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(54) COLD-ROLLED STEEL SHEET HAVING EXCELLENT SPOT WELDABILITY, AND MANUFACTURING METHOD THEREFOR

(57) A cold-rolled steel sheet having excellent spot weldability suitable for use in vehicles, electric appliances, etc. is provided. The cold-rolled steel sheet has a steel composition containing, in mass%: C: 0.05% to 0.13%; Si: 0.05% to 2.0%; Mn: 1.5% to 4.0%; P: 0.05% or less; S: 0.005% or less; Al: 0.01% to 0.10%; Cr: 0.05% to 1.0%; Nb: 0.010% to 0.070%; Ti: 0.005% to 0.040%; and N: 0.0005% to 0.0065%, with a mass ratio Ti/N of Ti and N being 2.5 or more and 7.5 or less, and a balance being Fe and incidental impurities, wherein 70 mass% or more ofTi in steel exists as a precipitate, and 15 mass% or more of Nb in the steel exists as solute Nb, and a tensile strength is 980 MPa or more.

EP 3 178 954 A1

Description

TECHNICAL FIELD

[0001] The disclosure relates to a cold-rolled steel sheet with a sheet thickness of 0.4 mm or more and 3.0 mm or less suitable for use in vehicles, electric appliances, etc., and particularly relates to a cold-rolled steel sheet having excellent spot weldability with a tensile strength of 980 MPa or more and a manufacturing method therefor.

BACKGROUND

[0002] In recent years, improved fuel efficiency of vehicles has become increasingly important for global environment protection, which has encouraged reductions in weight of automotive bodies. The most effective means for this is to strengthen the steel sheets used and reduce their sheet thickness. It is also important to improve the safety of vehicle occupants. Effective means for this is equally to strengthen the steel sheets used. For such steel sheet strengthening, conventionally the conditions of hot rolling and subsequent continuous annealing have been strictly managed while adding various alloying elements such as C and Mn in steel sheets.

[0003] When using cold-rolled steel sheets as an automotive member, typically the steel sheets that have been formed are joined by welding and made into a desired finished shape. To ensure excellent safety as an automotive body structure, not only the base material of the cold-rolled steel sheets but also the area including the weld metal and the heat-affected zone is required to have excellent mechanical property. A conventional measure to ensure excellent weld property as cold-rolled steel sheets for vehicles typically limits the addition amounts of alloying elements for enhancing quench hardenability such as C and Mn and the addition amounts of impurity elements for facilitating the microsegregation of welds such as P and S.

[0004] However, it is extremely difficult to achieve both tensile strength as high as 980 MPa or more and high spot weldability, as there is a trade-off between increasing strength and increasing spot weldability by the addition of alloying components such as C and Mn.

[0005] For example, in resistance spot welding used as a typical method of joining steel sheets for vehicles, the steel sheets are heated to the melting point and then quenched. As a result, the weld metal becomes a solidified martensite single-phase structure in coarse columnar form. The heat-affected zone heated to a temperature range of Ac_3 point or more (hereafter also referred to as "heat-affected zone of Ac_3 point or more") also becomes a relatively coarse martensite structure. The weld metal and the heat-affected zone of Ac_3 point or more are therefore higher in hardness than the base material, and susceptible to embrittlement. Besides, the heat-affected zone heated only to a temperature range less than Ac_3 point (hereafter also referred to as "heat-affected zone less than Ac_3 point") is likely to decrease in strength due to tempering effect, and tends to have a higher softening degree with respect to the base material when the base material has higher strength. The weld typically has a discontinuous shape unlike the base material, so that stress tends to concentrate and residual stress due to welding heat hysteresis is unavoidable. Especially in a high strength steel sheet, the discontinuity of strength in the area from the weld metal through the heat-affected zone to the base material is significant, and the fracture strength of the spot weld is likely to be lower than that of the base material.

CITATION LIST

Patent Literatures

[0006]

PTL 1: JP 2012-167338 A
PTL 2: JP 4530606 B2
PTL 3: JP 4883216 B2
PTL 4: JP 5142068 B2
PTL 5: JP 5323552 B2

SUMMARY

(Technical Problem)

[0007] High strength steel sheets proposed in JP 2012-167338 A (PTL 1), JP 4530606 B2 (PTL 2), JP 4883216 B2 (PTL 3), JP 5142068 B2 (PTL 4), JP 5323552 B2 (PTL 5), and the like fail to achieve both high strength of 980 MPa or more in tensile strength and sufficiently improved spot weldability while ensuring sufficient economic efficiency and productivity.

[0008] It could therefore be helpful to provide a cold-rolled steel sheet having excellent spot weldability with a tensile strength of 980 MPa or more and an advantageous manufacturing method therefor, without increasing manufacturing cost or decreasing productivity.

[0009] In the disclosure, "excellent spot weldability" means that the cross tensile strength is 10 kN/spot or more and the failure mode is plug failure in a cross tensile test according to JIS Z 3137 (1999), and the difference ΔHV between the maximum and minimum values of Vickers hardness in the area from the weld metal portion to the base material portion is less than 120 in a spot weld section test according to JIS Z 3139 (2009).

(Solution to Problem)

[0010] As a result of conducting extensive study on the chemical components of a steel sheet, a manufacturing method, and various factors determining microstructure, we discovered the following:

(1) To achieve a tensile strength of 980 MPa or more, it is important to strictly adjust the chemical composition of the steel sheet and appropriately control the mass% ratio ofTi and N (Ti/N).
By appropriately controlling Ti/N, strengthening by crystal grain refinement and strengthening by precipitation are realized through the generation of TiN. Moreover, the generation of Nb nitride is suppressed to secure solute Nb in the annealing process, which produces an effect of delaying the progress of recrystallization during heating and contributes to higher strength of the steel sheet.
(2) To achieve excellent spot weldability, it is important to suppress the embrittlement of the weld metal and heat-affected zone of Ac_3 point or more and also suppress the softening of the heat-affected zone less than Ac_3 point.
To suppress the embrittlement of the weld metal and heat-affected zone of Ac_3 point or more, it is necessary to minimize solute N, refine crystal grains, and suppress excessive hardening in the weld metal and heat-affected zone. Moreover, when an appropriate amount of solute Nb exists in the steel, NbC is formed in the low-temperature range in the cooling process during welding, thus suppressing softening in the heat-affected zone less than Ac_3 point.
(3) To effectively produce the aforementioned effects, the existence states of Ti and Nb in the cold-rolled steel sheet after annealing need to be appropriately controlled.

[0011] To attain the desired existence states of Ti and Nb, it is important to strictly adjust the chemical composition of the steel sheet and Ti/N and appropriately control the manufacturing conditions, in particular the hot rolling conditions and the annealing conditions.

[0012] The disclosure is based on the aforementioned discoveries and further studies.

[0013] We provide the following:

1. A cold-rolled steel sheet having excellent spot weldability, the cold-rolled steel sheet having a steel composition containing (consisting of), in mass%: C: 0.05% to 0.13%; Si: 0.05% to 2.0%; Mn: 1.5% to 4.0%; P: 0.05% or less; S: 0.005% or less, Al: 0.01% to 0.10%; Cr: 0.05% to 1.0%; Nb: 0.010% to 0.070%; Ti: 0.005% to 0.040%; and N: 0.0005% to 0.0065%, with a mass ratio Ti/N of Ti and N being 2.5 or more and 7.5 or less, and a balance being Fe and incidental impurities, wherein 70 mass% or more of Ti in steel exists as a precipitate, and 15 mass% or more of Nb in the steel exists as solute Nb, and a tensile strength is 980 MPa or more.
2. The cold-rolled steel sheet having excellent spot weldability according to the foregoing 1, wherein the steel composition further contains one or more selected from, in mass%: Mo: 0.01% to 1.0%, Cu: 1.0% or less; Ni: 1.0% or less; and V: 0.1% or less.
3. A manufacturing method for a cold-rolled steel sheet having excellent spot weldability, the manufacturing method including: heating a steel material having the steel composition according to the foregoing 1 or 2 to a temperature range of (Ts - 50) °C or more and (Ts + 200) °C or less where Ts is a temperature defined by the following Formula (1), hot rolling the steel material with a finisher delivery temperature of 850 °C or more to obtain a hot-rolled steel sheet, and then coiling the hot-rolled steel sheet at a temperature of 650 °C or less; cold rolling the hot-rolled steel sheet into a cold-rolled steel sheet; and continuously annealing the cold-rolled steel sheet by: heating the cold-rolled steel sheet to a temperature range of 700 °C or more and 900 °C or less; and, in a subsequent cooling process, cooling the cold-rolled steel sheet to a temperature range of 200 °C or more and 450 °C or less with an average cooling rate of 12 °C/s or more and 100 °C/s or less, and holding the cold-rolled steel sheet in the temperature range of 200 °C or more and 450 °C or less for a time of 30 s or more and 600 s or less,

$$Ts\,(^\circ C) = 6770/[2.26 - \log_{10}\{[\%Nb] \times ([\%C] + 0.86[\%N])\}] - 273 \quad \dots (1)$$

where [%Nb], [%C], and [%N] respectively denote Nb, C, and N contents in steel in mass%.

(Advantageous Effect)

[0014] It is thus possible to obtain a cold-rolled steel sheet having excellent spot weldability with a tensile strength of 980 MPa or more, without increasing manufacturing cost or decreasing productivity.
[0015] The use of the cold-rolled steel sheet according to the disclosure improves manufacturing efficiency when producing steel structures such as vehicles and safety for vehicle occupants, and also improves fuel efficiency and thus significantly contributes to lower environmental burden.

DETAILED DESCRIPTION

[0016] Detailed description is given below.
[0017] The reasons for limiting the chemical composition of the steel material to the aforementioned range are described first. While the unit of the content of each element in the chemical composition of the steel material is "mass%", the content is simply expressed in "%" unless otherwise stated.

C: 0.05% to 0.13%

[0018] C is the most important element in strengthening the steel, and has high solid solution strengthening ability. To achieve such effect, the C content needs to be 0.05% or more. If the C content is more than 0.13%, martensite phase in the base material increases and significantly hardens the material, causing degradation in hole expansion formability. The C content is therefore limited to the range of 0.05% to 0.13%. The C content is preferably in the range of 0.06% to 0.12%.

Si: 0.05% to 2.0%

[0019] Si is an element necessary in steelmaking, acting as a deoxidizing material. Si also has an effect of dissolving in the steel to strengthen the steel sheet by solid solution strengthening. To achieve such effects, the Si content needs to be 0.05% or more. If the Si content is more than 2.0%, the toughness of the weld metal and heat-affected zone degrades significantly, causing lower fracture strength of the weld. The Si content is therefore limited to the range of 0.05% to 2.0%. The Si content is preferably in the range of 0.10% to 1.60%.

Mn: 1.5% to 4.0%

[0020] Mn has an effect of increasing the quench hardenability of the steel at relatively low cost. To ensure a base material strength of 980 MPa or more in tensile strength, the Mn content needs to be 1.5% or more. If the Mn content is more than 4.0%, the fracture strength of the weld decreases, and the microsegregation of the base material increases, promoting a delayed fracture originating from the base material segregation area. The Mn content is therefore limited to the range of 1.5% to 4.0%. The Mn content is preferably in the range of 1.7% to 3.8%.

P: 0.05% or less

[0021] P is an element having high solid solution strengthening ability, but promotes microsegregation as with Mn. Accordingly, if the P content is more than 0.05%, not only the base material embrittles but also the grain boundary segregation area tends to become a delayed fracture origin. Hence, the P content is desirably minimized with the upper limit being 0.05%. Excessively reducing P, however, involves high refining cost and is economically disadvantageous. Therefore, the lower limit of the P content is desirably about 0.005%.

S: 0.005% or less

[0022] S segregates in the grain boundary and decreases ductility in hot rolling. Hence, the S content is desirably minimized with the upper limit being 0.005%.

Al: 0.01% to 0.10%

[0023] Al acts as a deoxidizer, and is the most generally used element in the molten steel deoxidizing process for steel sheets. Al also has an effect of fixing solute N in the steel to form AlN, thus suppressing embrittlement caused by solute N. To achieve such effects, the Al content needs to be 0.01% or more. If the Al content is more than 0.10%, surface cracking during slab manufacture is promoted. The Al content is therefore limited to the range of 0.01% to 0.10%. The Al content is preferably in the range of 0.02% to 0.07%.

Cr: 0.05% to 1.0%

[0024] Cr has an effect of increasing the quench hardenability of the steel at relatively low cost, and is an element that delays the bainite transformation of intermediate hardness phase in the annealing process and generates martensite of high hardness phase to contribute to improved strength of the steel. To achieve such effects, the Cr content needs to be 0.05% or more. If the Cr content is more than 1.0%, not only an excessive strength increase promotes embrittlement, but also an economic disadvantage is entailed. The Cr content is therefore limited to the range of 0.05% to 1.0%. The Cr content is preferably in the range of 0.07% to 0.8%.

Nb: 0.010% to 0.070%

[0025] Nb is an important element that, in annealing heating after cold rolling, exists as solute Nb to produce a solute drag effect and delay the recrystallization of the deformed microstructure generated in cold rolling, thus strengthening the steel sheet after annealing. Moreover, NbC generated in the hot rolling process and annealing process refines the microstructure in the base material and heat-affected zone, and improves toughness. To achieve such effects, the Nb content needs to be 0.010% or more. If the Nb content is more than 0.070%, coarse carbonitride precipitates, which promotes surface cracking during slag manufacture and may also become a fracture origin. The Nb content is therefore limited to the range of 0.010% to 0.070%. The Nb content is preferably in the range of 0.015% to 0.060%.

Ti: 0.005% to 0.040%

[0026] Ti is an important alloying element in the disclosure. By fixing solute N to form TiN, Ti has an effect of suppressing the coarsening of crystal grains in the weld metal and heat-affected zone and an effect of suppressing embrittlement by reducing solute N. Moreover, by forming TiN, Ti suppresses the generation of Nb nitride to secure a predetermined amount of solute Nb in the hot rolling and annealing steps, thus effectively contributing to higher strength of the steel sheet after annealing. To achieve such effects, the Ti content needs to be 0.005% or more. If the Ti content is more than 0.040%, very hard and brittle TiC precipitates, which promotes embrittlement. The Ti content is therefore limited to the range of 0.005% to 0.040%. The Ti content is preferably in the range of 0.010% to 0.035%.

N: 0.0005% to 0.0065%

[0027] N is contained in the steel as incidental impurity. However, when an appropriate amount of Ti is added, N forms TiN, and thus has an effect of suppressing the coarsening of crystal grains in the weld metal and heat-affected zone during welding. To achieve such effect, the N content needs to be 0.0005% or more. If the N content is more than 0.0065%, an increase of solute N causes a significant decrease in anti-aging property. The N content is therefore limited to the range of 0.0005% to 0.0065%. The N content is preferably in the range of 0.0010% to 0.0060%.

[0028] In the disclosure, it is important to appropriately control the mass% ratio of Ti and N, i.e. Ti/N, in addition to limiting the chemical composition as described above.

Ti/N: 2.5 or more and 7.5 or less

[0029] By controlling Ti/N in the aforementioned range, strengthening by crystal grain refinement and strengthening by precipitation are achieved through the generation of TiN. Moreover, an appropriate amount of solute Nb can be secured in the annealing process by suppressing the generation of Nb nitride, and the resulting effect of delaying the progress of recrystallization during heating contributes to higher strength of the steel sheet. The controlled ratio also contributes to reduced solute N and refined crystal grains in the weld metal and heat-affected zone, thus preventing the embrittlement of the weld metal and heat-affected zone.

[0030] If Ti/N is less than 2.5, solute N in the steel sheet increases, which promotes embrittlement. If Ti/N is more than 7.5, very hard and brittle TiC is generated in the steel sheet, causing lower ductility and significant embrittlement. Ti/N is therefore limited to the range of 2.5 to 7.5. Ti/N is preferably in the range of 3.0 to 7.0.

[0031] While the basic components have been described above, one or more selected from Mo, Cu, Ni, and V may also be contained according to need.

Mo: 0.01% to 1.0%

[0032] Mo is an element that contributes to improved strength of the steel. To achieve such effect, the Mo content needs to be 0.01% or more. If the Mo content is more than 1.0%, not only an excessive strength increase promotes embrittlement, but also an economic disadvantage is entailed. Accordingly, in the case of adding Mo, the Mo content is in the range of 0.01% to 1.0%. The Mo content is preferably in the range of 0.03% to 0.8%.

Cu: 1.0% or less

[0033] Cu is an element that contributes to improved strength of the steel. If the Cu content is more than 1.0%, however, hot shortness occurs and the surface characteristics of the steel sheet degrade. Accordingly, in the case of adding Cu, the Cu content is 1.0% or less.

Ni: 1.0% or less

[0034] Ni is an element that contributes to improved strength of the steel. If the Ni content is more than 1.0%, however, the effect saturates, which is economically disadvantageous. Accordingly, in the case of adding Ni, the Ni content is 1.0% or less.

V: 0.1% or less

[0035] V is an element that contributes to improved strength of the steel. If the V content is more than 0.1%, however, the ductility of the base material degrades. Accordingly, in the case of adding V, the V content is 0.1% or less.
[0036] In the chemical composition of the steel sheet according to the disclosure, the balance other than the aforementioned components is Fe and incidental impurities.
[0037] The chemical composition of the steel sheet according to the disclosure has been described above. In the disclosure, it is very important to appropriately control the existence forms of Ti and Nb in the steel.

Proportion of Ti existing as precipitate in steel: 70 mass% or more

[0038] In the annealing process, Ti precipitate refines the structure, thus improving the hole expansion formability of the eventually obtained cold-rolled steel sheet. In addition, when Ti exists as a precipitate in the cold-rolled steel sheet after annealing, the coarsening of crystal grains in the heat-affected zone due to welding heat hysteresis during welding is suppressed, so that the fracture strength of the weld is improved. To achieve such effects, 70 mass% or more of Ti in the steel need to exist as a precipitate. The proportion of Ti existing as a precipitate in the steel is preferably 75 mass% or more. The upper limit of the proportion of Ti existing as a precipitate in the steel is not particularly limited. If the proportion is 100 mass%, however, toughness degrades significantly due to remaining solute N. Accordingly, the proportion of Ti existing as a precipitate in the steel is preferably less than 100 mass%, and more preferably less than 98 mass%.
[0039] The form of the precipitate is mainly a single precipitate of TiN or a composite precipitate of TiN and another precipitate. Even when Ti oxide or Ti carbide is mixed, its effect is negligible as long as Ti oxide or Ti carbide is less than 10% of the total number of Ti-based precipitates. The existence form of Ti in the steel other than a precipitate is solute Ti.

Proportion of Nb existing as solute Nb in steel: 15 mass% or more

[0040] Nb existing as a solute has an effect of suppressing recrystallization during heating in the annealing process to effectively contribute to higher strength of the steel and also has an effect of suppressing the softening of the heat-affected zone less than Ac_3 point.
[0041] To achieve such effects, 15 mass% or more of Nb in the steel need to exist as solute Nb. The proportion ofNb existing as solute Nb in the steel is preferably 20 mass% or more.
[0042] The upper limit of the proportion of Nb existing as solute Nb in the steel is not particularly limited. If the amount of solute Nb in the steel is excessively high, however, the aforementioned effects saturate, and the manufacturing cost increases. Accordingly, the proportion of Nb existing as solute Nb in the steel is preferably 70 mass% or less.
[0043] The existence form of Nb in the steel other than solute Nb is Nb precipitate. Examples of the Nb precipitate include Nb carbide and Nb carbonitride such as NbC.
[0044] The following describes a manufacturing method according to the disclosure. Note that the temperature of the steel sheet in the manufacturing conditions is the surface temperature of the steel sheet.

[0045] Molten steel having the aforementioned chemical composition is obtained by steelmaking using a known method such as a converter or an electric heating furnace, and made into a steel material such as a slab having predetermined dimensions using a known method such as continuous casting or ingot casting and blooming. The molten steel may also be subjected to treatment such as refining with a ladle or vacuum degassing.
[0046] The obtained steel material is immediately or temporarily cooled, heated to a temperature range of (Ts - 50) °C or more and (Ts + 200) °C or less, and hot rolled with a finisher delivery temperature of 850 °C or more. The steel material is then coiled at 650 °C or less, to form a hot-rolled steel sheet.
[0047] Here, Ts is defined by the following Formula (1):

$$\mathrm{Ts}\ (^\circ\mathrm{C}) = 6770/[2.26 - \log_{10}\{[\%\mathrm{Nb}] \times ([\%\mathrm{C}] + 0.86[\%\mathrm{N}])\}] - 273 \quad \cdots (1)$$

where [%Nb], [%C], and [%N] respectively denote the Nb, C, and N contents (mass%) in the steel.

Heating temperature: (Ts - 50) °C or more and (Ts + 200) °C or less

[0048] Carbonitride containing coarse Nb which has crystallized during the steelmaking of the steel material does not contribute to higher strength of the steel sheet. It is therefore important to temporarily dissolve such coarse Nb-based crystallized product in the steel in the heating stage before hot rolling, and precipitate it again as fine Nb carbide or carbonitride in the subsequent processes such as rolling, cooling, and annealing.
[0049] If the heating temperature is less than (Ts - 50) °C, heating is insufficient and the Nb-based crystallized product does not sufficiently dissolve in the steel, leading to insufficient strength after annealing. If the heating temperature is more than (Ts + 200) °C, the aforementioned effects saturate. Besides, the Ti crystallized product dissolves completely, making it difficult to cause an appropriate amount of Ti to exist as a precipitate after annealing. Further, the fuel cost for heating increases and also the yield rate drops due to increased scale-off, which is economically disadvantageous. The heating temperature is therefore (Ts - 50) °C or more and (Ts + 200) °C or less. The heating temperature is preferably (Ts - 20) °C or more and (Ts + 170) °C or less.

Finisher delivery temperature: 850 °C or more

[0050] If the finisher delivery temperature is less than 850 °C, not only rolling efficiency drops, but also the rolling load increases, causing a greater load on the mill. The finisher delivery temperature is therefore 850 °C or more.

Coiling temperature: 650 °C or less

[0051] If the coiling temperature for the hot-rolled steel sheet is more than 650 °C, NbC which precipitates during coiling coarsens excessively, which facilitates embrittlement and is likely to provide a fracture origin. The coiling temperature for the hot-rolled steel sheet therefore needs to be 650 °C or less. The coiling temperature for the hot-rolled steel sheet is preferably 620 °C or less. The lower limit of the coiling temperature for the hot-rolled steel sheet need not be particularly limited. Given that an excessive temperature decrease causes lower manufacturing efficiency, however, the lower limit is preferably about 400 °C.
[0052] The obtained hot-rolled steel sheet is then cold rolled into a cold-rolled steel sheet. The cold rolling conditions need not be particularly limited. To ensure desired strength after annealing, however, the total rolling reduction is preferably 30% or more. Moreover, to avoid an excessive load on the mill, the total rolling reduction is preferably 80% or less.
[0053] The cold-rolled steel sheet obtained in this way is then continuously annealed under the following conditions.

Heating temperature in continuous annealing: 700 °C or more and 900 °C or less

[0054] If the heating temperature in continuous annealing is less than 700 °C, the reverse transformation of austenite is insufficient, and the amount of hard martensite or bainite generated in the subsequent cooling is insufficient, making it impossible to obtain desired strength. If the heating temperature in continuous annealing is more than 900 °C, austenite grains coarsen considerably, causing degradation in hole expansion formability of the base material and toughness of the heat-affected zone. The heating temperature in continuous annealing is therefore 700 °C or more and 900 °C or less. The heating temperature in continuous annealing is preferably 720 °C or more and 880 °C or less.
[0055] The holding time after heating need not be particularly limited. To ensure a uniform temperature distribution and a stable microstructure, however, the holding time is preferably 15 s or more. Meanwhile, a long holding time causes not only lower manufacturing efficiency but also coarser austenite grains, and so the holding time is preferably 600 s or less.

Average cooling rate: 12 °C/s or more and 100 °C/s or less

[0056] If the average cooling rate in the cooling process after heating in continuous annealing is less than 12 °C/s, soft ferrite phase is generated excessively during cooling, making it difficult to ensure desired strength. Besides, Nb reprecipitates excessively in the middle of cooling, making it difficult to secure a desired amount of solute Nb. Further, coarse ferrite phase or pearlite phase is generated in the middle of cooling, leading to a decrease in strength. If the average cooling rate after annealing is more than 100 °C/s, it is difficult to secure the shape of the steel sheet. The average cooling rate after annealing treatment is therefore 12 °C/s or more and 100 °C/s or less. The average cooling rate is preferably 14 °C/s or more and 70 °C/s or less.

Cooling stop temperature: 200 °C or more and 450 °C or less

[0057] If the cooling stop temperature is less than 200 °C, the conveyance speed for the steel sheet is to be lowered extremely, which is not preferable in terms of manufacturing efficiency. If the cooling stop temperature is more than 450 °C, relatively soft bainite phase is generated excessively after the cooling stop, making it difficult to ensure desired strength. Besides, Nb reprecipitates excessively after the cooling stop, making it difficult to secure a desired amount of solute Nb. Further, a soft structure such as ferrite is generated excessively, leading to insufficient strength. The cooling stop temperature is therefore 200 °C or more and 450 °C or less. The cooling stop temperature is preferably 230 °C or more and 420 °C or less.

Holding time in cooling stop temperature range: 30 s or more and 600 s or less

[0058] If the holding time in the cooling stop temperature range is less than 30 s, the uniformity of the temperature and material in the steel sheet decreases. If the holding time in the cooling stop temperature range is more than 600 s, manufacturing efficiency decreases. The holding time in the cooling stop temperature range is therefore 30 s or more and 600 s or less.

EXAMPLES

[0059] Steel having the chemical composition shown in Table 1 was obtained by steelmaking using a converter, refined with a ladle, and continuously cast into a steel slab. The steel slab was then hot rolled under the conditions shown in Table 2, into a hot-rolled steel sheet. The hot-rolled steel sheet was cold rolled and continuously annealed under the conditions shown in Table 2, thus obtaining a cold-rolled steel sheet as a product sheet.
[Table 1]

Table I

Steel No.	Chemical composition (mass%)														Ti/N	Ts (°C)	Ts-50 (°C)	Ts+200 (°C)	Remarks
	C	Si	Mn	P	S	Al	Cr	Nb	Ti	N	Mo	Cu	Ni	V					
1	0.074	0.52	2.86	0.013	0.0011	0.029	0.16	0.029	0.018	0.0044	-	-	-	-	4.1	1107	1057	1307	Confirming steel
2	0.114	1.46	1.84	0.005	0.0010	0.033	0.65	0.037	0.015	0.0036	-	-	-	-	4.2	1191	1141	1391	Conforming steel
3	0.083	0.22	3.10	0.019	0.0024	0.035	0.21	0.051	0.011	0.0029	-	-	-	-	3.8	1192	1142	1392	Conforming steel
4	0.098	0.13	1.96	0.025	0.0031	0.051	0.39	0.038	0.028	0.0052	0.36	-	-	-	5.4	1177	1127	1377	Conforming steel
5	0.106	0.83	3.28	0.010	0.0019	0.065	0.08	0.041	0.010	0.0016	-	0.12	0.19	-	6.3	1194	1144	1394	Conforming steel
6	0.119	0.26	2.76	0.008	0.0012	0.036	0.42	0.029	0.032	0.0060	-	-	-	0.05	5.3	1166	1116	1366	Confirming steel
7	0.067	1.12	3.74	0.036	0.0029	0.066	0.14	0.057	0.023	0.0046	0.06	-	-	-	5.0	1182	1132	1382	Conforming steel
8	0.124	0.28	2.41	0.012	0.0018	0.023	0.23	0.019	0.021	0.0056	-	-	-	-	3.8	1117	1067	1317	Conforming steel
9	<u>0.039</u>	0.58	2.71	0.024	0.0028	0.031	0.13	0.028	0.025	0.0046	-	-	-	-	5.4	1034	984	1234	Comparative steel
10	<u>0.165</u>	0.49	3.32	0.012	0.0024	0.030	0.20	0.045	0.015	0.0029	-	-	-	0.05	5.2	1272	1222	1472	Comparative steel
11	0.076	0.44	<u>1.01</u>	0.008	0.0014	0.022	0.24	0.030	0.012	0.0036	-	0.18	-	-	3.3	1113	1063	1313	Comparative steel
12	0,095	0.32	<u>4.38</u>	0.021	0.0031	0.041	0.32	0.029	0.028	0.0046	-	-	-	-	6.1	1137	1087	1337	Comparative steel
13	0.072	0.21	2.41	0.012	0.0028	0.048	<u>0.01</u>	0.021	0.015	0.0047	-	-	-	-	3.2	1066	1016	1266	Comparative steel
14	0.075	0.32	2.59	0.016	0.0015	0.025	0.17	<u>0.008</u>	0.013	0.0038	-	-	-	0.04	3.4	966	916	1166	Comparative steel
15	0.118	0.99	3.51	0.031	0.0033	0.050	0.20	0.042	<u>0.004</u>	0.0012	0.28	-	-	-	3.3	1211	1161	1411	Comparative steel
16	0.068	0.25	3.44	0.016	0.0029	0.032	0.26	0.021	<u>0.041</u>	0.0060	-	-	-	-	6.8	1061	1011	1261	Comparative steel
17	0.120	0.16	3.20	0.021	0.0025	0.030	0.09	0.049	0.033	<u>0.0076</u>	0.10	-	-	-	4.3	1242	1192	1442	Comparative steel
18	0.093	0.38	3.02	0.015	0.0012	0.046	0.35	0.024	0.014	0.0058	-	-	0.20	-	<u>2.4</u>	1112	1062	1312	Comparative steel
19	0.111	0.30	3.39	0.031	0.0030	0.026	0.15	0.041	0.032	0.0022	-	-	-	-	<u>14.5</u>	1200	1150	1400	Comparative steel

Underlines indicate outside the appropriate range

[Table 2] Table 2

Table 2

No.	Steel No	Material thickness (mm)	Hot rolling conditions: Heating temperature (°C)	Hot rolling conditions: Finisher delivery temperature (°C)	Hot rolling conditions: Coiling temperature (°C)	Hot rolling conditions: Sheet thickness (mm)	Cold rolling conditions: Total rolling reduction (%)	Cold rolling conditions: Sheet thickness (mm)	Annealing conditions: Heating temperature (°C)	Annealing conditions: Heating holding time (s)	Annealing conditions: Cooling rate (°C/s)	Annealing conditions: Cooling Stop temperature (°C)	Annealing conditions: Holding time (s)	Remarks
1-1	1	200	1200	900	590	2.8	50	1.4	790	100	15	320	200	Example
1-2	1	200	1200	860	590	2.8	50	1.4	790	100	15	280	500	Example
1-3	1	200	<u>1030</u>	860	590	2.8	50	1.4	790	100	15	300	200	Comparative Example
1-4	1	200	<u>1330</u>	930	590	2.8	50	1.4	790	100	15	300	200	Comparative Example
1-5	1	200	1200	900	<u>700</u>	2.8	50	1.4	790	100	15	300	200	Comparative Example
1-6	1	200	1200	900	590	2.8	50	1.4	<u>920</u>	100	15	300	200	Comparative Example
1-7	1	200	1200	900	590	2.8	50	1.4	<u>680</u>	100	15	300	200	Comparative Example
2	2	210	1200	890	600	2.8	50	1.4	820	60	15	270	120	Example
3-1	3	200	1230	900	600	2.8	50	1.4	780	80	25	310	150	Example
3-2	3	200	1230	900	600	2.8	50	1.4	780	80	<u>3</u>	310	150	Comparative Example
3-3	3	200	1230	900	600	2.8	50	1.4	780	80	20	<u>480</u>	150	Comparative Example
4	4	200	1200	870	520	2.8	50	1.4	820	70	70	230	150	Example
5	5	200	1250	880	600	2.8	50	1.4	760	150	13	310	400	Example
6	6	200	1280	900	620	2.8	50	1.4	880	90	20	330	200	Example

(continued)

No	Steel No	Material thickness	Hot rolling conditions				Cold rolling conditions		Annealing conditions					Remarks
			heating temperature	Finisher delivery temperature	Coiling temperature	Sheet thickness	Total rolling reduction	Sheet thickness	Heating temperature	Heating holding time	Cooling rate	Cooling slop temperature	Holding time	
		(mm)	(°C)	(°C)	(°C)	(mm)	(%)	(mm)	(°C)	(s)	(°C/s)	(°C)	(s)	
7	7	200	1150	920	600	28	50	1.4	750	90	20	290	200	Example
8	8	200	1100	860	450	2.8	50	1.4	770	90	25	300	120	Example
9	<u>9</u>	200	1200	880	580	2.8	50	1.4	780	90	15	300	200	Comparative Example
10	<u>10</u>	230	1280	920	550	2.8	50	1.4	810	60	40	250	120	Comparative Example
11	<u>11</u>	200	1220	880	560	28	50	1.4	830	90	30	300	180	Comparative Example
12	<u>12</u>	200	1250	900	600	28	50	1.4	780	60	20	300	120	Comparative Example
13	<u>13</u>	220	1200	860	550	2.8	50	1.4	840	100	20	310	230	Comparative Example
14	<u>14</u>	200	1150	850	500	2 8	50	1.4	810	100	25	280	200	Comparative Example
15	<u>15</u>	200	1250	930	600	2.8	50	1.4	810	90	20	300	180	Comparative Example
16	<u>16</u>	200	1250	900	560	2.8	50	1.4	800	120	15	280	300	Comparative Example
17	<u>17</u>	200	1250	900	600	2.8	50	1.4	790	100	20	300	250	Comparative Example
18	<u>18</u>	200	1200	900	550	2.8	50	1.4	780	60	25	320	100	Comparative Example
19	<u>19</u>	200	1250	900	600	2.8	50	1.4	800	90	20	290	150	Comparative Example

Underlines indicate outside the appropriate range.

[0060] Each cold-rolled steel sheet obtained as a result was subjected to (I) analysis of extracted residue of precipitate, (2) tensile test, and (3) spot weld test as follows.

(1) Analysis of extracted residue of precipitate

[0061] An electroextraction test piece was collected from each cold-rolled steel sheet obtained as mentioned above, and subjected to electrolytic treatment using a AA electrolytic solution (ethanol solution of acetylacetone tetramethylammonium chloride), to extract a residue by filtration.

[0062] The extracted residue was set to a constant volume of 100 ml using pure water, and the amount of Ti was measured by high-frequency inductively coupled plasma (ICP) emission spectrometry as the amount of Ti existing as a precipitate. Likewise, the amount of Nb in the extracted residue was measured, and the measured amount of Nb was subtracted from the total amount of Nb in the test piece to calculate the amount of solute Nb.

[0063] The calculated amount of Ti existing as a precipitate and amount of solute Nb were respectively divided by the total amount of Ti and total amount of Nb in the test piece, to find the proportion of Ti existing as a precipitate in the steel and the proportion of Nb existing as solute Nb in the steel. The evaluation results are shown in Table 3.

(2) Tensile test

[0064] A JIS No. 5 tensile test piece was collected in the direction orthogonal to the rolling direction, and tensile strength (TS) and total elongation (El) were measured according to JIS Z 2241 (2011). The evaluation results are shown in Table 3. Each sample with TS $\geq$ 980 MPa and El $\geq$ 13% was determined as favorable.

(3) Spot weld test

- Cross tensile test

[0065] Each cold-rolled steel sheet obtained as mentioned above was used to form a cross tensile test piece according to JIS Z 3137 (1999). Spot welding in the formation of the cross tensile test piece was performed under the welding conditions of a nugget diameter of 6.0 mm according to the Japan Welding Engineering Society Standard: WES7301.

[0066] The formed cross tensile test piece was then subjected to a cross tensile test according to JIS Z 3137 (1999). Each sample with a cross tensile strength of 10 kN/spot or more and a failure mode of plug failure was determined as excellent in spot weldability.

- Section test

[0067] A section test was conducted according to JIS Z 3139 (2009).

[0068] Two cold-rolled steel sheets of the same steel sample ID were spot welded under the same conditions as the aforementioned cross tensile test piece forming conditions. After polishing a weld section cut perpendicularly to the steel sheet surface, nital etching was applied to obtain a hardness measurement test piece. According to JIS Z 2244 (2009), a Vickers hardness test was conducted from the weld metal portion to the base material portion with a pitch of 0.5 mm from the center position of the nugget in two directions parallel to the steel sheet surface at the positions of 0.5 mm above and 0.5 mm below the center position in the sheet thickness direction, with a test force of 0.9807 N. The difference (ΔHV) between the maximum and minimum values of the measured Vickers hardness was then calculated. Each sample with ΔHV of less than 120 was determined as excellent in spot weldability.

[0069] The evaluation results are shown in Table 3.

[Table 3] Table 3

Table 3

No.	(1) Analysis result of extracted residue of precipitate		(2) Tensile test result		(3) Spot weld test result			Remarks
	Proportion of precipitate Ti (mass%)	Proportion of solute Nb (mass%)	TS (MPa)	El (%)	Cross tensile strength (kN/spot)	Failure mode	(Joint hardness distribution) Difference between maximum and minimum values of Vickers hardness ΔHV	
1-1	85.1	26.9	1039	16.4	12.0	Plug failure	77	Example
1-2	89.4	23.6	1082	15.2	11.6	Plug failure	80	Example
1-3	86.2	12.5	906	20.1	9.1	Plug failure	126	Comparative Example
1-4	51.4	48.6	1036	12.7	11.6	Plug failure	82	Comparative Example
1-5	95.2	10.4	948	18.1	9.8	Plug failure	125	Comparative Example
1-6	82.1	33.6	954	12.0	11.6	Plug failure	80	Comparative Example
1-7	69.4	10.8	789	20.3	8.7	Plug failure	139	Comparative Example
2	85.4	24.9	990	17.6	11.5	Plug failure	10.1	Example
3-1	90.1	24.3	1032	16.2	11.4	Plug failure	88	Example
3-2	93.2	10.7	852	18.8	9.6	Plug failure	135	Comparative Example
3-3	89.2	12.6	931	18.0	9.7	Plug failure	128	Comparative Example
4	80.6	60.8	991	16.0	11.7	Plug failure	94	Example
5	88.4	33.4	1098	13.6	10.5	Plug failure	72	Example
6	91.7	16.8	1028	16.7	11.4	Plug failure	110	Example

(continued)

Proportion of precipitate Ti (mass%)	Proportion of solute Nb (mass%)	TS (MPa)	El (%)	Cross tensile strength (kN/spot)	Failure mode	(Joint hardness distribution) Difference between maximum and minimum values of Vickers hardness ΔHV		
7	72.7	21.3	987	14.3	10.6	Plug failure	101	Example
8	87.4	24.1	992	16.2	11.1	Plug failure	90	Example
9	76.4	55.2	812	19.6	8.7	Plug failure	57	Comparative Example
10	78.4	12.7	1157	10.9	9.1	Interface failure	151	Comparative Example
11	77.5	19.3	882	17.4	9.2	Plug failure	135	Comparative Example
12	80.4	35.5	1162	11.8	9.1	Interface failure	125	Comparative Example
13	82.5	33.3	942	17.2	10.4	Plug failure	59	Comparative Example
14	82.1	69.4	862	17.1	8.9	Plug failure	121	Comparative Example
15	66.9	8.2	830	16.7	8.2	Plug failure	130	Comparative Example
16	89.2	36.1	1096	10.2	8.2	Interface failure	111	Comparative Example
17	92.3	11.9	973	18.4	9.5	Interface failure	127	Comparative Example
18	98.6	12.3	955	17.9	9.9	Plug failure	106	Comparative Example
19	52.4	38.6	1102	11.8	9.7	Plug failure	101	Comparative Example

Underlines indicate outside the appropriate range.

[0070] As shown in Table 3, all Examples had a tensile strength of 980 MPa or more, and had excellent spot weldability as the cross tensile strength was 10 kN/spot or more, the failure mode was plug failure, and the difference ΔHV between the maximum and minimum values of Vickers hardness was less than 120. All Examples also had a total elongation of 13% or more.

[0071] On the other hand, Comparative Examples had insufficient performance in at least one of the tensile strength and total elongation of the base material and the cross tensile strength, the failure mode, and the difference (ΔHV) between the maximum and minimum values of Vickers hardness in the spot weld test.

Claims

1. A cold-rolled steel sheet having excellent spot weldability, the cold-rolled steel sheet having a steel composition containing, in mass%:

    C: 0.05% to 0.13%;
    Si: 0.05% to 2.0%;
    Mn: 1.5% to 4.0%;
    P: 0.05% or less;
    S: 0.005% or less;
    Al: 0.01% to 0.10%;
    Cr: 0.05% to 1.0%;
    Nb: 0.010% to 0.070%;
    Ti: 0.005% to 0.040%; and
    N: 0.0005% to 0.0065%,
    with a mass ratio Ti/N of Ti and N being 2.5 or more and 7.5 or less, and a balance being Fe and incidental impurities,
    wherein 70 mass% or more ofTi in steel exists as a precipitate, and 15 mass% or more of Nb in the steel exists as solute Nb, and
    a tensile strength is 980 MPa or more.

2. The cold-rolled steel sheet having excellent spot weldability according to claim 1,
wherein the steel composition further contains one or more selected from, in mass%:

    Mo: 0.01% to 1.0%;
    Cu: 1.0% or less;
    Ni: 1.0% or less; and
    V: 0.1% or less.

3. A manufacturing method for a cold-rolled steel sheet having excellent spot weldability, the manufacturing method comprising:

    heating a steel material having the steel composition according to claim 1 or 2 to a temperature range of (Ts - 50) °C or more and (Ts + 200) °C or less where Ts is a temperature defined by the following Formula (1), hot rolling the steel material with a finisher delivery temperature of 850 °C or more to obtain a hot-rolled steel sheet, and then coiling the hot-rolled steel sheet at a temperature of 650 °C or less;
    cold rolling the hot-rolled steel sheet into a cold-rolled steel sheet; and
    continuously annealing the cold-rolled steel sheet by: heating the cold-rolled steel sheet to a temperature range of 700 °C or more and 900 °C or less; and, in a subsequent cooling process, cooling the cold-rolled steel sheet to a temperature range of 200 °C or more and 450 °C or less with an average cooling rate of 12 °C/s or more and 100 °C/s or less, and holding the cold-rolled steel sheet in the temperature range of 200 °C or more and 450 °C or less for a time of 30 s or more and 600 s or less,

$$Ts\ (^\circ C) = 6770/[2.26 - \log_{10}\{[\%Nb] \times ([\%C] + 0.86[\%N])\}] - 273 \quad \cdots (1)$$

    where [%Nb], [%C], and [%N] respectively denote Nb, C, and N contents in steel in mass%.

INTERNATIONAL SEARCH REPORT

International application No.
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A. CLASSIFICATION OF SUBJECT MATTER
C22C38/00(2006.01)i, *C21D9/46*(2006.01)i, *C22C38/38*(2006.01)i, *C22C38/58*(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	1996-2015
Kokai Jitsuyo Shinan Koho	1971-2015	Toroku Jitsuyo Shinan Koho	1994-2015

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 2008-274360 A (Nippon Steel Corp.), 13 November 2008 (13.11.2008), steel no.A (Family: none)	1-3
A	JP 2004-18912 A (JFE Steel Corp.), 22 January 2004 (22.01.2004), claims & WO 2003/106723 A1 & US 2004/0238082 A1 & EP 1514951 A1 claims	1-3
A	JP 9-176781 A (NKK Corp.), 08 July 1997 (08.07.1997), steel type 18 (Family: none)	1-3

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

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"&" document member of the same patent family

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