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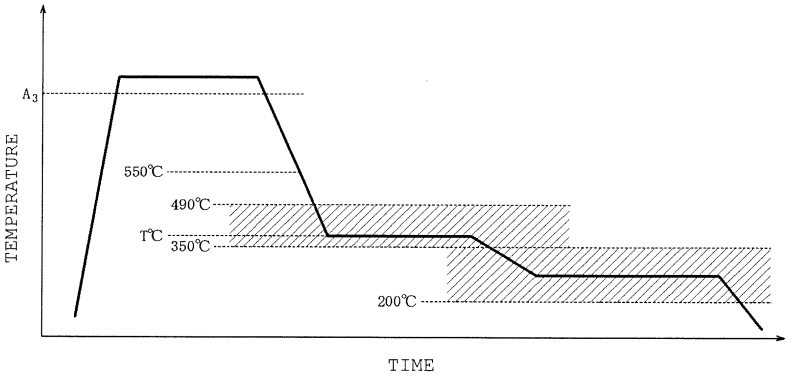
(54) HIGH-STRENGTH STEEL SHEET AND METHOD FOR PRODUCTION THEREOF

(57) A high strength steel sheet having excellent workability and a tensile strength (TS) of 980 MPa or more is provided. Regarding composition, on a percent by mass basis, C: 0.17% or more, and 0.73% or less, Si: 3.0% or less, Mn: 0.5% or more, and 3.0% or less, P: 0.1% or less, S: 0.07% or less, Al: 3.0% or less, and N: 0.010% or less are included while it is satisfied that Si + Al is 0.7% or more, and the remainder includes Fe and incidental impurities, wherein regarding the steel sheet microstructure, it is specified that the area percentage of a total amount of lower bainite and whole martensite is 10% or more, and 90% or less relative to the whole steel sheet microstructure, the amount of retained austenite is 5% or more, and 50% or less, the area percentage of bainitic ferrite in upper bainite is 5% or more relative to the whole steel sheet microstructure, as-quenched martensite is 75% or less of the total amount of lower bainite and whole martensite, the area percentage of polygonal ferrite is 10% or less (including 0%), and the average amount of C in the above-described retained austenite is 0.70% or more.

[FIG. 1]



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Description

[Technical Field]

[0001] The present invention relates to a high strength steel sheet, which is used in industrial fields of automobile, electric apparatus, and the like and which has excellent workability, especially elongation and stretch-flangeability, and a tensile strength (TS) of 980 MPa or more, and a method for manufacturing the same.

[Background Art]

[0002] In recent years, enhancement of fuel economy of the automobile has become an important issue from the viewpoint of global environmental conservation. Consequently, there is an active movement afoot to reduce the thicknesses of car components through increases in strength of car body materials, so as to reduce the weight of a car body itself.

[0003] In general, in order to increase the strength of a steel sheet, it is necessary to increase the proportion of a hard phase, e.g., martensite or bainite, relative to a whole microstructure of the steel sheet. However, the increase in strength of the steel sheet through the increase in proportion of the hard phase causes a reduction in workability. Therefore, development of a steel sheet having high strength and excellent workability in combination has been desired. Heretofore, various complex microstructure steel sheets, e.g., a ferrite-martensite double phase steel (DP steel) and a TRIP steel taking the advantage of the transformation induced plasticity of retained austenite, have been developed.

[0004] In the case where the proportion of the hard phase in the complex microstructure steel sheet increases, the workability of the steel sheet is affected by the workability of the hard phase significantly. This is because in the case where the proportion of the hard phase is small and that of soft polygonal ferrite is large, the deformability of polygonal ferrite is predominant over the workability of the steel sheet, and even in the case where the workability of the hard phase is inadequate, the workability, e.g., the elongation, is ensured, whereas in the case where the proportion of the hard phase is large, the deformability of the hard phase in itself rather than deformation of polygonal ferrite exerts an influence directly on the formability of the steel sheet and, therefore, if the workability of the hard phase in itself is inadequate, deterioration of the workability of the steel sheet becomes significant.

[0005] Consequently, as for a cold rolled steel sheet, after conducting a heat treatment to adjust the amount of polygonal ferrite generated during annealing and cooling thereafter, the steel sheet is water-quenched so as to generate martensite, the temperature is raised again, and the steel sheet is kept at high temperatures, so that martensite is tempered, carbides are generated in martensite, which is a hard phase, and thereby, the workability of martensite is improved. However, such quenching-tempering of martensite needs a specific production facility, for example, a continuous annealing facility having a water quenching function. Therefore, in the case where a common facility is used, in which after the steel sheet is water-quenched, it is not possible to raise the temperature again and keep at high temperatures, the strength of the steel sheet can be increased but the workability of martensite, which is a hard phase, cannot be improved.

[0006] Furthermore, as for a steel sheet, in which the hard phase is other than martensite, there is a steel sheet, in which a primary phase is specified to be polygonal ferrite, a hard phase is specified to be bainite and pearlite, and carbides are generated in these bainite and pearlite serving as the hard phase. This steel sheet is a steel sheet, in which the workability is improved not only by polygonal ferrite, but also by generating carbides in the hard phase so as to improve the workability of the hard phase in itself, and in particular, an improvement of the stretch-flangeability is intended. However, since the primary phase is specified to be polygonal ferrite, it is difficult to allow an increase in strength to 980 MPa or more in terms of tensile strength (TS) and the workability to become mutually compatible. In this connection, even when the workability of the hard phase in itself is improved by generating carbides in the hard phase, the level of workability is inferior to that of polygonal ferrite. Therefore, if the amount of polygonal ferrite is reduced in order to increase the strength to 980 MPa or more in terms of tensile strength (TS), adequate workability cannot be obtained.

[0007] Patent Document 1 proposes a high strength steel sheet having excellent bendability and impact characteristic, wherein alloy components are specified and the steel microstructure is specified to be fine uniform bainite including retained austenite.

[0008] Patent Document 2 proposes a complex microstructure steel sheet having excellent bake hardenability, wherein predetermined alloy components are specified, the steel microstructure is specified to be bainite including retained austenite, and the amount of retained austenite in the bainite is specified.

[0009] Patent Document 3 proposes a complex microstructure steel sheet having excellent impact resistance, wherein predetermined alloy components are specified, the steel microstructure is specified in such a way that bainite including retained austenite is 90% or more in terms of area percentage and the amount of austenite in the bainite is 1% or more, and 15% or less, and the hardness (HV) of the bainite is specified.

[Prior Art Documents]

[Patent Documents]

[0010]

[Patent Document 1] Japanese Unexamined Patent Application Publication No. 4-235253
[Patent Document 2] Japanese Unexamined Patent Application Publication No. 2004-76114
[Patent Document 3] Japanese Unexamined Patent Application Publication No. 11-256273

[Disclosure of Invention]

[Problems to be Solved by the Invention]

[0011] However, the above-described steel sheets have problems as described below.
Regarding the component composition described in Patent Document 1, it is difficult to ensure the amount of stable retained austenite, which exerts a TRIP effect in a high strain region in the case where a strain is applied to a steel sheet. Therefore, although the bendability is obtained, the elongation is low when the plasticity becomes unstable, and the punch stretchability is poor.

[0012] Regarding the steel sheet described in Patent Document 2, the bake hardenability is obtained. However, in the case where an increase in strength is intended in such a way that the tensile strength (TS) becomes 980 MPa or more, or furthermore, 1,050 MPa or more, it is difficult to ensure the strength or ensure the workability, e.g., the elongation and the stretch-flangeability, when the strength increases because the microstructure primarily contains bainite and, furthermore, ferrite while martensite is minimized.

[0013] The steel sheet described in Patent Document 3 is for the purpose of improving the impact resistance, and the microstructure contains bainite having a hardness of HV 250 or less as a primary phase, specifically at a content exceeding 90%. Therefore, it is difficult to make the tensile strength (TS) 980 MPa or more.

[0014] The present invention solves the above-described problems advantageously. Accordingly, it is an object to provide a high strength steel sheet having excellent workability, especially the elongation and the stretch-flangeability, and a tensile strength (TS) of 980 MPa or more, as well as an advantageous method for manufacturing the same.
The high strength steel sheets according to the present invention include a steel sheet, in which galvanizing or galvannealing is applied to a surface of the steel sheet.
Incidentally, in the present invention, excellent workability refers to that the value of TS $\times$ T.EL satisfies 20,000 MPa·% or more and the value of TS $\times \lambda$ satisfies 25,000 MPa·% or more. In this regard, TS represents a tensile strength (MPa), T.EL represents total elongation (%), and λ represents a hole-expansion limit (%).

[Means for Solving the Problems]

[0015] In order to solve the above-described problems, the present inventors conducted intensive research on the component composition and the microstructure of a steel sheet. As a result, it was found that the strength was increased through the use of a lower bainite microstructure and/or a martensite microstructure, stable retained austenite, which was advantageous to obtain a TRIP effect, was able to be ensured through the use of upper bainite transformation while the C content was increased in such a way that the amount of C in the steel sheet became 0.17% or more, a part of martensite was converted to tempered martensite and, thereby, a high strength steel sheet having excellent workability, especially a balance between the strength and the elongation and a balance between the strength and the stretch-flangeability in combination, and a tensile strength of 980 MPa or more was obtained.

[0016] The present invention is based on the above-described findings, and the gist and the configuration thereof are as described below.

1. A high strength steel sheet characterized by having a composition containing, on a percent by mass basis,
C: 0.17% or more, and 0.73% or less,
Si: 3.0% or less,
Mn: 0.5% or more, and 3.0% or less,
P: 0.1% or less,
S: 0.07% or less,
Al: 3.0% or less, and
N: 0.010% or less, while it is satisfied that Si + Al is 0.7% or more, and the remainder includes Fe and incidental impurities,

wherein regarding the steel sheet microstructure, it is satisfied that the area percentage of a total amount of lower bainite and whole martensite is 10% or more, and 90% or less relative to the whole steel sheet microstructure, the amount of retained austenite is 5% or more, and 50% or less, the area percentage of bainitic ferrite in upper bainite is 5% or more relative to the whole steel sheet microstructure, as-quenched martensite is 75% or less of the above-described total amount of lower bainite and whole martensite, and the area percentage of polygonal ferrite is 10% or less (including 0%) relative to the whole steel sheet microstructure, the average amount of C in the above-described retained austenite is 0.70% or more, and the tensile strength is 980 MPa or more.

[0017] 2. The high strength steel sheet according to the above-described item 1, characterized in that the above-described steel sheet further contains at least one type of element selected from, on a percent by mass basis,
Cr: 0.05% or more, and 5.0% or less,
V: 0.005% or more, and 1.0% or less, and
Mo: 0.005% or more, and 0.5% or less.

[0018] 3. The high strength steel sheet according to the above-described item 1 or item 2, characterized in that the above-described steel sheet further contains at least one type of element selected from, on a percent by mass basis,
Ti: 0.01% or more, and 0.1% or less and
Nb: 0.01% or more, and 0.1% or less.

[0019] 4. The high strength steel sheet according to any one of the above-described items 1 to 3, characterized in that the above-described steel sheet further contains, on a percent by mass basis,
B: 0.0003% or more, and 0.0050% or less.

[0020] 5. The high strength steel sheet according to any one of the above-described items 1 to 4, characterized in that the above-described steel sheet further contains at least one type of element selected from, on a percent by mass basis,
Ni: 0.05% or more, and 2.0% or less, and
Cu: 0.05% or more, and 2.0% or less.

[0021] 6. The high strength steel sheet according to any one of the above-described items 1 to 5, characterized in that the above-described steel sheet further contains at least one type of element selected from, on a percent by mass basis,
Ca: 0.001% or more, and 0.005% or less, and
REM: 0.001% or more, and 0.005% or less.

[0022] 7. A high strength steel sheet characterized by including a galvanized layer or a galvannealed layer on a surface of the steel sheet according to any one of the above-described items 1 to 6.

[0023] 8. A method for manufacturing a high strength steel sheet, characterized by including the steps of hot-rolling a billet having a component composition according to any one of the above-described items 1 to 6, conducting cold-rolling so as to produce a cold-rolled steel sheet, annealing the resulting cold-rolled steel sheet for 15 seconds or more, and 600 seconds or less in an austenite single phase region and, thereafter, conducting cooling to a cooling termination temperature: T°C determined in a first temperature range of 350°C or higher, and 490°C or lower, wherein cooling to at least 550°C is conducted while the average cooling rate is controlled at 5°C/s or more, subsequently, keeping is conducted in the first temperature range for 15 seconds or more, and 1,000 seconds or less and, then, keeping is conducted in a second temperature range of 200°C or higher, and 350°C or lower for 15 seconds or more, and 1,000 seconds or less.

[0024] 9. The method for manufacturing a high strength steel sheet according to the above-described item 8, characterized in that a galvanizing treatment or a galvannealing treatment is applied during cooling to the above-described cooling termination temperature: T°C or in the above-described first temperature range.

[Advantages]

[0025] According to the present invention, a high strength steel sheet having excellent workability, especially the elongation and the stretch-flangeability, and a tensile strength (TS) of 980 MPa or more, as well as an advantageous method for manufacturing the same can be provided. Therefore, the utility value in industrial fields of automobile, electric, and the like is very large, and in particular, the usefulness in weight reduction of an automobile body is significant.

[Brief Description of Drawing]

[0026]

[Fig. 1] Fig. 1 is a diagram showing a temperature pattern of a heat treatment in a manufacturing method according to the present invention.

[Best Modes for Carrying Out the Invention]

[0027] The present invention will be specifically described below.

Initially, the reason for limitation of the steel sheet microstructure in such a way that described above in the present invention will be described. Hereafter the area percentage refers to an area percentage relative to the whole steel sheet microstructure.

Area percentage of total amount of lower bainite and whole martensite: 10% or more, and 90% or less

[0028] The lower bainite and the martensite are microstructures necessary for increasing the strength of the steel sheet. If the area percentage of a total amount of lower bainite and whole martensite is less than 10%, the steel sheet does not satisfy the tensile strength (TS) of 980 MPa or more. On the other hand, if the total amount of lower bainite and whole martensite exceeds 90%, the upper bainite is reduced and, as a result, stable retained austenite, in which C is concentrated, cannot be ensured. Consequently, a problem occurs in that the workability, e.g., elongation, deteriorates. Therefore, the area percentage of the total amount of lower bainite and whole martensite is specified to be 10% or more, and 90% or less. A preferable range is 20% or more, and 80% or less. A more preferable range is 30% or more, and 70% or less.

Proportion of as-quenched martensite in total amount of lower bainite and whole martensite: 75% or less

[0029] If the proportion of as-quenched martensite in the martensite exceeds 75% of the total amount of lower bainite and whole martensite present in the steel sheet, the tensile strength becomes 980 MPa or more, but the stretch-flangeability is poor. The as-quenched martensite is very hard, and the deformability of the as-quenched martensite in itself is very low. Therefore, the workability, especially stretch-flangeability, of the steel sheet deteriorates significantly. Furthermore, since the difference in hardness between the as-quenched martensite and the upper bainite is significantly large, if the amount of as-quenched martensite is large, the interface between the as-quenched martensite and the upper bainite increases. Consequently, fine voids are generated at the interface between the as-quenched martensite and the upper bainite during punching or the like, and in stretch-flange forming conducted after the punching, voids are coupled to each other, so that cracking develops easily and, thereby, stretch-flangeability deteriorates. Therefore, the proportion of as-quenched martensite in the martensite is specified to be 75% or less relative to the total amount of lower bainite and whole martensite present in the steel sheet. Preferably, the proportion is 50% or less. In this regard, the as-quenched martensite is a microstructure, in which no carbide is detected in the martensite, and can be observed with SEM.

Amount of retained austenite: 5% or more, and 50% or less

[0030] The retained austenite undergoes martensitic transformation through a TRIP effect during working and, thereby, strain dispersive power is enhanced so as to improve the elongation.
Regarding the steel sheet according to the present invention, in particular, retained austenite, in which the amount of concentrated C is increased, is formed in the upper bainite through the use of upper bainite transformation. As a result, retained austenite capable of making the TRIP effect apparent even in a high strain region during working can be obtained. In the case where such retained austenite and martensite are present in combination and used, good workability is obtained even in a high strength region, in which the tensile strength (TS) is 980 MPa or more. Specifically, the value of TS $\times$ T.El can be made 20,000 MPa·% or more, and a steel sheet having an excellent balance between the strength and the elongation can be obtained.
Here, since the retained austenite in the upper bainite is formed between laths of bainitic ferrite in the upper bainite and distributes finely, large amounts of measurement at high magnification is necessary for determination of the amount (area percentage) thereof through microstructure observation, and it is difficult to quantify accurately. However, the amount of retained austenite formed between laths of the bainitic ferrite is an amount corresponding to the amount of formed bainitic ferrite to some extent. Then, the present inventors conducted research. As a result, it was found that an adequate TRIP effect was able to be obtained and the tensile strength (TS) of 980 MPa or more and TS $\times$ T. El of 20,000 MPa·% or more were able to be achieved if the area percentage of bainitic ferrite in the upper bainite was 5% or more, and the amount of retained austenite determined by an intensity measurement with X-ray diffraction (XRD), which was a previously employed technique to measure the amount of retained austenite, specifically, an X-ray diffraction intensity ratio of ferrite to austenite, was 5% or more. In this regard, it has been ascertained that the amount of retained austenite determined by the previously employed technique to measure the amount of retained austenite is equivalent to the area percentage of retained austenite relative to the whole steel sheet microstructure.
In the case where the amount of retained austenite is less than 5%, an adequate TRIP effect is not obtained. On the other hand, if the amount exceeds 50%, hard martensite generated after the TRIP effect is made apparent becomes excessive, deterioration of tenacity and the like become problems. Therefore, the amount of retained austenite is specified to be within the range of 5% or more, and 50% or less. The range is preferably more than 5%, and more preferably within the range of 10% or more, and 45% or less. The range is further preferably within the range of 15% or more, and

40% or less.

Average amount of C in retained austenite: 0.70% or more

[0031] Regarding a high strength steel sheet having a tensile strength (TS) of 980 MPa to 2.5 GPa class, in order to obtain excellent workability through the use of the TRIP effect, the amount of C in the retained austenite is important. In the steel sheet according to the present invention, C is concentrated into the retained austenite formed between laths of bainitic ferrite in the upper bainite. It is difficult to accurately evaluate the amount of C concentrated into the retained austenite between the laths. However, as a result of research of the present inventors, it was found that excellent workability was obtained in the present invention when the average amount of C in the retained austenite determined from the amount of shift of a diffraction peak in the X-ray diffraction (XRD), which was a previously employed method for measuring the average amount of C in the retained austenite (an average of the amount of C in the retained austenite), was 0.70% or more.
In the case where the average amount of C in the retained austenite is less than 0.70%, martensitic transformation occurs in a low strain region during working, so that the TRIP effect in a high strain region to improve the workability is not obtained. Therefore, the average amount of C in the retained austenite is specified to be 0.70% or more. The amount is preferably 0.90% or more. On the other hand, if the average amount of C in the retained austenite exceeds 2.00%, the retained austenite becomes excessively stable, martensitic transformation does not occur during working, and the TRIP effect is not made apparent, so that the elongation deteriorates. Therefore, it is preferable that the average amount of C in the retained austenite is specified to be 2.00% or less. more preferably, the average amount is 1.50% or less.

Area percentage of bainitic ferrite in upper bainite: 5% or more

[0032] Generation of bainitic ferrite due to upper bainite transformation is necessary for concentrating C in untransformed austenite so as to obtain retained austenite, which makes the TRIP effect apparent in a high strain region during working and which enhances strain resolution. The transformation from austenite to bainite occurs over a wide temperature range of about 150°C to 550°C, and bainite generated in this temperature range include various types. In many cases in the previous technology, such various types of bainite has been specified as bainite simply. However, in order to obtain the workability desired in the present invention, it is necessary that the bainite microstructure is specified clearly. Therefore, the upper bainite and the lower bainite are defined as described below.
The upper bainite is characterized in that lath-shaped bainitic ferrite and retained austenite and/or carbides present between bainitic ferrite are included and fine carbides regularly arranged in the lath-shaped bainitic ferrite are not present. On the other hand, the lower bainite is characterized in that lath-shaped bainitic ferrite and retained austenite and/or carbides present between bainitic ferrite are included, as is common to the upper bainite, and in the lower bainite, fine carbides regularly arranged in the lath-shaped bainitic ferrite are present.
That is, the upper bainite and the lower bainite are distinguished on the basis of presence or absence of fine carbides regularly arranged in the bainitic ferrite. The above-described difference in the generation state of carbides in the bainitic ferrite exerts a significant influence on concentration of C into the retained austenite. That is, in the case where the area percentage of bainitic ferrite in the upper bainite is less than 5%, even when bainite transformation proceeds, the amount of C formed into carbides in the bainitic ferrite increases. As a result, the amount of concentration of C into the retained austenite present between laths decreases, and a problem occurs in that the amount of retained austenite, which exerts the TRIP effect in a high strain region during working, decreases. Therefore, it is necessary that the area percentage of bainitic ferrite in the upper bainite is 5% or more in terms of area percentage relative to the whole steel sheet microstructure. On the other hand, if the area percentage of bainitic ferrite in the upper bainite exceeds 85% relative to the whole steel sheet microstructure, it may become difficult to ensure the strength. Consequently, it is preferable that the area percentage is specified to be 85% or less.

Area percentage of polygonal ferrite: 10% or less (including 0%)

[0033] If the area percentage of polygonal ferrite exceeds 10%, it becomes difficult to satisfy the tensile strength (TS): 980 MPa or more and, at the same time, strain is concentrated on soft polygonal ferrite present together in the hard microstructure during working, so that cracking occurs easily during working. As a result, a desired workability is not obtained. Here, if the area percentage of the polygonal ferrite is 10% or less, even when the polygonal ferrite is present, a state, in which a small amount of polygonal ferrite is discretely dispersed in a hard phase, is brought about, concentration of strain can be suppressed, and deterioration of the workability can be avoided. Therefore, the area percentage of the polygonal ferrite is specified to be 10% or less. The area percentage is preferably 5% or less, further preferably 3% or less, and may be 0%.
[0034] Incidentally, regarding the steel sheet according to the present invention, the hardness of the hardest micro-

structure in the steel sheet microstructure is HV ≤ 800. That is, in the case where as-quenched martensite is not present in the steel sheet according to the present invention, any one of the tempered martensite, the lower bainite, and the upper bainite becomes the hardest phase. All of these microstructures are phases which become HV ≤ 800. Alternatively, in the case where as-quenched martensite is present, the as-quenched martensite becomes the hardest microstructure. Regarding the as-quenched martensite in the steel sheet according to the present invention, the hardness becomes HV ≤ 800, a significantly hard martensite exhibiting HV > 800 is not present, and good stretch-flangeability can be ensured.

[0035] The steel sheet according to the present invention may include pearlite, Widmanstaetten ferrite, and lower bainite as the remainder microstructure. In that case, it is preferable that the allowable content of the remainder microstructure is specified to be 20% or less in terms of area percentage. More preferably, the allowable content is 10% or less.

[0036] The basic configuration of the steel sheet microstructure of the high strength steel sheet according to the present invention is as described above, and the following configuration may be added as necessary.

[0037] Next, the reason for limitation of component composition of the steel sheet in such a way that described above in the present invention will be described. In this connection, % hereafter representing the following component composition refers to percent by mass.

C: 0.17% or more, and 0.73% or less

The element C is an indispensable element to increase the strength of the steel sheet and ensure the amount of stable retained austenite, and an element necessary to ensure the amount of martensite and retain austenite at room temperature. If the amount of C is less than 0.17%, it is difficult to ensure the strength and the workability of the steel sheet. On the other hand, if the amount of C exceeds 0.73%, hardening of a welded zone and a heat-affected zone is significant, so that the weldability deteriorates. Therefore, the amount of C is specified to be within the range of 0.17% or more, and 0.73% or less. The range is preferably within the range of more than 0.20%, and 0.48% or less, and further preferably 0.25% or more.

[0038] Si: 3.0% or less (including 0%)

The element Si is a useful element, which contributes to an improvement in the strength of steel by strengthening through solid solution. However, if the amount of Si exceeds 3.0%, an increase in the amount of solid solution into the polygonal ferrite and the bainitic ferrite causes deterioration of the workability and the tenacity, and causes deterioration of surface characteristics due to occurrence of red scale and the like and deterioration of the wettability and the adhesion of the coating in the case where hot dipping is applied. Therefore, the amount of Si is specified to be 3.0% or less. The amount is preferably 2.6% or less. The amount is further preferably 2.2% or less.

Moreover, Si is an element useful for suppressing generation of carbides and facilitating generation of retained austenite. Therefore, it is preferable that the amount of Si is specified to be 0.5% or more. However, in the case where generation of carbides is suppressed by merely Al, Si is not necessarily added, and amount of Si may be 0%.

[0039] Mn: 0.5% or more, and 3.0% or less

The element Mn is an element useful for strengthening steel. If the amount of Mn is less than 0.5%, carbides are deposited in a temperature range higher than the temperature, at which bainite and martensite are generated, during cooling after annealing. Consequently, it is not possible to ensure the amount of hard phase, which contributes to strengthening of steel. On the other hand, the amount of Mn exceeding 3.0% causes deterioration of castability and the like. Therefore, the amount of Mn is specified to be within the range of 0.5% or more, and 3.0% or less. The range is preferably 1.5% or more, and 2.5% or less.

[0040] P: 0.1% or less

The element P is an element useful for strengthening steel. If the amount of P exceeds 0.1%, the impact resistance deteriorates due to embrittlement based on grain boundary segregation, and in the case where galvannealing is applied to a steel sheet, the alloying rate is reduced significantly. Therefore, the amount of P is specified to be 0.1% or less. The amount is preferably 0.05% or less. In this connection, it is preferable that the amount of P is reduced. However, reduction to less than 0.005% causes a significant increase in cost. Therefore, it is preferable that the lower limit thereof is specified to be about 0.005%.

[0041] S: 0.07% or less

The element S generates MnS so as to become an inclusion and causes deterioration of the impact resistance and cracking along a metal flow of a welded zone. Therefore, it is preferable that the amount of S is minimized. However, since excessive reduction in the amount of S causes an increase in a production cost, the amount of S is specified to be 0.07% or less. Preferably, the amount is 0.05% or less, and more preferably 0.01% or less. In this connection, reduction of S to less than 0.0005% is attended with a significant increase in production cost. Therefore, the lower limit thereof is about 0.0005% from the viewpoint of the production cost.

[0042] Al: 3.0% or less

The element Al is an element useful for strengthening steel and, in addition, is a useful element, which is added as a deoxidizing agent in a steel making process. If the amount of Al exceeds 3.0%, inclusion in a steel sheet increases and the elongation deteriorates. Therefore, the amount of Al is specified to be 3.0% or less. The amount is preferably 2.0% or less.

Moreover, Al is an element useful for suppressing generation of carbides and facilitating generation of retained austenite. Furthermore, it is preferable that the amount of Al is specified to be 0.001% or more in order to obtain a deoxidation effect, and more preferably 0.005% or more. In this regard, the amount of Al in the present invention is the amount of Al contained in the steel sheet after deoxidation.

[0043] N: 0.010% or less

The element N is an element, which causes maximum deterioration of the aging resistance of steel, and is preferably minimized. If the amount of N exceeds 0.010%, deterioration of the aging resistance becomes significant and, therefore, the amount of N is specified to be 0.010% or less. In this connection, reduction of N to less than 0.001% causes a significant increase in production cost, so that the lower limit thereof is about 0.001% from the viewpoint of the production cost.

[0044] Up to this point, the basic components have been described. However, in the present invention, only satisfaction of the above-described component ranges is not adequate, and it is necessary that the following formula is satisfied.

$$Si + Al \geq 0.7\%$$

As described above, both Si and Al are elements useful for suppressing generation of carbides and facilitating generation of retained austenite. Regarding suppression of generation of carbides, an effect is exerted by containing Si or Al alone, but it is necessary to satisfy that a total of the amount of Si and the amount of Al is 0.7% or more. In this connection, the amount of Al in the above-described formula is the amount of Al contained in the steel sheet after deoxidation.

[0045] In addition, in the present invention, the components described below can be contained appropriately besides the above-described basic components.

At least one type selected from Cr: 0.05% or more, and 5.0% or less, V: 0.005% or more, and 1.0% or less, and Mo: 0.005% or more, and 0.5% or less

The elements Cr, V, and Mo are elements having a function of suppressing generation of pearlite during cooling from an annealing temperature. The effect thereof is obtained at Cr: 0.05% or more, V: 0.005% or more, and Mo: 0.005% or more. On the other hand, if Cr: 5.0%, V: 1.0%, and Mo: 0.5% are exceeded, the amount of hard martensite becomes too large, and the strength becomes high more than necessary. Therefore, in the case where Cr, V, and Mo are contained, the ranges are specified to be Cr: 0.05% or more, and 5.0% or less, V: 0.005% or more, and 1.0% or less, and Mo: 0.005% or more, and 0.5% or less.

[0046] At least one type selected from Ti: 0.01% or more, and 0.1% or less and Nb: 0.01% or more, and 0.1% or less

The elements Ti and Nb are elements useful for strengthening steel through deposition, and the effect thereof is obtained when the individual contents are 0.01% or more. On the other hand, if the individual contents exceed 0.1%, the workability and the shape fixability deteriorate. Therefore, in the case where Ti and Nb are contained, the ranges are specified to be Ti: 0.01% or more, and 0.1% or less and Nb: 0.01% or more, and 0.1% or less.

[0047] B: 0.0003% or more, and 0.0050% or less

The element B is an element useful for suppressing generation·growth of ferrite from austenite grain boundaries. The effect thereof is obtained when the content is 0.0003% or more. On the other hand, if the content exceeds 0.0050%, the workability deteriorates. Therefore, in the case where B is contained, the range is specified to be B: 0.0003% or more, and 0.0050% or less.

[0048] At least one type selected from Ni: 0.05% or more, and 2.0% or less and Cu: 0.05% or more, and 2.0% or less

The elements Ni and Cu are elements useful for strengthening steel. Furthermore, in the case where galvanizing or galvannealing is applied to a steel sheet, internal oxidation of a steel sheet surface layer portion is facilitated and, thereby, adhesion of the coating is improved. These effects are obtained when individual contents are 0.05% or more. On the other hand, if the individual contents exceed 2.0%, the workability of the steel sheet deteriorates. Therefore, in the case where Ni and Cu are contained, the ranges are specified to be Ni: 0.05% or more, and 2.0% or less and Cu: 0.05% or more, and 2.0% or less.

[0049] At least one type selected from Ca: 0.001% or more, and 0.005% or less and REM: 0.001% or more, and 0.005% or less

The elements Ca and REM are useful for spheroidizing the shape of sulfides and improve the adverse effect of sulfides on the stretch-flangeability. The effects thereof are obtained when individual contents are 0.001% or more. On the other hand, if the individual contents exceed 0.005%, increases of inclusion and the like are invited so as to cause surface defects, internal defects, and the like. Therefore, in the case where Ca and REM are contained, the ranges are specified to be Ca: 0.001% or more, and 0.005% or less and REM: 0.001% or more, and 0.005% or less.

[0050] In the steel sheet according to the present invention, the components other than those described above are Fe and incidental impurities. However, components other than those described above may be contained within the bounds of not impairing the effects of the present invention.

[0051] Next, a method for manufacturing a high strength steel sheet according to the present invention will be described. After a billet adjusted to have the above-described favorable component composition is produced, hot-rolling is conducted and, then, cold-rolling is conducted so as to produce a cold-rolled steel sheet. In the present invention, these treatments are not specifically limited and may be conducted following usual methods.

Favorable production conditions are as described below. After the billet is heated to a temperature within the range of 1,000°C or higher, and 1,300°C or lower, the hot rolling is terminated in a temperature range of 870°C or higher, and 950°C or lower. The resulting hot-rolled steel sheet is taken up in a temperature range of 350°C or higher, and 720°C or lower. Subsequently, the hot-rolled steel sheet is pickled and, thereafter, cold-rolling is conducted at a reduction ratio within the range of 40% or more, and 90% or less, so as to produce a cold-rolled steel sheet.

In this connection, in the present invention, it is assumed that the steel sheet is produced through usual individual steps of steel making, casting, hot rolling, pickling, and cold rolling. However, for example, production may be conducted through thin slab casting or strip casting while a part of or an entire hot rolling step is omitted.

[0052] A heat treatment shown in Fig. 1 is applied to the resulting cold-rolled steel sheet. The explanation will be conducted below with reference to Fig. 1.

Annealing is conducted for 15 seconds or more, and 600 seconds or less in an austenite single phase region. The steel sheet according to the present invention contains upper bainite, lower bainite, and martensite, which are transformed from untransformed austenite in a relatively low temperature range of 350°C or higher, and 490°C or lower, as primary phases. Therefore, it is preferable that polygonal ferrite is minimized, and annealing in an austenite single phase region is required. The annealing temperature is not specifically limited insofar as it is in the austenite single phase region. If the annealing temperature exceeds 1,000°C, growth of austenite grains is significant, coarser configuration phases are generated by downstream cooling, and the tenacity and the like deteriorate. On the other hand, in the case where the annealing temperature is lower than A_3 point (austenite transformation point), polygonal ferrite has already been generated in an annealing stage, and it becomes necessary that a temperature range of 500°C or more is cooled very rapidly in order to suppress growth of polygonal ferrite during cooling. Therefore, it is necessary that the annealing temperature is specified to be the A_3 point or higher, and preferably, 1,000°C or lower.

Furthermore, if the annealing time is less than 15 seconds, in some cases, reverse transformation to austenite does not proceed adequately or carbides in the steel sheet are not dissolved adequately. On the other hand, if the annealing time exceeds 600 seconds, an increase in cost is invited along with high energy consumption. Therefore, the annealing time is specified to be within the range of 15 seconds or more, and 600 seconds or less. Preferably, the annealing time is within the range of 60 seconds or more, and 500 seconds or less. Here, the A_3 point can be calculated on the basis of

$$A_3 \text{ point } (^\circ C) = 910 - 203 \times [C\%]1/2 + 44.7 \times [Si\%] - 30 \times [Mn\%] + 700 \times [P\%] + 130 \times [Al\%] - 15.2 \times [Ni\%] - 11 \times [Cr\%] - 20 \times [Cu\%] + 31.5 \times [Mo\%] + 104 \times [V\%] + 400 \times [Ti\%]$$

In this connection, [X%] represents percent by mass of component element X of the steel sheet.

[0053] The cold-rolled steel sheet after annealing is cooled to a cooling termination temperature: T°C determined in a first temperature range of 350°C or higher, and 490°C or lower, wherein cooling to at least 550°C is conducted while the average cooling rate is controlled at 5°C/s or more. In the case where the average cooling rate is less than 5°C/s, excessive generation and growth of polygonal ferrite, deposition of pearlite, and the like occur, so that a desired steel sheet microstructure is not obtained. Therefore, the average cooling rate from the annealing temperature to the first temperature range is specified to be 5°C/s or more. Preferably, the average cooling rate is 10°C/s or more. The upper limit of the average cooling rate is not specifically limited insofar as variations do not occur in the cooling termination temperature. Regarding general facility, if the average cooling rate exceeds 100°C/s, variations in microstructure in a longitudinal direction and a sheet width direction of a steel sheet becomes large significantly. Therefore, 100°C/s or less is preferable.

[0054] The steel sheet cooled to 550°C is cooled succeedingly to the cooling termination temperature: T°C. The rate of cooling of the steel sheet in the temperature range of T°C or higher, and 550°C or lower is not specifically limited except that a keeping time in the first keeping temperature range is specified to be 15 seconds or more, and 1,000 seconds or less. However, in the case where the steel sheet is cooled at a too low rate, carbides are generated from untransformed austenite and, thereby, there is a high probability that a desired microstructure is not obtained. Therefore, it is preferable that the steel sheet is cooled at an average rate of 1°C/s or more in a temperature range of T°C or higher, and 550°C or lower.

[0055] The steel sheet cooled to the cooling termination temperature: T°C is kept in the first temperature range of

350°C or higher, and 490°C or lower for a period of 15 seconds or more, and 1,000 seconds or less. If the upper limit of the first temperature range exceeds 490°C, carbides are deposited from the untransformed austenite and, thereby, a desired microstructure is not obtained. On the other hand, in the case where the lower limit of the first temperature range is lower than 350°C, a problem occurs in that lower bainite is generated rather than upper bainite and the amount of C concentrated into austenite is reduced. Therefore, the first temperature range is specified to be within the range of 350°C or higher, and 490°C or lower. Preferably, the range is 370°C or higher, and 460°C or lower.

Moreover, in the case where the keeping time in the first temperature range is less than 15 seconds, a problem occurs in that the amount of upper bainite transformation is reduced and the amount of C concentrated into untransformed austenite is reduced. On the other hand, in the case where the keeping time in the first temperature range exceeds 1,000 seconds, carbides are deposited from untransformed austenite which serves as retained austenite in the final microstructure of the steel sheet, stable retained austenite, into which C has been concentrated, is not obtained and, as a result, a desired workability is not obtained. Therefore, the keeping time is specified to be 15 seconds or more, and 1,000 seconds or less. preferably, the range is 30 seconds or more, and 600 seconds or less.

[0056] After keeping in the first temperature range is completed, the resulting steel sheet is cooled to a second temperature range of 200°C or higher, and 350°C or lower at any rate and is kept in the second temperature range for a period of 15 seconds or more, and 1,000 seconds or less. If the upper limit of the second temperature range exceeds 350°C, a problem occurs in that lower bainite transformation does not proceed and, as a result, the amount of as-quenched martensite increases. On the other hand, in the case where the lower limit of the second temperature range is lower than 200°C as well, a problem occurs in that lower bainite transformation does not proceed and the amount of as-quenched martensite increases. Therefore, the second temperature range is specified to be within the range of 200°C or higher, and 350°C or lower. Preferably, the range is 250°C or higher, and 340°C or lower.

Moreover, in the case where the keeping time is less than 15 seconds, an adequate amount of lower bainite is not obtained, and desired workability is not obtained. On the other hand, in the case where the keeping time exceeds 1,000 seconds, carbides are deposited from the stable retained austenite in the upper bainite generated in the first temperature range and, as a result, desired workability is not obtained. Therefore, the keeping time is specified to be 15 seconds or more, and 1,000 seconds or less. preferably, the range is 30 seconds or more, and 600 seconds or less.

[0057] In this regard, in a series of heat treatments according to the present invention, the keeping temperature is not necessarily a constant insofar as the keeping temperature is within the above-described predetermined temperature range, and fluctuation within a predetermined temperature range does not impair the gist of the present invention. The same goes for the cooling rate. Furthermore, The steel sheet may be heat-treated with any facility insofar as only the thermal history is satisfied. In addition, the scope of the present invention includes that temper rolling is applied to the surface of the steel sheet or a surface treatment, e.g., electroplating, is applied after the heat treatment in order to correct the shape.

[0058] The method for manufacturing a high strength steel sheet according to the present invention can further include a galvanizing treatment or a galvannealing treatment, in which an alloying treatment is further added to the galvanizing treatment. The galvanizing treatment or, furthermore, the galvannealing treatment may be conducted during the above-described cooling to the first temperature range or in the first temperature range. In this case, the keeping time in the first temperature range is specified to be 15 seconds or more, and 1,000 seconds or less, in which a treatment time of the galvanizing treatment or the galvannealing treatment in the first temperature range is included. In this connection, it is preferable that the galvanizing treatment or the galvannealing treatment is conducted with a continuous galvanizing and galvannealing line.

[0059] Furthermore, the method for manufacturing a high strength steel sheet according to the present invention can include that the high strength steel sheet is produced following the above-described manufacturing method according to the present invention, where steps up to the heat treatment have been completed, and thereafter, the galvanizing treatment or, furthermore, the galvannealing treatment is conducted.

Alternatively, after the keeping in the second temperature range following the manufacturing method according to the present invention, the galvanizing treatment or the galvannealing treatment can be conducted succeedingly.

[0060] A method for applying a galvanizing treatment or a galvannealing treatment to a steel sheet is as described below. The steel sheet is immersed into a plating bath, and the amount of adhesion is adjusted through gas wiping or the like. It is preferable that the amount of Al dissolved in the plating bath is specified to be within the range of 0.12% or more, and 0.22% or less in the case of the galvanizing treatment and within the range of 0.08% or more, and 0.18% or less in the case of the galvannealing treatment.

Regarding the treatment temperature, as for the galvanizing treatment, the temperature of the plating bath may be within the range of usual 450°C or higher, and 500°C or lower, and furthermore, in the case where the galvannealing treatment is applied, it is preferable that the temperature during alloying is specified to be 550°C or lower. In the case where the alloying temperature exceeds 550°C, carbides are deposited from untransformed austenite and in some cases, pearlite is generated. Consequently, the strength or the workability, or the two are not obtained.

In addition, the powdering property of the coating layer deteriorates. On the other hand, if the temperature during alloying

is lower than 450°C, in some cases, alloying does not proceed. Therefore, it is preferable that the alloying temperature is specified to be 450°C or higher.

It is preferable that the coating mass is specified to be within the range of 20 g/m^2 or more, and 150 g/m^2 or less per surface. If the coating mass is less than 20 g/m^2, the corrosion resistance becomes inadequate. On the other hand, even when 150 g/m^2 is exceeded, the corrosion-resisting effect is saturated and merely an increase in the cost is invited.

It is preferable that the degree of alloying of the coating layer (Fe percent by mass (Fe content)) is within the range of 7 percent by mass or more, and 15 percent by mass or less. If the degree of alloying of the coating layer is less than 7 percent by mass, alloying variations occur, so that the quality of outward appearance deteriorates, or a so-called a ξ phase is generated in the coating layer, so that the sliding property of the steel sheet deteriorates. On the other hand, if the degree of alloying of the coating layer exceeds 15 percent by mass, large amounts of hard brittle Γ phase is formed, so that the adhesion of the coating deteriorates.

[EXAMPLES]

[0061] The present invention will be described below in further detail with reference to the examples. However, the following examples do not limit the present invention. In this connection, modification of the configuration within the range of the gist configuration of the present invention is included in the scope of the present invention.

[0062] An ingot obtained by melting a steel having a component composition shown in Table 1 was heated to 1,200°C and was subjected to finish hot rolling at 870°C. The resulting hot-rolled steel sheet was taken up at 650°C and, subsequently, the hot-rolled steel sheet was pickled. Thereafter, cold rolling was conducted at a reduction ratio of 65% so as to produce a cold-rolled steel sheet having a sheet thickness: 1.2 mm. The resulting cold-rolled steel sheet was subjected to a heat treatment under the condition shown in Table 2. In this connection, the cooling termination temperature: T in Table 2 refers to a temperature at which cooling of a steel sheet is terminated in cooling of the steel sheet from the annealing temperature.

Furthermore, a part of cold-rolled steel sheets were subjected to a galvanizing treatment or a galvannealing treatment. Here, as for the galvanizing treatment, plating was conducted on both surfaces at a plating bath temperature: 463°C in such a way that a mass per unit area (per surface): 50 g/m^2 was ensured. Moreover, as for the galvannealing treatment, plating was conducted on both surfaces while the alloying condition was adjusted in such a way that a mass per unit area (per surface): 50 g/m^2 was ensured and the degree of alloying (Fe percent by mass (Fe content)) became 9 percent by mass. In this connection, the galvanizing treatment and the galvannealing treatment were conducted after cooling was once conducted to T°C shown in Table 2.

[0063] The resulting steel sheet was subjected to temper rolling at a reduction ratio (elongation percentage): 0.3 after a heat treatment in the case where a plating treatment is not conducted, or after a galvanizing treatment or a galvannealing treatment in the case where these treatments were conducted.

[0064] [Table 1]

Table 1

(percent by mass)

Steel type	C	Si	Mn	Al	P	S	N	Cr	V	Mo	Ti	Nb	B	Ni	Cu	Ca	REM	Si+Al	A_3point (°C)	Remarks
A	0.311	1.96	1.54	0.041	0.009	0.0024	0.0025	–	—	—	–	–	–	–	–	–	–	2.00	850	Invented steel
B	0.299	1.98	1.99	0.042	0.013	0.0019	0.0034	–	—	—	–	–	–	–	–	–	–	2.02	842	Invented steel
C	0.305	2.52	2.03	0.043	0.010	0.0037	0.0042	–	—	—	–	–	–	–	–	–	–	2.56	862	Invented steel
D	0.413	2.03	1.51	0.038	0.012	0.0017	0.0025	–	—	—	–	–	–	–	–	–	–	2.07	838	Invented steel
E	0.417	1.99	2.02	0.044	0.010	0.0020	0.0029	–	–	–	–	–	–	–	–	–	–	2.03	820	Invented steel
F	0.330	1.45	2.82	0.040	0.012	0.0031	0.0043	–	–	–	–	–	–	–	–	–	–	1.49	787	Invented steel
G	0.185	1.52	2.32	0.048	0.020	0.0050	0.0044	–	–	–	–	–	–	–	–	–	–	1.57	841	Invented steel
H	0.522	1.85	1.48	0.040	0.011	0.0028	0.0043	–	–	–	–	–	–	–	–	–	–	1.89	815	Invented steel
I	0.320	0.99	2.25	0.041	0.014	0.0018	0.0042	–	–	–	–	–	–	–	–	–	–	1.03	787	Invented steel
J	0.263	1.50	2.29	0.039	0.011	0.0010	0.0036	0.9	–	–	–	–	–	–	–	–	–	1.54	807	Invented steel
K	0.270	1.35	2.27	0.043	0.004	0.0020	0.0035	–	0.21	–	–	–	–	–	–	–	–	1.39	827	Invented steel
L	0.221	1.22	1.99	0.040	0.040	0.0030	0.0043	–	–	0.19	–	–	–	–	–	–	–	1.26	849	Invented steel
M	0.202	1.75	2.52	0.045	0.044	0.0020	0.0044	–	–	–	0.035	–	–	–	–	–	–	1.80	872	Invented steel
N	0.175	1.51	2.18	0.042	0.022	0.0020	0.0044	–	–	–	–	0.07	–	–	–	–	–	1.55	848	Invented steel
O	0.212	1.51	2.37	0.043	0.030	0.0010	0.0029	–	–	–	0.020	–	0.0011	–	–	–	–	1.55	848	Invented steel
P	0.480	1.52	1.33	0.044	0.015	0.0020	0.0038	–	–	–	–	–	–	0.52	–	–	–	1.56	806	Invented steel
Q	0.310	1.42	2.02	0.043	0.015	0.0030	0.0023	–	–	–	–	–	–	–	0.55	–	–	1.46	805	Invented steel
R	0.335	2.01	2.22	0.043	0.004	0.0028	0.0041	–	–	–	–	–	–	–	–	0.003	–	2.05	824	Invented steel
S	0.329	1.88	1.65	0.040	0.021	0.0020	0.0031	–	–	–	–	–	–	–	–	–	0.002	1.92	848	Invented steel
T	0.330	0.01	2.33	1.010	0.025	0.0020	0.0033	–	–	–	–	–	–	–	–	–	–	1.02	873	Invented steel
U	0.291	–	2.75	0.042	0.012	0.0040	0.0024	–	–	–	–	–	–	–	–	–	–	0.04	732	Comparative steel
V	0.290	0.48	2.22	0.130	0.006	0.0020	0.0035	–	–	–	–	–	–	–	–	–	–	0.61	777	Comparative steel
W	0.145	0.50	1.42	0.320	0.007	0.0018	0.0041	–	–	–	–	–	–	–	–	–	–	0.82	859	Comparative steel
X	0.190	1.00	0.41	0.036	0.013	0.0020	0.0038	–	–	–	–	–	–	–	–	–	–	1.04	868	Comparative steel

Note) Underline indicates that the value is out of the appropriate range.

Table 2

Sample No.	Steel type	Coating *2	Annealing temperature (°C)	Annealing time (s)	Average cooling rate to 550°C (°C/s)	Cooling rate 550°C to T°C (°C/s)	Cooling termination temperature (°C)	Keeping time in first temperature range (s)	Second temperature range		Remarks
									Keeping temperature (°C)	Keeping time(s)	
1	A	CR	880	180	4	15	430	100	300	100	Comparative example
2	A	CR	900	180	20	20	400	5	320	90	Comparative example
3	A	CR	900	200	50	50	420	100	330	180	Invention example
4	A	CR	900	200	50	50	400	100	330	300	Invention example
5	B	CR	800	200	20	20	400	120	300	100	Comparative example
6	B	CR	880	200	20	20	520	200	330	300	Comparative example
7	B	CR	880	350	35	35	400	100	330	350	Invention example
8	C	CR	890	150	25	25	400	80	110	120	Comparative example
9	C	CR	900	200	20	20	380	120	310	300	Invention example
10	D	CR	900	200	20	20	400	100	330	300	Invention example
11	D	CR	900	200	50	50	400	300	250	10	Comparative example
12	E	CR	880	250	15	15	400	200	340	550	Invention example
13	F	CR	870	300	20	20	450	100	330	250	Invention example

(continued)

Sample No.	Steel type	Coating *2	Annealing temperature (°C)	Annealing time (s)	Average cooling rate to 550°C (°C/s)	Cooling rate 550°C to T°C (°C/s)	Cooling termination temperature (°C)	Keeping time in first temperature range (s)	Second temperature range		Remarks
									Keeping temperature (°C)	Keeping time(s)	
14	F	GI	870	300	12	12	450	100	330	200	Invention example
15	G	CR	890	200	20	20	400	90	240	420	Invention example
16	H	CR	880	200	25	25	370	400	200	500	Invention example
17	I	CR	900	250	30	30	400	150	250	300	Invention example
18	I	GA	900	250	20	20	450	100	280	100	Invention example
19	J	CR	900	200	20	20	370	90	300	300	Invention example
20	K	CR	900	200	40	40	420	90	300	300	Invention example
21	L	CR	900	200	30	30	420	200	300	300	Invention example
22	M	CR	900	200	20	20	420	180	300	300	Invention example
23	N	CR	900	200	20	20	420	100	300	300	Invention example
24	O	CR	900	200	20	20	420	100	300	300	Invention example
25	P	CR	900	200	20	20	420	300	300	300	Invention example
26	Q	CR	900	200	30	30	420	120	300	300	Invention example

(continued)

Sample No.	Steel type	Coating *2	Annealing temperature (°C)	Annealing time (s)	Average cooling rate to 550°C (°C/s)	Cooling rate 550°C to T°C (°C/s)	Cooling termination temperature (°C)	Keeping time in first temperature range (s)	Second temperature range		Remarks
									Keeping temperature (°C)	Keeping time(s)	
27	R	CR	900	200	30	30	420	100	300	300	Invention example
28	S	CR	900	200	30	30	420	100	300	300	Invention example
29	T	CR	900	200	30	30	420	120	300	300	Invention example
30	U	CR	900	200	13	13	420	100	300	300	Comparative example
31	V	CR	900	200	20	20	420	100	300	300	Comparative example
32	W	CR	900	200	40	40	420	60	300	300	Comparative example
33	X	CR	900	200	15	15	420	60	300	300	Comparative example

*1 Underline indicates that the value is out of the appropriate range.
*2 CR:No coating (cold-rolled steel sheet) GI:Galvanized steel sheet GA:Galvannealed steel sheet

[0065] Various characteristics of the thus obtained steel sheet were evaluated by the following methods.
A sample was cut from each steel sheet and was polished. Microstructures of ten fields of view of a surface parallel to the rolling direction were observed with a scanning electron microscope (SEM) at 3,000-fold magnification, the area percentage of each phase was measured, and a phase structure of each crystal grain was identified.

[0066] The steel sheet was ground-polished up to one-quarter of a sheet thickness in the sheet thickness direction and the amount of retained austenite was determined by X-ray diffractometry. As for an incident X-ray, Co-Kα was used and the amount of retained austenite were calculated from the average value of the intensity ratio of each of (200), (220), and (311) faces of austenite to the diffraction intensity of each of (200), (211), and (220) faces of ferrite.

[0067] As for the average amount of C in the retained austenite, a lattice constant was determined from the intensity peak of each of (200), (220), and (311) faces of austenite based on the X-ray diffractometry, and the average amount of C (percent by mass) in the retained austenite was determined from the following calculation formula.

$$a0 = 0.3580 + 0.0033 \times [C\%] + 0.00095 \times [Mn\%] + 0.0056 \times [Al\%] + 0.022 \times [N\%]$$

where, aO represents a lattice constant (nm) and [X%] represents percent by mass of an element X. In this connection, the percent by mass of an element other than C was percent by mass relative to whole steel sheet.

[0068] The tensile test was conducted based on JIS Z2241 by using a test piece of JIS No. 5 size taken in a direction perpendicular to the rolling direction of the steel sheet. The TS (tensile strength) and the T.E1 (total elongation) were measured, a product of the strength and the total elongation (TS $\times$ T.E1) was calculated and, thereby, the balance between the strength and the workability (elongation) was evaluated. In this connection, in the present invention, the case where TS $\times$ T.E1 $\geq$ 20,000 MPa·% was evaluated as good.

[0069] The stretch-flangeability was evaluated on the basis of the Japan Iron and Steel Federation Standard JFST 1001. Each of the resulting steel sheets was cut into 100 mm $\times$ 100 mm, a hole having a diameter: 10 mm was punched with a clearance of 12% of sheet thickness. Thereafter, a dice having an inside diameter: 75 mm was used, a 60° circular cone punch was pushed into the hole while holding was conducted with a holddown force: 88.2 kN, a hole diameter at crack occurrence limit was measured, and a hole-expansion limit λ (%) was determined from the formula (1).

$$\text{hole-expansion limit } \lambda\ (\%) = \{(Df - D0)/D0\} \times 100 \cdots (1)$$

where Df represents a hole diameter (mm) at occurrence of crack and D0 represents an initial hole diameter (mm).
The thus measured λ was used, the product of the strength and the hole-expansion limit (TS $\times$ λ) was calculated and, thereby, the balance between the strength and the stretch-flangeability was evaluated.
In this connection, in the present invention, the stretch-flangeability was evaluated as good in the case where TS $\times$ λ $\geq$ 25,000 MPa·%.

[0070] Furthermore, the hardness of the hardest microstructure in the steel sheet microstructure was determined by a method described below. That is, as a result of microstructure observation, in the case where as-quenched martensite was observed, 10 points of the as-quenched martensite were measured with an ultramicro-Vickers at a load: 0.02 N, and an average value thereof was assumed to be the hardness of the hardest microstructure in the steel sheet microstructure. In this connection, in the case where as-quenched martensite is not observed, as described above, the microstructure of any one of the tempered martensite, the upper bainite, and the lower bainite becomes the hardest phase in the steel sheet according to the present invention. In the case of steel sheet according to the present invention, the hardest phase was a phase showing HV $\leq$ 800.

[0071] The above-described evaluation results are shown in Table 3.

[0072] [Table 3]

Table 3

Sample No.	Steel type	Area percentage relative to whole steel sheet microstructure (%)							(As-quenched M)/(M+LB) (%)	Average amount of C in retained γ (%)	TS (MPa)	T.EL (%)	λ (%)	TS × T.EL (MPa·%)	TS × λ (MPa·%)	Remarks
		αb*2	LB*2+M*2	As-quenched M	α*2	γ*2 *3	Remainder	αb+LB+M+γ								
1	A	3	6	0	58	1	32	10	0	=	841	21	38	17661	31958	Comparative example
2	A	4	89	10	3	4	0	97	11	0.91	1492	12	20	17904	29840	Comparative example
3	A	54	31	10	2	13	0	98	32	1.14	1166	19	34	22154	39644	Invention example
4	A	56	30	7	2	12	0	98	23	1.23	1156	21	34	24276	39304	Invention example
5	B	21	49	10	21	6	3	76	20	0.68	1296	13	20	16848	25920	Comparative example
6	B	37	49	10	3	8	3	94	20	0.57	1467	11	22	16137	32274	Comparative example
7	B	50	38	10	0	12	0	100	26	1.22	1302	18	23	23436	29946	Invention example
8	C	50	35	28	0	15	0	100	80	0.94	1482	20	5	29640	7410	Comparative example
9	C	52	34	11	0	14	0	100	32	1.16	1371	19	20	26049	27420	Invention example
10	D	45	39	9	0	16	0	100	23	1.36	1335	24	21	32040	28035	Invention example
11	D	58	21	18	0	21	0	100	86	1.20	1203	29	8	34887	9624	Comparative example
12	E	25	63	30	0	12	0	100	48	1.15	1695	15	18	25425	30510	Invention example
13	F	15	78	30	0	7	0	100	38	0.81	1710	14	19	23940	32490	Invention example

(continued)

Sample No.	Steel type	Area percentage relative to whole steel sheet microstructure (%)							(As-quenched M)/(M+LB) (%)	Average amount of C in retained γ (%)	TS (MPa)	T.EL (%)	λ (%)	TS × T.EL (MPa·%)	TS × λ (MPa·%)	Remarks
		αb*2	LB*2+M*2	As-quenched M	α*2	γ*2 *3	Remainder	αb+LB+M+γ								
14	F	14	76	30	2	8	0	98	39	0.75	1632	13	19	21216	31008	Invention example
15	G	70	14	2	7	9	0	93	14	0.74	1098	21	45	23058	49410	Invention example
16	H	16	78	17	0	6	0	100	22	1.09	1820	14	18	25480	32760	Invention example
17	I	37	52	20	0	11	0	100	38	0.85	1395	16	21	22320	29295	Invention example
18	I	36	55	38	0	9	0	100	69	0.82	1314	17	20	22338	26280	Invention example
19	J	16	75	14	1	9	0	100	19	0.81	1783	12	17	21396	30311	Invention example
20	K	22	69	21	0	9	0	100	30	0.83	1612	13	19	20956	30628	Invention example
21	L	20	69	22	0	11	0	100	32	0.73	1870	11	14	20570	26180	Invention example
22	M	36	56	13	0	8	0	100	23	0.82	1285	21	20	26985	25700	Invention example
23	N	33	58	35	0	9	0	100	60	0.79	1045	25	38	26125	39710	Invention example
24	O	35	55	15	0	10	0	100	27	0.86	1230	19	28	23370	34440	Invention example
25	P	30	57	25	0	13	0	100	44	0.92	1771	14	19	24794	33649	Invention example
26	Q	40	44	18	0	16	0	100	41	0.95	1596	13	20	20748	31920	Invention example

(continued)

Sample No.	Steel type	Area percentage relative to whole steel sheet microstructure (%)							(As-quenched M)/(M+LB) (%)	Average amount of C in retained γ (%)	TS (MPa)	T.EL (%)	λ (%)	TS × T.EL (MPa·%)	TS × λ (MPa·%)	Remarks
		αb*2	LB*2+M*2	As-quenched M	α*2	γ*2 *3	Remainder	αb+LB+M+γ								
27	R	22	68	17	0	10	0	100	25	0.96	1482	14	37	20748	54834	Invention example
28	S	60	29	12	0	11	0	100	41	1.05	1465	17	28	24905	41020	Invention example
29	T	42	47	25	0	11	0	100	53	1.07	1355	19	33	25745	44715	Invention example
30	U	40	41	20	9	2	8	83	49	=	1183	13	23	15379	27209	Comparative example
31	V	39	54	24	4	3	0	96	44	=	1288	12	23	15456	29624	Comparative example
32	W	78	8	3	0	3	11	89	38	=	901	14	32	12614	28832	Comparative example
33	X	8	1	1	70	0	21	9	100	=	735	14	30	10290	22050	Comparative example

*1 Underline indicates that the value is out of the appropriate range.
*2 αb: Bainitic ferrite in upper bainite LB: Lower bainite M : Martensite α: Polygonal ferrite γ: Retained austenite
*3 Amount of retained austenite determined by X-ray diffractometry was assumed to be area percentage relative to whole steel sheet microstructure.

[0073] As is clear from Table 3, every steel sheet according to the present invention satisfies that the tensile strength is 980 MPa or more, the value of TS × T.El is 20,000 MPa·% or more, and TS × λ ≥ 25,000 MPa·% Therefore, it was able to be ascertained that high strength and excellent workability, especially excellent stretch-flangeability, were provided in combination.

[0074] On the other hand, regarding Sample No. 1, the average cooling rate to 550°C was out of the appropriate range. Therefore, a desired steel sheet microstructure was not obtained. Although TS × λ ≥ 25,000 MPa·% was satisfied, the tensile strength (TS) ≥ 980 MPa and TS × T.El ≥ 20,000 MPa·% were not satisfied. Regarding Sample No. 2, the keeping time in the first temperature range was out of the appropriate range. Regarding Sample No. 5, the annealing temperature was lower than A_3 point. Regarding Sample No. 6, the cooling termination temperature: T was out of the first temperature range. Regarding Sample No. 8, the keeping temperature in the second temperature range was out of the appropriate range. Regarding Sample No. 11, the keeping time in the second temperature range was out of the appropriate range. Therefore, a desired steel sheet microstructure was not obtained. Although the tensile strength (TS) ≥ 980 MPa was satisfied, any one of TS × T.El ≥ 20,000 MPa·% and TS × λ ≥ 25,000 MPa·% was not satisfied. Regarding Sample Nos. 30 to 34, the component compositions were out of the appropriate range. Therefore, a desired steel sheet microstructure was not obtained, and at least one of the tensile strength (TS) ≥ 980 MPa, TS × T.El ≥ 20,000 MPa·%, and TS × λ ≥25,000 MPa·% was not satisfied.

Claims

1. A high strength steel sheet **characterized by** having a composition comprising, on a percent by mass basis,
C: 0.17% or more, and 0.73% or less;
Si: 3.0% or less;
Mn: 0.5% or more, and 3.0% or less;
P: 0.1% or less;
S: 0.07% or less;
Al: 3.0% or less; and
N: 0.010% or less,
while it is satisfied that Si + Al is 0.7% or more, and the remainder includes Fe and incidental impurities,
wherein regarding the steel sheet microstructure, it is satisfied that the area percentage of a total amount of lower bainite and whole martensite is 10% or more, and 90% or less relative to the whole steel sheet microstructure, the amount of retained austenite is 5% or more, and 50% or less, the area percentage of bainitic ferrite in upper bainite is 5% or more relative to the whole steel sheet microstructure, as-quenched martensite is 75% or less of the total amount of lower bainite and whole martensite, and the area percentage of polygonal ferrite is 10% or less (including 0%) relative to the whole steel sheet microstructure, the average amount of C in the retained austenite is 0.70% or more, and the tensile strength is 980 MPa or more.

2. The high strength steel sheet according to Claim 1, **characterized in that**
the steel sheet further comprises at least one type of element selected from, on a percent by mass basis,
Cr: 0.05% or more, and 5.0% or less;
V: 0.005% or more, and 1.0% or less; and
Mo: 0.005% or more, and 0.5% or less.

3. The high strength steel sheet according to Claim 1 or Claim 2, **characterized in that**
the steel sheet further comprises at least one type of element selected from, on a percent by mass basis,
Ti: 0.01% or more, and 0.1% or less; and
Nb: 0.01% or more, and 0.1% or less.

4. The high strength steel sheet according to any one of Claims 1 to 3, **characterized in that**
the steel sheet further comprises, on a percent by mass basis,
B: 0.0003% or more, and 0.0050% or less.

5. The high strength steel sheet according to any one of Claims 1 to 4, **characterized in that**
the steel sheet further comprises at least one type of element selected from, on a percent by mass basis,
Ni: 0.05% or more, and 2.0% or less; and
Cu: 0.05% or more, and 2.0% or less.

6. The high strength steel sheet according to any one of Claims 1 to 5, **characterized in that**

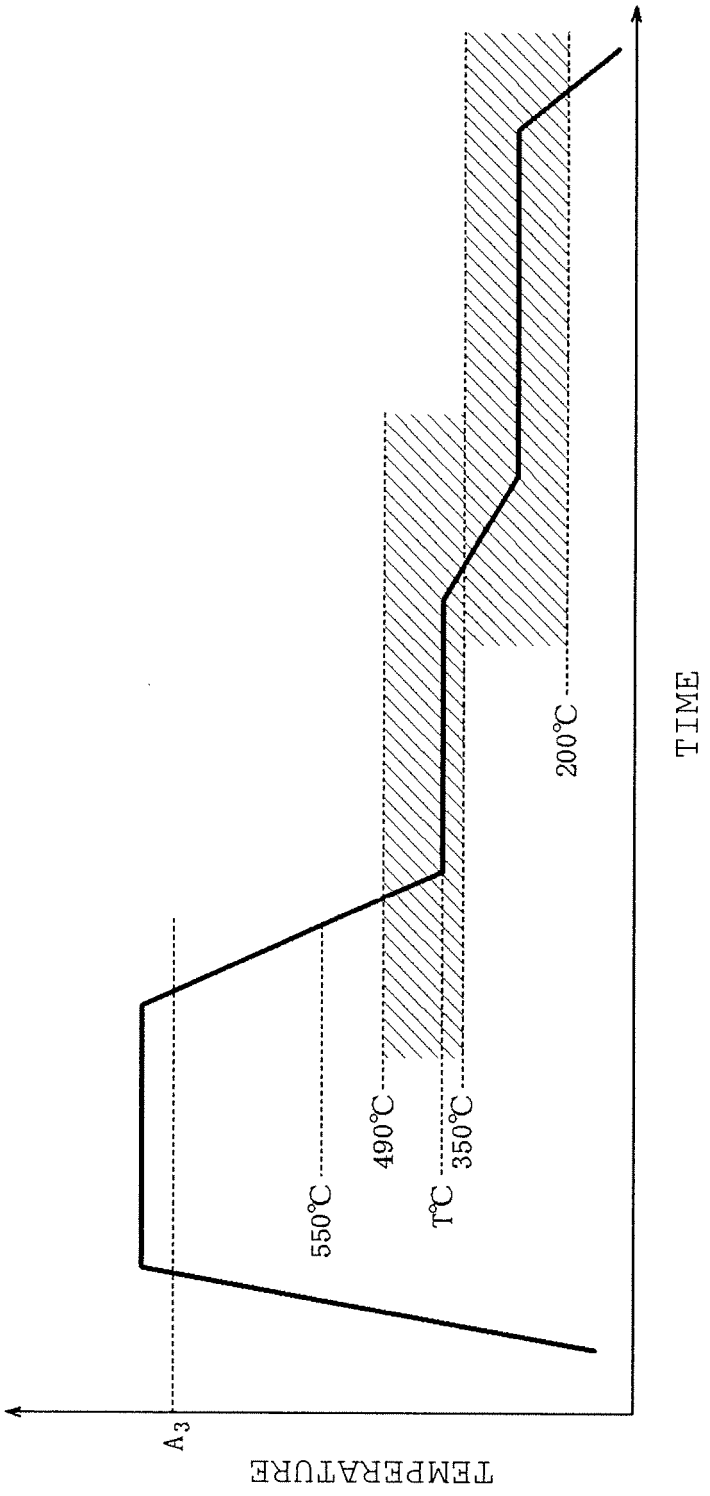
the steel sheet further comprises at least one type of element selected from, on a percent by mass basis,
Ca: 0.001% or more, and 0.005% or less; and
REM: 0.001% or more, and 0.005% or less.

7. A high strength steel sheet **characterized by** comprising a galvanized layer or a galvannealed layer on a surface of the steel sheet according to any one of Claims 1 to 6.

8. A method for manufacturing a high strength steel sheet, **characterized by** comprising the steps of hot-rolling a billet having a component composition according to any one of Claims 1 to 6, conducting cold-rolling so as to produce a cold-rolled steel sheet, annealing the resulting cold-rolled steel sheet for 15 seconds or more, and 600 seconds or less in an austenite single phase region and, thereafter, conducting cooling to a cooling termination temperature: T°C determined in a first temperature range of 350°C or higher, and 490°C or lower, wherein cooling to at least 550°C is conducted while the average cooling rate is controlled at 5°C/s or more, subsequently, keeping is conducted in the first temperature range for 15 seconds or more, and 1,000 seconds or less and, then, keeping is conducted in a second temperature range of 200°C or higher, and 350°C or lower for 15 seconds or more, and 1,000 seconds or less.

9. The method for manufacturing a high strength steel sheet according to Claim 8, **characterized in that** a galvanizing treatment or a galvannealing treatment is applied during cooling to the cooling termination temperature: T°C or in the first temperature range.

[FIG. 1]



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2009/065981

A. CLASSIFICATION OF SUBJECT MATTER
C22C38/06(2006.01)i, *C22C38/60*(2006.01)i, *C21D9/46*(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C22C38/00-38/60, C21D9/46-9/48

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Jitsuyo Shinan Koho 1922-1996 Jitsuyo Shinan Toroku Koho 1996-2009
Kokai Jitsuyo Shinan Koho 1971-2009 Toroku Jitsuyo Shinan Koho 1994-2009

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2004-076114 A (Kobe Steel, Ltd.), 11 March 2004 (11.03.2004), claims; paragraphs [0041] to [0043], [0048], [0049] & US 2004/0035500 A1 & EP 1391526 A2	1-9
A	JP 2005-220440 A (Kobe Steel, Ltd.), 18 August 2005 (18.08.2005), claims; tables 1 to 5 & US 2005/0150580 A1 & EP 1553202 A1	1-9
A	JP 2004-190050 A (Kobe Steel, Ltd.), 08 July 2004 (08.07.2004), claims; paragraphs [0046] to [0049]; tables 1 to 4 (Family: none)	1-9

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

* Special categories of cited documents:
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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
17 November, 2009 (17.11.09)	01 December, 2009 (01.12.09)
Name and mailing address of the ISA/ Japanese Patent Office Facsimile No.	Authorized officer Telephone No.

Form PCT/ISA/210 (second sheet) (April 2007)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2009/065981

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2003-193193 A (Nippon Steel Corp.), 09 July 2003 (09.07.2003), claims; paragraphs [0023], [0024]; tables 1 to 3 (Family: none)	1-9

Form PCT/ISA/210 (continuation of second sheet) (April 2007)

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 4235253 A **[0010]**
- JP 2004076114 A **[0010]**
- JP 11256273 A **[0010]**