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(54) HIGH STRENGTH STEEL SHEET AND METHOD FOR MANUFACTURING SAME

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(57) ABSTRACT

The high strength steel sheet consists essentially of 0.05 to 0.15% C, 0.5% or less Si, 1.00 to 2.00% Mn, 0.09% or less P, 0.01% or less S, 0.005% or less N, 0.01 to 0.1% Sol.Al, and balance of Fe and inevitable impurities; and contains 60% or more polygonal ferrite by volume, and 5 to 30% martensite by volume. The steel sheet is manufactured by the steps of: casting a slab having the specified composition; hot-rolling the slab at Ar3 point or more temperature; beginning cooling the hot-rolled steel sheet within 2 seconds after completing the hot-rolling to a temperature of from 750° C. to 600° C. at a cooling rate of 150° C./s or more; holding the cooled steel sheet at a temperature between 750° C. and 600° C. for 2 to 15 seconds; cooling the steel sheet at a cooling rate of 20° C./s or more; and coiling the cooled steel sheet at a temperature of 400° C. or less.

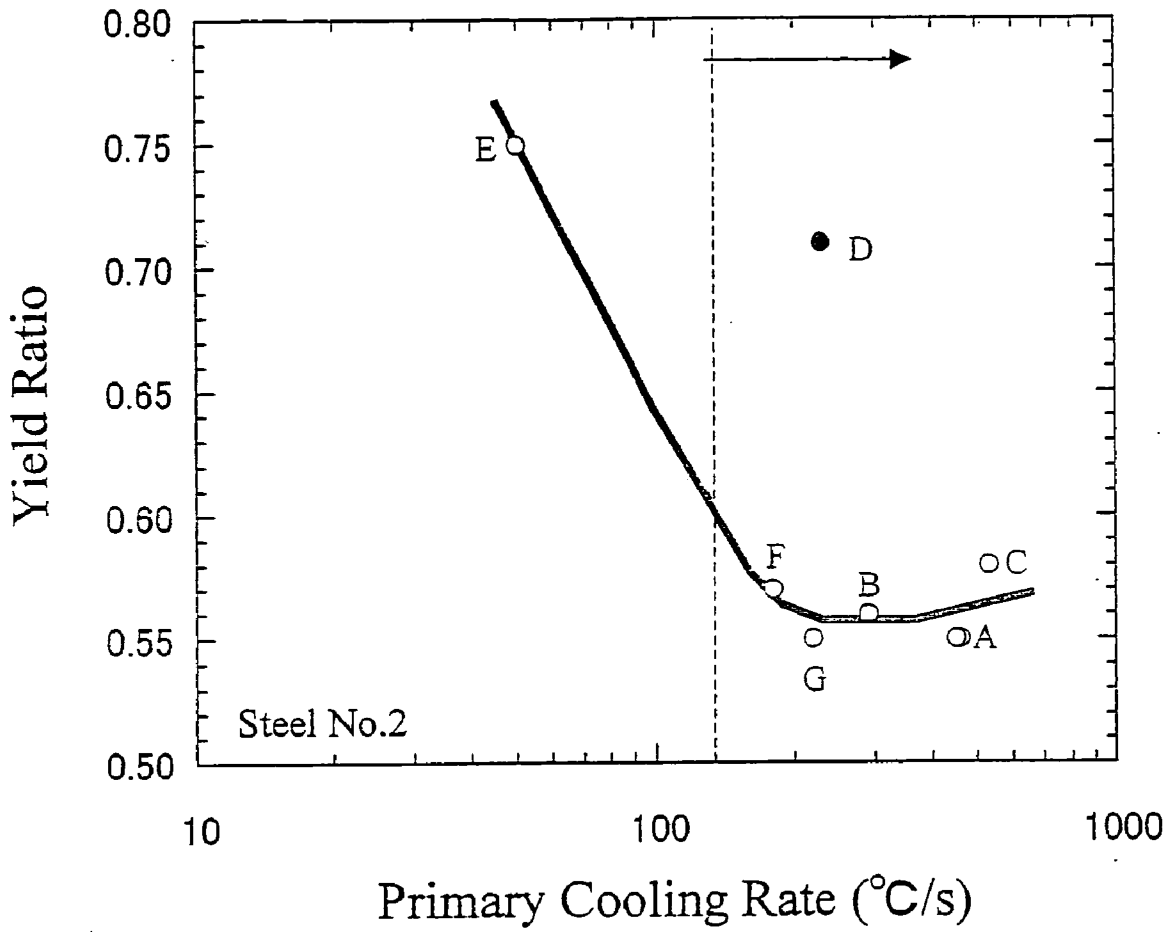
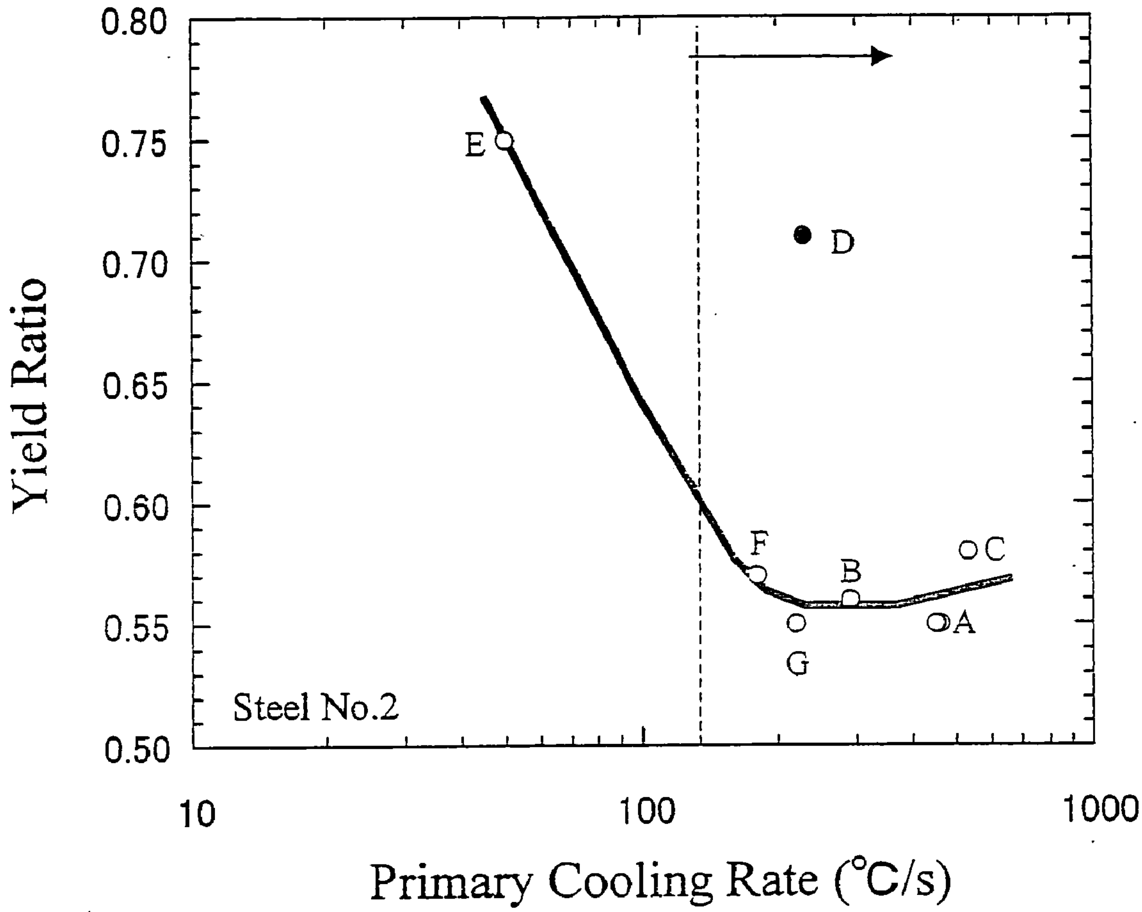


Fig. 1


0.80
0.75
0.70
0.65
0.60
0.55
0.50
Yield Ratio
E
D
F
B
C
A
G
Steel No.2
10
100
1000
Primary Cooling Rate (°C/s)

HIGH STRENGTH STEEL SHEET AND METHOD FOR MANUFACTURING SAME

FIELD OF THE INVENTION

[0001] The present invention relates to a high strength steel sheet most suitable for automobile body, reinforcements, wheels, and chassis parts and further for all kinds of machine structural parts, and to a method for manufacturing same.

DESCRIPTION OF THE RELATED ARTS

[0002] For global environmental protection and further improvement of the safety of passengers, automobile steel sheets are studied to increase the strength and to decrease the thickness. Since, however, increase in the strength of a material generally decreases the press-formability, the widening of application fields of high strength steel sheets faces an important issue of increase in the formability.

[0003] A known response to the requirement is dual phase steel sheet structured by ferrite and martensite as the main phases, (the steel has several names of Dual Phase steel, DP steel, and composite structural steel). Owing to low yield ratio, (hereinafter referred to simply as YR), and high elongation, the dual phase steel sheet is superior in the press-formability such as draw-forming property and surface precision after press-forming (shape accuracy), thus the dual phase steel sheet drew attention as an automobile material, and the development thereof has been enhanced.

[0004] For example, the dual phase micro-structure in a hot-rolled steel sheet is achieved during the cooling step after hot-rolling by transformation to polygonal ferrite much enough to enrich a solute element in the residual austenite, thus increasing in the quench-hardenability due to the transformation to martensite. The technology emphasizes the control of precipitated amount of polygonal ferrite to form the micro-structure and to improve the mechanical characteristics. Accordingly, various development studies on the control of polygonal ferrite precipitation have been given.

[0005] Patent Documents 1 through 11 disclose methods combining with what is called the two-stage cooling process as a steel composition design. The methods include the steps of: adding large amount of ferrite-stabilizing elements represented by Si, (and including P, Al, and the like); stopping cooling, in the cooling step after hot-rolling, at near A_1 temperature where the ferrite precipitation is accelerated; holding the temperature for about 10 seconds; and applying cooling again.

[0006] Patent Documents 12 through 15 disclose manufacturing methods to obtain desired steel sheet without adding the ferrite-stabilizing element. That is, the methods adopt a cooling-control pattern different from conventional method, for example, dividing the rapid cooling after finish-rolling into two stages.

[0007] Patent Documents 16 through 18 disclose methods to apply rapid cooling immediately after the hot-rolling. In particular, Patent Document 16 adopts the above-method for a low Si steel.

[0008] Patent Document 1: JP-A-60-121225, (the term "JP-A" referred to herein signifies "Japanese Patent Laid-Open Publication".)

[0009] Patent Document 2: JP-A-3-10049

[0010] Patent Document 3: JP-A-4-235219

[0011] Patent Document 4: JP-A-4-289126

[0012] Patent Document 5: JP-A-4-337026

[0013] Patent Document 6: JP-A-4-341523

[0014] Patent Document 7: JP-A-7-150294

[0015] Patent Document 8: JP-A-9-67641

[0016] Patent Document 9: JP-A-9-125194

[0017] Patent Document 10: JP-A-9-137249

[0018] Patent Document 11: JP-A-10-195588

[0019] Patent Document 12: JP-A-54-065118

[0020] Patent Document 13: JP-A-56-136928

[0021] Patent Document 14: JP-A-3-126813

[0022] Patent Document 15: JP-A-4-276024

[0023] Patent Document 16: JP-A-2002-69534

[0024] Patent Document 17: JP-A-2001-192736

[0025] Patent Document 18: JP-A-2001-355023

[0026] Patent Documents 1 through 11, however, need to add excess Si, P, and Al, though they show favorable mechanical characteristics, thus they have problems of degradation in surface property caused by red-scale formation, degradation in coatability, and degradation in weldability. Consequently, their applications are limited.

[0027] The steel sheets manufactured by the methods according to Patent Documents 12 through 15 contain small amount of Si, P, and Al so that the cooling method in related art cannot fully progress the transformation from austenite to ferrite on the runout table after hot-rolling. As a result, the volume percentage of polygonal ferrite becomes small, the volume percentage of martensite becomes large, and the polygonal ferrite grains become coarse by the same reason, which fails to attain adequate metallic micro-structure which is specified by the present invention. Thus, the manufactured steel sheet shows higher than 0.6 of YR in the mechanical characteristics, which is an inferior characteristic. To increase the strain dispersion and to improve the shape accuracy, YR is required to be 0.6 or less.

[0028] As described above, the method for manufacturing hot-rolled dual phase steel sheet according to the related art adopts either the addition of ferrite-stabilizing element (Si, P, Al, or the like) sacrificing the surface property and other features or the sacrification of mechanical characteristics.

[0029] Patent Documents 16 and 17, however, do not consider YR and the metallic micro-structure to attain the YR.

[0030] Since Patent Document 18 is a technology to manufacture a high Si steel, the surface property of the steel sheet becomes poor. To improve the surface property, Si may be decreased. If, however, the Si content is decreased, no adequate metallic micro-structure is obtained, and the YR characteristic becomes poor. Both the YR and the surface property cannot be satisfied at a time.

SUMMARY OF THE INVENTION

[0031] It is an object of the present invention to provide a high strength steel sheet having excellent formability (YR≦0.6) and excellent surface property through the development of a method for adequately controlling the metallic micro-structure and improving the mechanical characteristics of the steel sheet without adding excess ferrite-stabilizing elements (Si, P, and Al) which degrade the surface property, weldability, and the like, and to provide a method for manufacturing same.

[0032] The inventors of the present invention found a phenomenon which significantly enhances the fine ferrite formation compared with conventional two-stage cooling process, even without adding excess ferrite-stabilization elements, by beginning the ultra-rapid cooling at 150° C./s or higher cooling rate within 2 seconds after the hot-rolling, followed by holding the temperatures between 750° C. and 600° C. for a specified period of time. The inventors of the present invention applied the finding to the manufacture of dual phase hot-rolled high strength steel sheet, and have perfected the present invention.

[0033] The present invention provides a high strength steel sheet which consists essentially of 0.05 to 0.15% C, 0.5% or less Si, 1.00 to 2.00% Mn, 0.09% or less P, 0.01% or less S, 0.005% or less N, 0.01 to 0.1% Sol.Al, by mass, and the balance being Fe and inevitable impurities; and 60% or more of polygonal ferrite by volume, and 5 to 30% of martensite by volume.

[0034] The polygonal ferrite is preferably from 60 to 95% by volume. The polygonal ferrite preferably has a mean grain size of 5 to 10 μm.

[0035] The martensite is preferably from 10 to 20% by volume.

[0036] The high strength steel sheet preferably contains 0.01 to 0.5% Si by mass. The Si content is more preferably 0.25% or less by mass. Since Si has an effect to increase the strength, the Si content is preferably 0.01% or more. The P content is preferably from 0.020 to 0.06% by mass.

[0037] The high strength steel sheet may further contain at least one element selected from the group consisting of 0.01 to 0.3% Mo, 0.001 to 0.05% Nb, 0.001 to 0.1% Ti, 0.0003 to 0.002% B, and 0.05 to 0.49% Cr, by mass.

[0038] The high strength steel sheet preferably has a yield ratio of 0.6 or lower. If the yield ratio exceeds 0.6, the shape accuracy deteriorates during press-forming.

[0039] The present invention also provides a method for manufacturing high strength steel sheet comprising the steps of: casting a slab consisting essentially of 0.05 to 0.15% C, 0.5% or less Si, 1.00 to 2.00% Mn, 0.09% or less P, 0.01% or less S, 0.005% or less N, 0.01 to 0.1% Sol.Al, by mass, and the balance being Fe and inevitable impurities; hot-rolling the cast slab, directly or heating thereof, at a temperature of Ar3 point or more to form a hot-rolled steel sheet; a primary cooling step of cooling the hot-rolled steel sheet beginning cooling thereof within 2 seconds after completing the hot-rolling to a temperature of from 750° C. to 600° C. at a cooling rate of 150° C./s or more; holding the cooled steel sheet at a temperature between 750° C. and 600° C. for 2 to 15 seconds; a secondary cooling step of cooling the temperature-held steel sheet at a cooling rate of 20° C./s or more; and coiling the steel sheet at a coiling temperature of 400° C. or less.

[0040] The slab may further contain at least one element selected from the group consisting of 0.01 to 0.3% Mo, 0.001 to 0.05% Nb, 0.001 to 0.1% Ti, 0.0003 to 0.002% B, and 0.05 to 0.49% Cr, by mass.

[0041] The cooling rate in the primary cooling step is preferably in a range from 150 to 1000° C./s, and more preferably from 200 to 700° C./s.

[0042] The cooling rate in the secondary cooling step is preferably in a range from 20 to 1000° C./s.

[0043] The coiling temperature is preferably in a range from 0° C. to 400° C.

[0044] The percentage for the ingredients of the steel, given in the description, is % by mass.

[0045] The term "high strength steel sheet" referred to herein signifies a steel sheet having more than 590 MPa of tensile strength (TS), which TS values are suitable for the machine structural parts.

[0046] The present invention provides high strength steel sheet having excellent formability and surface property. The steel sheet manufactured by the present invention has low YR (0.6 or less) with high strength, high ductility, excellent press-formability, excellent surface property, and excellent spot weldability, thus the steel sheet can readily be applied to the automobile parts and machine structural parts. Since the high strength steel sheet can be manufactured by the conventional process for manufacturing mild steel sheet, and since the attained performance thereof is favorable without adding spec-ial elements, the manufacturing cost can be decreased. Accordingly, the high strength steel sheet according to the present invention is highly expected in practical uses in the future, and is expected to contribute to the conservation of global environment by the weight reduction of automobile and to the social development through the improvement of safety of automobile.

BRIEF DESCRIPTION OF THE DRAWING

[0047] **FIG. 1** is a graph showing the relation between the yield ratio (YR) and the primary cooling rate.

EMBODIMENTS OF THE INVENTION

[0048] The high strength steel sheet according to the present invention specifies the composition as below, specifies the volume percentage of polygonal ferrite to 60% or more, specifies the volume percentage of martensite to a range from 5 to 30%, and specifies the mean grain size of polygonal ferrite to a range from 5 to 10 μm. These specifications are the most important conditions of the present invention. With the composition and micro-structure specified above, the high strength steel sheet having excellent formability and surface property can be obtained. The high strength steel sheet can be manufactured by the sequential steps of: hot-rolling the steel at Ar3 pint or higher temperature; beginning cooling of the steel sheet within 2 seconds after the completion of hot-rolling; cooling the steel sheet to temperatures between 750° C. and 600° C. at cooling rates of 150° C./s or more; holding the temperature of steel sheet in a range from 750° C. to 600° C. for 2 to 15 seconds;

cooling the steel sheet at cooling rates of 20° C./s or more; and coiling the steel sheet at 400° C. or below. In the manufacturing method, the beginning of cooling within 2 seconds after completing the hot-rolling, the ultra-rapid cooling at 150° C./s or higher cooling rate, and the holding in a temperature range from 750° C. to 600° C. are also critical conditions of the present invention.

[0049] The present invention is described in more detail in the following.

[0050] First, the reason of specifying the chemical composition of the steel sheet according to the present invention is described.

[0051] C: 0.05 to 0.15%

[0052] Carbon is an important element to strengthen the martensitic phase. To attain satisfactory strength, the C content needs to be 0.05% or more. If, however, the C content exceeds 0.15%, austenite stabilizes, and the dual phase formation becomes difficult, which degrades the ductility. Accordingly, the C content is specified to a range from 0.05% to 0.15%. Regarding the spot weldability, the C content below 0.07% may degrade the tensile shear strength. If the C content exceeds 0.10%, the cross tension strength may decrease. Therefore, the C content is preferably in a range from 0.07 to 0.10%.

[0053] Si: 0.5% or less

[0054] Silicon degrades the surface property by red scale and also degrades the coatability and weldability. If the Si content exceeds 0.5%, the bad influence of Si becomes significant. Consequently, the Si content is specified to 0.5% or less. If the application of steel sheet emphasizes the surface property, the Si content is preferably 0.25% or less. Since Si has an effect to increase the strength, the Si content is preferably 0.01% or more.

[0055] Mn: 1.00 to 2.00%

[0056] Manganese plays an important role for forming dual phase micro-structure by suppressing the pearlite formation during cooling after hot-rolling. If the Mn content is less than 1.00%, however, the effect is not sufficient, and pearlite is formed to increase YR, thus degrading the press-formability. If the Mn content exceeds 2.00%, austenite excessively stabilizes to prevent the formation of polygonal ferrite. Therefore, the Mn content is specified to a range from 1.00 to 2.00%. Furthermore, the Mn content below 1.30% may decrease the strength so that the Mn content is preferably 1.30% or more. When the Mn content exceeds 1.80%, the elongation may degrade so that the Mn content is preferably 1.80% or less.

[0057] P: 0.09% or Less

[0058] When the P content exceeds 0.09%, the elongation is significantly degraded. Accordingly, the P content is specified to 0.09% or less. If the P content exceeds 0.06%, the toughness at welded section degrades to decrease the joint strength in some cases. Therefore, the P content is preferably 0.06% or less. Furthermore, the P content of 0.020% or more enhances the formation of polygonal ferrite to decrease YR. Thus the P content is preferably 0.020% or more.

[0059] S: 0.01% or Less

[0060] Sulfur is an impurity in the crude steel and degrades the formability and weldability of steel sheet as the base material. Accordingly, it is preferred to remove or reduce S in the steel making process as far as possible. Since, however, excess reduction of S increases the refining cost, the S content is specified to 0.01% or less, which level brings the S substantially harmless.

[0061] N: 0.005% or Less

[0062] Nitrogen is an impurity in the crude steel and degrades the formability of steel sheet as the base material. Accordingly, it is preferred to remove or reduce N in the steel making process as far as possible. Since, however, excess reduction of N increases the refining cost, the N content is specified to 0.005% or less, which level brings the N substantially harmless.

[0063] Sol.Al: 0.01 to 0.1%

[0064] Aluminum is added for deoxidization and for precipitating N as AlN. If the Al content is less than 0.01%, the effect of deoxidization and denitrification becomes in sufficient. If the Al content exceeds 0.1%, the effect of Al addition saturates, which is uneconomical. Consequently, the Sol.Al content is specified to a range from 0.01 to 0.1%.

[0065] The steel according to the present invention attains the desired characteristics by the addition of above essential elements. Adding to the essential elements, however, the steel according to the present invention may further include one or more element of Mo, Nb, Ti, B, and Cr at need for further increasing the strength. In that case, the respective contents of below 0.01%, 0.001%, 0.001%, 0.0003%, and 0.05% cannot give the satisfactory effect of addition. If the content of Mo, Nb, Ti, and B exceeds 0.3%, 0.05%, 0.1%, and 0.002%, respectively, the formation of dual phase micro-structure is hindered and the precipitation hardening becomes excessive so that the mechanical characteristics degrade (YR increases or elongation decreases). If the Cr content exceeds 0.49%, the performance of chemical conversion treatment degrades. When these element are added, therefore, the Mo content is specified to a range from 0.01 to 0.3%, Nb from 0.001 to 0.05%, Ti from 0.001 to 0.1%, B from 0.0003 to 0.002%, and Cr from 0.05 to 0.49%.

[0066] The balance of the above composition is Fe and inevitable impurities. Regarding the inevitable impurities, for example, 0 is preferably specified to 0.003% or less because 0 forms a non-metallic inclusion to degrade the quality. According to the present invention, the steel may further include trace elements which do not harm the function and use of the present invention, namely Ni, V, Cu, Sb, Sn, Mg, and REM within a range of 0.1% or less.

[0067] Secondly, the reason to specify the metallic micro-structure according to the present invention is described below.

[0068] The volume percentage of polygonal ferrite is specified to 60% or more. The volume percentage of polygonal ferrite is a critical condition to achieve the low YR characteristic which is a feature of the present invention. To attain 0.6 or lower YR, the volume percentage of polygonal ferrite is required to become 60% or more. The polygonal ferrite is found in the ferritic phase, and is distinguished from the acicular ferrite in the morphology, and is limited to the one having 5 or lower ratio of maximum diameter to minimum diameter of the ferritic crystal grain.

[0069] The volume percentage of martensite is specified to a range from 5 to 30%. Similar with the volume percentage of polygonal ferrite, the volume percentage of martensite is an important condition of the present invention because the volume percentage thereof influences the strength, the ductility, and the low YR characteristic. If the volume percentage of martensite is less than 5%, the strength becomes low, and no low YR characteristic is attained. If the volume percentage of martensite exceeds 30%, the ductility degrades. Therefore, the volume percentage of martensite is specified to a range from 5 to 30%. To attain better low YR characteristic, the volume percentage of martensite is preferably in a range from 10 to 20%. The residual micro-structure contains acicular ferrite, bainite, pearlite, and the like. The volume percentage of residual micro-structure is, however, not specifically limited because the respective volume percentages of polygonal ferrite and martensite within the above-specified range assure the effect of the present invention.

[0070] For further improving the balance between the strength and the ductility, or the product of strength and elongation, the mean grain size of polygonal ferrite is preferably specified to a range from 5 to 10 μm. Generally, the elongation in tensile test is expressed by the sum of uniform elongation and local elongation. If the grain size of polygonal ferrite is less than 5 μm, the uniform elongation may decrease in some cases. If the grain size of polygonal ferrite exceeds 10 μm, the local elongation degrades, though the value of local elongation is within allowable range. Presumable reason of the phenomenon is the following. For a dual phase steel, if the grains become coarse, the deformation becomes nonuniform so that stress intensifies into a certain section, which enhances the generation of micro-cracks.

[0071] The method for manufacturing high strength steel sheet having excellent formability and surface property according to the present invention is described in the following.

[0072] The high strength steel sheet according to the present invention is manufactured by the steps of: casting a slab prepared to have the chemical composition given above; applying hot-rolling to the slab, directly or heating thereof, at Ar3 point or higher temperature; beginning cooling the slab within 2 seconds after completing the hot-rolling to temperatures ranging from 750° C. to 600° C. at cooling rates of 150° C./s or more; holding the cooled slab at temperatures between 750° C. and 600° C. for 2 to 15 seconds; applying cooling to the temperature-held slab at cooling rates of 20° C./s or more; and coiling the cooled slab at temperatures of 400° C. or below.

[0073] The method for casting the slab is not specifically limited. For the case of continuous casting, hot-rolling may be done directly or may be done after reheating after cooling.

[0074] The hot-rolling is conducted at Ar3 point or higher temperature. If the hot-rolling is done below the Ar3 point, the hot-rolling proceeds in the dual phase region of ferrite and austenite, which hinders the formation of polygonal ferrite, increases YR, and decreases the ductility.

[0075] After completing the hot-rolling, the cooling begins within 2 seconds to cool the steel to a temperature range from 750° C. to 600° C., which is the holding temperature range, at cooling rates of 150° C./s or more. The primary cooling which is given immediately after the hot-rolling is the most important condition to attain the effect of the present invention, (the effect of low YR attained by the enhancement of polygonal ferrite formation) With thus specified primary cooling and conduction of immediate rapid cooling, the holding step at temperatures of from 750° C. to 600° C. succeeding to the primary cooling allows the fine transformed polygonal ferrite to be drastically enhanced. If the period between the completion of hot-rolling and the beginning of cooling exceeds 2 seconds, ferrite is irregularly formed in the austenite grain boundaries to hinder the transformation to polygonal ferrite during the holding step after the cooling. If the cooling rate is less than 150° C./s, the irregular precipitation of ferrite in the austenite grain boundaries during the cooling step cannot be prevented, which hinders the transformation to polygonal ferrite during the holding step after cooling. For further increasing the effect, the primary cooling rate is preferably 200° C./s or more. If the primary cooling rate exceeds 1000° C./s, the metallic micro-structure becomes nonuniform within the sheet thickness range, and the mechanical characteristics may degrade. Accordingly, the primary cooling rate is preferably 1000° C./s or less, and more preferably 700° C./s or less.

[0076] After completing the primary cooling, the steel is held to a temperature range from 750° C. to 600° C. for 2 to 15 seconds. If the temperature range for holding the steel is above 750° C., the driving force of ferrite transformation becomes small, and no transformation enhancement effect is attained. If the temperature range therefor is below 600° C., the ferrite transformation which is controlled by the diffusion of Fe atoms delays, and satisfactory polygonal ferrite formation cannot be attained. If the holding time is less than 2 seconds, the ferrite transformation time is not sufficient, which fails to attain the low YR characteristic. If the holding time exceeds 15 seconds, the pearlite formation begins to degrade the mechanical characteristics.

[0077] After holding the steel sheet, the secondary cooling is conducted at cooling rates of 20° C./s or more, and the coiling of the steel sheet is done at temperatures of 400° C. or below. The cooling rate in the secondary cooling is required to be 20° C./s or more to suppress the formation of pearlite and bainite during cooling. If the secondary cooling rate exceeds 1000° C./s, the metallic micro-structure becomes nonuniform within the sheet thickness range, and the mechanical characteristics may degrade. Therefore, the secondary cooling rate is preferably 1000° C./s or less.

[0078] The coiling temperature is required to be 400° C. or below to prevent the formation of pearlite and bainite after coiling, to form martensite, and to attain the target of 0.6 or lower YR. Furthermore, to prevent the fluctuations of strength within the coil, the coiling temperature is preferably 300° C. or below, and more preferably 200° C. or below. If the coiling temperature becomes below 0° C., the cooling by water becomes difficult so that the coiling temperature is preferably 0° C. or above.

[0079] To thus obtained high strength steel sheet according to the present invention, a skin pass rolling may further be applied for shape-correction. In addition, various surface treatments such as hot-dip galvanization and electro-galvanization may be applied to the high strength steel sheet according to the present invention as the base material.

EXAMPLE 1

[0080] Slabs having respective chemical compositions given in Table 1 were prepared by continuous casting. They were cooled, then heated to temperatures from 1100° C. to 1300° C., and were treated by final rolling at temperatures in a range from Ar3 point to 850° C. to obtain steel sheets having thicknesses of from 1.6 to 3.2 mm. Within 1 second after completing the final rolling, cooling began on the steel sheets to conduct the primary cooling to a temperature range from 680° C. to 720° C. at cooling rates from 300 to 500° C./s. After that, the steel sheets were held at the temperature range for 7 to 12 seconds. Then, the steel sheets were cooled at cooling rates from 25 to 30° C./s, and were coiled at 350° C. or lower temperature to obtain the respective hot-rolled steel sheets. As for Steel No. 4, however, the temperature to stop the primary cooling was 550° C., and Steel No. 5 was coiled at 450° C., thus adjusting the micro-structure thereof given in Table 1. The percentage of polygonal ferrite and the percentage of martensite were determined by observing the cross section vertical to the sheet width direction and by measuring the area percentage of each phase. Regarding the grain size of polygonal ferrite, the segmental method was applied to measure the above-described cross sectional micro-structure to derive an average value of the value in the rolling direction and the value in the sheet thickness direction.

TABLE 1

Classi-fication	Steel No.	Chemical composition (mass %) C	Si	Mn	P	S	Sol.Al	N	Other	Volume percentage of polygonal ferrite (%)	Volume percentage of martensite (%)	Main micro-structure of residual portion	Grain size of polygonal ferrite (μm)
Comparative Example	1	0.03	0.30	1.60	0.015	0.003	0.04	0.003	—	70	5	Bainite 10%	12
Example	2	0.06	0.01	1.50	0.010	0.002	0.05	0.004	—	80	10	Acicular ferrite 10%	10
Example	3	0.06	0.01	1.50	0.010	0.002	0.05	0.004	0.0008B	70	15	Acicular ferrite 10%	5
Comparative Example	4	0.06	0.01	1.50	0.010	0.002	0.05	0.004	—	40	10	Acicular ferrite 50%	11
Comparative Example	5	0.06	0.01	1.50	0.010	0.002	0.05	0.004	—	70	0	Bainite 15%	8
Example	6	0.08	0.20	1.50	0.010	0.005	0.05	0.004	—	90	10	—	6
Example	7	0.11	0.01	1.40	0.015	0.001	0.04	0.003	0.1Mo	85	15	—	8
Example	8	0.14	0.05	1.44	0.020	0.007	0.07	0.002	—	70	15	Pearlite 10%	6
Comparative Example	9	0.17	0.15	1.60	0.012	0.004	0.06	0.004	—	50	35	Pearlite 10%	4
Example	10	0.07	0.01	1.70	0.013	0.003	0.03	0.004	—	80	15	Bainite 5%	9
Example	11	0.06	0.24	1.65	0.008	0.001	0.01	0.003	—	70	10	Bainite 5%	8
Example	12	0.08	0.45	1.45	0.018	0.005	0.05	0.002	0.02Nb	85	15	—	7
Comparative Example	13	0.09	0.70	1.55	0.011	0.002	0.06	0.004	—	85	15	—	5
Comparative Example	14	0.07	0.30	0.80	0.009	0.003	0.04	0.004	—	80	0	Pearlite 10%	12
Example	15	0.11	0.05	1.75	0.012	0.002	0.07	0.003	—	80	20	—	9
Comparative Example	16	0.08	0.22	2.20	0.014	0.001	0.06	0.002	—	50	50	—	7
Example	17	0.10	0.31	1.65	0.040	0.004	0.03	0.004	—	85	15	—	6
Comparative Example	18	0.12	0.10	1.54	0.100	0.005	0.05	0.004	—	90	10	—	10
Example	19	0.07	0.13	1.35	0.025	0.004	0.04	0.003	0.04Ti	79	21	—	5
Example	20	0.06	0.08	1.10	0.045	0.004	0.04	0.004	0.40Cr	84	16	—	9

[0081] For each of thus obtained hot-rolled steel sheets, the mechanical characteristics, the surface property, and the spot weldability were evaluated. The result is given in Table 2. The evaluation methods are the following. The mechanical characteristics were determined by the test per JIS Z2241 with a JIS No. 5 Tensile Test sample (prepared by cutting the steel sheet lateral to the rolling direction). The surface property was determined by visual observation in terms of presence/absence of red scale. Regarding the spot weldability, spot-welding was given under a condition to form a nugget having the size of (5 x sheet thickness (mm)), and then the peal test using a chisel was applied to break the sheet to observe the fracture mode. Fracture on main portion of the sheet was evaluated to O, and fracture on welded section was evaluated to X.

TABLE 2

		Mechanical characteristics				Surface	Spot
Classification	Steel No.	YP(MPa)	TS(MPa)	EI(%)	YR	property	weldability
Comparative Example	1	390	520	36.5	0.75	Δ	○
Example	2	354	610	31.1	0.58	○	○
Example	3	352	640	29.7	0.55	○	○
Comparative Example	4	390	600	31.7	0.65	○	○
Comparative Example	5	428	570	33.3	0.75	○	○
Example	6	345	650	29.2	0.53	○	○
Example	7	373	690	27.5	0.54	○	○
Example	8	462	810	23.5	0.57	○	○
Comparative Example	9	683	1050	18.1	0.65	○	X
Example	10	369	670	28.4	0.55	○	○
Example	11	336	590	32.2	0.57	○	○
Example	12	352	640	29.7	0.55	Δ	○
Comparative Example	13	369	670	28.4	0.55	X	○
Comparative Example	14	451	530	35.8	0.85	Δ	○
Example	15	383	710	26.8	0.54	○	○
Comparative Example	16	723	850	22.4	0.85	○	○
Example	17	385	700	27.1	0.55	Δ	○
Comparative Example	18	468	780	24.4	0.60	○	X
Example	19	398	675	28.1	0.59	○	○
Example	20	389	695	27.3	0.56	○	○

[0082] Table 2 shows that all the steels according to the present invention, (Example steels), have excellent mechanical characteristics (YR≦0.6), and give favorable surface property and weldability. Steel Nos. 12 and 17 gave somewhat degraded surface property owing to slightly high Si content. However, Steel Nos. 12 and 17 were judged to be at a level of raising no significant problem in practical use.

[0083] In contrast, Steel No. 1 which is a comparative example had low C content, outside the range of the present invention, so that the hardness of martensite was unsatisfactory, which increased the YR value. Steel Nos. 4 and 5 had the volume percentage of polygonal ferrite or the volume percentage of martensite outside the range of the present invention so that they failed to form favorable dual phase micro-structure and they gave high YR value. Steel No. 9 had large C content outside the range of the present invention so that the ferrite formation delayed to fail in attaining favorable dual phase micro-structure, and resulted in high YR value, as well as degrading the spot weldability. Steel No. 13 had large Si content outside the range of the present invention so that red scale was generated to give poor surface property. Steel No. 14 had small Mn content outside the range of the present invention so that the austenite became instable and the pearlite was generated, thus giving high YR value. Steel No. 16 had large Mn content outside the range of the present invention so that the amount of formed polygonal ferrite became small, and the YR value became high. Steel No. 18 had large P content outside the range of the present invention so that the spot weldability significantly degraded.

EXAMPLE 2

[0084] Some of the slabs having the respective chemical compositions given in Table 1 were treated by hot-rolling, cooling, and coiling under the respective manufacturing conditions given in Table 3, thus obtained the respective hot-rolled steel sheets.

TABLE 3

Classification	Symbol	Steel No.	Heating temperature (° C.)	Finish temperature (° C.)	Cooling beginning time (s)	Primary cooling speed (° C./s)	Stop temperature (° C.)	Holding time (s)	Secondary cooling rate (° C./s)	Coiling temperature (° C.)
Example	A	2	1200	850	0.5	460	738	4	45	382
Example	B	2	1250	830	1	290	738	4	21	373
Example	C	2	1230	840	2	530	644	11	38	324
Comparative example	D	2	1050	820	5	230	701	12	42	144
Comparative example	E	2	1150	830	1	50	707	12	45	136
Example	F	2	1250	850	1	180	717	6	40	317
Example	G	2	1200	840	1	220	686	7	24	259
Example	H	2	1100	830	1	450	698	6	20	116
Comparative example	I	6	1120	820	1	340	800	8	50	217
Example	J	6	1150	810	1	280	730	10	22	184
Example	K	6	1280	830	1	530	680	10	22	181
Example	L	6	1200	830	1	270	850	13	30	347
Comparative example	M	6	1130	820	1	390	350	11	41	285
Comparative example	N	6	1180	840	1	240	634	—	46	158
Example	O	6	Hot direct rolling	820	1	560	682	8	33	350
Example	P	6	1230	830	1	590	725	10	30	342
Comparative example	Q	6	1210	840	1	580	646	25	21	219
Comparative example	R	17	1200	850	1	500	719	12	10	293
Example	S	17	1180	830	1	330	656	6	25	272
Example	T	17	1240	820	1	470	632	12	35	382
Example	U	17	1200	830	1	500	634	10	33	<100
Example	V	17	1150	830	1	460	663	3	39	353
Comparative example	W	17	1220	830	1	480	712	7	20	450

[0085] For each of thus obtained hot-rolled steel sheets, the mechanical characteristics, the surface property, and the spot weldability were evaluated. The result is given in Table 4. The evaluation methods were the same with those in Example 1.

TABLE 4

Classification	Symbol	Volume percentage of polygonal ferrite (%)	Volume percentage of martensite (%)	Grain size of polygonal ferrite (μm)	Mechanical characteristics			
					YP (MPa)	TS (MPa)	EI (%)	YR
Example	A	75	10	8	341	620	30.6	0.55
Example	B	75	10	9	342	610	31.1	0.56
Example	C	80	10	10	354	610	31.1	0.58
Comparative example	D	50	10	13	447	630	30.2	0.71
Comparative example	E	40	5	15	488	650	29.2	0.75
Example	F	80	10	9	365	640	29.7	0.57
Example	G	75	10	7	330	600	31.7	0.55
Example	H	80	10	6	369	670	28.4	0.55
Comparative example	I	30	15	10	490	680	27.9	0.72
Example	J	85	12	8	381	680	27.9	0.56
Example	K	90	10	7	336	590	32.2	0.57
Example	L	80	10	5	364	650	29.2	0.56
Comparative example	M	35	5	4	446	550	34.5	0.81
Comparative example	N	45	10	4	441	630	30.2	0.70

TABLE 4-continued

Classification	Symbol	Volume percentage of polygonal ferrite (%)	Volume percentage of martensite (%)	Grain size of polygonal ferrite (μm)	Mechanical characteristics YP (MPa)	TS (MPa)	El (%)	YR
Example	O	85	13	9	389	670	28.4	0.58
Example	P	80	10	8	358	640	29.7	0.56
Comparative example	Q	80	0	12	451	530	35.8	0.85
Comparative example	R	80	3	11	498	560	33.9	0.89
Example	S	85	8	9	369	670	28.4	0.55
Example	T	75	18	8	412	710	26.8	0.58
Example	U	85	15	5	366	690	27.5	0.53
Example	V	85	15	8	385	700	27.1	0.55
Comparative example	W	75	0	9	475	650	29.2	0.73

[**0086**] Table 4 shows that all the steels according to the present invention, (Example steels), have excellent mechanical characteristics (YR≦0.6). All the Example steels showed favorable surface property and spot weldability within the range of Example 2.

[**0087**] In contrast, Symbol D which is a comparative example had a long period between the completion of rolling and the beginning of primary cooling, outside the range of the present invention, thus ferrite was formed irregularly before beginning the cooling, which resulted in unfavorable dual phase micro-structure and high YR value. Symbol E had low primary cooling rate outside the range of the present invention so that ferrite was formed irregularly before beginning the cooling, which resulted in unfavorable dual phase micro-structure and high YR value. Symbol I had high temperature of stopping the primary cooling outside the range of the present invention so that the formation of ferrite during the succeeding holding step became insufficient, which resulted in unfavorable dual phase micro-structure and high YR value. Symbol M had low temperature of stopping the primary cooling outside the range of the present invention so that the formation of ferrite during the succeeding holding step became insufficient, which resulted in unfavorable dual phase micro-structure and high YR value. Symbol N had insufficient holding time after the primary cooling outside the range of the present invention so that the formation of ferrite became insufficient, which resulted in unfavorable dual phase micro-structure and high YR value. Symbol Q had long holding time after the primary cooling outside the range of the present invention so that pearlite was formed during holding step, which resulted in unfavorable dual phase micro-structure and high YR value. Symbol R had low secondary cooling rate outside the range of the present invention so that bainite was formed during cooling step, which resulted in unfavorable dual phase micro-structure and high YR value. Symbol W had high coiling temperature outside the range of the present invention so that bainite was formed after coiling, which resulted in unfavorable dual phase micro-structure and high YR value.

[**0088**] **FIG. 1** shows the relation between YR and the primary cooling rate for Steel No. 2. The figure shows that favorable characteristics giving low YR value is attained at 150° C./s or higher primary cooling rate, which is the range of the present invention. Symbol D failed to attain favorable result because the time before the primary cooling was 5 seconds, which is outside the range of the present invention.

[**0089**] Since the steel sheet according to the present invention has excellent press-formability and excellent surface property, the steel is also applicable to formed parts which emphasize the appearance.

What is claimed is:

1. A high strength steel sheet consisting essentially of: 0.05 to 0.15% C, 0.5% or less Si, 1.00 to 2.00% Mn, 0.09% or less P, 0.01% or less S, 0.005% or less N, 0.01 to 0.1% Sol.Al, by mass, and the balance being Fe and inevitable impurities; and

60% or more polygonal ferrite by volume, and 5 to 30% martensite by volume.

2. The high strength steel sheet according to claim 1, wherein the polygonal ferrite is 60 to 95% by volume.

3. The high strength steel sheet according to claim 1, wherein the martensite is 10 to 20% by volume.

4. The high strength steel sheet according to claim 1, wherein the polygonal ferrite has a mean grain size of 5 to 10 μm.

5. The high strength steel sheet according to claim 1, further containing at least one element selected from the group consisting of 0.01 to 0.3% Mo, 0.001 to 0.05% Nb, 0.001 to 0.1% Ti, 0.0003 to 0.002% B, and 0.05 to 0.49% Cr, by mass.

6. The high strength steel sheet according to claim 1, wherein the Si content is 0.01 to 0.5% by mass.

7. The high strength steel sheet according to claim 1, wherein the Si content is 0.01 to 0.25% by mass.

8. The high strength steel sheet according to claim 1, wherein the P content is 0.020 to 0.06% by mass.

9. The high strength steel sheet according to claim 1, having a yield ratio of 0.6 or less.

10. A method for manufacturing high strength steel sheet comprising the steps of:

casting a slab consisting essentially of 0.05 to 0.15% C, 0.5% or less Si, 1.00 to 2.00% Mn, 0.09% or less P, 0.01% or less S, 0.005% or less N, 0.01 to 0.1% Sol.Al, by mass, and the balance being Fe and inevitable impurities;

hot-rolling the cast slab, directly or heating thereof, at a temperature of Ar3 point or more to form a hot-rolled steel sheet;

a primary cooling step of cooling the hot-rolled steel sheet at a cooling rate of 150° C./s or more to a temperature of from 750° C. to 600° C., beginning cooling thereof within 2 seconds after completing the hot-rolling;

holding the cooled steel sheet at a temperature between 750° C. and 600° C. for 2 to 15 seconds;

a secondary cooling step of cooling the temperature-held steel sheet at a cooling rate of 20° C./s or more; and

coiling the cooled steel sheet at a coiling temperature of 400° C. or less.

11. The method according to claim 10, wherein the slab further contains at least one element selected from the group consisting of 0.01 to 0.3% Mo, 0.001 to 0.05% Nb, 0.001 to 0.1% Ti, 0.0003 to 0.002% B, and 0.05 to 0.49% Cr, by mass.

12. The method according to claim 10, wherein the cooling rate in the primary cooling step is from 150 to 1000° C./s.

13. The method according to claim 12, wherein the cooling rate in the primary cooling step is from 200 to 700° C./s.

14. The method according to claim 10, wherein the cooling rate in the secondary cooling step is from 20 to 1000° C./s.

15. The method according to claim 10, wherein the coiling temperature is from 0° C. to 400° C.

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