(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 2 431 490 A1

(12) EUROPEAN PATENT APPLICATION
published in accordance with Art. 153(4) EPC

(43) Date of publication:
21.03.2012 Bulletin 2012/12

(21) Application number: **10769548.8**

(22) Date of filing: **19.02.2010**

(51) Int Cl.:
***C22C 38/00** (2006.01)* ***C21D 9/46** (2006.01)*
***C22C 38/06** (2006.01)*

(86) International application number:
PCT/JP2010/053017

(87) International publication number:
WO 2010/125848 (04.11.2010 Gazette 2010/44)

(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO SE SI SK SM TR

(30) Priority: **28.04.2009 JP 2009108820**

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(54) COLD-ROLLED STEEL SHEET WITH EXCELLENT FORMABILITY, SHAPE RETENTIVITY, AND SURFACE APPEARANCE AND PROCESS FOR PRODUCING SAME

(57) In low-carbon steel, a cold-rolled steel sheet and a method for manufacturing the same are provided. The cold-rolled steel sheet can satisfy both workability and shape fixability; can be subjected to drawing, bending, and stretching; can ensure shapes required for large-size parts; have high flatness; is free from appearance defects; and is excellent in formability, shape fixability, and surface appearance. The cold-rolled steel sheet has a composition of 0.030% to 0.060% C, 0.05% or less Si, 0.1% to 0.3% Mn, 0.05% or less P, 0.02% or less S, 0.02% to 0.10% Al, and 0.005% or less N on a mass basis, the remainder being iron and unavoidable impurities. The Lankford value thereof is 0.7 to 1.4 in a rolling direction and a direction perpendicular to the rolling direction. The in-plane anisotropy (Δr) of the Lankford value thereof satisfies the inequality $-0.2 \leq \Delta r \leq 0.2$. The mean yield strength thereof is 230 MPa or less and the mean elongation thereof is 40% or more in three directions: the rolling direction, a direction at 45 degrees to the rolling direction, and a direction perpendicular to the rolling direction. The yield elongation of the cold-rolled steel sheet held at 170°C for 60 minutes is 2% or less in each of the three directions.

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Description

[Technical Field]

[0001] The present invention relates to a cold-rolled steel sheet which is most suitable for members of large-size tabular parts such as backlight chassis for large-size liquid crystal display televisions and which has excellent formability, shape fixability, and surface appearance and also relates to a method for manufacturing the same.

[Background Art]

[0002] In recent years, the upsizing of thin-screen televisions has led to the upsizing of backlight chassis for liquid crystal display televisions. In addition, there are significant needs for lighter televisions and the reduction of material costs and thinner backlight chassis are used. However, backlight chassis need to have rigidity to support lights, need to be good in flatness, and need to hardly be deformed such that the lights do not hit liquid crystal sections or crack, that is, backlight chassis need to be free from so-called "twist". Requirements for rigidity and flatness have become more severe because of the upsizing and thinning of backlight chassis.

[0003] In order to ensure rigidity, it is effective to form a bead on a flat surface of a backlight chassis by stretching. However, the machining of the flat surface causes new problems such as the deterioration of flatness and the increase of "twist". In the case of ensuring rigidity by bending an end portion, similar problems occur. Since the deterioration of flatness is a phenomenon caused by poor shape fixability, steel sheets used as members are increasingly required to have workability and shape fixability.

[0004] An example of a conventional steel sheet with excellent shape fixability is a steel sheet in which the texture is controlled and in which at least one of the Lankford value in the rolling direction and the Lankford value in a direction perpendicular to the rolling direction is 0.7 or less as disclosed in Patent Literature 1. It is disclosed that the springback of this steel sheet is small during bending. Patent Literature 2 discloses a method for suppressing springback or camber during bending by controlling the anisotropy of local elongation or uniform elongation. Furthermore, Patent Literature 3 discloses a method for suppressing springback during bending by adjusting the ratio of the {100} plane to the {111} plane to 1.0 or more.

[0005] Backlight chassis, formed by drawing, for large-size televisions have the problem of "twist". This is due to that the feed of a steel sheet is uneven during drawing and therefore the thickness of a shaped portion is uneven.

[0006] Furthermore, markings called stretcher strains are caused during the shaping of these backlight chassis, leading to the problem of the poor flatness and poor appearance of these backlight chassis. Patent Literature 4 discloses a method for reducing the yield elongation of low-carbon steel that is responsible for stretcher strains. In this method, an appropriate amount of B is added and the center line valley depth (Rv) and the center line average (Ra), which are surface roughness parameters, are adjusted to 0.5 to 10 μm and 0.5 μm or more, respectively, during cold rolling.

[Citation List]

[Patent Literature]

[0007]

PTL 1 : Japanese Patent No. 3532138
PTL 2: Japanese Unexamined Patent Application Publication No. 2004-183057
PTL 3: International Publication No. WO 00/06791
PTL 4: Japanese Unexamined Patent Application Publication No. 4-276023

[Summary of Invention]

[Technical Problem]

[0008] In backlight chassis for 32-inch and larger liquid crystal display televisions, for which the market has been greatly expanding In recent years, dome height or the number of flared portions is usually increased for the purpose of ensuring rigidity in spite of a reduction in thickness; hence, high elongation is needed to machine these portions. However, there is a problem in that techniques disclosed in Patent Literatures 1 to 3 are incapable of achieving workability to ensure required part geometry and rigidity.

[0009] A reduction in yield strength is known to be effective in suppressing springback. In general, low-carbon steels have high yield strength and insufficient elongation. Therefore, ultra-low-carbon steels are used for portions that are difficult to machine. The softening of steel is effective in reducing the yield strength and an increase in annealing temperature and an increase in cold-rolling reduction are effective as techniques therefor. However, the softening of steel develops a (111)-oriented texture to increase the Lankford value. Low-carbon steel can be probably applied to parts such as backlight chassis for large-size TVs only by achieving both the softening of steel for the purpose of suppressing springback and the reduction of the Lankford value for the purpose of suppressing the strain caused by bending. However, in conventional low-carbon steels, the softening of steel and high Lankford values have been principally required.

[0010] For the problem of geometrical flatness and poor appearance, it is important that the yield strength of a steel sheet is small not only just after the steel sheet is manufactured but also until the steel sheet is shaped, that is, properties thereof after aging are important. However, the method disclosed in Patent Literature 4 needs to meet all the requirement of the surface roughness of a cold-rolled sheet, the requirement of the cooling rate thereof during recrystallization annealing, and the requirements of overaging conditions and therefore has a problem that the control of manufacturing conditions is complicated.

[0011] It is an object of the present invention to solve problems associated with such conventional techniques. That is, in low-carbon steel, it is an object of the present invention to provide a cold-rolled steel sheet and a method for manufacturing the same. The cold-rolled steel sheet satisfies both workability and shape fixability; can be subjected to drawing, bending, and stretching; can ensure shapes required for large-size parts; has high flatness; is free from appearance defects; and is excellent in formability, shape fixability, and surface appearance.

[Solution to Problem]

[0012] Features of the present invention that are intended to solve the problems are as described below.

(1) A cold-rolled steel sheet having a composition of 0.030% to 0.060% C, 0.05% or less Si, 0.1% to 0.3% Mn, 0.05% or less P, 0.02% or less S, 0.02% to 0.10% Al, and 0.005% or less N on a mass basis, the remainder being iron and unavoidable impurities, wherein the mean yield strength (YS_m) thereof is 230 MPa or less as determined by the following equation (a); the mean elongation (El_m) thereof is 40% or more as determined by the following equation (b); the Lankford value thereof is 0.7 to 1.4 in a rolling direction and a direction perpendicular to the rolling direction; the in-plane anisotropy (Δr) of the Lankford value thereof satisfies the inequality $-0.2 \leq \Delta r \leq 0.2$ as determined by the following equation (c); and the yield elongation of the cold-rolled steel sheet held at 170°C for 60 minutes is 2% or less in the rolling direction, a direction at 45 degrees to the rolling direction, and the direction perpendicular to the rolling direction:

$$YS_m = (YS_L + 2YS_D + YS_C) / 4 \qquad (a)$$

$$El_m = (El_L + 2El_D + El_C) / 4 \qquad (b)$$

$$\Delta r = (r_L - 2r_D + r_C) / 2 \qquad (c)$$

where YS_m is the mean yield strength, El_m is the mean elongation, Δr is the in-plane anisotropy of the Lankford value, YS_L is the yield strength in the rolling direction, YS_D is the yield strength in the direction at 45 degrees to the rolling direction, YS_C is the yield strength in the direction perpendicular to the rolling direction, El_L is the elongation in the rolling direction, El_D is the elongation in the direction at 45 degrees to the rolling direction, El_C is the elongation in the direction perpendicular to the rolling direction, r_L is the Lankford value in the rolling direction, r_D is the Lankford value in the direction at 45 degrees to the rolling direction, and r_C is the Lankford value in the direction perpendicular to the rolling direction.

(2) A method for manufacturing a cold-rolled steel sheet includes heating a slab of steel having the composition specified in Item (1) to a heating temperature of 1200°C or higher, performing hot rolling such that finish rolling is ended at a temperature of (A1 transformation temperature - 50°C) to (A1 transformation temperature + 100°C), performing coiling at 550°C to 680°C, performing pickling, performing cold rolling at a rolling reduction of 50% to 85%, performing heating to an annealing temperature of 700°C or higher from 600°C or higher at an average heating rate of 1 to 30 °C/s, and then performing cooling to 600°C at an average cooling rate of 3 °C/s or more.

[0013] The present invention has been made as a result of intensive investigations performed to solve the above-mentioned problems. In the case where a large rectangular flat plate is taken from a steel sheet and is then machined into a required part, in view of material yield and operation, it is advantageous that the plate is taken therefrom such that the long sides of the rectangular plate are parallel to the rolling direction of the steel sheet or a direction perpendicular to the rolling direction thereof. In the case of taking materials in such a way, the present invention allows even large-size parts to satisfy workability and surface quality. That is, drawing and stretching can be performed by increasing the mean elongation, whereby shapes required for parts can be ensured. The occurrence of springback can be suppressed after machining by reducing the yield strength, whereby shape fixability can be ensured. The Lankford value is adjusted to 0.7 to 1.4 in the rolling direction and the direction perpendicular to the rolling direction and the inequality $-0.2 \le \Delta r \le 0.2$ holds; hence, shape fixability can be ensured. Furthermore, it is most important that adjusting the aged yield strength to 2% or less allows the formation of stretcher strains to be suppressed during machining, surface appearance to be rendered excellent, the occurrence of springback to be suppressed after machining, and shape fixability to be ensured.

[0014] In the present invention, the mechanism of an increase in elongation and a reduction in yield strength is believed as described below. That is, in hot rolling, the finish temperature is adjusted to (A1 transformation temperature - 50°C) to (A1 transformation temperature + 100°C) and rolling is ended such that austenite is not formed but ferrite is formed, whereby the grain size of a ferrite microstructure is coarsened. This allows the size of grains to be coarsened after cold rolling or recrystallization annealing and enables softening.

[0015] Meanwhile, in hot rolling, finish rolling is ended within a range from (A1 transformation temperature - 50°C) to (A1 transformation temperature + 100°C), whereby the (110) orientation is formed in a surface layer of a hot-rolled steel sheet. The hot-rolled steel sheet is cold-rolled and is then recrystallization-annealed, whereby the Lankford value is maintained low because of the development of the (110) orientation. This enables softening due to the coarsening of ferrite grains with the Lankford value maintained low. Furthermore, yield elongation is completely eliminated and aged yield strength is reduced; hence, a steel sheet in which the formation of stretcher strains is suppressed after shaping and which has excellent surface appearance can be obtained. In the present invention, details of the reason for the elimination of yield strength are not clear but the mechanism thereof is believed as described below. That is, the (110) orientation is known to be an orientation in which strain is likely to be accumulated and the development of this orientation in the surface layer allows strain due to cold rolling or temper rolling to be readily introduced. This is likely to cause so-called dislocation; hence, the formation of stretcher strains is supposed to be difficult.

[0016] Even if the cold-rolled steel sheet according to the present invention is converted into a thin cold-rolled steel sheet with a thickness of 1.0 mm to 0.5 mm, this steel sheet is free from stretcher strains and has excellent surface appearance. Cold-rolled steel sheets contemplated by the present invention include steel sheets manufactured by subjecting cold-rolled steel sheets to surface treatment such as electrogalvanizing or galvanizing and steel sheets manufactured by providing coatings on those steel sheets.

[0017] The steel sheet according to the present invention can be widely used for not only backlight chassis for large-size TVs but also common members, such as panels for refrigerators and air conditioner outdoor units, for home appliance use, the common members having flat portions and being subjected to bending, stretching, or slight drawing. The present invention can be used to manufacture a backlight chassis with a size of about 850 mm x 650 mm (42V type) from a steel sheet with a thickness of, for example, 0.8 mm.

[Advantageous Effects of Invention]

[0018] According to the present invention, the following sheet can be obtained: a cold-rolled steel sheet which is capable of achieving low yield elongation, excellent elongation, low yield strength, and low aged yield elongation; which satisfies both workability and shape fixability; which can be subjected to drawing, bending, and stretching; and which is excellent in formability, shape fixability, and surface appearance. This allows tabular shapes required for large-size parts to be ensured; hence, members such as backlight chassis for large-size liquid crystal display televisions can be manufactured.

[Description of Embodiments]

[0019] Chemical components of a steel sheet according to the present invention will now be described. In descriptions below, the content % of each component element is expressed in mass percent.

C: 0.030% to 0.060%

[0020] During recrystallization annealing, solute C is reduced by forming cementite. In this operation, when the content of C is less than 0.030%, the yield strength cannot be adjusted to 230 MPa or less because the degree of supersaturation is too small to precipitate carbides and therefore the precipitation of the carbides is insufficient. Thus, the lower limit is

0.030%. When the content thereof is more than 0.060%, the workability is seriously deteriorated. Thus, the upper limit is 0.060%.

Si: 0.05% or less

[0021] When a large amount of Si is contained, the workability is deteriorated because of hardening or the platability is impaired because of the formation of silicon oxide during annealing. Furthermore, scale is formed on the surface because of the concentration of Si and therefore the surface appearance may probably be impaired. Thus, the upper limit is 0.05%.

Mn: 0.1% to 0.3%

[0022] Mn converts harmful S in steel into MnS, which is harmless, and therefore the content thereof needs to be 0.1% or more. However, a large amount of Mn causes the deterioration of workability because of hardening or suppresses the recrystallization of ferrite during annealing; hence, the content thereof needs to be 0.3% or less.

P: 0.05% or less

[0023] Since P segregates at grain boundaries to deteriorate ductility and toughness, the content thereof needs to be 0.05% or less and is preferably 0.03% or less.

S: 0.02% or less

[0024] S seriously reduces hot ductility and therefore causes hot cracking to seriously deteriorate surface quality. Furthermore, S hardly contributes to strength and reduces ductility because S serves as an impurity element to form coarse MnS. These problems are serious when the content of S is more than 0.02%; hence, the content thereof is preferably minimized. Thus, the content of S needs to be 0.02% or less.

Al: 0.02% to 0.10%

[0025] Al fixes nitrogen in the form of a nitride, whereby age hardening due to solute N can be suppressed. In order to achieve such an effect, the content of Al needs to be 0.02% or more. However, a large amount of Al causes the deterioration of workability. Thus, the content of Al needs to be 0.10% or less.

N: 0.005% or less

[0026] When a large amount of N is contained, surface flaws may possibly be caused because slab cracking occurs during hot rolling. The presence of solute N causes age hardening after cold rolling or annealing. Thus, the content of N needs to be 0.005% or less.

[0027] Component other than the above are iron and unavoidable impurities. Examples of the unavoidable impurities include 0.05% or less Cu and Cr, which are likely to be contained in scraps, and 0.01% or less of other elements such as Sn, Mo, W, V, Ti, Nb, Ni, and B.

[0028] The metallographic structure of the steel sheet according to the present invention is substantially made of ferrite and cementite. The average ferrite grain size of a ferrite microstructure is 7 μm or more. Coarse ferrite grains are achieved in a hot rolling step as described below.

[0029] The steel sheet according to the present invention has a mean yield strength of 230 MPa or less as determined by above Equation (a). When the mean yield strength thereof exceeds 230 MPa, shape failures such as springback are caused in some cases. Thus, the mean yield strength thereof is 230 MPa or less.

[0030] The steel sheet according to the present invention has a Lankford value of 0.7 to 1.4 in the rolling direction thereof and a direction perpendicular to the rolling direction. The phenomenon "twist", which is due to shape fixability as described above, is known to be caused by edge warp during bending or stretching and can be suppressed by reducing the Lankford value. However, when the Lankford value is small, drawing is difficult. The inventors have found that the Lankford value needs to be 0.7 to 1.4 as an indicator showing that edge warp is suppressed and drawing is possible.

[0031] In the case of machining large rectangular flat plates into required parts, in view of material yield and operation, it is advantageous that the plates are taken from steel sheets such that the long sides of the rectangular plates are parallel to the rolling direction of the steel sheets or a direction perpendicular to the rolling direction thereof. In the steel sheet according to the present invention, materials are taken in such a way and are machined into parts. In order to

balance the workability and flatness of large-size parts, the upper limit of the Lankford value is limited to 1.4 in the rolling direction and a direction perpendicular to the rolling direction, whereby in the case of bending an end portion of a long side and an end portion of a short side of a rectangular flat plate, a material can be prevented from being fed into a corner portion thereof and the flatness of the parts can be maintained.
Furthermore, the lower limit of the Lankford value is limited to 0.7, whereby the rigidity of the parts can be prevented from being reduced due to the reduction in thickness of the corner portion. The lower limit of the Lankford value is preferably more than 0.7 and more preferably 0.75 or more.

[0032] The steel sheet according to the present invention has a mean elongation of 40% or more as determined by above Equation (b). In addition to the above properties, the mean elongation thereof is increased to 40% or more, whereby the steel sheet can be drawn and stretched and shapes necessary for parts can be ensured.

[0033] In the steel sheet according to the present invention, the in-plane anisotropy (Δr) of the Lankford value satisfies the inequality $-0.2 \leq \Delta r \leq 0.2$ as determined by above Equation (c). In the case of forming backlight chassis for large-size TVs or the like by drawing, "twist" occurs after drawing in some cases. This occurs because the feed of a plate is uneven during drawing and therefore the thickness of a drawn portion is uneven. Therefore, the in-plane anisotropy (Δr) of the Lankford value is preferably close to "0" and the feed of a plate is preferably even; hence, Δr is limited to the range of -0.2 to 0.2.

[0034] In addition to the above, the steel sheet according to the present invention has a yield elongation of 2% or less in each of the rolling direction thereof, a direction at 45 degrees to the rolling direction thereof, and a direction perpendicular to the rolling direction thereof after the steel sheet is aged at 170°C for 60 minutes. The yield elongation thereof is reduced not only just after the manufacture of the steel sheet but also the aging thereof, whereby stretcher strains are suppressed after shaping and the steel sheet can be manufactured so as to have excellent surface appearance.

[0035] Conditions for manufacturing the steel sheet according to the present invention are described below. In the present invention, a slab having the above composition is hot-rolled in such a manner that the finish rolling temperature thereof is adjusted to (A1 transformation temperature - 50°C) to (A1 transformation temperature + 100°C), whereby a hot-rolled steel sheet is manufactured such that the grain size of ferrite is increased and the (110) orientation is developed in a surface layer of the hot-rolled steel sheet during hot rolling. The hot-rolled steel sheet is cold-rolled and is then recrystallization-annealed, whereby coarse ferrite grains are formed. This allows low yield strength and excellent elongation to be achieved and yield elongation to be completely eliminated, whereby an appropriate Lankford value can be obtained.

Heating temperature: 1200°C or higher

[0036] Since it is necessary that carbides such as A1N are once converted into solid solutions during heating before hot rolling and are then finely precipitated after coiling, the heating temperature during hot rolling needs to be 1200°C or higher.

Finish rolling final temperature: (A1 transformation temperature - 50°C) to (A1 transformation temperature + 100°C)

[0037] Hot rolling needs to be performed at a finish temperature of (A1 transformation temperature - 50°C) to (A1 transformation temperature + 100°C), which is a key point of the present invention. This ends rolling such that the microstructure of steel is not austenite but ferrite. Rolling is ended with ferrite microstructure, whereby the transformation from austenite to ferrite is completed and strain is caused by rolling at about 700°C to 800°C; hence, ferrite grains coarsen. This allows the hot-rolled steel sheet to have a coarse grain size. Herein, the A1 transformation temperature is about 720°C.

Coiling temperature: 550°C to 680°C

[0038] During coiling, the grain size is increased, carbides are aggregated, and the amount of solute C is reduced.

[0039] When the coiling temperature after finish rolling is low, the formation of acicular ferrite hardens the steel sheet to cause an increase in rolling force during subsequent cold rolling and therefore the difficulty of operation is caused. Furthermore, the aggregation of carbides is insufficient and therefore a large amount of solute C remains; hence, the yield strength cannot be reduced. Thus, the coiling temperature needs to be 550°C or higher and is preferably 600°C or higher. However, when the coiling temperature is higher than 680°C, the temperature of an edge portion of a steel sheet coil (the steel sheet coiled in the form of a coil) decreases relatively, the control of the temperature in the coil is difficult, and the yield is reduced. Furthermore, the steel sheet coil is seized, a large amount of scale is caused, it is insufficient to remove the scale by pickling prior to cold rolling, and defects are caused during cold rolling. Thus, the coiling temperature needs to be 680°C or lower.

Rolling reduction (cold-rolling reduction) during cold rolling: 50% to 85%

[0040] The cold-rolling reduction may be within a common range. When the cold-rolling reduction is low, the thickness of a hot-rolled sheet for obtaining a steel sheet with a desired thickness is extremely small and the load during hot rolling is large. Therefore, the lower limit of the cold-rolling reduction is 50%. The upper limit thereof may be about 85%, which is common for cold rolling mills.

Average heating rate at 600°C or higher: 1 to 30 °C/s

[0041] In the annealing of the cold-rolled steel sheet, when the heating rate from 600°C to the annealing temperature is small, carbides produced in the hot-rolled steel sheet are dissolved and solute C increases. Thus, the average heating rate from 600°C to the annealing temperature needs to be 1 °C/s or more. However, when the heating rate is large, the concentration of C in precipitated carbides is insufficient; hence, a large amount of solute C remains and the yield elongation cannot be reduced. Thus, the average heating rate is 30 °C/s or less.

Annealing temperature: 700°C or higher

[0042] The annealing temperature may be a temperature suitable for recrystallization. For low-carbon steels, recrystallization usually occurs at 700°C or higher and therefore the annealing temperature is 700°C or higher. Since the steel sheet is hard when the annealing temperature exceeds the AC_3 transformation temperature, the annealing temperature is preferably not lower than the AC_3 transformation temperature and more preferably not lower than 800°C.
[0043] When the time (soaking time) to hold the annealing temperature (also referred to as the soaking temperature is short, the growth of grains is suppressed even though recrystallization is completed or not; hence, sufficient elongation cannot be ensured in some cases. Thus, soaking time is preferably 30 s or more. However, when the soaking time is excessively long, the grains are grown to be large; hence, the problem of surface roughness occurs during machining and therefore surface quality is likely to be impaired. Thus, the soaking time is preferably 200 s or less.
[0044] Average cooling rate at down to 600°C: 3 °C/s or more After being heated to the annealing temperature, the steel sheet is cooled. The average cooling rate from the annealing temperature to 600°C is less than 3 °C/s, C precipitated in the form of carbides forms solid solutions again to increase the yield strength. Thus, the average cooling rate from the annealing temperature to 600°C needs to be 3 °C/s or more. However, when the cooling rate exceeds 30 °C/s, the growth of ferrite grains is likely to be insufficient; hence, the yield strength is likely to be high and the steel sheet is likely to be hard. Thus, the average cooling rate is preferably 30 °C/s or less.
[0045] A production process such as a common converter process or electric furnace process can be used to carry out the present invention. Produced steel is cast into a slab, which is directly hot-rolled or is cooled, heated and then hot-rolled. The hot-rolled steel sheet is finished under the above-mentioned finish conditions and is then coiled at the above-mentioned coiling temperature. The cooling rate from finish rolling to coiling is not particularly limited and may be a rate equal to or greater than that obtained by air cooling. Quenching may be performed at 100 °C/s or more as required. After common pickling is performed, cold rolling is performed as described above. Annealing is performed after cold rolling in such a manner that heating and then cooling are performed under the above-mentioned conditions. The cooling rate at temperatures lower than 600°C is arbitrary. Galvanizing may be performed at about 480°C as required. After galvanizing is performed, a coating may be alloyed by reheating the coating to 500°C or higher. Alternatively, thermal history may be preserved by holding or the like in the course of cooling. Furthermore, temper rolling may be performed at an elongation of about 0.5% to 2% as required. If plating is not performed in the course of annealing, electrogalvanizing or the like may be performed for the purpose of enhancing corrosion resistance. Furthermore, a coating may be provided on a cold-rolled steel sheet or a plated steel sheet by chemical conversion or the like.

[EXAMPLE 1]

[0046] Examples of the present invention will now be described.
[0047] Table 1 shows the chemical composition, manufacturing conditions, and properties of each specimen.
[0048]

[Table 1]

Specimen No.	Chemical components (mass %)								Hot rolling			Cold-rolling reduction (%)	Annealing				Microstructure	Mechanical properties								Remarks
	C	Si	Mn	P	S	Al	N	Others	RT (°C)	FT (°C)	CT (°C)		Heating rate (°C/s)	Annealing temperature (°C/s)	Soaking time (s)	Cooling rate (°C/s)	Ferrite grain size (mm)	YSm (MPa)	TS (MPa)	El_m (%)	r_L	r_C	r_D	Δr	Aged yield elongation (%)	
1	0.034	0.01	0.15	0.01	0.005	0.04	0.003	-	1250	780	600	83	10	750	130	20	11.7	210	335	42	0.80	1.15	0.83	0.15	0.3	Inventive Example
2	0.041	0.03	0.10	0.01	0.011	0.03	0.004	-	1200	780	565	70	20	780	135	25	11.6	215	340	43	0.72	1.05	0.75	0.14	0.5	Inventive Example
3	0.033	0.02	0.10	0.02	0.020	0.06	0.002	-	1230	760	640	80	30	780	60	25	10.5	220	340	42	0.78	1.12	0.78	0.17	1.2	Inventive Example
4	0.045	0.05	0.20	0.04	0.013	0.05	0.001	-	1200	770	600	85	20	800	60	10	12.2	205	345	42	0.82	1.09	0.85	0.11	0.8	Inventive Example
5	0.038	0.01	0.10	0.01	0.017	0.02	0.003	-	1210	740	620	70	15	850	30	15	11.1	210	350	44	0.74	1.02	0.76	0.12	1.6	Inventive Example
6	0.045	0.04	0.15	0.01	0.013	0.03	0.002	-	1220	780	580	70	7	800	50	10	14.2	220	340	45	0.84	1.11	0.85	0.13	1.1	Inventive Example
7	0.060	0.02	0.30	0.02	0.004	0.02	0.005	-	1250	750	680	75	10	815	60	10	13.2	210	340	45	0.86	1.15	0.87	0.14	0.3	Inventive Example
8	0.032	0.03	0.20	0.01	0.007	0.03	0.003	-	1240	880	650	70	15	750	135	10	6.5	265	340	42	1.15	1.56	1.0	0.36	4.5	Comparative Example
9	0.042	0.02	0.30	0.01	0.010	0.04	0.004	-	1230	920	600	55	21	800	200	8	5.9	250	350	43	1.21	1.48	1.1	0.25	5.2	Comparative Example
10	0.003	0.01	0.10	0.05	0.011	0.03	0.002	Ti/0.010 Nb/0.016 B/0.0006	1200	750	650	80	25	810	120	12	5.8	210	300	47	1.75	1.95	0.95	0.90	0.0	Comparative Example
11	0.015	0.01	0.10	0.01	0.012	0.05	0.002	B/0.0008	1210	780	500	80	13	800	180	15	6.4	250	335	41	1.37	1.75	1.1	0.46	2.1	Comparative Example

Underlines show that values are outside the scope of the present invention.

Aging conditions: holding at 170°C for 60 minutes.

[0049] After slabs having chemical compositions shown in Table 1 were produced, each slab was heated at a heating temperature (RT) for one hour, was roughly rolled, and was then treated at a finish temperature (FT) and coiling temperature (CT). Steels according to the present invention had an A1 transformation temperature of about 720°C. Hot-rolled sheets had a thickness of 2.0 mm to 3.5 mm. After the hot-rolled sheets were pickled, the hot-rolled sheets were cold-rolled and then annealed under conditions shown in Table 1. The cold-rolled sheets had a thickness of 0.6 mm to 1.0 mm. Herein, the heating rate is the average heating rate from 600°C to the soaking temperature and the cooling rate is the average cooling rate from the soaking temperature to 600°C. Cooling was performed from 600°C to room temperature at a similar cooling rate. After annealing was performed, temper rolling was performed at a rolling reduction of 1.0%. The ferrite grain size and mechanical properties of ferrite microstructures were investigated.
For tensile properties, JIS No. 5 tensile specimens were cut out in a rolling direction (L-direction), a direction (D-direction) at 45 degrees to the rolling direction, and a direction (C-direction) perpendicular to the rolling direction and were then subjected to a tensile test at a cross-head speed of 10 mm/min. JIS No. 5 tensile specimens were cut out in the L-direction, the D-direction, and the C-direction and were then measured for Lankford value with a prestrain of 15%. The Lankford value (r_L) in the L-direction, the Lankford value (r_C) in the C-direction, the Lankford value (r_d) in the D-direction, the mean yield strength (YSm), and the mean elongation (Elm) were determined. Furthermore, the yield strength was measured in each of the rolling direction (L-direction), the direction (D-direction) at 45 degrees to the rolling direction, and the direction (C-direction) perpendicular to the rolling direction and the aged yield strength was also measured after holding at 170°C for 60 minutes. Herein, the following equation holds:

$$El_m = (El_L + 2El_D + El_C) / 4$$

where the subscripts L, D, and C each denote El in a corresponding one of the above directions.
[0050] The average ferrite grain size was determined in accordance with JIS G 0551 (2005).
[0051] The measurement results are summarized in Table 1. The yield strength is the maximum value of the measurements in each direction.
[0052] According to Table 1, steel sheets which were manufactured by a method according to the present invention and which have compositions according to the present invention have an average ferrite grain size of 7 μm or more; a mean yield strength (YSm) of 230 MPa or less in each of the rolling direction, the direction at 45 degrees to the rolling direction, and the direction perpendicular to the rolling direction; a mean elongation (Elm) of 40% or more; a Lankford value (r_L, r_C) of 0.7 to 1.4 in each of the rolling direction and the direction perpendicular to the rolling direction; and an aged yield strength of 0%. The in-plane anisotropy (Δr) of the Lankford value of the steel sheets satisfies the inequality $-0.2 \leq \Delta r \leq 0.2$. In contrast, steel sheets which have compositions outside the scope of the present invention or which have compositions within the scope of the present invention and were manufactured by methods outside the scope of the present invention are inferior in any one of YSm, Elm, r_L, r_C, Δr, and yield elongation.

Claims

1. A cold-rolled steel sheet having a composition of 0.030% to 0.060% C, 0.05% or less Si, 0.1% to 0.3% Mn, 0.05% or less P, 0.02% or less S, 0.02% to 0.10% A1, and 0.005% or less N on a mass basis, the remainder being iron and unavoidable impurities, wherein the mean yield strength (YS_m) thereof is 230 MPa or less as determined by the following equation (a); the mean elongation (El_m) thereof is 40% or more as determined by the following equation (b); the Lankford value thereof is 0.7 to 1.4 in a rolling direction and a direction perpendicular to the rolling direction; the in-plane anisotropy (Δr) of the Lankford value thereof satisfies the inequality $-0.2 \leq \Delta r \leq 0.2$ as determined by the following equation (c); and the yield elongation of the cold-rolled steel sheet held at 170°C for 60 minutes is 2% or less in the rolling direction, a direction at 45 degrees to the rolling direction, and the direction perpendicular to the rolling direction:

$$YS_m = (YS_L + 2YS_D + YS_C) / 4 \quad (a)$$

$$El_m = (El_L + 2El_D + El_C) / 4 \quad (b)$$

$$\Delta r = (r_L - 2r_D + r_C) / 2 \quad (C)$$

where YS_m is the mean yield strength, El_m is the mean elongation, Δr is the in-plane anisotropy of the Lankford value, YS_L is the yield strength in the rolling direction, YS_D is the yield strength in the direction at 45 degrees to the rolling direction, YS_C is the yield strength in the direction perpendicular to the rolling direction, El_L is the elongation in the rolling direction, El_D is the elongation in the direction at 45 degrees to the rolling direction, El_C is the elongation in the direction perpendicular to the rolling direction, r_L is the Lankford value in the rolling direction, r_D is the Lankford value in the direction at 45 degrees to the rolling direction, and r_C is the Lankford value in the direction perpendicular to the rolling direction.

2. A method for manufacturing a cold-rolled steel sheet, comprising heating a slab of steel having the composition specified in Claim 1 to a heating temperature of 1200°C or higher, performing hot rolling such that finish rolling is ended at a temperature of (A1 transformation temperature - 50°C) to (A1 transformation temperature + 100°C), performing coiling at 550°C to 680°C, performing pickling, performing cold rolling at a rolling reduction of 50% to 85%, performing heating to an annealing temperature of 700°C or higher from 600°C or higher at an average heating rate of 1 to 30 °C/s, and then performing cooling to 600°C at an average cooling rate of 3 °C/s or more.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2010/053017

A. CLASSIFICATION OF SUBJECT MATTER
C22C38/00(2006.01)i, *C21D9/46*(2006.01)i, *C22C38/06*(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, C21D9/46, C22C38/06

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	1996-2010
Kokai Jitsuyo Shinan Koho	1971-2010	Toroku Jitsuyo Shinan Koho	1994-2010

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 50-121118 A (Nippon Steel Corp.), 22 September 1975 (22.09.1975), claims; tables 1, 2 (Family: none)	1,2
A	JP 10-237548 A (Nippon Steel Corp.), 08 September 1998 (08.09.1998), claims 1 to 3; paragraphs [0017] to [0019] (Family: none)	1,2
A	JP 58-96821 A (Nippon Steel Corp.), 09 June 1983 (09.06.1983), claims; page 4, upper right column, line 10 to page 5, lower right column, line 16 (Family: none)	1,2

☒ 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

Date of the actual completion of the international search	Date of mailing of the international search report
02 June, 2010 (02.06.10)	15 June, 2010 (15.06.10)
Name and mailing address of the ISA/ Japanese Patent Office	Authorized officer
Facsimile No.	Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2010/053017

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 63-86819 A (Kawasaki Steel Corp.), 18 April 1988 (18.04.1988), claims; page 4, lower right column, line 15 to page 5, upper right column, line 20 (Family: none)	1,2
A	JP 55-110734 A (Kobe Steel, Ltd.), 26 August 1980 (26.08.1980), claims; tables 1, 2 (Family: none)	1,2

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REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 3532138 B **[0007]**
- JP 2004183057 A **[0007]**
- WO 0006791 A **[0007]**
- JP 4276023 A **[0007]**