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(54) **HIGH-STRENGTH STEEL SHEETS AND PROCESSES FOR PRODUCTION OF THE SAME**
HOCHFESTE STAHLBLECHE UND HERSTELLUNGSVERFAHREN DAFÜR
FEUILLES D'ACIER TRÈS RÉSISTANTES ET PROCÉDÉS DE PRODUCTION DE CELLES-CI

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- **SUGIMOTO K. ET AL.: 'Ductility and formability
of newly developed high strength low alloy TRIP-
aided sheet steels with annealed martensite
matrix' ISIJ INTERNATIONAL vol. 42, no. 8,
August 2002, pages 910 - 915, XP001182009**

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Description

[Technical Field]

[0001] The present invention relates to a high strength steel sheet for which high press formability is required, typically including steel sheets for automobiles, particularly to a high strength steel sheet with both elongation and stretch-flanging performance and a method for manufacturing the same.

[Background Art]

[0002] High strength steel sheets, which are generally used by being press-molded, are used in industrial product such as automobiles, electric devices and industrial machines. Since high strength steel sheets are used for the purpose of lightening industrial products, they need not only have high strength, but also have the ability to form various configurations of the products. Accordingly, it is required for high strength steel sheets to have excellent press formability. To meet this requirement, high-strength steel sheets having excellent elongation and stretch-flanging performance, which are necessary for improving press formability, are required.

[0003] Examples of known steels having such characteristics include dual phase steel (DP steel) whose metal structure is composed of a ferrite phase and a martensite phase, as described in Patent document 1. Since this DP steel can ensure ductility (elongation) due to its soft ferrite and strength due to its rigid martensite, it has both strength and elongation (in particular, uniform elongation). However, because of the coexistence of soft ferrite and rigid martensite, distortion (stress) is concentrated at the interface of the two phases when deformed, and therefore the interface is likely to serve as the starting point of rupture, thereby disadvantageously preventing ensuring stretch-flanging performance (local elongation).

[0004] Examples of steel sheets which expectedly have ductility (especially, uniform elongation) higher than those of DP steels include TRIP steels utilizing the TRIP (Transformation Induced Plasticity) phenomenon, as described in Patent document 2. This TRIP steel is a steel sheet in which uniform elongation is increased by transforming retained austenite into martensite during deformation (working-induced transformation). However, since martensite which has been transformed from retained austenite in the TRIP steel is extremely hard, it likely serves as the starting point of rupture, lowering the stretch-flanging performance of the steel sheet.

[0005] Other methods of improving the stretch-flanging performance of the high strength steel sheets include that in which the metal structure is single-phase structure and localization of process distortion is suppressed by homogenizing the in the metal structure, and that in which a difference in strength between a soft phase having a multi-phase metal structure and a hard phase is reduced.

Since martensite single-phase structure steel sheet has a uniform structure, it is known as a steel sheet which has both strength and stretch-flanging performance. However, the martensite single-phase structure steel sheet disadvantageously has low ductility, and insufficient elongation.

[0006] Patent document 3 discloses a high-stretch-strength cold-rolled steel sheet in which martensite single-phase structure is achieved by justifying the composition and heat treatment conditions of the steel sheet, and tensile strength is 880 to 1170 MPa. That is, the high-stretch-strength cold-rolled steel sheet of Patent document 3 is produced by heating and retaining a steel sheet having a predetermined composition range at 850°C, which is normally reachable temperature industrially, to transform the steel sheet into austenite, and then rendering it a martensite single-phase structure. A steel sheet of a martensite single-phase structure produced by this invention has a tensile strength of 880 to 1170 MPa, and thus has excellent stretch-flanging performance. However, it has elongation EL (%) lower than 8% and thus has low ductility. In the high strength steel sheet of the invention of Patent document 3; if ductility is improved, press formability can be further improved.

[0007] Moreover, Patent document 4 discloses a method for manufacturing a high tensile strength steel sheet, in which a steel sheet in which the ratio by volume of a low-temperature transformation phase comprising a martensite phase and others and a retained austenite phase is 90% or higher of the entire metal structure is heated and retained to produce a two phase region: a ferrite phase and an austenite phase, a metal structure comprising a fine ferrite phase which has succeeded the laths of the low-temperature transformation phase and the austenite phase is provided, and finally the steel sheet is given such a metal structure that comprises ferrite and the low-temperature transformation phase finely dispersed in the form of laths.

[0008] However, since the steel sheet produced by the steelmaking method disclosed in Patent document 4 has a relatively high cooling stop temperature in the steelmaking process, a large amount of bainite is deposited, while a large amount of retained austenite also remains therein, and therefore the steel sheet has excellent ductility, but has insufficient stretch-flanging performance. By the steelmaking method of Patent document 4, a steel sheet which is excellent in both elongation and stretch-flanging performance cannot be produced.

[0009] JP 2004 091924 discloses a high strength steel sheet having the contents of C, Si+Al, Mn, P, S, Ca and rare

earth elements as prescribed, optionally one or more kinds of the metals selected from Mo, Ni, Cu, Cr and optionally one or more metals selected from Ti, Nb and V, having a space factor of tempered martensite or tempered bainite or ferrite in a base phase structure to the whole structure and the space factor of retained austenite in a second phase structure to the whole structure, the C concentration in the retained austenite and the ratio of the lath-shaped retained austenite occupied in the while retained austenite are described.

[0010] EP 1 365 037 discloses a high strength steel sheet having a base phase structure, the base phase structure being tempered martensite or tempered bainite and accounting for 50% or more in terms of a space factor relative to the whole structure, or the base phase structure comprising tempered martensite or tempered bainite which accounts for 15% or more in terms of a space factor relative to the whole structure and further comprising ferrite, the tempered martensite or the tempered bainite having a hardness which satisfies the relation of Vickers hardness (Hv) $\geq 500 [C] + 30 [Si] + 3 [Mn] + 50$ where [] represents the content (mass %) of each element; and a second phase structure comprising retained austenite which accounts for 3 to 30% in terms of a space factor relative to the whole structure and optionally further comprising bainite and/or martensite,; the retained austenite having a C concentration of 0.8% or more.

[0011] US 2003/0084966 discloses a dual-phase steel sheet containing (on the mass% basis). C: 0.01-0.20%, Si: 0.5% or less, Mn: 0.5-3%, sol. Al: 0.06% or less (inclusive 0%), P: 0.15% or less (exclusive 0%), and S: 0.02% or less (inclusive 0%), and in which the matrix phase contains tempered martensite; tempered martensite and ferrite; tempered bainite; or tempered bainite and ferrite, and the second phase comprises 1 to 30% of martensite at an area ratio based on the entire structure.

[Patent document 1] Japanese Unexamined Patent Application Publication (JP-A) No. S55-122820

[Patent document 2] JP-A-S60-43425

[Patent document 3] Japanese Patent No. 3729108

[Patent document 4] JP-A-2005-272954

[Disclosure of the Invention]

[Problem to be Solved by the Invention]

[0012] As mentioned above, since DP steel sheets, TRIP steel sheets, and martensite single-phase structure steel sheets have their advantages and disadvantages, a steel sheet which has high strength and excellent elongation and stretch-flanging performance at the same time is required. The present invention has been made to solve such a problem, and an object thereof is to provide a high strength steel sheet excellent in both elongation and stretch-flanging performance and a method for manufacturing the same.

[0013] Another object of the present invention is to provide a high strength steel sheet having a tensile strength of 780 MPa or higher, in which elongation and stretch-flanging performance are both improved, and a method for manufacturing the same.

[Means for Solving the Problem]

[0014] The high strength steel sheet of the present invention is constituted of, in percent by mass, C: 0.05 to 0.3%, Si: 3% or less (not including 0%), Mn: 0.5 to 3.0%; Al: 0.01 to 0.1%, optionally further comprising at least an element selected from Ti, Nb, V and Zr in an amount of 0.01 to 1% by mass in total, optionally further comprising Ni and/or Cu in an amount of 1% by mass or lower in total, optionally further comprising Cr: 2% by mass or less and/or Mo: 1% by mass or less, optionally further comprising 0.0001 to 0.005% by mass of B, optionally further comprising Ca and/or REM in an amount of 0.003% by mass or lower in total, and the remainder comprising iron and inevitable impurities, wherein the structure which is a main part of the metal structure is the martensite phase, which is tempered martensite, and finely dispersed annealed bainite; the space factor of the tempered martensite is 70 to 95%; the space factor of the annealed bainite is 5 to 30%; and the total space factor of tempered martensite and annealed bainite is 95% or higher; and a mean grain size of the tempered martensite is 10 μm or lower in terms of the equivalent of a circle diameter, and has a tensile strength of 590 MPa or higher.

[0015] To this end, the inventors of the present invention have studied various structures that can ensure high strength and improve elongation, especially stretch-flanging performance at the same time. As a result, the inventors found the following: by annealed bainite, which is a fine lath-shaped structure, as an initial structure in a two phase temperature region of ferrite + austenite (hereinafter referred to as "two-phase region annealing"), fine annealed bainite produced in a base material acts in a manner of suppressing the growth of austenite, fine tempered martensite is produced from austenite by the following hardening and tempering, and the entire structure is formed from these microstructures. Therefore, elongation and stretch-flanging performance are improved. The inventors accomplished the present invention based on these findings.

[0016] The term "equivalent of a circle diameter" means the diameter of an anticipated circle having the same area

as the grains of tempered martensite, and is determined by subjecting a structure picture to image analysis. Moreover, the term "space factor" means the percentage by volume, and is determined by corroding a structure observation test piece with nital, observing the test piece with an optical microscope (1000 times), and by subjecting the observed structure picture to image analysis. Moreover, annealed bainite is observed as a body centered cubic structure in terms of a crystal structure.

[0017] The method for manufacturing a high strength steel sheet with excellent elongation and stretch-flanging performance according to the present invention comprises using a steel sheet having a space factor of bainite in the entire metal structure of 90% or higher as a material steel sheet; heating and retaining the steel sheet at a temperature of (Ac_3 point $-100^{\circ}C$) or higher but not higher than Ac_3 point for 0 to 2400 seconds (including 0 seconds), and then cooling to a transformation start temperature of martensite, Ms point, or lower at an average cooling rate of $10^{\circ}C/sec.$ or higher, subsequently heating and retaining the steel sheet at a temperature of 300 to $550^{\circ}C$ for 60 to 1200 seconds. The high strength steel sheet of the present invention is thus produced. The material steel sheet can be produced by hot rolling a steel piece having the above-mentioned chemical component or further by cold rolling the same.

Herein, Ac_3 point is a temperature at which a two-phase region comprising an austenite phase and a ferrite phase transforms into an austenite single-phase region that is stable at high temperatures in a temperature raising step.

[0018] The high strength steel sheet according to the present invention may comprise, in addition to the above-mentioned basic components, any of the element groups (a) to (e) described below, or one or more elements selected from a plurality of groups within a range defined for each element group.

(a) an element selected from Ti, Nb, V and Zr: 0.01 to 1% by mass in total

(b) Ni and/or Cu: 1% by mass or less in total

(c) Cr: 2% by mass or less and/or Mo: 1% by mass or less

(d) 0.0001 to 0.005% by mass of B

(e) Ca and/or REM: 0.003% by mass or less in total

[Effect of the Invention]

[0019] In the present invention, a structure which is mainly composed of especially tempered martensite and finely dispersed annealed bainite is provided, wherein the space factors thereof are defined to have predetermined amounts, and the mean grain size of tempered martensite is defined $10\text{ }\mu m$ or smaller. Accordingly, a high strength steel sheet which has strength as high as 590 MPa or higher, excellent elongation and stretch-flanging performance, and thus excellent press formability can be provided.

[Best Mode for Carrying out the Invention]

(1) The best mode for carrying out the invention will be described below in detail.

[0020] A high strength steel sheet according to one embodiment of the present invention is designed to have a structure, as the main body, in which annealed bainite is finely dispersed in tempered martensite, a space factor of the tempered martensite of 70 to 95%, a space factor of the annealed bainite of 5 to 30%, a mean grain size of the tempered martensite of $10\text{ }\mu m$ or smaller in terms of the equivalent of a circle diameter, wherein the structure which is a main part of the metal structure is the martensite phase, which is tempered martensite, and finely dispersed annealed bainite; the space factor of the tempered martensite is 70 to 95%; the space factor of the annealed bainite is 5 to 30%; and the total space factor of tempered martensite and annealed bainite is 95% or higher; and a mean grain size of the tempered martensite is $10\text{ }\mu m$ or lower in terms of the equivalent of a circle diameter, and a tensile strength of 590 MPa or higher. The reasons for limitation of the structure will be described below.

[0021] When the space factor of the annealed bainite is 5% or lower, the pinning effect, which suppresses the growth of austenite, is weak, and austenite grains grow so that martensite grains become large, thereby preventing ensuring good elongation. In contrast, when the space factor is higher than 30%, stretch-flanging performance is lowered. For this reason, the lower limit of annealed bainite is 5%, and preferably 7%, while its upper limit is 30%, and preferably 25%.

[0022] When the space factor of tempered martensite is lower than 50%, strength and stretch-flanging performance are lowered. In contrast, when the space factor is higher than 95%, the steel sheet becomes too hard and thus elongation is lowered. For this reason, the lower limit of the tempered martensite phase is 70%, while its upper limit is 95%, and preferably 85%.

[0023] The mean grain size of the tempered martensite varies depending on the amount of annealed bainite finely dispersed. When the grain size is larger than $10\text{ }\mu m$ in terms of the equivalent of a circle diameter, elongation and stretch-flanging performance are lowered. For this reason, the upper limit is $10\text{ }\mu m$.

[0024] The structure in which the tempered martensite and annealed bainite coexist constitutes the main part of the

structure of the high strength steel sheet of the present invention. Herein, the main part means 95% or higher, and other structures contained in an amount of less than about 10% are permitted because they hardly affect elongation, especially stretch-flanging performance. Examples of other structures include ferrite, pearlite, retained austenite and the like. Of course, the less these structures, the better.

[0025] Chemical component (unit: % by mass) which is preferable for obtaining the structure and strength of the steel sheet according to the present invention will be described now. Examples of such a chemical component include that comprises the followings: C: 0.05 to 0.3%, Si: 0.01 to 3.0%, Mn: 0.5 to 3.0%, and Al: 0.01 to 0.1%, and Fe and inevitable impurities as the remainder. The reasons for component limitation will be described below.

[C: 0.05 to 0.3%]

[0026] C is an important element in producing martensite, and increasing the strength of the steel sheet. When the amount of C is lower than 0.05%, such an effect is excessively lowered. In contrast, from the perspective of increasing strength, the higher the amount of C, the more preferable. However, when the amount of C is higher than 0.3%, a large amount of retained austenite is produced and stretch-flanging performance is lowered. Moreover, weldability is also deteriorated. For this reason, the lower limit of the amount of C is 0.05%, and preferably 0.07%, while its upper limit is 0.3%, and preferably 0.25%.

[Si: 0.01 to 3.0%]

[0027] Si acts as a deoxidizing element when steel is melted, and is an element effective in increasing strength without deteriorating the ductility of steel. Si also acts to suppress deposition of coarse carbide which deteriorates stretch-flanging performance. When the amount of Si is lower than 0.01%, these actions are excessively lowered, while addition of the same in an amount higher than about 3.0% saturates the effect. For this reason, the lower limit of the amount of Si is 0.01%, and preferably 0.1%, while its upper limit is 3.0%, and preferably 2.5%.

[Mn: 0.5 to 3%]

[0028] Mn is an element useful in increasing the hardening characteristics of steel to ensure high strength, but when its amount is lower than 0.5%, such an action is excessively lowered. In contrast, when its amount is higher than 3%, ductility is lowered and processability is thus adversely affected. For this reason, the lower limit of the amount of Mn is 0.5%, and preferably 0.7%, while its upper limit is 3%, and preferably 2.5%.

[Al: 0.01 to 0.1%]

[0029] Al is an element which has a deoxidation effect, and needs to be added in an amount of 0.01% or higher to perform the effect. In contrast, even if it is added in an amount higher than 0.1%, the deoxidation effect is saturated, and it becomes a source of non-metallic mediators to deteriorate physical properties and surface properties. For this reason, the lower limit of the amount of Al is 0.01%, and preferably 0.03%, while its upper limit is 0.1%, and preferably 0.08%.

[0030] Preferable chemical components of the steel sheet the present invention include, in addition to the above-mentioned basic components, Fe and impurities which inevitably get in, for example, P, S, N and O. However, to improve the mechanical characteristics of the steel sheet, any of the auxiliary element groups (a) to (e) described below, or one or more element selected from a plurality of groups may be added within the additional permissible range of each group.

(a) One or more elements selected from Ti, Nb, V and Zr in a total amount of 0.01 to 1%

(b) One or more elements selected from Ni and Cu in a total amount of 1% or lower

(c) One or more elements of Cr: 2% or lower, Mo: 1% or lower

(d) B in an amount of 0.0001 to 0.005%

(e) One or more elements selected from Ca and REM in a total amount of 0.003% or lower

[One or more member of Ti, Nb, V and Zr: in a total amount of 0.01 to 1%]

[0031] These elements form precipitates such as carbides, nitrides, and carbonitrides together with C and N, and contribute to the improvement of strength. They also have an action to increase elongation and stretch-flanging performance by micronizing crystal grains during hot rolling. When the total amount of these elements added is 0.01%, such an action is excessively lowered. In contrast, when the amount is higher than 1%, elongation and stretch-flanging performance are lowered rather than increased. For this reason, the lower limit of the total amount of one or more of

these elements is 0.01%, and preferably 0.03%, while its upper limit is 1.0%, and preferably 0.7%.

[One or more members of Ni and Cu: in a total amount of 1% or lower]

[0032] These elements are effective in maintaining the balance of strength and ductility high and realizing high strength at the same time. To effectively exhibit such an effect, it is preferable to add the elements in an amount of 0.05% or higher. Meanwhile, the higher the amount of these elements contained, the higher the above-mentioned effect, but when the total amount of one or more of these elements is higher than 1%, such an effect is saturated, and cracks may occur during hot rolling. For this reason, the upper limit of the total amount of these elements is 1.0%, and preferably 0.7%.

[One or more members of Cr: 2% or lower, Mo: 1% or lower]

[0033] These elements are both effective in stabilizing the austenite phase, and facilitating the generation of bainite in the course of cooling. The higher the amount of the elements contained, the higher the effect, but when they are contained in an excessive amount, ductility is deteriorated rather than improved. For this reason, the amount of Cr is 2.0% or lower, and more preferably 1.5% or lower, while the amount of Mo is 1.0% or lower, and more preferably 0.7% or lower.

[B: 0.0001 to 0.005%]

[0034] B is an element effective in improving hardening characteristics, and increasing the strength of the steel sheet when added in a minute amount. To perform such an effect, it is preferable that the element is contained in an amount of 0.0001% or higher. However, when the amount of B contained is excessive and higher than 0.005%, crystal grain boundaries may be embrittled and cracks may occur during rolling. For this reason, the upper limit of the amount of B is 0.005%.

[One or more members of Ca and REM: in a total amount of 0.003% or lower]

[0035] These elements are effective in controlling the form of sulfide in the steel and improving processability. The higher the amount of the elements contained, the higher such an effect, but when they are contained in an excessively high amount, the above-mentioned effect is saturated. Therefore, the upper limit of the total amount of one or more members of these elements is 0.003%.

[0036] The method for manufacturing the high strength steel sheet according to an embodiment of the present invention will be now described. First, a material steel sheet which has the above-mentioned chemical components and a space factor of bainite to the entire structure of 90% or higher is prepared. Second, this material steel sheet is retained at a temperature of (Ac_3 point-100) °C or higher but not higher than Ac_3 for 0 sec. or longer but not longer than 2400 sec., and then an annealing heat treatment is carried out, in which the material steel sheet is cooled to the martensite transformation start temperature, M_s point, or lower at an average cooling rate of 10°C/sec. or higher. Subsequently, a tempering heat treatment is carried out, in which the material steel sheet is retained at 300°C or higher but not higher than 550°C for 60 sec. or longer but not longer than 1200 sec., whereby a microstructure steel sheet mainly composed of the tempered martensite and annealed bainite and having a tensile strength of 590 MPa or higher is obtained.

[0037] The material steel sheet can be produced by the steps described below. First, steel having the above-mentioned chemical components is melted. By using the steel slab, hot rolling is terminated in such a manner that the finishing temperature is not lower than Ar_3 point. Second, the steel slab is cooled at an average cooling rate of 10°C/sec. or higher to the bainite transformation temperature (about 350 to 450°C), and is wound up at the same temperature. When the finishing temperature is lower than Ar_3 point or the cooling rate after the hot rolling is lower than 10°C/sec., a ferrite phase is likely to be produced in the hot-rolled steel sheet, and the space factor of bainite of the material steel sheet becomes lower than 90%. The material steel sheet used may be a cold-rolled steel sheet produced by hot rolling steel and then subjecting the steel to an acid cleaning process and cold rolling. In the steel types which contain Ti, Nb, V and Zr, to re-solutionize precipitates containing the elements produced before hot rolling, it is preferable to heat and retain the steel piece at a relatively high temperature during hot rolling.

[0038] As for the material steel sheet, the space factor of bainite can be made 90% or higher by subjecting a hot-rolled steel sheet which does not meet the above hot rolling condition and cooling condition to preliminary annealing. This preliminary annealing is a heat treatment in which a hot-rolled steel sheet is retained in a temperature range of Ac_3 point or higher for about 5 seconds, and then the steel sheet is cooled at an average cooling rate of 10°C/sec. or higher to the bainite transformation temperature. When the retaining temperature is lower than Ac_3 point, the ferrite phase is likely to be produced in the steel sheet, and the space factor of bainite is lowered. Even when the steel sheet is retained at a temperature Ac_3 point or higher, if the retaining time is shorter than about 5 seconds, transformation into austenite is

insufficient, and therefore the space factor becomes lower than 90%. Even when the steel sheet is subjected to the preliminary annealing, it can be cold-rolled thereafter to prepare as a cold-rolled steel sheet, and this can be used as the material steel sheet.

[0039] After the material steel sheet is prepared, the material steel sheet is retained at a temperature (Ac_3 point -100) °C or higher but not higher than Ac_3 for 0 sec. or longer (including 0 sec.) but not longer than 2400 sec., and then two-phase region annealing is carried out, in which the material steel sheet is cooled to the martensite transformation start temperature, Ms point, or lower at an average cooling rate of 10°C/sec. or higher, followed by tempering. By such a heat treatment, the structure of the high strength steel sheet according to the present invention is obtained. First, the conditions of the two-phase region annealing will be described below.

[0040] The reason why the annealing temperature of the two-phase region annealing is set to (Ac_3 point -100) °C or higher but not higher than Ac_3 is as follows: When the annealing temperature is set to a temperature range higher than Ac_3 point in which the austenite single phase is stable, the crystal grains of austenite grow in the material steel sheet and combine with each other to become coarse, and the growth inhibitory effect (pinning effect) of austenite by finely dispersed annealed bainite cannot be obtained. For this reason, a fine dual phase steel sheet cannot be obtained, and the stretch-flanging performance of the high strength steel sheet is lowered. In contrast, if the steel sheet is annealed at a temperature lower than (Ac_3 point -100) °C, transformation into austenite does not proceed sufficiently, and the space factor of martensite after the heat treatment becomes lower than 50%, and the stretch-flanging performance of the steel sheet is thus lowered.

[0041] As for the annealing time (heating and retaining time), austenite having a space factor of about 50% and thus martensite can be obtained simply by heating the steel sheet to the annealing temperature, but the time is preferably 1 sec. or longer, and more preferably 5 seconds or longer. In contrast, if the material steel sheet is retained longer than necessary, austenite grains become coarse, and fine martensite cannot be obtained. Therefore, it is preferable that the retaining time is limited to 2400 sec. or shorter, and preferably 1200 sec. or shorter.

[0042] When the average cooling rate after heating and retaining is lower than 10°C/sec. or the cooling stop temperature is higher than the martensite transformation start temperature, Ms point, a retained austenite phase, a pearlite phase and a ferrite phase are produced, a cementite phase is deposited, and structures other than martensite are formed from austenite in large amounts, whereby elongation and stretch-flanging performance are lowered.

[0043] Tempering (reheating treatment) is carried out after the two-phase region annealing, which is a process for improving elongation and stretch-flanging performance by softening hard martensite, and decomposing retained austenite which produces martensite by working-induced transformation. Tempering conditions are as follows: the material steel sheet is retained at a temperature of 300°C or higher but not higher than 550°C for 60 sec. or longer but not longer than 1200 sec. The cooling rate after retaining is not especially limited.

[0044] When the tempering temperature is lower than 300°C, softening of martensite is insufficient, and the elongation and stretch-flanging performance of the steel sheet are lowered. In contrast, when the temperature is higher than 550°C, a coarse cementite phase is deposited, and the stretch-flanging performance of the steel sheet is lowered. For this reason, tempering is carried out at a temperature of 300°C or higher but not higher than 550°C.

[0045] When the retaining time of tempering is shorter than 60 sec., softening of martensite is insufficient, while when the time is longer than 1200 sec., martensite is too softened, which makes ensuring strength difficult, and deposition of cementite lowers the stretch-flanging performance of the steel sheet. For this reason, the lower limit of the retaining time during tempering is 60 sec., preferably 90 sec. or longer, and more preferably 120 sec., and the upper limit is 1200 sec., preferably 900 sec., and more preferably 600 sec.

[0046] The present invention will be described in more detail below with reference to Examples, but the present invention should not be interpreted as being restricted by such Examples.

(Example 1)

[0047] Steel slabs having chemical compositions shown in Table 1 below were melted, and the steel slabs were heated to about 1000 to 1100°C. The steel slabs were subjected to hot rolling or further preliminary annealing under the conditions described in Table 2 below, producing material steel sheets. The average cooling rate after the hot rolling was 50°C/sec. test pieces for observing structures were collected from the material steel sheets, and the space factors of bainite were determined by observing structure constitutions with a microscope and subjecting microscope structure pictures after being corroded with nital to image analysis. The values of Ac_3 point and Ms point calculated from the components by a known equation are also shown in Table 1 for reference. Moreover, the results of structure observation are also shown in Table 2. The obtained material steel sheets were subjected to final annealing (two-phase region annealing) and tempering under the conditions shown in Table 3 below, producing sample steel sheets.

[0048]

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TABLE 1

5	Steel symbol	Chemical components (% by mass)							Transformation temperature (° C.)		Remarks
		C	Si	Mu	P	S	Al	Others	Ac ₃	Ms	
	A	0.11	1.21	1.62	0.011	0.001	0.044	-	873	448	Component of invention
10	B	0.18	1.54	2.06	0.120	0.002	0.048	-	934	406	Component of invention
	C	0.01	0.88	1.56	0.012	0.002	0.044	-	908	487	Component of comparison
15	D	0.08	1.86	2.29	0.016	0.001	0.039	-	894	433	Component of invention
	E	0.25	1.55	2.01	0.020	0.002	0.034	-	845	382	Component of invention
20	F	0.35	1.51	2.01	0.012	0.002	0.033	-	819	346	Component of comparison
	G	0.18	0.05	2.05	0.009	0.001	0.031	-	783	406	Component of invention
25	H	0.16	2.63	1.22	0.009	0.002	0.034	-	930	446	Component of invention
	I	0.21	3.52	1.99	0.011	0.001	0.038	-	938	398	Component of comparison
30	J	0.14	1.54	0.38	0.009	0.003	0.039	-	913	486	Component of comparison
	K	0.13	1.56	0.62	0.009	0.001	0.038	-	909	480	Component of invention
35	L	0.21	1.24	2.78	0.006	0.002	0.033	Zr: 0.021	806	367	Component of invention
	M	0.19	1.53	3.49	0.013	0.001	0.033	-	808	346	Component of comparison
40	N	0.17	1.38	2.02	0.015	0.002	0.005	V: 0.018	842	409	Component of invention
	O	0.19	1.32	1.97	0.011	0.003	0.089	-	865	407	Component of invention
45	P	0.17	1.42	2.06	0.012	0.001	0.167	-	903	413	Component of comparison
	Q	0.17	1.39	2.00	0.009	0.002	0.019	Ni: 0.2	842	411	Component of invention
50	R	0.16	1.56	1.93	0.010	0.001	0.031	Cu: 0.1	860	418	Component of invention
	S	0.17	1.33	2.19	0.012	0.002	0.042	Cr: 0.35	841	397	Component of invention
55	T	0.16	1.27	2.03	0.015	0.003	0.042	Mo: 0.1	855	414	Component of invention
	U	0.18	1.36	1.93	0.016	0.003	0.045	B: 0.0002	856	411	Component of invention

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(continued)

5	Steel	Chemical components (% by mass)							Transformation temperature (° C.)		Remarks
	symbol	C	Si	Mu	P	S	Al	Others	Ac ₃	Ms	
	V	0.17	1.40	1.97	0.014	0.002	0.039	Ca + REM: 0.001	855	413	Component of invention
10	(Note) Remainder is Fe and inevitable impurities										

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TABLE 2

Sample No.	Steel symbol	Hot-rolling conditions			Preliminary annealing conditions			Material steel sheet structure		
		Finishing temperature °C.	Winding temperature °C.	Heating temperature °C.	Retaining time sec.	Cooling rate °C./sec.	Cooling stop temperature °C.	Phase constitution	Space factor of bainite %	Remarks
1	A	930	550	900	120	50	400	B + γ	97	Conditions of invention
2	B	950	550	950	120	50	400	B + γ	94	Conditions of invention
3	C	870	500	930	90	20	420	B + α + γ	85	Conditions of comparison
4	D	860	550	930	240	50	400	B + γ	96	Conditions of invention
5	E	890	550	900	180	50	370	B + γ	92	Conditions of invention
6	F	850	500	930	120	50	350	B + γ	91	Conditions of comparison
7	G	800	500	910	60	40	400	B + γ	100	Conditions of invention
8	H	850	600	930	120	50	400	B + γ	91	Conditions of invention
9	I	900	550	930	120	50	400	B + γ	87	Conditions of comparison
10	J	900	500	930	60	50	400	B + γ	95	Conditions of comparison
11	K	900	550	930	120	50	430	B + γ	96	Conditions of invention
12	L	900	550	930	360	50	400	B + γ	94	Conditions of invention
13	M	850	500	900	120	50	400	B + γ	92	Conditions of comparison
14	N	900	500	860	120	50	400	B + γ	95	Conditions of invention
15	O	900	500	880	30	50	430	B + γ	94	Conditions of invention

(continued)

Sample No.	Hot-rolling conditions			Preliminary annealing conditions			Material steel sheet structure			Remarks
	Steel symbol	Finishing temperature °C.	Winding temperature °C.	Heating temperature °C.	Retaining time sec.	Cooling rate °C./sec.	Cooling stop temperature °C.	Phase constitution	Space factor of bainite %	
16	P	900	550	930	180	50	400	B + γ	96	Conditions of comparison
17	Q	870	550	870	120	40	400	B + γ	93	Conditions of invention
18	R	880	550	890	120	50	400	B + γ	94	Conditions of invention
19	S	900	550	880	10	50	400	B + γ	94	Conditions of invention
20	T	900	550	870	120	50	430	B + γ	96	Conditions of invention
21	U	900	550	900	120	50	400	B + γ	93	Conditions of invention
22	V	900	550	890	120	50	400	B + γ	94	Conditions of invention
23	B	930	400	-	-	-	-	B + γ	92	Conditions of invention
24	B	930	420	-	-	-	-	B + γ	91	Conditions of invention
25	A	900	400	-	-	-	-	B + γ	96	Conditions of invention
26	B	930	350	-	-	-	-	B + γ	96	Conditions of invention
27	A	930	430	-	-	-	-	B + γ	98	Conditions of invention
(Note)										
α : Ferrite,										
B: Bainite.										
γ : Austenite										

[0049] The structures (space factors of annealed bainite, space factors and mean grain sizes of tempered martensite), and mechanical characteristics (tensile strength TS, elongation EL and stretch-flanging performance) of the sample steel sheets were determined in the manner described below.

Test pieces for observing structures were collected from the sample steel sheets, and the space factors of annealed bainite and tempered martensite were determined by subjecting microscope structure pictures after being corroded with nital to image analysis. Moreover, the mean grain sizes of tempered martensite were determined by measuring the areas of the grains by structure analysis using FE/SEM-EBSP, determining the diameters of circles corresponding to the grains, and averaging the diameters.

TABLE 3

	Sample No.	Steel symbol	Final annealing conditions			Tempering conditions			Remarks
			Heating temperature °C.	Retaining time sec.	Cooling rate °C./sec.	Cooling stop temperature °C.	Heating temperature °C.	Retaining time sec.	
	1	A	850	180	500	20	400	180	Conditions of invention
	2	B	850	180	500	20	400	120	Conditions of invention
	3	C	850	200	100	20	500	180	Conditions of comparison
	4	D	870	180	200	20	500	180	Conditions of invention
	5	E	815	80	300	20	520	120	Conditions of invention
	6	F	810	220	300	20	350	180	Conditions of comparison
	7	G	750	120	300	100	400	120	Conditions of invention
	8	H	910	350	300	50	500	180	Conditions of invention
	9	I	870	100	200	20	350	120	Conditions of comparison
	10	J	800	100	200	20	450	180	Conditions of comparison
	11	K	850	180	500	20	520	180	Conditions of invention
	12	L	770	120	300	20	500	180	Conditions of invention
	13	M	770	180	200	20	400	180	Conditions of comparison
	14	N	820	120	500	20	500	180	Conditions of invention
	15	O	850	180	300	20	500	180	Conditions of invention
	16	P	880	120	100	20	400	120	Conditions of comparison

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(continued)

			Final annealing conditions			Tempering conditions			Remarks
			Heating temperature °C.	Retaining time sec.	Cooling rate °C./sec.	Cooling stop temperature °C.	Heating temperature °C.	Retaining time sec.	
5									
	Sample No.	Steel symbol							
	17	Q	825	180	500	20	500	120	Conditions of invention
10									Conditions of invention
	18	R	830	120	500	20	500	180	Conditions of invention
	19	S	810	120	300	20	500	180	Conditions of invention
15									Conditions of invention
	20	T	850	60	300	20	500	180	Conditions of invention
	21	U	820	180	500	20	500	180	Conditions of invention
20									Conditions of invention
	22	V	830	120	500	20	500	180	Conditions of invention
	23	B	880	180	300	20	450	180	Conditions of invention
	24	B	900	120	300	20	500	120	Conditions of invention
25									Conditions of invention
	25	A	850	180	300	20	450	180	Conditions of invention
	26	B	850	180	300	20	500	180	Conditions of invention
30									Conditions of invention
	27	A	800	120	500	20	500	180	Conditions of invention

[0050] Among the mechanical properties, tensile strength and elongation were determined by using a universal tensile tester manufactured by Instron and JIS No. 5 tensile test piece. Stretch-flanging performance was determined by measuring a hole expansion rate (A) by using a 20-ton hole expansion tester manufactured by Tokyo Koki, according to The Japan Iron and Steel Federation standard (JFST 1001-1996), and was evaluated based on this. The results of these measurements are also shown in Table 4. In Table 4, as for "evaluation", tensile strength (TS) of 590 MPa or higher, elongation (EL) of 10% or higher, and hole expansion rate (λ) of 80% or higher were rated excellent characteristics. The samples which were excellent in all three characteristics were rated o; those which were excellent in two characteristics out of three were rated Δ ; and those which were excellent in only one characteristic out of three were rated x.

[0051] It can be seen from Table 4 that the sample steel sheets (examples of the invention) sample Nos. 1, 2, 4, 5, 7, 8, 11, 12, 14, 15 and 17 to 27 in which the conditions of the present invention were met in terms of all of chemical components, material steel sheet structures, final annealing conditions and tempering conditions all have tensile strengths as high as 590 MPa or higher, elongations of 10% or higher, and stretch-flanging performances of hole expansion rates of 80% or higher. That is, it can be seen that these samples have high strength and yet excellent elongation and stretch-flanging performance, and excellent press formability.

(2)

[0052]

TABLE 4

5	Structure parameters									
	Sample No.	Steel symbol	Space factor	Space factor	Mean grain size of	Mechanical characteristics			Evaluation	Remarks
			of annealed B %	of tempered M %	tempered M μm	TS MPa	EL %	λ %		
10										
	1	A	12	86	7.4	984	13.5	127.0	○	Example of invention
	2	B	29	70	8.3	689	32.1	80.8	○	Example of invention
15	3	C	19	80	8.1	554	31.9	81.5	△	Comparative example
	4	D	12	86	7.3	992	11.9	114.2	○	Example of invention
20	5	E	13	84	7.8	1108	12.1	107.9	○	Example of invention
	6	F	10	89	8.3	1388	6.7	53.2	X	Comparative example
25	7	G	16	83	8.9	782	18.1	106.8	○	Example of invention
	8	H	12	86	7.9	1022	12.9	104.0	○	Example of invention
	9	I	25	76	9.1	1382	5.8	27.4	X	Comparative example
30	10	J	35	65	8.8	588	28.8	64.9	X	Comparative example
	11	K	22	75	8.2	603	28.3	86.3	○	Example of invention
35	12	L	14	85	7.9	1109	12.5	100.5	○	Examples of invention
	13	M	12	85	8.1	1299	8.1	58.7	X	Comparative example
40	14	N	11	88	7.3	1031	13.9	124.0	○	Example of invention
	15	O	10	89	7.2	1017	14.7	127.9	○	Example of invention
	16	P	13	86	8.1	1031	10.3	61.1	△	Comparative example
45	17	Q	10	89	8.0	1022	14.3	122.8	○	Example of invention
	18	R	13	86	7.9	1098	12.9	121.4	○	Example of invention
50	19	S	12	86	8.5	1139	10.9	114.9	○	Example of invention
	20	T	7	92	8.8	1222	10.7	98.7	○	Example of invention
	21	U	12	87	8.1	1154	11.1	104.8	○	Example of invention
55	22	V	12	86	7.9	1095	11.9	106.3	○	Example of invention

(continued)

	Structure parameters					Mechanical characteristics				
	Sample No.	Steel symbol	Space factor of annealed B %	Space factor of tempered M %	Mean grain size of tempered M μm					
						TS MPa	EL %	λ %	Evaluation	Remarks
5										
10	23	B	13	86	7.9	989	13.2	112.8	○	Example of invention
	24	B	12	87	7.7	981	14.3	127.3	○	Example of invention
15	25	A	12	86	7.5	789	17.5	117.7	○	Example of invention
	26	B	24	75	8.7	708	19.8	103.2	○	Example of invention
20	27	A	19	80	8.3	737	18.9	128.3	○	Example of invention
	(Note) B: Bainite, M: Martensite									

[Industrial Applicability]

[0053] The high strength steel sheet according to the present invention has excellent elongation and stretch-flanging performance at the same time, and thus has excellent press formability. Therefore, the high strength steel sheet according to the present invention can be processed by press molding to be used for various industrial products such as automobiles, especially for industrial products where weight reduction is necessary.

Claims

1. A high strength steel sheet which comprises, in percent by mass, C: 0.05 to 0.3%; Si: 3% or less (not including 0%.); Mn: 0.5 to 3.0%; Al: 0.01 to 0.1%; optionally further comprising at least an element selected from Ti, Nb, V and Zr in an amount of 0.01 to 1% by mass in total, optionally further comprising Ni and/or Cu in an amount of 1% by mass or lower in total, optionally further comprising Cr: 2% by mass or less and/or Mo: 1% by mass or less, optionally further comprising 0.0001 to 0.005% by mass of B, optionally further comprising Ca and/or REM in an amount of 0.003% by mass or lower in total, and the remainder comprising iron and inevitable impurities, wherein the structure which is a main part of the metal structure is the martensite phase, which is tempered martensite, and finely dispersed annealed bainite; the space factor of the tempered martensite is 70 to 95%; the space factor of the annealed bainite is 5 to 30%; and the total space factor of tempered martensite and annealed bainite is 95% or higher; and a mean grain size of the tempered martensite is 10 μm or lower in terms of the equivalent of a circle diameter, and a tensile strength of 590 MPa or higher.
2. A method for manufacturing a high strength steel sheet according to claim 1, the method comprising using a steel sheet having a space factor of bainite in the entire metal structure of 90% or higher as a material steel sheet; heating and retaining the material steel sheet at a temperature of (A_{c3} point -100°C) or higher but not higher than A_{c3} point for 0 to 2400 seconds (including 0 seconds); then cooling the material steel sheet to a transformation start temperature of martensite, M_s point, or lower at an average cooling rate of 10°C/sec. or higher; and subsequently conducting a heat treatment in which the steel sheet is heated and retained at a temperature of 300 to 550°C for 60 to 1200 seconds.

Patentansprüche

1. Hochfestes Stahlblech, das in Masseprozent umfasst: C: 0,05 bis 0,3 %; Si: 3 % oder weniger (ausgenommen 0

5 %); Mn: 0,5 bis 3,0 %; Al: 0,01 bis 0,1 %; optional weiterhin umfassend wenigstens ein Element ausgewählt aus Ti, Nb, V und Zr in einer Menge von insgesamt 0,01 bis 1 Masse%, optional weiterhin umfassend Ni und/oder Cu in einer Menge von insgesamt 1 Masse% oder weniger, optional weiterhin umfassend Cr: 2 Masse% oder weniger und/oder Mo: 1 Masse% oder weniger, optional weiterhin umfassend 0,0001 bis 0,005 Masse% B, optional weiterhin umfassend Ca und/oder Seltenerdmetalle in einer Menge von insgesamt 0,003 Masse% oder weniger, und wobei der Rest Eisen und unvermeidbare Verunreinigungen umfasst, wobei die Struktur, die ein Hauptbestandteil der Metallstruktur ist, die Martensitphase, bei der es sich um angelassenen Martensit handelt, und fein verteilter geglähter Bainit ist; der Raumfaktor des angelassenen Martensits 70 bis 95 % beträgt; der Raumfaktor des geglähten Bainits 5 bis 30 % beträgt; und der Gesamt-Raumfaktor des angelassenen Martensits und des geglähten Bainits 95 % oder mehr beträgt; und eine mittlere Korngröße des angelassenen Martensits, bezogen auf das Äquivalent eines Kreis-

10 durchmessers, 10 μm oder weniger beträgt, und eine Zugfestigkeit von 590 MPa oder mehr.

2. Verfahren zur Herstellung eines hochfesten Stahlblechs nach Anspruch 1, wobei das Verfahren umfasst: Verwenden eines Stahlblechs mit einem Raumfaktor von Bainit in der gesamten Metallstruktur von 90 % oder mehr als Material-
- 15 Stahlblech; Erhitzen und Halten des Material-Stahlblechs auf/bei eine(r) Temperatur von (A_{c3} -Punkt - 100 °C) oder höher, jedoch nicht höher als der A_{c3} -Punkt, für 0 bis 2400 Sekunden (einschließlich 0 Sekunden); dann Abkühlen des Material-Stahlblechs auf eine Umwandlungsstarttemperatur von Martensit, den M_s -Punkt, oder niedriger mit einer durchschnittlichen Abkühlgeschwindigkeit von 10 °C/s oder höher; und anschließend Durchführen einer Wärmebehandlung, bei der das Stahlblech 60 bis 1200 Sekunden lang auf/bei eine(r) Temperatur von 300 bis 550 °C
- 20 erhitzt und gehalten wird.

Revendications

- 25 1. Feuille d'acier à haute résistance qui comprend, en pour cent en masse, C : 0,05 à 0,3 % ; Si : 3 % ou moins (sans inclure 0 %) ; Mn : 0,5 à 3,0 % ; Al : 0,01 à 0,1 % ; comprenant facultativement au moins un élément choisi parmi Ti, Nb, V et Zr dans une quantité de 0,01 à 1 % en masse au total, comprenant en outre facultativement Ni et/ou Cu dans une quantité de 1 % en masse ou moins au total, comprenant en outre facultativement Cr : 2 % en masse ou moins et/ou Mo : 1 % en masse ou moins, comprenant en outre facultativement 0,0001 à 0,005 % en masse de
- 30 B, comprenant en outre facultativement Ca et/ou des métaux de terres rares dans une quantité de 0,003 % en masse ou moins au total, et le reste comprenant du fer et des impuretés inévitables, dans laquelle la structure qui est une partie principale de la structure métallique est la phase de martensite qui est de la martensite revenue, et de la bainite recuite finement dispersée ; le facteur d'espacement de la martensite revenue est de 70 à 95 % ; le facteur d'espacement de la bainite recuite est de 5 à 30 % ; et le facteur d'espacement total de martensite revenue et de bainite recuite est de 95 % ou plus ; et une taille moyenne de grain de la martensite revenue est de 10 μm ou moins en termes de l'équivalent d'un diamètre de cercle, et une résistance à la traction de 590 MPa ou plus.
- 35 2. Procédé de fabrication d'une feuille d'acier à haute résistance selon la revendication 1, le procédé comprenant l'utilisation d'une feuille d'acier ayant un facteur d'espacement de bainite dans la totalité de la structure métallique de 90 % ou plus en tant que feuille d'acier de matériau ; le chauffage et le maintien de la feuille d'acier de matériau à une température de (point A_{c3} -100 °C) ou plus mais non supérieure au point A_{c3} pendant 0 à 2400 secondes (y compris 0 seconde) ; puis le refroidissement de la feuille d'acier de matériau à une température de démarrage de transformation de la martensite, point M_s , ou moins à une vitesse de refroidissement moyenne de 10 °C/s ou plus ; et ensuite la réalisation d'un traitement thermique dans lequel la feuille d'acier est chauffée et maintenue à une
- 40 température de 300 à 550 °C pendant 60 à 1200 secondes.
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REFERENCES CITED IN THE DESCRIPTION

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