or less.

[Sn: 0 to 1.00%]

[0118] Sn is an element suppressing coarsening of crystal grains and contributing to improvement of the strength of steel sheet. The Sn content may also be 0%, but to sufficiently obtain these effects, the Sn content is preferably 0.001% or more. The Sn content may also be 0.01% or more, 0.05% or more, or 0.08% or more. On the other hand, if excessively including Sn, sometimes embrittlement of the steel sheet is triggered. Therefore, the Sn content is preferably 1.00% or less. The Sn content may also be 0.80% or less, 0.50% or less, 0.20% or less, or 0.15% or less.

[Sb: 0 to 0.200%]

[0119] Sb is an element suppressing coarsening of crystal grains and contributing to improvement of the strength of steel sheet. The Sb content may also be 0%, but to sufficiently obtain these effects, the Sb content is preferably 0.001% or more. The Sb content may also be 0.003% or more, 0.005% or more, or 0.010% or more. On the other hand, if excessively including Sb, sometimes embrittlement of the steel sheet is triggered. Therefore, the Sb content is preferably 0.200% or less. The Sb content may also be 0.150% or less, 0.100% or less, 0.050% or less, or 0.020% or less.

[Ca: 0 to 0.0100%]

[Mg: 0 to 0.0100%]

[Zr: 0 to 0.0100%]

[REM: 0 to 0.0100%]

[0120] Ca, Mg, Zr, and REM are elements contributing to improvement of the formability of steel sheet. The Ca, Mg, Zr, and REM contents may also be 0%, but to sufficiently obtain these effects, the Ca, Mg, Zr, and REM contents are preferably respectively 0.0001% or more and may be 0.0005% or more, 0.0010% or more, or 0.0015% or more. On the other hand, if excessively including these elements, sometimes the steel sheet falls in ductility. Therefore, the Ca, Mg, Zr and REM contents are preferably respectively 0.0100% or less and may be 0.0080% or less, 0.0060% or less, 0.0030% or less, or 0.0020% or less. The "REM" in this Description is the general name for the 17 elements of the atomic number 21 scandium (Sc), atomic number 39 yttrium (Y), and the lanthanoids atomic number 57 lanthanum (La) to atomic number 71 lutetium (Lu). The REM content is the total content of these elements.

[0121] In the steel sheet according to an embodiment of the present invention, the balance other than these elements consists of Fe and impurities. The "impurities" are constituents, etc., entering due to various factors in the production process starting from materials such as ore and scrap, etc., when industrially producing a steel sheet. The impurities include, for example, H, Na, Cl, Co, Zn, Ga, Ge, As, Se, Y, Tc, Ru, Rh, Pd, Ag, Cd, In, Te, Cs, Ta, Re, Os, Ir, Pt, Au, Pb, Bi, and Po. The impurities may be included in a total of 0.100% or less.

[0122] The chemical composition of the steel sheet may be measured by a general analysis method. For example, the chemical composition of the steel sheet may be measured using inductively coupled plasma-atomic emission spectrometry (ICP-AES). C and S may be measured using the combustion-infrared absorption method, N may be measured using the inert gas melting-thermal conductivity method, and O may be measured by the inert gas melting-nondispersion type infrared absorption method.

[Ferrite: 70 to 97% and Hard Phase: 3 to 30%]

[0123] The microstructure of the steel sheet is comprised of, by area %, ferrite: 70 to 97% and hard phase: 3 to 30%, more specifically only ferrite: 70 to 95% and hard phase: 5 to 30%. By making the microstructure of the steel sheet such a composite structure, it is possible to maintain the strength of the steel sheet within a suitable range, more specifically achieve a tensile strength of 500 MPa or more, while improving the appearance after forming. From the viewpoint of further raising the strength of steel sheet, the area percentage of the hard phase may be 5% or more, 7% or more, 10% or more, or 12% or more. Similarly, the area percentage of the ferrite may be 95% or less, 93% or less, 90% or less, or 88% or less. On the other hand, from the viewpoint of better improving the appearance after forming, the area percentage of the hard phase may be 28% or less, 26% or less, 23% or less, 20% or less, 18% or less, 16% or less, or 14% or less. Similarly, the area percentage of the ferrite may be 72% or more, 74% or more, 77% or more, 80% or more, 82% or more, 84% or more, or 86% or more.

[0124] In the steel sheet according to an embodiment of the present invention, the "hard phase" means structures harder than ferrite. For example, it includes at least one of martensite, bainite, tempered martensite, and pearlite or is comprised of at least one of the same. In particular, it is at least one of martensite, bainite, tempered martensite, and pearlite. From the viewpoint of improving the strength of the steel sheet, the hard phase preferably is comprised of at least one of martensite, bainite, and tempered martensite or is at least one of the same, more preferably is comprised of martensite or is martensite. In an embodiment of the present invention, the microstructure of the steel sheet preferably has little retained austenite. Specifically, the retained austenite is preferably present in an area % of less than 1% or less than 0.5%, more preferably 0%.

[Identification of Microstructure and Calculation of Area Percentage]

[0125] The microstructure is identified and the area percentage is calculated as follows: First, from the W/4 position or 3W/4 position of the width W of the obtained steel sheet (i.e., the W/4 position in the width direction from either end part of the steel sheet in the width direction), a sample for examination of the microstructure (size of generally 20 mm in rolling direction×20 mm in width direction×thickness of steel sheet) is taken. Next, an optical microscope is used to examine the microstructure at sheet thickness ½ thickness from the surface and the area percentage of the hard phase from the surface of the steel sheet (in case of plating being present, the surface after removing the plating layer) to the sheet thickness ½ thickness is calculated. For preparation of the sample, the cross-section of sheet thickness in a direction perpendicular to rolling is polished as the examined surface and is etched by LePera's reagent. Next, the "microstructure" is classified from the 500 or 1000× power optical micrograph. If examining the surface by an optical microscope after LePera corrosion, for example, the different structures are observed colored-with bainite and pearlite black, martensite (including tempered martensite) white, and ferrite gray, therefore ferrite and other hard structures can be easily differentiated. In the optical micrograph, the regions other than the gray color showing ferrite are the hard phase.

[0126] In the region of the steel sheet etched by LePera's reagent from the surface to the sheet thickness ½ position in the sheet thickness direction, 10 fields are examined at a power of 500× or 1000×. The "Photoshop CS5" image analysis software made by Adobe is used for image analysis to find the area percentage of the hard phase. As the image analysis method, for example, the maximum luminance value Lm ax and the minimum luminance value L_{min} of the steel sheet are acquired from the image. Parts having pixels of a luminance of L_{max}−0.3 (L_{max}−L_{min}) to L_{max} are defined as white regions, parts having pixels of L_{min} to L_{min}+0.3 (L_{max}−L_{min}) are defined as black regions, and other parts are defined as gray regions and the area percentage of the hard phase of the regions other than the gray regions is calculated. The examined fields of the total 10 locations are analyzed in the same way as the above and the area percentages of the hard phase measured. The area percentages are averaged to calculate an average value. This average value is deemed the area percentage of the hard phase and the balance is deemed the area percentage of the ferrite. Note that, the examined area is 150 μm in the sheet thickness direction and 250 μm in the rolling direction (the examined area in this case is 150×250=37500 pm^2).

[0127] Note that when the area percentage of the retained austenite has to be measured, X-ray diffraction of the examined surface can be used to measure the area percentage of the retained austenite. Specifically, Co-Kα rays are used to find the integrated intensity of the total six peaks of the α(110), α(200), α(211), γ(111), γ(200), and γ(220) at the sheet thickness direction ¼ position and the intensity averaging method is used to calculate the volume percentage of the retained austenite. The volume percentage of the retained austenite obtained is the area percentage of the retained austenite.

[Str of Surface: 0.35 to 0.75]

[0128] In the embodiments of the present invention, the Str of the surface of the steel sheet (if there is a plating layer on the surface of the steel sheet, the surface of the plating layer) is 0.35 to 0.75.

[0129] By controlling the initial Str of the surface of the steel sheet (i.e., the as manufactured) to within such a range and keeping the later explained ΔStr to within a predetermined range, even if strain is imparted due to press-forming or other forming, it is possible to remarkably suppress or reduce the occurrence of ghost lines at the steel sheet surface. As explained previously, if the value of the Str is closer to 0 and therefore the anisotropy of the surface becomes stronger and striations become noticeable at the steel sheet surface, only naturally, the appearance after forming by press-forming, etc., deteriorates. On the other hand, even if the value of the Str is closer to 1 and therefore the surface properties become more isotropic, after forming by press-forming, etc., relative in relation to the initial more isotropic surface properties, the ghost lines become more remarkably in extent and the appearance deteriorates. Therefore, if the value of the Str is too low or too high, there is a high possibility of it acting disadvantageously from the viewpoint of suppression or reduction of the ghost lines at the steel sheet surface. Therefore, in the embodiment of the present invention, the Str of the steel sheet surface has to be controlled to within as suitable range as stated above. For example, the Str may be 0.40 or more, 0.45 or more, or 0.50 or more and/or may be 0.70 or less, 0.65 or less, or 0.60 or less.

[Difference ΔStr of Str and Str After Imparting 5% Tensile Strain: 0.15 or Less]

[0130] In the embodiment of the present invention, the difference ΔStr of the Str and the Str after imparting 5% tensile strain is 0.15 or less. Here, the "ΔStr" means the value of the initial Str minus the Str after imparting 5% tensile strain, i.e., ΔStr=initial Str-Str after imparting 5% tensile strain. By controlling the initial Str to the above range while keeping the ΔStr to 0.15 or less, it is possible to reliably suppress or reduce the formation of ghost lines at the time of press-forming or other work. As explained previously, if the ΔStr is suppressed to 0.15 or less, it is believed that the segregation of Mn in steel is sufficiently suppressed or reduced. In relation to this, the formation of the banded hard phase in the microstructure of the steel sheet is sufficiently suppressed, so even at the time of press-forming or other work, the formation of ghost lines at the steel sheet surface can be remarkably suppressed or reduced. From the viewpoint of suppressing or reducing the formation of ghost lines, the lower the ΔStr, the more preferable. For example, it may be 0.12 or less, 0.10 or less, 0.08 or less, or 0.05 or less. If imparting tensile strain, the value of the Str generally becomes smaller compared with before imparting tensile strain (sometimes does not change), therefore even if considering measurement error, etc., the ΔStr never becomes a large value to the negative side. Therefore, the lower limit is not particularly prescribed, but for example the ΔStr may be-0.03 or more, 0.00 or more, or 0.01 or more.

[Measurement of Str and ΔStr]

[0131] The Str and ΔStr are determined in the following way. First, a No. 5 tensile test piece of JIS Z2241:2011 having a direction (C direction) perpendicular to the rolling direction (L direction) as the test direction is taken from a position separated from the end faces of the steel sheet by 100 mm or more, then the surface of the steel sheet sample taken (if there is a plating layer present on the surface of the steel sheet sample, the surface of the plating layer) is analyzed by 3D image analysis using a VK-X250/150 shape analysis laser microscope made by Keyence and the initial Str is determined based on the provisions of JIS B0681-2: 2018. The region covered by the 3D image analysis is made 5 mm (C direction)×2 mm (L direction). Next, the steel sheet sample is given 5% tensile strain at a single axis, then is measured in the same way as previously to determine the Str after imparting 5% tensile strain. Finally, the Str after imparting 5% tensile strain is subtracted from the initial Str to determine the ΔStr.

[Sheet Thickness]

[0132] The steel sheet according to an embodiment of the present invention is not particularly limited, but for example has a 0.1 to 2.0 mm sheet thickness. The steel sheet having such a sheet thickness is optimal in the case of use as a material for a door, hood, or other external sheet member. The sheet thickness may also be 0.2 mm or more, 0.3 mm or more, 0.4 mm or more. Similarly, the sheet thickness may also be 1.8 mm or less, 1.5 mm or less, 1.2 mm or less, or 1.0 mm or less. For example, by making the sheet thickness 0.2 mm or more, it is possible to obtain the additional effects of increased ease of maintaining flat the shape of a shaped part and improved dimensional precision and shape precision. On the other hand, by making the sheet thickness 1.0 mm or less, the effect of lightening the weight of the member becomes remarkable. The sheet thickness of the steel sheet is measured by a micrometer.

[Plating]

[0133] The steel sheet according to an embodiment of the present invention is a cold rolled steel sheet, but may also include a plating layer at its surface for the purpose of improving the corrosion resistance, etc. The plating layer may be either a hot dip coated layer or an electroplated layer. That is, the steel sheet according to an embodiment of the present invention may be a cold rolled steel sheet having a hot dip coated layer or an electroplated layer at its surface. The hot dip coated layer includes, for example, a hot dip galvanized layer (GI), hot dip galvannealed layer (GA), hot dip aluminum coated layer, hot dip Zn—Al alloy coated layer, hot dip Zn—Al—Mg alloy coated layer, hot dip Zn—Al—Mg—Si alloy coated layer, etc. The electroplated layer includes, for example, an electrogalvanized layer (EG), electro Zn—Ni alloy plated layer, etc. Preferably, the plating layer is a hot dip galvanized layer, hot dip galvannealed layer, or electrogalvanized layer. The amount of deposition of the plating layer is not particularly limited and may be a general amount of deposition.

[Mechanical Properties]

[0134] According to the steel sheet having the above chemical composition and microstructure, it is possible to achieve a high tensile strength, specifically a tensile strength of 500 MPa or more. The tensile strength is preferably 540 MPa or more, more preferably 570 MPa or more or 600 MPa or more. The upper limit is not particularly prescribed, but for example the tensile strength may be 980 MPa or less, 850 MPa or less, 750 MPa or less, 700 MPa or less, or 650 MPa or less. By making the tensile strength 850 MPa or less, there is the advantage that it is easy to secure formability when press-forming the steel sheet. The tensile strength is measured by taking from the steel sheet a JIS Z2241:2011 No. 5 tensile test piece having a direction perpendicular to the rolling direction as the test direction and running a tensile test based on JIS Z2241:2011.

[0135] The steel sheet according to an embodiment of the present invention has a high strength, specifically a tensile strength of 500 MPa or more. Despite this, it is possible to maintain an excellent appearance even after press-forming or other forming. For this reason, the steel sheet according to an embodiment of the present invention is for example extremely useful for application as a roof, hood, fender, door, or other outer panel in automobiles where high design freedom is demanded.

<Method of Production of Steel Sheet>

[0136] Next, a preferred method of production of the steel sheet according to an embodiment of the present invention will be explained. The following explanation is intended to illustrate the characterizing method for producing the steel sheet according to an embodiment of the present invention and is not intended to limit the steel sheet to one produced by the method of production such as explained below:

[0137] The method of production of the steel sheet according to the embodiment of the present invention is characterized by comprising:

[0138] hot rolling a slab having a chemical composition explained above in relation to the steel sheet, then coiling by a temperature of less than 550° C. (hot rolling step),

[0139] cold rolling the obtained hot rolled steel sheet so that the cumulative rolling reduction is 50 to 90% (cold rolling step),

[0140] holding the obtained cold rolled steel sheet in an atmosphere of a dew point of −20 to 5° C. at a temperature region of 750° C. or more for 30 to 200 seconds (annealing step), and temper rolling the cold rolled steel sheet using rolls having an arithmetic mean roughness Ra of 1.3 μm or less by a rolling reduction of 0.6% or less (temper rolling step). Below, the steps will be explained in detail.

[Hot Rolling Step]

[0141] First, a slab having the chemical composition explained above relating to the steel sheet is supplied for hot rolling. The slab used is preferably cast by the continuous casting method from the viewpoint of productivity, but may also be produced by the ingot-making method or thin slab casting method. The slab is preferably heated to 1100° Cs or more before hot rolling. By the heating temperature being 1100° C. or more, in the hot rolling, the rolling reaction force does not become excessively large and the targeted product thickness can be easily obtained. The upper limit of the heating temperature is not particularly prescribed, but from the viewpoint of economy, the heating temperature is preferably less than 1300° C. Further, the heated slab may be optionally rough rolled before the finish rolling so as to adjust the sheet thickness, etc. Such rough rolling is only required to secure the desired sheet bar dimensions. The conditions are not particularly limited. The hot rolling is not particularly limited, but generally is performed under conditions giving an end temperature of the finish rolling of 650° C. or more. If the end temperature of the finish rolling is too low, the rolling reaction force becomes high and it is difficult to stably obtain the desired sheet thickness. The upper limit is not particularly prescribed, but generally the end temperature of the finish rolling is 950° C. or less.

[Coiling]

[0142] Next, the finish rolled steel sheet is coiled at a temperature of less than 550° C. If the coiling temperature is high, sometimes formation of internal oxides of Si, Mn, etc., is promoted at the surface layer of the hot rolled steel sheet. The internal oxides formed cannot be sufficiently removed even by subsequent pickling, therefore the subsequent cold rolling step and annealing step, in particular the annealing step, are performed in a state including a relatively large amount of internal oxides. This time, it was discovered by the inventors that to control the initial Str at the steel sheet surface to 0.35 to 0.75 in range, at the annealing step, the steel sheet surface has to be suitably and evenly decarburized. However, if performing the subsequent annealing step in the state where large amounts of internal oxides are formed in the hot rolling step, the decarburization at the annealing step cannot be made a suitable one. That is, the decarburization of the steel sheet surface layer at the annealing step is obstructed by the internal oxides and its variation becomes greater. As a result, the Str at the surface of the finally obtained steel sheet can no longer be controlled to within the desired range. As opposed to this, by making the coiling temperature less than 550° C. to reliably suppress or reduce the formation of internal oxides of Si, Mn, etc., at the surface layer of the hot rolled steel sheet, it is possible to realize suitable decarburization at the following annealing step and in turn realize the desired initial Str at the surface of the finally obtained steel sheet. In relation to this, even if just reducing the coiling temperature to less than 550° C., if the Si and/or Mn content at the steel sheet is excessively high, sometimes the internal oxidation of these elements cannot be sufficiently suppressed. In such a case, similarly the variation in decarburization of the steel sheet surface layer at the annealing step becomes greater and the Str at the surface of the finally obtained steel sheet can no longer be controlled to within the desired range. Therefore, in the present method of production, controlling the Si and Mn contents in the steel sheet to respectively 1.500% or less and 2.50% or less while controlling the coiling temperature of the hot rolling step to less than 550° C., preferably 500° C. or less, so as to sufficiently suppress or reduce the formation of internal oxides at the hot rolling step becomes extremely important in realizing suitable decarburization in the following annealing step and in turn the desired Str at the final steel sheet surface. The lower limit of the coiling temperature is not particularly prescribed, but if the coiling temperature is too low, the strength of the hot rolled steels sheet becomes excessive and sometimes the cold rollability is impaired. Therefore, the coiling temperature is preferably 450° C. or more.

[Cold Rolling Step]

[0143] The obtained hot rolled steel sheet is suitably pickled to remove the scale, then is sent on to the cold rolling step. In the cold rolling step, for example, it is preferable to cold roll the hot rolled steel sheet so that the cumulative rolling reduction is 50 to 90%. By controlling the cumulative rolling reduction to such a range, it is possible to secure the desired sheet thickness and, further, sufficiently secure uniformity of the material quality in the sheet width direction while preventing the rolling load from becoming excessive and the rolling from becoming difficult.

[Annealing Step]

[0144] In the annealing step, the obtained cold rolled steel sheet is held in an atmosphere with a dew point of −20 to 5° C. in a temperature region of 750° C. or more for 30 to 200 seconds. If the dew point is less than −20° C., the annealing temperature is less than 750° C., and/or the holding time is less than 30 seconds, the steel sheet surface layer becomes insufficiently decarburized and the Str becomes a value closer to 1 and can no longer be controlled to 0.75 or less. On the other hand, if the dew point is more than 5° C. and/or the holding time is more than 200 seconds, the decarburization of the steel sheet surface layer proceeds too much and the Str becomes a value closer to 0 and can no longer be controlled to 0.35 or more. Therefore, in the annealing step, suitably decarburizing the steel sheet surface layer at the above dew point, annealing temperature, and holding time becomes extremely important in realizing the desired initial Str.

[0145] Preferably, the dew point is −15 to 0° C. and the holding time is 50 to 150 seconds. Further, the upper limit of the annealing temperature is not particularly limited, but for example, from the viewpoint of suppressing coarsening of the crystal grains and securing sufficient strength, the annealing temperature is preferably 900° C. or less.

[Cooling Step]

[0146] After the annealing step, the cold rolled steel sheet is cooled at the next cooling step. The cooling step is not particularly limited. If need only be performed while suitably selecting any suitable conditions so that a microstructure as explained above in relation to the steel sheet and including ferrite and a hard phase in predetermined area percentages is obtained. For example, in the cooling step, the steel sheet is preferably cooled so that the average cooling speed from the annealing temperature becomes 5 to 50° C./s. By making the average cooling speed 5° C./s or more, it is possible to suppress excessive transformation to ferrite and increase the amount of formation of martensite and other types of hard phase to obtain the desired strength. Further, by making the average cooling speed 50° C./s or less, it is possible to cool the steel sheet more uniformly in the width direction.

[Plating Step]

[0147] The obtained cold rolled steel sheet may be plated on the surface in accordance with need for the purpose of improving the corrosion resistance, etc. The plating may be hot dip coating, hot dip alloyed coating, electroplating, or other treatment. For example, as the plating, the steel sheet may be hot dip galvanized or may be hot dip galvanized, then alloyed. The specific conditions of the plating and the alloying are not particularly limited and may be any suitable conditions known to persons skilled in the art. For example, the alloying temperature may also be 450 to 600° C.

[Temper Rolling Step]

[0148] Finally, the cold rolled steel sheet or plated steel sheet is temper rolled using rolls having an arithmetic mean roughness Ra of 1.3 μm or less by a rolling reduction of 0.6% or less. The arithmetic mean roughness Ra is measured based on the provisions of JIS B0601:2013. In general, temper rolling is performed on steel sheet after annealing or plating for the purpose of correcting the shape of the steel sheet, adjusting the surface roughness, etc. In this method of production, the surface properties of the finally obtained steel sheet are extremely important. Such surface properties are built in by the previous hot rolling step and annealing step in particular. For this reason, in the temper rolling step, to maintain the thus built in surface properties of the cold rolled steel sheet or plated steel sheet, the rolling has to be performed under relatively mild conditions. For example, if the arithmetic mean roughness ra of the rolls used in the temper rolling is more than 1.3 μm and/or the rolling reduction of the temper rolling is more than 0.6%, the roughness of the rolls will be strongly transferred to the steel sheet surface, the surface properties built in at the hot rolling step and annealing step in particular will be partially or completely destroyed, and as a result sometimes the initial Str will become outside the desired range. As opposed to this, rolls having an arithmetic mean roughness Ra of 1.3 μm or less can be used to temper roll the steel sheets by a rolling reduction of 0.6% or less so as to sufficiently maintain the surface properties built in by the previous steps and realize an initial Str within the desired range while suitably correcting the shapes of the steel sheets. Preferably, the arithmetic mean roughness Ra of the rolls is 1.2 μm or less and the rolling reduction of the temper rolling is 0.5% or less.

[0149] Below, examples will be used to explain the present invention in more detail, but the present invention is not limited to these examples in any way.

EXAMPLES

[0150] In the following examples, steel sheets according to the embodiments of the present invention were produced under various conditions and the obtained steel sheets were investigated for tensile strength and features of appearance after forming.

[0151] First, the continuous casting method was used to cast slabs having the chemical compositions shown in Table 1 and thicknesses of 200 to 300 mm. The balance other than the constituents shown in Table 1 is Fe and impurities. Next, the obtained slabs were subjected to a hot rolling step (heating temperature 1200° C. and finish rolling end temperature 800° C.), cold rolling step (cumulative rolling reduction 80%), annealing step, and cooling step (average cooling speed 10° C./s) to produce sheet thickness 0.4 mm cold rolled steel sheets. In the examples, cases where the condition I of the coiling temperature at the hot rolling step (less than 550° C.) and condition II of the annealing step (dew point: −20 to 5° C., annealing temperature: 750° C. or more, and holding time 30 to 200 seconds) are satisfied are indicated in Table 2 as "satisfied" and cases where they are not satisfied as "not satisfied", "A", or "B". Specifically, in examples where the condition I is satisfied, coiling is performed at a temperature of 500° C., while in examples where the condition I is not satisfied, the coiling was performed at a temperature of 650° C. Further, in examples where the condition II is satisfied, the annealing step was performed under conditions of a dew point of −5° C., an annealing temperature of 800° C., and a holding time of 150 seconds. On the other hand, in examples not satisfying the condition II, the annealing step was performed under conditions of the condition A (dew point −40° C., annealing temperature of 800° C., and holding time of 60 seconds) or the condition B (dew point of 8° C., annealing temperature of 800° C., and holding time of 280 seconds).

[0152] Next, the surface of the obtained cold rolled steel sheet was suitably plated to form a hot dip galvanized layer (GI), hot dip galvannealed layer (GA), or electrogalvanized layer (EG). Further, a sample taken from the produced cold rolled steel sheet was analyzed for chemical composition, whereupon there was no change from the chemical composition of the slab shown in Table 1. Finally, the obtained cold rolled steel sheet or plated steel sheet was temper rolled. In the examples, cases where the condition III of the temper rolling step (arithmetic mean roughness Ra of roll: −1.3 μm or less and rolling reduction: 0.6% or less) was satisfied are indicated as "satisfied" in Table 2 and cases where it was not satisfied are indicated as "not satisfied". Specifically, in examples satisfying condition III, rolls having an arithmetic mean roughness Ra of 1.2 μm were used to temper roll the steel sheets by a rolling reduction of 0.5% while in examples not satisfying condition III, rolls having an arithmetic mean roughness Ra of 1.8 μm were used to temper roll the steel sheets by a rolling reduction of 1.0%.

TABLE 1

	Chemical composition (mass %), balance: Fe and impurities												
Steel	C	Mn	P	S	Al	N	O	Si	Cr	Mo	B	Ti	Others
A	0.052	1.84	0.008	0.0018	0.031	0.0035	0.0009	0.356					
B	0.041	1.12	0.025	0.0021	0.112	0.0038	0.0013	0.089	0.35	0.26			
C	0.061	1.72	0.036	0.0026	0.295	0.0045	0.0010	0.026	0.40	0.07	0.0020	0.012	
D	0.059	1.72	0.020	0.0017	0.302	0.0035	0.0019	0.013	0.36	0.07	0.0015		Nb: 0.011, Sb: 0.005
E	0.076	1.86	0.018	0.0016	0.357	0.0039	0.0015	0.282	0.46	0.11	0.0018	0.021	
F	0.060	1.65	0.013	0.0020	0.034	0.0031	0.0009	0.115	0.28	0.07			V: 0.02, REM: 0.0017
G	0.060	1.75	0.020	0.0021	0.035	0.0044	0.0009	0.010	0.58		0.0019	0.011	W: 0.02, Cu: 0.05
H	0.047	2.01	0.054	0.0013	0.105	0.0048	0.0019						
I	0.052	1.15	0.065	0.0012	0.080	0.0036	0.0014	0.380	0.19	0.30			
J	0.072	1.80	0.022	0.0017	0.300	0.0035	0.0015	0.012	0.42	0.07			Ni: 0.05, Sn: 0.08
K	0.060	1.72	0.020	0.0028	0.054	0.0042	0.0015	0.152	0.55	0.07	0.0020	0.011	Zr: 0.0015, REM: 0.0020
L	0.060	1.70	0.015	0.0021	0.051	0.0038	0.0015	0.152	0.53	0.07			Mg: 0.0034
M	0.062	1.73	0.018	0.0024	0.057	0.0035	0.0015	0.153	0.55	0.07	0.0017	0.010	Ca: 0.0018
N	0.071	1.88	0.020	0.0014	0.296	0.0035	0.0012	0.461	0.25	0.06			
O	<u>0.110</u>	1.31	0.020	0.0028	0.034	0.0035	0.0015	0.010	0.40	0.09			
P	0.074	<u>2.61</u>	0.016	0.0026	0.033	0.0030	0.0014	0.102		0.07	0.0015	0.020	
Q	0.058	1.73	0.009	0.0019	0.054	0.0035	0.0011	<u>1.589</u>	0.35		0.0018	0.031	
R	<u>0.018</u>	1.81	0.015	0.0029	0.030	0.0033	0.0015	0.105	0.18		0.0018		
S	0.056	<u>0.85</u>	0.011	0.0032	0.028	0.0029	0.0010	0.080	0.52				
T	0.066	1.54	0.012	0.0006	0.589	0.0051	0.0016	0.124		0.39		0.061	
U	0.053	1.85	0.022	0.0015	0.034	0.0011	0.0008	0.786	0.15			0.012	V: 0.15
V	0.049	1.45	0.011	0.0028	0.678	0.0026	0.0021	0.036	0.18	0.14			Nb: 0.039
W	0.071	1.26	0.015	0.0052	0.068	0.0032	0.0013	0.210	0.36		0.0011	0.013	Cu: 0.34, Ni: 0.13

Underlines indicate outside scope of present invention.

TABLE 2

Steel sheet no.	Steel	Production conditions I	II	III	Microstructure: Ferrite area percentage (%)	Hard phase area percentage (%)	Initial Str	Str after imparting 5% tensile strain	ΔStr	Plating type	Properties: Tensile strength (MPa)	Appearance after forming	Remarks
1	A	Satisfied	Satisfied	Satisfied	91	9	0.51	0.48	0.03	GA	554	2	Inv. ex.
2	B	Satisfied	Satisfied	Satisfied	94	6	0.61	0.60	0.01	GA	508	1	Inv. ex.
3	C	Satisfied	Satisfied	Satisfied	88	12	0.62	0.58	0.04	GA	608	3	Inv. ex.
4	C	Satisfied	Satisfied	Not satisfied	89	11	0.78	0.79	−0.01	GA	604	4	Comp. ex.
5	C	Not satisfied	A	Not satisfied	89	11	0.85	0.82	0.03	GA	610	5	Comp. ex.
6	D	Satisfied	Satisfied	Satisfied	87	13	0.66	0.62	0.04	GI	621	3	Inv. ex.
7	E	Satisfied	Satisfied	Satisfied	82	18	0.54	0.48	0.06	GA	789	3	Inv. ex.
8	F	Satisfied	Satisfied	Satisfied	90	10	0.54	0.47	0.07	無	592	3	Inv. ex.
9	G	Satisfied	Satisfied	Satisfied	87	13	0.59	0.55	0.04	EG	656	3	Inv. ex.
10	H	Satisfied	Satisfied	Satisfied	92	8	0.62	0.60	0.02	GA	568	2	Inv. ex.
11	H	Not satisfied	Satisfied	Satisfied	91	9	0.88	0.82	0.06	GA	569	4	Comp. ex.
12	H	Satisfied	A	Satisfied	91	9	0.79	0.70	0.09	GA	558	4	Comp. ex.
13	H	Satisfied	B	Satisfied	92	8	0.28	0.28	0.00	GA	508	5	Comp. ex.
14	I	Satisfied	Satisfied	Satisfied	82	18	0.43	0.45	−0.02	GA	662	3	Inv. ex.
15	J	Satisfied	Satisfied	Satisfied	88	12	0.63	0.57	0.06	GA	625	3	Inv. ex.
16	K	Satisfied	Satisfied	Satisfied	89	11	0.58	0.55	0.03	GI	613	3	Inv. ex.
17	L	Satisfied	Satisfied	Satisfied	88	12	0.57	0.55	0.02	GA	609	3	Inv. ex.
18	L	Not satisfied	B	Satisfied	89	11	0.18	0.18	0.00	GA	546	5	Comp. ex.
19	M	Satisfied	Satisfied	Satisfied	75	25	0.56	0.50	0.06	GA	792	3	Inv. ex.
20	N	Satisfied	Satisfied	Satisfied	87	13	0.48	0.45	0.03	GA	643	3	Inv. ex.
21	O	Satisfied	Satisfied	Satisfied	80	20	0.61	0.37	0.24	GI	710	5	Comp. ex.
22	P	Satisfied	Satisfied	Satisfied	69	31	0.89	0.41	0.48	GA	845	5	Comp. ex.
23	Q	Satisfied	Satisfied	Satisfied	83	17	0.14	0.15	−0.01	GA	675	5	Comp. ex.
24	R	Satisfied	Satisfied	Satisfied	98	2	0.71	0.68	0.03	GA	425	1	Comp. ex.
25	S	Satisfied	Satisfied	Satisfied	93	7	0.72	0.70	0.02	GI	478	3	Comp. ex.
26	T	Satisfied	Satisfied	Satisfied	88	12	0.72	0.68	0.04	GA	648	3	Inv. ex.
27	U	Satisfied	Satisfied	Satisfied	90	10	0.68	0.68	0.00	GA	592	2	Inv. ex.
28	V	Satisfied	Satisfied	Satisfied	92	8	0.53	0.51	0.02	GI	582	1	Inv. ex.
29	W	Satisfied	Satisfied	Satisfied	89	11	0.58	0.59	−0.01	GA	610	2	Inv. ex.

Underlines indicate outside scope of present invention or not preferable properties.

[0153] The properties of the obtained steel sheets were measured and evaluated by the following methods:

[Str and ΔStr]

[0154] The Str and ΔStr were determined in the following way. First, a No. 5 tensile test piece of JIS Z2241:2011 having a direction (C direction) perpendicular to the rolling direction (L direction) as the test direction was taken from a position separated from the end faces of the steel sheet by 100 mm or more, then the surface of the steel sheet sample taken (if there is a plating layer present on the surface of the steel sheet sample, the surface of the plating layer) was analyzed by 3D image analysis using a VK-X250/150 shape analysis laser microscope made by Keyence and the initial Str was determined based on the provisions of JIS B0681-2:2018. The region covered by the 3D image analysis was made 10 mm (C direction)×2 mm (L direction). Next, the steel sheet sample was given 5% tensile strain at a single axis, then was measured in the same way as previously to determine the Str after imparting 5% tensile strain. Finally, the Str after imparting 5% tensile strain was subtracted from the initial Str to determine the ΔStr.

[Tensile Strength]

[0155] The tensile strength was measured by taking from the steel sheet a JIS Z2241:2011 No. 5 tensile test piece having a direction perpendicular to the rolling direction as the test direction and running a tensile test based on JIS Z2241:2011.

[Appearance After Forming]

[0156] The appearance after forming was evaluated by the extent of ghost lines appearing at the surface of an outer door after forming. The surface after press-forming was ground, a striated pattern of several mm order pitch formed at the surface was judged as ghost lines, and the striated pattern was evaluated as 1 to 5 by the extent of formation. Any 100 mm ×100 mm region was visually checked. A case where no striated pattern at all was confirmed was evaluated as "1", a case where a maximum length of the striated pattern was 20 mm or less was evaluated as "2", a case where a maximum length of the striated pattern was more than 20 mm and 50 mm or less was evaluated as "3", a case where a maximum length of the striated pattern was more than 50 mm and 70 mm or less was evaluated as "4", and a case where a maximum length of the striated pattern was more than 70 mm was evaluated as "5". If evaluated as "3" or less, it was judged that the door was excellent in appearance after forming and passed. On the other had, if evaluated as "4" or more, the door was evaluated as inferior in appearance after forming and failed.

[0157] If the tensile strength was 500 MPa or more and the appearance after forming was evaluated as "3" or less, the steel sheet was evaluated as high strength steel sheet having an improved appearance after forming. The results are shown in Table 2. In the microstructure shown in Table 2, the hard phase included at least one of martensite, bainite, tempered martensite, and pearlite or was at least one of these. Further, as a result of measurement of retained austenite by X-ray diffraction, the area ratio of the retained austenite was less than 1% in all of the examples.

[0158] Referring to Table 2, in Comparative Example 4, the roll roughness in the temper rolling step was great and the rolling reduction was also high, therefore the roughness of the rolls were strongly transferred to the steel sheet surface and the initial Str became more than 0.75. As a result, the appearance after forming deteriorated. In Comparative Example 5, the conditions I to III in the production conditions were not satisfied at all and the initial Str became more than 0.75. As a result, the appearance after forming deteriorated. In Comparative Example 11, the coiling temperature in the hot rolling step was high, therefore it is believed formation of internal oxides of Mn, etc., at the surface layer of the hot rolled steel sheet was promoted. As a result, the decarburization treatment in the annealing step could not be made a suitable one, the initial Str became outside the desired range, and the appearance after forming deteriorated. In Comparative Example 12, the dew point in the annealing step was low, therefore it is believed the decarburization of the steel sheet surface was insufficient, the Str became more than 0.75, and the appearance after forming deteriorated. In Comparative Example 13, the dew point in the annealing step was high and the annealing time was also long, therefore it is believed the decarburization of the steel sheet surface proceeded too much. As a result, the Str became less than 0.35 and the appearance after forming deteriorated. In Comparative Example 18, the conditions I and II in the production conditions were not satisfied and the initial Str became less than 0.35. As a result, the appearance after forming deteriorated. In each of Comparative Examples 21 and 22, the content of

[0159] C or Mn was high, diffusion of Mn at the time of solidification during slab casting was inhibited, and therefore it is believed segregation of Mn could not be sufficiently suppressed. As a result, it was not possible to keep the ΔStr to 0.15 or less and the appearance after forming deteriorated. In Comparative Example 23, the Si content was high, therefore it is believed formation of internal oxides was promoted at the surface layer of the hot rolled steel sheet in the hot rolling step. As a result, it was not possible to make the decarburization treatment in the annealing step a suitable one, the initial Str became outside the desired range, and the appearance after forming deteriorated. In each of Comparative Examples 24 and 25, the content of C or Mn was low, sufficient strength could not be obtained.

[0160] In contrast to this, in each of Invention Examples. 1 to 3, 6 to 10, 14 to 17, 19, 20, and 26 to 29, by having a predetermined chemical composition and microstructure, in particular by controlling the initial Str of the steel sheet surface and the ΔStr after imparting tensile strain respectively to 0.35 to 0.75 and 0.15 or less, it is possible to maintain the high strength of the tensile strength 500 MPa or more while remarkably suppressing formation of ghost lines at the steel sheet surface even when strain is imparted due to press-forming to thereby realize improved appearance after forming.

1. A steel sheet having a chemical composition comprising, by mass %,
C: 0.020 to 0.100%,
Mn: 1.00 to 2.50%,
P: 0.100% or less,
S: 0.0200% or less,
Al: 0.005 to 0.700%,
N: 0.0150% or less,
O: 0.0100% or less,
Si: 0 to 1.500%,
Cr: 0 to 0.80%,
Mo: 0 to 0.50%,
B: 0 to 0.0100%,
Ti: 0 to 0.100%,
Nb: 0 to 0.060%,
V: 0 to 0.50%,
Ni: 0 to 1.00%,
Cu: 0 to 1.00%,
W: 0 to 1.00%,
Sn: 0 to 1.00%,
Sb: 0 to 0.200%,
Ca: 0 to 0.0100%,
Mg: 0 to 0.0100%,
Zr: 0 to 0.0100%,
REM: 0 to 0.0100%, and
balance: Fe and impurities, and
a microstructure comprising, by area %,
ferrite: 70 to 97%, and
a hard phase: 3 to 30%, wherein
an Str of the surface is 0.35 to 0.75, and
a difference ΔStr of the Str and the Str after imparting a 5% tensile strain is 0.15 or less.

2. The steel sheet according to claim **1**, wherein the chemical composition contains, by mass %, one or more of
Si: 0.005 to 1.500%,
Cr: 0.001 to 0.80%,
Mo: 0.001 to 0.50%,
B: 0.0001 to 0.0100%,
Ti: 0.001 to 0.100%,
Nb: 0.001 to 0.060%,
V: 0.001 to 0.50%,
Ni: 0.001 to 1.00%,
Cu: 0.001 to 1.00%,
W: 0.001 to 1.00%,
Sn: 0.001 to 1.00%,
Sb: 0.001 to 0.200%,
Ca: 0.0001 to 0.0100%,
Mg: 0.0001 to 0.0100%,
Zr: 0.0001 to 0.0100%, and
REM: 0.0001 to 0.0100%.

3. The steel sheet according to claim **1**, wherein the hard phase is comprised of one or more of martensite, bainite, tempered martensite, and pearlite.

4. The steel sheet according to claim **2**, wherein the hard phase is comprised of one or more of martensite, bainite, tempered martensite, and pearlite.

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