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(54) **HIGH-STRENGTH STEEL SHEET AND PRODUCTION METHOD THEREFOR**

HOCHFESTES STAHLBLECH UND HERSTELLUNGSVERFAHREN DAFÜR

TÔLE D'ACIER À HAUTE RÉSISTANCE ET SON PROCÉDÉ DE PRODUCTION

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Description

Technical Field

[0001] The present invention relates to high-strength steel sheets which are suited as can-making materials used in the production of food cans and beverage cans, and to methods for manufacturing such steel sheets. The high-strength steel sheets of the invention exhibit highly excellent formability and can be suitably used for the manufacturing of easy-open-ends (EOEs) and welded can bodies.

Background Art

[0002] Steel sheets called DR (double reduced) steels are sometimes used as can-making steel sheets for the production of beverage cans and food cans and are formed into parts such as lids, bottoms and three-piece can bodies. In the manufacturing of DR steels, the steel sheets are cold rolled again after annealing. The DR steels can be easily reduced in thickness while increasing hardness as compared to SR (single reduced) steels whose production involves only temper rolling with a small rolling reduction.

[0003] In recent years, considerations for the reduction of environmental load and the saving of cost require that the amount of steel sheets used in beverage cans and food cans be reduced. This trend has led to a greater demand for the use of DR steels as can-making steel sheets in order to facilitate the thinning of steel sheets.

[0004] With the hardness being increased as a result of work hardening, the DR steels generally have low formability. It is therefore necessary that the formability of the DR steels be improved in order for the DR steels to be suitably used as can-making steel sheets. For example, Patent Literatures 1 and 2 propose DR steels having improved formability.

[0005] WO2008018531 proposes DR steels characterized in that the steel contains, in mass%, C: 0.02% to 0.06%, Si: 0.03% or less, Mn: 0.05% to 0.5%, P: 0.02% or less, S: 0.02% or less, Al: 0.02% to 0.10% and N: 0.008% to 0.015%, the balance being Fe and inevitable impurities, the amount of solute N (Ntotal - NasAlN) in the steel sheet is 0.006% or more, the total elongation in the rolling direction after aging treatment is 10% or more, the total elongation in the sheet width direction after aging treatment is 5% or more, and the average Lankford value after aging treatment is 1.0 or less.

[0006] Patent Literature 2 proposes high-strength thin steel sheets with excellent flangeability for welded cans characterized in that the steel contains, in mass%, C: more than 0.04% and 0.08% or more, Si: 0.02% or less, Mn: 1.0% or less, P: 0.04% or less, S: 0.05% or less, Al: 0.1% or less and N: 0.005 to 0.02%, the total of solute C and solute N dissolved in the steel sheet satisfies 50 ppm ≤ solute C + solute N ≤ 200 ppm, the amount of solute C in the steel sheet is 50 ppm or more and the amount of solute N in the steel sheet is 50 ppm or more, the balance of the composition being Fe and inevitable impurities. WO2013151085 discloses a high strength and high form ability steel sheet comprising, by mass: more than 0.020% and less than 0.040% C; 0.003% to 0.100% Si; 0.10% to 0.60% Mn; 0.001% to 0.100% P; 0.001 % to 0.020% S; 0.005% to 0.100% Al, and more than 0.0130% to 0.0170% of N, remainder Fe and inevitable impurities. The steel sheet has a tensile strength in a rolling direction of not lower than 520 MPa; an Erichsen value of not less than 5.0 mm; and a resin film layer at least on a side to be an inner surface of a can.

Summary of Invention

Technical Problem

[0007] However, the above techniques in the art have the following problems.

[0008] The technique described in WO2008018531 does not necessarily realize good formability depending on conditions such as the number of steps in the formation of rivets in EOE cans. Further, the technique described in Patent Literature 1 does not attain sufficient workability such as flangeability for three-piece cans.

[0009] In the technique described in JP2002294399 rivet formability required for the production of EOE cans is insufficient. Further, the technique entails prolonged over-aging treatment in order to decrease the amount of solute C, causing a decrease in production efficiency.

[0010] The present invention has been made in light of the circumstances discussed above. To solve the problems in the art described hereinabove, an object of the invention is to provide high-strength steel sheets having good formability (workability) and strength and methods for manufacturing such steel sheets.

Solution to Problem

[0011] To achieve the above object, the present inventors carried out extensive studies. As a result, the present inventors have found that the optimization of chemical composition of steel, hot rolling conditions, cold rolling conditions, annealing conditions and secondary cold rolling conditions (DR conditions) attains a tensile strength of 530 MPa or more and an elongation of 7% or more in the transverse direction after aging treatment. Further, the present inventors have found that the average ferrite grain size and the density of dislocations at 1/4 sheet thickness contribute to the satisfaction of the above tensile strength and elongation. The present invention has been completed based on the findings. Specifically, the invention resides in the following aspects.

(1) a high-strength steel sheet as specified in claim 1;
(2) a method for manufacturing the high-strength steel sheet as specified in claim 2.

Advantageous Effects of Invention

[0012] The high-strength steel sheets of the invention have high formability as described above, and may be suitably used in applications in which the steel sheets are formed into rivets or are flanged. In particular, the inventive high-strength steel sheets have a tensile strength of 530 MPa or more. This sufficient strength allows the sheets to form quality can bodies or lids even when the sheet thickness is reduced compared to the conventional materials. The reduction of sheet thickness saves resources and costs.

[0013] The high-strength steel sheets of the invention, which are excellent in formability and strength, are not only used in various types of metal cans but are also expected to find use in a wide range of applications such as battery interior cases, various home appliance and electrical parts, and automobile parts.

Description of Embodiments

[0014] Hereinbelow, some embodiments of the invention will be described. However, the scope of the invention is not limited to such embodiments.

[0015] The high-strength steel sheets of the invention have a specific chemical composition, and the average ferrite grain size and the density of dislocations at 1/4 sheet thickness are controlled to fall in the specific ranges. By virtue of this configuration, the inventive high-strength steel sheets attain excellent formability while exhibiting high strength. In the following, the chemical composition, the average ferrite grain size, the density of dislocations at 1/4 sheet thickness, the quality (high strength, high formability) of the high-strength steel sheets, and the methods for manufacturing the high-strength steel sheets will be sequentially described.

<Chemical composition>

[0016] The high-strength steel sheet of the invention has a chemical composition including, in mass%, C: 0.010% to 0.080%, Si: 0.05% or less, Mn: 0.10% to 0.70%, P: 0.03% or less, S: 0.020% or less, Al: 0.005% to 0.070% and N: 0.0120% to 0.0180%, the balance being Fe and inevitable impurities. Of the N content in the steel, 0.0100% or more is the content of solute nitrogen. These components will be described below. In the following description, "%" indicates "mass%".

C: 0.010% to 0.080%

[0017] Carbon is an element that contributes to increasing the strength of the steel sheets. By limiting the C content to 0.010% or more, the steel can attain a tensile strength of 530 MPa or more in the transverse direction after aging treatment. If the C content exceeds 0.080%, the elongation in the transverse direction after aging treatment falls to below 7% and the steel sheets exhibit poor flangeability or rivet formability. Thus, the C content needs to be limited to 0.080% or less. To ensure good flangeability and rivet formability, it is preferable that the C content be less than 0.040%. Because the average ferrite grain size is reduced with increasing C content, it is preferable that the C content be 0.020% or more in order to ensure that the steel sheets will exhibit high strength.

Si: 0.05% or less

[0018] If the steel sheets contain an excessively large amount of silicon, the element is enriched at the surface to cause a decrease in the surface treatment properties of the steel sheets. Consequently, the corrosion resistance of the steel sheets is reduced. Thus, the Si content needs to be limited to 0.05% or less. The Si content is preferably 0.03% or less.

Mn: 0.10% to 0.70%

[0019] Manganese has an effect of enhancing the hardness of the steel sheets by solution strengthening. Further, manganese forms MnS and thereby effectively prevents the decrease in hot ductility (casting properties) ascribed to sulfur present in the steel. To obtain these effects, the Mn content needs to be limited to 0.10% or more. Because manganese has an effect of reducing the grain size, it is preferable that the Mn content be 0.20% or more. Further, manganese decreases the rate of the diffusion of nitrogen and thereby inhibits the formation of AlN to ensure the presence of nitrogen as solute. Thus, the addition of manganese is effective particularly when the tensile strength is to be increased to 590 MPa or more. In view of these facts, it is more preferable that the Mn content be more than 0.50%. The Mn content is limited to 0.70% or less because any excessive addition of manganese not only results in the saturation of the above effects but also causes a marked decrease in elongation.

P: 0.03% or less

[0020] Abundant phosphorus causes a decrease in formability by excessive hardening or central segregation. Further, the presence of a large amount of phosphorus causes a decrease in corrosion resistance. Thus, the P content is limited to 0.03% or less. The P content is preferably 0.02% or less.

S: 0.020% or less

[0021] Sulfur forms sulfides in the steel to cause a decrease in the hot ductility of the steel sheets. Thus, the S content is limited to 0.020% or less. The S content is preferably 0.015% or less.

Al: 0.005% to 0.070%

[0022] Aluminum is an element added as a deoxidizer. To obtain this effect, the Al content needs to be limited to not less than 0.005%. Aluminum decreases the amount of solute nitrogen in the steel by forming AlN with nitrogen. The decrease in the amount of solute nitrogen results in a decrease in the strength of the steel sheets. Thus, the Al content is limited to 0.070% or less. To ensure that the amount of solute nitrogen will be stably 0.0100% or more, it is preferable that the Al content be 0.020% or less, and more preferably 0.018% or less.

N: 0.0120% to 0.0180%, Solute N: 0.0100% or more

[0023] Nitrogen present in the form of solute nitrogen contributes to increasing the strength of the steel sheets. When solute nitrogen is present in 0.0100% or more, the introduction of dislocations during secondary cold rolling is facilitated and consequently the balance between high strength and formability is enhanced. To obtain these effects, the content of nitrogen in the form of solute nitrogen needs to be limited to 0.0100% or more. The solute N content is more preferably 0.0120% or more. To ensure that the solute N content will be 0.0100% or more, the N content needs to be limited to 0.0120% or more. The N content is preferably more than 0.0130%. To ensure that the solute N content will be stably 0.0120% or more, it is preferable that the formation of AlN during the manufacturing steps be suppressed by one or a combination of any of (1) controlling the Mn content to more than 0.50%, (2) controlling the coiling temperature during hot rolling to 640°C or less, preferably 600°C or less, and more preferably 580°C or less, and (3) controlling the annealing temperature to 690°C or less, and more preferably less than 680°C. When the tensile strength is increased to 600 MPa or more in order to further increase the strength or to further reduce the thickness of cans, it is preferable that all the above three conditions be combined so that the steel will exhibit high formability with the elongation being 10% or more. On the other hand, adding a large amount of nitrogen causes a decrease in elongation and consequently results in decreases in rivet formability and flangeability. Thus, the N content is limited to 0.0180% or less. The N content is preferably 0.0170% or less. With the N content being in the above range, the content of nitrogen in the form of solute nitrogen is 0.0180% or less.

[0024] The balance after the deduction of the above essential components is iron and inevitable impurities.

<Average ferrite grain size: 7.0 μm or less>

[0025] In the steel sheets which satisfy the above chemical composition and also have a specific density of dislocations at a depth of 1/4 sheet thickness, the balance between high strength and formability is enhanced by reducing the size of ferrite grains so that the average ferrite grain size will be 7.0 μm or less. Further, the reduction in average ferrite grain size provides another advantage that the roughening of skin after working is prevented. In view of this, the average ferrite grain size is preferably 6.5 μm or less. The average ferrite grain size is a value measured by the method described in EXAMPLES. With the size of ferrite grains after annealing being finer, the introduction of dislocations during secondary cold rolling is facilitated more efficiently and consequently high strength is obtained even with a smaller rolling reduction. Consequently, the balance between high strength and formability is further enhanced. The average ferrite grain size after secondary cold rolling is reduced compared to that after annealing (before the secondary cold rolling). In view of this fact, it is more preferable that the average ferrite grain size after the secondary cold rolling be 6.0 μm or less in order to obtain the above effects. The lower limit of the average ferrite grain size is not particularly limited. If, however, the grains are excessively fine, the balance between high strength and formability is decreased. For this reason, the average grain size is preferably 1.0 μm or more. The microstructure of the inventive steel is based on ferrite and the ferrite phase represents 98 vol% or more.

<Density of dislocations at 1/4 sheet thickness: 4.0×10^{14} m^{-2} to 2.0×10^{15} m^{-2}>

[0026] In the invention, the control of the density of dislocations in the steel sheets is important in order to satisfy the strength and formability of the steel sheets at the same time. In the invention, the density of dislocations at a depth of 1/4 sheet thickness needs to be controlled to 4.0×10^{14} m^{-2} or more in order to attain an increase in strength. Dislocations present in an excessively high density induce the occurrence of voids during forming and thus cause a decrease in the formability of the steel sheets. Thus, the dislocation density needs to be controlled to 2.0×10^{15} m^{-2} or less. To control the dislocation density in the above range, in particular, it is important that the solute N content be controlled to 0.0100% or more or preferably 0.0120% or more, and the average ferrite grain size be controlled to 7.0 μm or less, preferably 6.5 μm or less or more preferably 6.0 μm or less. The density of dislocations at 1/4 sheet thickness is a value measured by the method described in EXAMPLES.

<Quality>

[0027] The high-strength steel sheets of the present invention achieve high formability while having high strength by virtue of having the chemical composition described hereinabove and also because of the average ferrite grain size and the density of dislocations at 1/4 sheet thickness being controlled to 7.0 μm or less and from 4.0×10^{14} m^{-2} to 2.0×10^{15} m^{-2}.

[0028] In general, it is very difficult for thin steel sheets to satisfy both high strength and high formability. The term "thin" means that the thickness is not more than 0.26 mm. According to the present invention, the sheet thickness can be reduced to 0.12 mm while still ensuring that high strength and high formability can be satisfied at the same time.

[0029] The term "high strength" means that the tensile strength in the transverse direction perpendicular to the rolling direction after aging treatment is not less than 530 MPa. With the tensile strength being not less than 530 MPa, sufficient strength of cans may be ensured when the steel sheets are formed into can lids or can bodies. The tensile strength is preferably 550 MPa or more, and more preferably 590 MPa or more. With the tensile strength being 550 MPa or more, high strength and high formability can be satisfied simultaneously even when the sheets are extremely thin. The phrase "extremely thin" means that the thickness is 0.18 mm or less.

[0030] By the term "high formability", it is meant that the elongation in the transverse direction perpendicular to the rolling direction after aging treatment is 7% or more. With the elongation being 7% or more, the high-strength steel sheets of the invention applied to can bodies or EOE cans exhibit sufficient flangeability required for the production of can bodies or rivet formability demanded in the manufacturing of EOE cans. Higher formability is necessary when the tensile strength is as high as 550 MPa or more, and in this case it is preferable that the elongation in the transverse direction after aging treatment be 10% or more.

[0031] In the production of cans, steel sheets are frequently formed after coatings are baked on the steel sheets. In view of this, the aging treatment prior to the quality evaluation should be equivalent to such baking.

<Methods for manufacturing high-strength steel sheets>

[0032] Hereinbelow, an example of the methods for manufacturing the high-strength steel sheets of the invention will be described.

[0033] The high-strength steel sheets of the invention may be produced by a method including a hot rolling step, a primary cold rolling step, an annealing step and a secondary cold rolling step. These steps will be described below.

Hot rolling step

[0034] In the hot rolling step, a slab having the aforementioned chemical composition except the solute N content (the solute N content may be satisfied or not satisfied) is heated at a heating temperature of 1180°C or more, rolled with the hot rolling finish temperature being 820 to 900°C, and coiled at a coiling temperature of 640°C or less.

[0035] If the slab heating temperature is excessively low, part of AlN is not dissolved and consequently the solute N content is reduced. Thus, the heating temperature is limited to 1180°C or more. The heating temperature is preferably 1200°C or more. While the upper limit of the heating temperature is not particularly limited, an excessively high heating temperature may give rise to the occurrence of excessive scales, resulting in defects on the product surface. Thus, the heating temperature is preferably 1300°C or less.

[0036] If the hot rolling finish temperature is more than 900°C, the grains in the hot-rolled sheet are coarsened and consequently the grain size in the annealed sheet is increased and the hardness of the steel sheet is decreased. Thus, the hot rolling finish temperature is limited to 900°C or less. If the hot rolling finish temperature is less than 820°C, the rolling takes place at or below the Ar3 transformation point, and consequently the formability is decreased due to the formation of coarse grains and the remaining of deformation microstructure. Thus, the hot rolling finish temperature is limited to 820°C or more. The hot rolling finish temperature is preferably 840°C or more.

[0037] If the coiling temperature is more than 640°C, a large amount of AlN is formed during the coiling and consequently the amount of solute nitrogen is reduced. Further, coiling at more than 640°C results in the coarsening of the grains in the hot-rolled sheet and thus causes the grain size after annealing to be increased. For these reasons, the coiling temperature is limited to 640°C or less. The coiling temperature is preferably 600°C or less, and more preferably 580°C or less. The lower limit of the coiling temperature is not particularly limited. If, however, the coiling temperature is excessively low, a great variation in temperature is caused during cooling possibly to give rise to wide variations in tensile strength and elongation. In view of this, the coiling temperature is preferably 500°C or more.

Primary cold rolling step

[0038] In the primary cold rolling step, the hot-rolled steel sheet is pickled and primarily cold rolled with a rolling reduction of 85% or more.

[0039] The pickling conditions are not particularly limited as long as skin scales can be removed. Usual pickling methods may be used.

[0040] The grain size after annealing may be reduced and the balance between tensile strength and elongation may be enhanced by appropriately controlling the rolling reduction during the primary cold rolling. To obtain these effects, the rolling reduction is limited to 85% or more. Rolling with an excessively large reduction causes tensile strength and elongation to be widely anisotropic in plane, resulting in a decrease in formability. Thus, the rolling reduction in this step is preferably less than 91.5%.

Annealing step

[0041] In the annealing step, the cold-rolled sheet is annealed at an annealing temperature of 620°C or more and 690°C or less.

[0042] To ensure formability, the microstructure should be sufficiently recrystallized during annealing. For this purpose, the annealing temperature needs to be limited to 620°C or more. If the annealing temperature is excessively high, the average ferrite grain size is increased and the balance between tensile strength and elongation is lowered. In view of this, the annealing temperature is limited to 690°C or less. At high annealing temperatures, AlN tends to be formed to cause a decrease in the amount of solute nitrogen. Thus, it is preferable that the annealing temperature be 680°C or less. The annealing method is not particularly limited. From the point of view of quality uniformity, a continuous annealing method is preferable. The holding time in the annealing step is not particularly limited but is preferably not less than 5 seconds from the point of view of the uniformity in steel sheet temperature, and is preferably 90 seconds or less in order to prevent the increase in average ferrite grain size.

Secondary cold rolling (DR rolling) step

[0043] In the secondary cold rolling step, the annealed sheet is secondarily cold rolled with a rolling reduction of 8 to 20%.

[0044] The annealed steel sheet is strengthened by being subjected to the secondary rolling. Further, the thickness of the steel sheet is reduced by the secondary rolling. To increase the density of dislocations at a depth of 1/4 sheet thickness from the surface and thereby to increase the strength of the steel sheet, the rolling reduction (the DR ratio) in the secondary cold rolling is limited to 8% or more. If the DR ratio is too high, the dislocation density is excessively increased and the formability is decreased. In view of this, the DR ratio is limited to 20% or less. When formability is particularly required, the DR ratio is preferably controlled to 15% or less.

[0045] The high-strength steel sheets of the invention are obtained in the manner described hereinabove. The advantageous effects of the invention may be still attained even when the steel sheets obtained are subjected to surface treatments such as plating and chemical conversion.

EXAMPLES

[0046] Steels A to N having the chemical compositions described in Table 1, the balance being iron and inevitable impurities, were smelted and cast into steel slabs. Under the conditions described in Table 2, the steel slabs were heated, hot rolled and pickled to remove scales. Thereafter, the steel sheets were primarily cold rolled with the primary cold rolling reductions described in Table 2, annealed in a continuous annealing furnace at the respective annealing temperatures, and subjected to secondary cold rolling (DR rolling) with the respective secondary cold rolling reductions. In this manner, steel sheets (steel sheets Nos. 1 to 22) having a sheet thickness of 0.15 to 0.26 mm were obtained. Both sides of each steel sheet obtained were plated with tin in a coating mass of 2.8 g/m^2 per side. The tin-plated steel sheets were subjected to evaluations of characteristics by the following methods.

Amount of solute nitrogen

[0047] The amount of solute nitrogen was determined by subtracting the amount of nitrogen as AlN measured by extraction analysis with 10% Br methanol, from the total amount of nitrogen.

Tensile strength and elongation in transverse direction after aging treatment

[0048] After an aging treatment equivalent to baking at 210°C for 10 minutes, a JIS No. 5 tensile test piece was sampled in the transverse direction and was tested in accordance with JIS Z 2241 to evaluate the tensile strength and the elongation (total elongation).

Average ferrite grain size

[0049] A cross section in the rolling direction was buried, polished, and etched with Nital to expose the grain boundaries. In accordance with JIS G 0551, the average crystal grain sizes were measured by a linear intercept method. The average ferrite grain size was thus evaluated.

Dislocation density

[0050] The dislocation density was measured by the Williamson-Hall method. Specifically, half-value widths of the diffraction peaks assigned to (110), (211) and (220) planes were measured at a depth of 1/4 sheet thickness and the results were corrected using the half value widths obtained with respect to a strain-free Si sample. The strain ε was determined. The dislocation density (m^{-2}) was evaluated based on $\rho = 14.4\ \varepsilon^2 / (0.25 \times 10^{-9})^2$.

EOE rivet formability

[0051] After an aging treatment equivalent to baking at 210°C for 10 minutes, a rivet for the attachment of an EOE tab was formed to evaluate the rivet formability. The rivet was formed by 3-step pressing. The steel sheet was bulged and was thereafter shrunk (reduced in diameter) to form a cylindrical rivet 4.0 mm in diameter and 2.5 mm in height. The rivet formability was evaluated as "×" when wrinkles or cracks had occurred on the rivet surface, and as "○" when the surface was free from wrinkles or cracks.

Can body flangeability

[0052] After an aging treatment equivalent to baking at 210°C for 10 minutes, the steel sheet was seam welded to form a can body 52.8 mm in outer diameter. The end portions were necked in to an outer diameter of 50.4 mm and were thereafter flanged to an outer diameter of 55.4 mm. The presence or absence of flange cracks was evaluated. The can body formed was of 190 g beverage can size. The welding was performed along the steel sheet rolling direction. The necking-in was carried out by a die-necking process, and the flanging by a spin-flanging process. The flangeability was evaluated as "x" when the flanged portions had been cracked, and as "O" when there was no cracks.

Strength of cans

[0053] Cans were fabricated by sealing lids to those samples which had been successfully necked-in and flanged. The strength of the cans was measured by a dent test. An indenter having a tip radius of 10 mm and a length of 42 mm was pressed against the center of the can body opposite to the weld, and the load which caused the can body to be buckled was measured. The strength of the cans was evaluated as good "○" when the load was 70 N or more, and as "×" when the load was less than 70 N. The hyphens "-" indicate that the steel sheet had been cracked during the flanging and the fabrication of a can failed.

[0054] The results are described in Table 3. In all Inventive Examples, the steel sheets achieved excellent strength and formability, with the tensile strength being not less than 530 MPa, the elongation being not less than 7%, the ferrite grain size being not more than 7.0 μm, and the density of dislocations at a depth of 1/4 sheet thickness being 4.0 × 10^{14} m^{-2} to 2.0 × 10^{15} m^{-2}. In contrast, the steel sheets of Comparative Examples were poor in one or more of these characteristics.

[Table 1]

						(mass%)		
Steel	C	Si	Mn	P	S	Al	N	Remarks
A	0.034	0.01	0.24	0.012	0.011	0.015	0.0155	Inv. Ex.
B	0.020	0.02	0.30	0.014	0.010	0.012	0.0144	Inv. Ex.
C	0.039	0.01	0.14	0.009	0.013	0.010	0.0163	Inv. Ex.
D	0.035	0.01	0.58	0.013	0.009	0.018	0.0122	Inv. Ex.
E	0.028	0.01	0.70	0.008	0.008	0.008	0.0175	Inv. Ex.
F	0.078	0.01	0.35	0.010	0.009	0.019	0.0132	Inv. Ex.
G	<u>0.083</u>	0.01	0.26	0.013	0.012	0.015	0.0132	Comp. Ex.
H	<u>0.005</u>	0.01	0.22	0.011	0.010	0.016	0.0149	Comp. Ex.
I	0.036	0.01	0.25	0.009	0.012	0.012	<u>0.0191</u>	Comp. Ex.
J	0.031	0.01	0.35	0.010	0.008	<u>0.090</u>	<u>0.0038</u>	Comp. Ex.
K	0.034	0.01	0.35	0.013	0.010	0.023	0.0149	Inv. Ex.
L	0.042	0.01	0.26	0.015	0.011	0.016	0.0126	Inv. Ex.
M	0.022	0.01	0.61	0.013	0.009	0.018	0.0153	Inv. Ex.
N	0.035	0.01	0.51	0.012	0.010	0.017	0.0148	Inv. Ex.

[Table 2]

Steel sheet No.	Steel	Slab heating temp.	Hot rolling finish temp.	Hot-rolled sheet coiling temp.	Thickness of hot-rolled sheet	Primary cold rolling reduction	Annealing temp.	Secondary cold rolling reduction	Sheet thickness	Remarks
		°C	°C	°C	mm	%	°C	%	mm	
1	A	1230	870	540	2.3	89.6	660	12	0.21	Inv. Ex.
2	B	1230	890	580	2.6	88.9	620	10	0.26	Inv. Ex.
3	C	1210	900	500	2.0	90.2	630	8	0.18	Inv. Ex.
4	D	1180	820	620	1.8	88.9	670	15	0.17	Inv. Ex.
5	E	1260	850	520	2.1	91.1	690	20	0.15	Inv. Ex.
6	F	1220	890	610	2.0	89.8	680	12	0.18	Inv. Ex.
7	<u>G</u>	1240	880	550	2.0	89.8	680	12	0.18	Comp. Ex.
8	<u>H</u>	1195	870	540	1.8	90.7	650	10	0.15	Comp. Ex.
9	<u>I</u>	1240	880	590	2.2	88.8	660	15	0.21	Comp. Ex.
10	<u>J</u>	1250	850	550	2.4	90.4	650	9	0.21	Comp. Ex.
11	A	1220	<u>970</u>	560	2.3	92.3	640	15	0.15	Comp. Ex.
12	A	1220	<u>780</u>	560	2.3	90.8	640	15	0.18	Comp. Ex.
13	A	1230	860	<u>680</u>	2.0	90.9	670	12	0.16	Comp. Ex.
14	B	<u>1150</u>	870	600	1.6	<u>80.0</u>	670	10	0.20	Comp. Ex.
15	B	1210	840	580	2.3	87.7	<u>740</u>	8	0.26	Comp. Ex.
16	B	1210	840	540	2.3	87.7	<u>550</u>	8	0.26	Comp. Ex.

(continued)

Steel sheet No.	Steel	Slab heating temp.	Hot rolling finish temp.	Hot-rolled sheet coiling temp.	Thickness of hot-rolled sheet	Primary cold rolling reduction	Annealing temp.	Secondary cold rolling reduction	Sheet thickness	Remarks
		°C	°C	°C	mm	%	°C	%	mm	
17	B	1190	890	610	0.18	91.2	625	5	0.15	Comp. Ex.
18	B	1190	890	610	2.6	90.1	625	30	0.18	Comp. Ex.
19	K	1210	870	580	2,0	90.3	670	12	0.17	Inv. Ex.
20	L	1190	900	560	2.0	90.0	650	10	0.18	Inv. Ex.
21	M	1220	880	530	2.0	90.0	650	10	0.18	Inv. Ex.
22	N	1220	880	530	2.0	90.0	650	10	0.18	Inv. Ex.

[Table 3]

Steel sheet No.	Steel	Solute N	Tensile strength	Elongation	Dislocation density	Average ferrite grain size	EOE rivet formability	Flangeability	Strength of cans	Evaluation of strength of cans	cans Remarks
		mass%	MPa	%	10^{14} m^{-2}	μm			N		
1	A	0.0148	580	11	7.1	5.6	○	○	155	○	Inv. Ex.
2	B	0.0140	550	12	6.5	5.2	○	○	260	○	Inv. Ex.
3	C	0.0159	555	14	5.5	5.1	○	○	98	○	Inv. Ex.
4	D	0,0106	620	9	10.2	5.9	○	○	90	○	Inv. Ex.
5	E	0.0166	675	7	14.6	5.4	○	○	75	○	Inv. Ex.
6	F	0.0105	590	7	8.0	6.0	○	○	102	○	Inv. Ex.
7	G	0.0121	600	4	6.8	5.6	×	×	-	-	Comp. Ex.
8	H	0.0136	480	13	6.4	7.9	×	○	51	×	Comp. Ex.
9	I	0.0186	640	4	11.2	6.3	×	×	-	-	Comp. Ex.
10	J	0,0019	490	9	5.8	6.7	×	×	-	-	Comp. Ex.
11	A	0.0145	515	7	9.7	7.5	○	○	55	×	Comp. Ex.
12	A	0.0146	600	5	11.7	6.3	×	×	-	-	Comp. Ex.
13	A	0.0115	520	9	6.9	7.3	○	○	63	×	Comp. Ex.
14	B	0.0122	523	10	6.3	8.6	×	×	-	-	Comp. Ex.
15		0.0142	518	11	4.9	8.1	×	×	-	-	Comp. Ex.
16	B	0.0139	580	3	7.6	4.3	×	×	-	-	Comp. Ex.

(continued)

Steel sheet No.	Steel	Solute N	Tensile strength	Elongation	Dislocation density	Average ferrite grain size	EOE rivet formability	Flangeability	Strength of cans	Evaluation of strength of cans	cans Remarks
		mass%	MPa	%	10^{14} m^{-2}	μm			N		
17	B	0.0126	480	15	2.8	6.2	○	○	50	×	Comp. Ex.
18	B	0.0125	690	4	26.1	6.1	×	×	-	-	Comp. Ex.
19	K	0.0112	545	9	7.8	4.7	○	○	83	○	Inv. Ex.
20	L	0.0106	540	8	5.8	6.2	○	○	95	○	Inv. Ex.
21	M	0.0139	620	11	6.8	5.0	○	○	101	○	Inv. Ex.
22	N	0.0123	595	13	6.3	5.4	○	○	96	○	Inv. Ex.

Claims

1. A high-strength steel sheet having a chemical composition comprising, in mass%, C: 0.010% to 0.080%, Si: 0.05% or less, Mn: more than 0.50% to 0.70%, P: 0.03% or less, S: 0.020% or less, Al: 0.005% to 0.070% and N: 0.0120% to 0.0180%, the balance being Fe and inevitable impurities,
nitrogen present as solute nitrogen having a content of 0.0120% or more in the N content,
an average ferrite grain size being 7.0 μm or less,
a density of dislocations at a depth of 1/4 sheet thickness from the surface being 4.0×10^{14} m^{-2} to 2.0×10^{15} m^{-2}, wherein the dislocation density (m^{-2}) is evaluated based on $\rho = 14 .4\varepsilon^2/ (0. 25 \text{ x } 10^{-9})^2$ and ε being a strain,
a tensile strength and an elongation in the transverse direction perpendicular to the rolling direction after aging treatment being 600 MPa or more and 10% or more.

2. A method for manufacturing the high-strength steel sheet described in Claim 1, comprising:

    a hot rolling step of heating a slab at a heating temperature of 1180°C or more, rolling the slab with a hot rolling finish temperature of 820 to 900°C and coiling the sheet at a coiling temperature of 640°C or less,
    a primary cold rolling step of pickling the hot-rolled steel sheet and cold rolling the sheet with a rolling reduction of 85% or more,
    an annealing step of annealing the primarily cold-rolled steel sheet at 620°C to 690°C, and
    a secondary cold rolling step of secondarily cold rolling the annealed steel sheet with a rolling reduction of 8 to 20%.

Patentansprüche

1. Hochfestes Stahlblech mit einer chemischen Zusammensetzung, die in Masse-%, 0,010% bis 0,080% C, 0,05% oder weniger Si, mehr als 0,50% bis 0,70% Mn, 0,03% oder weniger P, 0,020% oder weniger S, 0,005% bis 0,070% Al sowie 0,0120% bis 0,0180% N umfasst, wobei der Rest Eisen und unvermeidbare Verunreinigungen sind,
Stickstoff, der als gelöster Stickstoff vorliegt, einen Gehalt von 0,0120% oder mehr in dem N-Gehalt hat,
eine durchschnittliche Ferrit-Korngröße 7,0 μm oder weniger beträgt,
eine Dichte von Versetzungen in einer Tiefe von 1/4 Blechdicke von der Oberfläche $4,0 \times 10^{14}$ m^{-2} bis $2,0 \times 10^{15}$ m^{-2} beträgt, wobei die Versetzungs-Dichte (m^{-2}) basierend auf $\rho = 14,4\varepsilon^2/(0,25 \text{ x } 10^{-9})^2$ bewertet wird und ε eine Verformung ist,
eine Zugfestigkeit und eine Dehnung in der Querrichtung senkrecht zu der Walzrichtung nach Alterungsbehandlung 600 MPa oder mehr und 10% oder mehr betragen.

2. Verfahren zum Herstellen des hochfesten Stahlblechs nach Anspruch 1, das umfasst:

    einen Warmwalzschritt, in dem eine Bramme auf eine Erwärmungstemperatur von 1180°C oder darüber erhitzt wird, die Bramme mit einer Warmwalz-Endtemperatur von 820 bis 900°C gewalzt wird und das Blech bei einer Wickeltemperatur von 640°C oder darunter gewickelt wird,
    einen primären Kaltwalzschritt, in dem das warmgewalzte Stahlblech gebeizt wird und das Blech mit einer Walzreduktion von 85% oder mehr kaltgewalzt wird,
    einen Glühschritt, in dem das primärem Kaltwalzen unterzogene Stahlblech bei 620°C bis 690°C geglüht wird, sowie
    einen sekundären Kaltwalzschritt, in dem das geglühte Stahlblech sekundärem Kaltwalzen mit einer Walzreduktion von 8 bis 20% unterzogen wird.

Revendications

1. Tôle d'acier à haute résistance ayant une composition chimique comprenant, en % en masse, C : de 0,010 % à 0,080 %, Si : 0,05 % ou moins, Mn : de plus de 0,50 % à 0,70 %, P : 0,03 % ou moins, S : 0,020 % ou moins, Al : de 0,005 % à 0,070 % et N : de 0,0120 % à 0,0180 %, le reste étant du fer et des impuretés inévitables,
l'azote présent en tant qu'azote dissous ayant une teneur de 0,0120 % ou plus dans la teneur de N,
une taille moyenne des grains de ferrite étant de 7,0 μm ou moins,
une densité de dislocations à une profondeur égale à ¼ de l'épaisseur de tôle depuis la surface allant de $4,0 \times 10^{14}$ m^{-2} à $2,0 \times 10^{15}$ m^{-2}, la densité de dislocations (m^{-2}) étant évaluée sur la base de $\rho = 14,4\varepsilon^2 / (0,25 \times 10^{-9})$

et ε étant une contrainte,
une résistance à la traction et un allongement dans le sens travers perpendiculaire au sens de laminage après un traitement de vieillissement étant de 600 Mpa ou plus et de 10 % ou plus.

2. Procédé de fabrication de la tôle d'acier à haute résistance décrite dans la revendication 1, comprenant :

une étape de laminage à chaud consistant à chauffer une brame à une température de chauffage de 1180 °C ou plus, laminer la brame avec une température de finissage de laminage à chaud de 820 à 900 °C et enrouler la tôle à une température d'enroulement de 640 °C ou moins,
une étape de laminage à froid primaire consistant à décaper la tôle d'acier laminée à chaud et laminer à froid la tôle avec une réduction par laminage de 85 % ou plus,
une étape de recuit consistant à recuire la tôle d'acier ayant subi un laminage à froid primaire de 620 °C à 690 °C, et
une étape de laminage à froid secondaire consistant à soumettre la tôle d'acier recuite à un laminage à froid secondaire avec une réduction par laminage de 8 à 20 %.

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- WO 2008018531 A **[0005] [0008]**
- WO 2013151085 A **[0006]**
- JP 2002294399 B **[0009]**