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

(11) Publication number: **0 572 666 A1**

(12) EUROPEAN PATENT APPLICATION published in accordance with Art. 158(3) EPC

(21) Application number: **92905304.9**

(22) Date of filing: **20.02.92**

(86) International application number: **PCT/JP92/00181**

(87) International publication number: **WO 92/14854 (03.09.92 92/23)**

(51) Int. Cl.5: **C22C 38/14**, C21D 8/04, C21D 9/48, C23C 2/06, C23C 2/28, C25D 5/26

(30) Priority: **20.02.91 JP 45665/91**
05.06.91 JP 159831/91
11.07.91 JP 196039/91

(43) Date of publication of application: **08.12.93 Bulletin 93/49**

(84) Designated Contracting States: **DE ES FR GB IT**

(71) Applicant: **NIPPON STEEL CORPORATION**
6-3 Otemachi 2-chome
Chiyoda-ku
Tokyo 100-71(JP)

(72) Inventor: **MATSUZU, Nobuhiko**
Nippon Steel Corporation Kimitsu Works
1, Kimitsu
Kimitsu-shi Chiba 299-11(JP)
Inventor: **KOYAMA, Kazuo**
Nippon Steel Corporation Kimitsu Works
1, Kimitsu
Kimitsu-shi Chiba 299-11(JP)
Inventor: **ASANO, Hirohide**
Nippon Steel Corporation Kimitsu Works
1, Kimitsu
Kimitsu-shi Chiba 299-11(JP)

(74) Representative: **VOSSIUS & PARTNER**
Postfach 86 07 67
D-81634 München (DE)

(54) COLD-ROLLED STEEL SHEET AND GALVANIZED COLD-ROLLED STEEL SHEET WHICH ARE EXCELLENT IN FORMABILITY AND BAKING HARDENABILITY, AND PRODUCTION THEREOF.

(57) A cold-rolled steel sheet, which may be further galvanized if desired, is produced by hot rolling steel containing, on a mass base, 0.0010 to 0.0040 % of C, at most 0.0030 % of N, at most 0.5 % of Si, 0.02 to 1.5 % of Mn, at most 0.08 % of P, at most 0.01 % of S, 0.005 to 0.07 % of acid-soluble Al, at most 0.05 % of Nb (where 0 < Nb % - 93/12 C % ≦ 0.025 %), 24/14 N % to 72/14N % of Ti, and the balance of Fe and unavoidable impurities at a finish terminating temperature of the Ar_3 transformation point or above, rapidly cooling the steel within 2 s after the hot rolling at a cooling rate of 30 °C/s to the extend of temperature fall of at least 100 °C, winding at 650 to 770 °C, cold rolling at the rolling reduction of 72 to 92 %, conducting recrystallization annealing at 820 to 880 °C for at least 20 s, and cooling from this temperature to room temperature at a cooling rate of a least 3 °C/s. The obtained sheet contains carbon in solid solution form formed by dissolving deposited carbides through recrystallization annealing and has a recrystallization texture wherein the value of log-(I{222}/I{200}) is 2.7 or above, wherein I{222} and I{200} are the intensities of diffraction of the {222} plane and the {200} plane, respectively, in X-ray diffractometry. The sheet is excellent in formability and workability in chemical conversion coating and high in work hardenability and baking hardenability.

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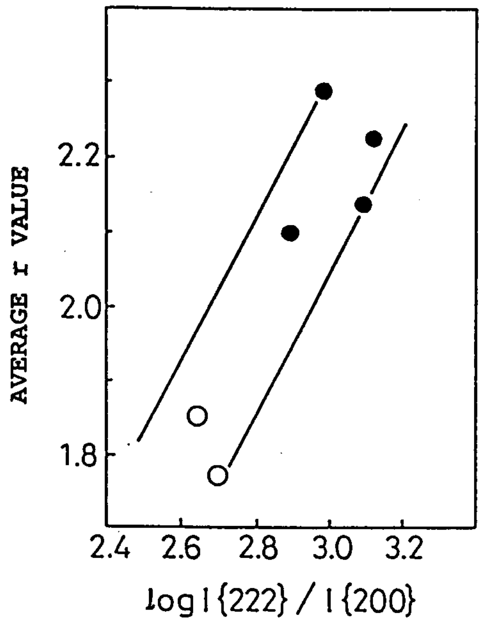
Fig. 1



[Technical Field]

The present invention relates to a cold-rolled steel sheet and a galvanized cold-rolled steel sheet that have high moldability, workability and painting-baking hardenability and are suitable for use as panels etc. for automobiles, and a process for producing the same.

[Background Art]

A reduction in the weight of automobiles originated from world-wide environmental problems has again become a major problem. Panels for automobiles are no exception to materials suitable for a reduction in weight, and technical development is increasingly directed to a reduction in the thickness of the panels. On the other hand, in cold-rolled steel sheets for automobiles, there is an ever-increasing demand for an increase in the degree of freedom of molding for coping with the progress of CAD and CAM in design of molds and the lists of customers. Specifically, there is an ever-increasing demand for the development of materials capable of withstanding molding to a high degree. Further, a great improvement in the quality of face is required of the panels and other materials. The technical significance of the quality of panel face resides in both the shape of face and plastic deformation resistance, i.e., dent resistance, of the panel.

A representative measure of the moldability is an r value (Lankford value), elongation value or an n value, and the necessary level of these values has increased more and more.

On the other hand, face strain resistance and dent resistance are important to the face quality of panels. The former is related to the shape retainability, and a low strength at yield point is required. On the other hand, the dent resistance is the strength of the product, that is, the strength after molding, assembling, mounting and painting-baking. Among these treatments, the painting-baking is usually a heat treatment at 170 °C for about 20 min, and the material should have a good painting-baking hardenability (usually called "BH property") which is a hardening property in this heat treatment. The dent resistance is expressed in terms of the sum of the BH property and the work hardening.

In the painting-baking, use is made of strain aging by C and N contained in a solid solution form in the steel and sufficiently diffusible usually even at a low temperature of about 170 °C. In this case, the strain is the sum of a strain caused in temper rolling which is the final step in the production of a steel sheet, and a strain caused in molding at an automobile manufacturing plant.

Further, the need for corrosion resistance in recent years has lead to a strong demand for galvanized steel sheets, particularly alloyed hot-dip galvanized steel sheets. Specifically, there is a demand for a steel sheet wherein iron has been diffused in and alloyed with a zinc layer to improve the corrosion resistance, weldability and corrosion resistance of plating.

Ultra low carbon steel is usually used for these applications.

As described above, C and N in a solid solution form are used as a solute element involved in the impartment of the BH property to the steel. However, the BH property is a kind of aging property and gives rise to a deterioration in the moldability at room temperature, so that an excessively high moldability leads to a problem. In other words, it is necessary to attain a combination of delayed aging or non-aging at room temperature with accelerated aging at a temperature of about 170 °C. C and N are different from each other in the temperature dependence of aging, that is, activation energy of aging, and the activation energy of C is larger than that of N. The effect of C on aging has a feature that aging at room temperature is slow and becomes fast with increasing the temperature. For this reason, it is a common practice to use C in a solid solution form for imparting the BH property.

The technique for imparting the BH property to extra low carbon steel is roughly classified into two methods. In one method, steel used is not literally an IF steel, and a carbide forming element is added in a stoichiometrically equivalent amount or less relative to the carbon content. This technique is described in Japanese Unexamined Patent Publication (Kokai) Nos. 59-31827, 59-38337, 63-128149 and 2-197549. In all cases, Nb is added in a stoichiometrically equivalent amount or less relative to the carbon content. Japanese Unexamined Patent Publication (Kokai) No. 2-194126 describes a technique where Ti is added in such an amount that C is not completely immobilized as TiC.

In the other method, although a carbide forming element is added in an excessive amount relative to carbon, the carbide is dissolved in the step of recrystallization annealing (corresponding to a heat treatment in a reduction zone in a plating line) in the production of a plated steel sheet to ensure carbon in a solid solution form. This technique is described in Japanese Unexamined Patent Publication (Kokai) No. 63-241122 wherein a hot-dip galvanized steel sheet is described as an example.

The above-described methods, however, have serious problems that make it impossible to attain individual properties contemplated in the present invention, particularly a combination of workability with BH property.

Specifically, in the former method, carbon in a solid solution form exists over the whole process in the production of steel sheets. When the presence of carbon in a solid solution form prior to cold rolling has an adverse effect on the aggregate structure formed through cold rolling and recrystallization, so that no satisfactory r value can be provided. Further, grain growth during recrystallization is insufficient, and it is difficult to provide an elongation value and an n value each on a very high level contemplated in the present invention.

On the other hand, in the latter method described in Japanese Unexamined Patent Publication (Kokai) No. 63-241122, the treatment for facilitating the dissolution of a carbide in the step of annealing in a final plating line results in refinement of the carbide in the step of hot rolling, which causes cold rolling recrystallization to proceed in the presence of a fine carbide, so that the r value becomes unsatisfactory.

The above-described known techniques will now be briefly described.

Japanese Unexamined Patent Publication (Kokai) No. 59-31827: A soft BH cold-rolled steel sheet wherein Ti and Nb are added together (Ti + Nb = 0.014 to 0.027) so as to satisfy a requirement of $93/12[C - 0.005] \leqq Nb \leqq 93/12 [C - 0.001]$. Specifically, as specified on page 3 of the specification, 10 ppm or more of carbon in a solid solution form is allowed to exist in a stage prior to annealing for the purpose of regulating the amount of addition of Nb to a stoichiometrically equivalent amount or less relative to C (excess C (= C - 12/93Nb) being regulated to 10 to 50 ppm).

Japanese Unexamined Patent Publication (Kokai) No. 59-38337: The applicant is the same as that for the above-described application. This technique is somewhat different from the above-described technique in that B is added. However, as with the above-described technique, the amount of addition of Nb is stoichiometrically equivalent or less relative to C, so that carbon in a solid solution form exists in a stage prior to annealing.

Japanese Unexamined Patent Publication (Kokai) No. 63-128149: A cold-rolled BH steel sheet wherein Nb is added (Nb: 93/12C to 0.5 x 93/12C). The amount of addition of Nb is stoichiometrically equivalent or less relative to C so that 5 ppm or more of carbon in a solid solution form exists in a stage prior to annealing.

Japanese Unexamined Patent Publication (Kokai) No. 2-197549: A cold-rolled high-strength BH steel sheet wherein Nb (Nb: 93/12C or less) and Ti are added. The amount of addition of Nb is stoichiometrically equivalent or less relative to C. In this technique, Ti is further added for the purpose of regulating C in a solid solution form. Nb is added only for ensuring the elongation value and r value.

Japanese Unexamined Patent Publication (Kokai) No. 2-194126: A BH steel sheet wherein Ti is added alone or in combination with Nb. In this technique, Ti is used for the purpose of immobilizing N and S, and Nb is added in such an amount range that NbC is not formed (Nb: 0.001 to 0.008 %). Therefore, in this method, substantially the whole amount of C in the steel exists in a solid solution form before annealing.

Japanese Unexamined Patent Publication (Kokai) No. 63-241122: A hot-dip galvanized BH steel sheet wherein Ti and Nb are added together ($Nb \geqq 93/12C$). Although the amount of addition of Nb is stoichiometrically equivalent or more relative to C, the coiling temperature of the steel sheet as hot-rolled is 600°C or below, which renders the formation of NbC unsatisfactory (In the text, there is a description to the effect that "When the coiling temperature exceeds 600°C, the formation of NbC becomes excessive, so that the separation and dissolution in a solid solution form of Nb and C in a continuous hot-dip galvanizing line are inhibited, which renders the regulation of C in a solid solution form difficult.") Further, in usual hot rolling, 2 sec or more is necessary for cooling to be effected after the completion of finishing. Since this application is silent on quenching immediately after the completion of hot rolling, it is considered that the size of ferrite grains are large. This technique is different from the present invention in the coiling temperature and greatly different from the present invention also in metallurgy or workability of the product. Specifically, when the coiling temperature is 600°C or below as in this technique, C in a solid solution form exists in a hot-rolled steel sheet (before annealing), and, even when a carbide precipitates during coiling, it is so fine that recrystallization during cold rolling proceeds in the presence of a fine carbide, which results in an unsatisfactory r value. In working examples, the $\bar{r}$ value is 1.9 when TS is 30 kgf/mm^2, and 1.8 when TS is 36 or 40 kgf/mm^2.

[Disclosure of the Invention]

An object of the present invention is to realize a process for producing a cold-rolled steel sheet and a galvanized cold-rolled steel sheet having a combination of moldability capable of withstanding a high degree of working with face strain resistance and dent resistance and further free from embrittlement during fabricating. More specifically, the object of the present invention is to provide a steel sheet such that, with respect to the workability, r value ≧ 2.0, El ≧ 50 %, n value ≧ 0.25 and tensile strength = 350 to 400 N/mm^2 for a soft steel sheet having a tensile strength of less than 350 N/mm^2, and r value ≧ 1.9, El ≧ 38 % (in all cases, the El value being a value for a steel sheet thickness of 0.8 mm; the El value depending upon the steel sheet thickness), n value ≧ 0.22 and strength at yield point = 180 to 250 N/mm^2 for a high-strength steel sheet having a tensile strength of 350 to 400 N/mm^2, and, with respect to the dent resistance, various property requirements, such as high work hardening specified by n value and a BH property of 30 N/mm^2 or more, are satisfied in addition to initial strength at yield point.

The BH property is evaluated by applying a preliminary strain of 2 % in a tensile test, removing the strain, heat-treating the steel sheet at 170 °C for 20 min, again pulling the steel sheet, and subtracting the strength value at yield point from the flow stress value at 2 % preliminary strain. That is, this value is an increment allowance of yield point in a strain aging test under conditions of 2 % preliminary strain, 170 °C and 20 min. Further, the plated steel sheet has plating properties including a powdering property. The powdering resistance is a measure of unpeelability of the plating layer during molding.

The above-described r value, El value and n value are each an in-plane average value, and when values in directions at angles of 0°, 45° and 90° to the rolling direction are X0, X45 and X90, the in-plane average value is defined by the equation (X0 + 2X45 + X90) ÷ 4.

In this case, the r value is a measure of deep drawability and defined by [(logarithmic strain in width direction) ÷ (logarithmic strain in sheet thickness)] for the direction of pull. El is an elongation at break. The n value is a work hardening index which represents an inflow property of the material and is a representative index for workability.

According to the present invention, in order to solve the above-described problem, use is made of a combination of the regulation of a particular minor element and, further, the addition of a particular solid solution strengthening element for a high-strength steel, and particular conditions in a line from hot rolling to continuous annealing or electrogalvanizing or hot-dip galvanizing.

Specifically, the present invention is characterized by comprising constituent features of ① 0 < Nb (%) - 93/12C (%) ≦ 0.25, ② Ti: 24/14N (%) to 72/14N (%), ③ quenching within 2 sec after the completion of hot rolling, ④ a coiling temperature of 650 to 770 °C and ⑤ an annealing temperature of 820 °C or above.

Specifically, the steel sheet is quenched immediately after finish rolling in the step of hot rolling for the purpose of refining ferrite in the hot-rolled steel sheet. Further, the whole carbon in the hot-rolled steel sheet is immobilized as a precipitate NbC to eliminate C in a solid solution form. For this purpose, Nb is added in a stoichiometrically equivalent amount (93/12C) or more relative to C, and coiling is effected at a temperature of 650 °C or above. When the amount of addition of Nb is less than the stoichiometrically equivalent amount (93/12C) relative to C or the coiling temperature is below 650 °C, C in a solid solution form remains. The presence of C in a solid solution form in a stage before annealing inhibits the development of an aggregate structure having an orientation useful for improving the r value during annealing, so that it becomes difficult to ensure a high r value. An aggregate structure having an orientation useful for improving the r value is developed during temperature rise in the step of annealing by refining ferrite in the hot-rolled steel sheet and rendering C in a solid solution form absent in the hot-rolled steel sheet. Thus, a high r value can be obtained.

On the other hand, the presence of C in a solid solution form is necessary for imparting the BH property. In the present invention, C in a solid solution form is provided by decomposing the precipitate NbC into Nb and C (NbC → Nb + C) immediately after annealing, that is, around an annealing temperature after recrystallization at which grain growth is substantially completed. In order to obtain a desired BH through the decomposition of NbC into Nb and C, it is necessary for the annealing temperature to be 820 °C or above. Ti is added for the purpose of immobilizing the N which is detrimental to the BH property. However, when the amount of addition of Ti in an excessive amount causes fine TiC to be formed in the stage of hot rolling, which makes it impossible to provide a good recrystallized aggregate structure. For this reason, the amount of addition of Ti should be in the range of from 0.5 to 1.5 relative to the stoichiometrically equivalent amount of N (48/14 x Ti). Further, when Ti combines with S to form TiS, Ti cannot exhibit its inherent function, so that it is necessary for TiS to be substantially absent. For this reason, the content of S should be 0.01 % or less, preferably less than 0.004 %.

In the present invention, although the contents of C and N are lowered to the extreme limit, doping addition of C in an amount of about 20 ppm is effected for the purpose of imparting BH. Basically, in the stage before cold rolling, C and N are immobilized by Nb and Ti, respectively. Immobilization of N is compensated for also by Al.

In the present invention, as described above, ferrite is refined under particular hot rolling conditions, and a hot-rolled steel sheet, wherein impurities in a solid solution form have been sufficiently scavenged, that is, a hot-rolled sheet in a state satisfactory in a stage before cold rolling, is provided, and the steel sheet is then subjected to particular cold rolling and recrystallization annealing and, in the case of the production of a plated steel sheet, further subjected to a plating treatment.

According to one aspect of the present invention, there is provided a (galvanized) cold-rolled steel sheet for an automobile, comprising, in terms of % by mass, 0.0010 to 0.0040 % of C, 0.0030 % or less of N, 0.02 to 1.5 % of Mn, 0.08 % or less of P, 0.01 % or less of S, 0.005 to 0.07 % of acid soluble Al, 0.05 % or less of Nb satisfying a requirement of a {Nb (%) - 93/12C (%)} value of more than zero to 0.025 %, 24/14•N (%) to 72/14•N (%) of Ti and 0.5 % or less of Si with the balance consisting of Fe and unavoidable impurities and having an aggregate structure such that, in X-ray diffraction, the natural logarithm ratio (log(I{222}/I{200})) of the diffraction intensity I {222} of a {222} plane to the diffraction intensity I {200} of a {200} plane is 2.7 or more.

According to another aspect of the present invention, there is provided a process for producing a (galvanized) cold-rolled steel sheet for an automobile, comprising hot-rolling a steel composed of the above-described ingredients at a finish termination temperature of the Ar_3 transformation point or above, quenching the hot-rolled steel sheet within 2 sec after the completion of the hot-rolling at a rate of 30 to 300 °C/sec to attain a temperature fall of 100 °C or above, coiling the cooled steel sheet at a temperature of 650 to 770 °C, subsequently cold-rolling the coiled steel sheet with a reduction ratio of 72 to 92 %, subjecting the cold-rolled steel sheet to annealing in a temperature range of from 820 to 880 °C for 20 sec or more and cooling the annealed steel sheet from that temperature to room temperature at a cooling rate of 3 °C/sec or more.

In connection with a process for producing a cold-rolled steel sheet having an extra low carbon content and a good deep drawability, wherein Ti and Nb are added together, Japanese Unexamined Patent Publication (Kokai) Nos. 61-276927 and 61-276930 disclose a technique where quenching is effected after the completion of finish rolling in the step of hot rolling. This technique is different from the present invention in the chemical ingredients of the steel, and gives no consideration to the BH property, so that the difference between this technique and the present invention is self-explanatory.

Specifically, in the above-described patent applications, the amounts of addition of Ti and Nb are Ti ≧ 48/14N + 48/32S and Nb ≦ 93/12C, respectively. Ti is added in a stoichiometrically equivalent amount or more relative to N and S to immobilize the whole N and S, and part of C is immobilized by the remaining Ti. On the other hand, Nb is added in a stoichiometrically equivalent amount or less relative to C, and the remaining C not immobilized by Ti is immobilized by Nb. Therefore, the technique disclosed in the above-described patent applications, wherein N is immobilized by Ti or Al and the whole C is immobilized by Nb, and the present invention are different from each other in not only metallurgy but also percentage composition. Specifically, in the present invention, Ti may be a stoichiometrically equivalent amount or less relative to N (Ti ≧ 24/14N), and Nb is larger than a stoichiometrically equivalent amount relative to C (Nb > 93/12C), so that the amount of addition of at least Nb specified in the present invention is outside the scope of the invention described in the above-described patent applications. Further, in the above-described patent applications, that an improvement in the BH property is not contemplated is apparent also from the fact that the target quality is Al ≦ 3 kgf/mm^2 and, in an application example in the working example, Al is 1.2 kgf/mm^2 or less.

[Brief Description of the Drawings]

Fig. 1 is a diagram showing the relationship between the average r value and log(I{222}/I{200}) with respect to a soft cold-rolled steel sheet; and

Fig. 2 is a diagram showing the relationship between the average r value and log(I{222}/I{200}) with respect to a high-strength cold-rolled steel sheet.

[Best Mode for Carrying Out the Invention]

The best mode for carrying out the present invention will now be described. At the outset, ingredients of the steel of the present invention will be described together with contents (all the contents being in % by mass) of these ingredients.

C is an interstitial element in a solid solution form and detrimental to the impartment of workability to cold-rolled steel sheets, that is, the formation of an aggregate structure or the growth of sufficiently large grains, so that the content thereof should be minimized. On the other hand, since the BH property depends upon the content of carbon in a solid solution form in a final product sheet, carbon should be present in a minimum amount necessary for ensuring the BH property. Further, in hot-dip plating, it is preferred for carbon in a solid solution to be present at grain boundaries for the purpose of preventing zinc from penetrating into the grain boundary of the matrix. In this respect as well, carbon in a solid solution form should be ensured in the latter period of the recrystallization annealing. For these reasons, the lower limit and upper limit of the C content should be 0.0010 % and 0.0050 %, respectively. The upper limit is desirably 0.0040 %.

N too is an interstitial element in a solid solution form and detrimental to the steel sheet contemplated in the present invention. Further, since N is diffusible at room temperature, it is also difficult to attain a combination of the BH property with the cold aging resistance, so that the use thereof for ensuring the BH property is disadvantageous. For this reason, the N content should be 0.0030 % or less.

Si strengthens a steel through solid solution strengthening. It, however, is detrimental to the workability, and since an oxide of Si is stable and cannot be easily reduced, there occurs a failure of plating adhesion during galvanizing. Therefore, when Si is added for the purpose of increasing the strength, the amount of addition thereof is 0.5 % or less, and the lower limit is 0.1 %. In the case of a soft steel sheet, the amount of addition of Si may be less than 0.1 %, and the lower limit is at an unavoidably included level, for example, 0.004 %.

Mn too strengthens a steel through solid solution strengthening. It is a favorable element particularly because it is less liable to deteriorate the ductility for its function of strengthening the steel. Further, it has been found that Mn serves to alleviate an adverse effect of Si and P on plating properties. The addition of Mn in an excessive amount reduces the ductility of the material and deteriorates the workability. For this reason, in the case of a high-strength steel sheet, Mn is added in an amount of 0.3 to 1.5 %. On the other hand, in the case of a soft steel sheet, the upper limit of addition of Mn is less than 0.3 % from the viewpoint of preventing the deterioration of the workability, and the lower limit is 0.02 % from the viewpoint of preventing hot shortness.

P too is a solid solution strengthening element which is useful for increasing the strength but deteriorates the workability and gives rise to brittle fracture and, in the case of a plated steel sheet, further deteriorates alloying of the steel sheet after plating. For this reason, P should be minimized for a soft steel sheet, and the upper limit is less than 0.03 %, preferably 0.010 % or less. The lower limit is an unavoidably included level, for example, 0.001 %. In the case of a high-strength steel sheet, although P should be added, the amount of addition is limited to 0.03 to 0.08 % from the above-described viewpoint.

In the present invention, when an increase in strength is intended, Si, Mn, P and optionally Cr are properly added. Among these elements, Mn plays a particularly important role in plated steel plates. Specifically, in a hot-dip galvanizing treatment, although the surface layer of the steel sheet is usually subjected to reduction after heating in a non-oxidizing furnace, if the strengthening element is concentrated on the surface, the plating treatment cannot be successfully effected, which gives rise to various problems including that the adhesion of plating to the steel sheet is deteriorated, alloying does not proceed or a proper alloy layer cannot be provided to render the powdering resistance unsatisfactory.

With respect to the above-described plating properties, it has been found that the function of additional elements varies from element to element and, even though they are added in the production of a high-strength steel, satisfactory plating properties can be imparted if the following requirement is met. Specifically, the Mn/(Si + 10P) value should be 1.0 or more. This means that Mn serves to alleviate an adverse effect of Si or P on plating properties. Although the reason why Mn exhibits the above-described function is believed to reside in the difference in properties between formed oxides, it has not been fully elucidated yet. This effect cannot be attained when the above-described value is less than 1.0.

S is an impurity and forms an inclusion to deteriorate the workability of the steel, so that the S content is preferably as low as possible. Further, if S combines with Ti to form TiS, $Ti_4C_2S_2$ is further formed, which often gives rise to scattering of the BH property. Therefore, it is also important for substantially no TiS to be contained in the steel. Also for this reason, the S content should be lowered. For the reasons set out above, the S content is limited to 0.01 % or less, preferably less than 0.004 %.

Al is used for deoxidation. Further, it is used also as assistant to immobilization of N which is an interstitial impurity. For this reason, Al should be present in an amount of 0.005 % in terms of acid soluble Al. On the other hand, the addition of Al in an amount exceeding 0.07 % deteriorates the workability of the steel.

Nb is a very important element for the present invention. In order to attain a sufficiently scavenged state in a stage before cold rolling, Nb is added in an amount exceeding a stoichiometrically equivalent amount relative to the precipitated carbide NbC. That is, the addition of Nb in an amount exceeding 93/12xC is necessary. On the other hand, the addition of Nb in an excessive amount deteriorates the workability of the steel. For this reason, the upper limit is 0.05 %.

In the present invention, C and Nb should further have the following relationship.

Nb (%) - 93/12C (%) = more than 0 to 0.025 %.

This lower limit means that Nb is added in an amount exceeding a stoichiometrically equivalent amount relative to C. As described above, this constituent feature is important to the present invention for attaining a sufficiently scavenged state in the stage before cold rolling to impart a high workability to the steel sheet. On the other hand, the upper limit is an indicator for specifying the dissolution of NbC in a continuous annealing line or a hot-dip galvanizing line, and when the value exceeds the upper limit, no satisfactory BH property can be provided.

Ti is added to immobilize N. However, the addition of Ti in an excessive amount causes fine TiC to be formed in the stage of hot rolling, so that a good recrystallized aggregate structure cannot be provided. For this reason, Ti is added in an amount in the range of from 0.5 to 1.5 relative to the stoichiometrically equivalent amount (48/14xTi) of N. In some cases, the N content becomes somewhat excessive. In this case, the residual N is immobilized as AlN by particular hot rolling according to the present invention, and there is no possibility that N in a solid solution form remains in a stage before cold rolling.

In the present invention, carbon in a solid solution form is allowed to remain in the final product for the purpose of imparting the BH property and segregates also at grain boundaries, which has a favorable effect on fabrication embrittlement. When a further strict fabrication embrittlement resistance is required, B is added. When the amount of addition of B is less than 0.0001 %, no contemplated effect can be attained, while the addition of B in an amount exceeding 0.0020 % deteriorates the workability of the steel. The amount of addition of B is preferably 0.0008 % or less.

When a further supplementation of the strength is desired, Cr is added in an amount of 1.2 % or less. Although the solid solution strengthening capability of Cr is small, Cr is a favorable element because it improves the work hardening property and minimizes the deterioration of the n value for its function of increasing the strength of the steel. If Cr is added in an amount exceeding 1.2 %, since plating properties deteriorate due to the formation of a passive film of Cr on the surface layer, when Cr is added, the upper limit of amount of addition thereof is 1.2 %.

The process for producing a cold-rolled steel sheet according to the present invention will now be described.

A steel comprising the above-described chemical ingredients according to the present invention is refined in a converter, decarbonized by a vacuum degassing process and subjected to ingot making/blooming or continuous casting to form a slab.

Then, the slab is heated to a temperature in the range of from an Ar_3 transformation point to 1,250 °C and hot-rolled. Since hot rolling in an α phase region has an adverse effect on the r value, the finish rolling temperature is the Ar_3 transformation point or above, preferably in the range of from 960 °C to Ar_3 transformation point. The total reduction ratio in the hot rolling is preferably in the range of from 80 to 99 %. In one embodiment, a slab having a thickness of 240 mm is rolled in the above-described temperature range into a hot rolled sheet (a steel strip) having a thickness of 3.5 to 6 mm.

Conditions for cooling after hot rolling are important. Grain boundaries of the hot-rolled sheet are positions where nuclei having a crystal orientation favorable for the r value occur during annealing for recrystallization, and the nucleation becomes increasingly active with increasing fineness of the structure, so that a better r value can be provided. For this reason, quenching should be effected within 2 sec after the completion of rolling. When the time between the completion of the hot rolling and the initiation of cooling exceeds 2 sec, the hot-rolled structure becomes so coarse that a good r value cannot be provided. It is preferred for the cooling to be initiated within 0.8 sec after the completion of hot rolling. The rapid cooling rate may be about 30 °C/sec or more, which is a cooling rate attained by spray according to conventional means, preferably 50 °C/sec or more, to attain a temperature fall of about 100 °C or more. The upper limit of the cooling rate is 300 °C/sec from the viewpoint of the capacity of facilities.

The coiling temperature should be in the range of from 650 to 770 °C. This causes impurities in a solid solution form, such as C, remaining in the stage of hot rolling to be sufficiently scavenged. Specifically, with respect to C as an example, the reaction $Nb + C \rightarrow NbC$ is allowed to proceed. When the temperature is below 650 °C, the diffusion is insufficient, and no scavenging effect can be attained. On the other hand, when the temperature exceeds 770 °C, grains grow, so that the effect attained by the particular hot rolling is lost.

The hot-rolled sheet is then cold-rolled. In this case, in order to provide a high r value, it is necessary for the reduction ratio in the cold rolling to be a relatively high 72 to 92 %. The reduction ratio is preferably 77 % or more. A reduction ratio exceeding 92 % is unfeasible from the viewpoint of the limitation of current facilities.

After the completion of cold rolling, the steel sheet is held in a temperature range of from 820 to 880 °C for 20 to 600 sec to effect recrystallization annealing. Such annealing is effected for the purpose of providing an aggregate structure of recrystallized grains having a uniform {III} orientation and a sufficiently large size and, at the same time, dissolving part of the NbC into Nb and C to ensure carbon in a solid solution form for imparting the BH property, which is very important to the present invention. The annealing temperature for this purpose should be 820 °C at the lowest. In the process of the present invention, since the material is in a sufficiently scavenged state in the stage before cold rolling, the annealing at a high temperature provides very high r value and elongation, and an n value which is not excessively high. On the other hand, in annealing at a temperature above 880 °C, grains becomes excessively large, which leads to a rough surface defect in the press molding. The holding time at a high temperature is important for ensuring the workability and BH property, and, in a continuous annealing line, the holding time should be 20 to 600 sec.

The rate of cooling after annealing should be 3 °C/sec or more. When the cooling rate is lower than this range, NbC precipitates again during cooling, so that no satisfactory BH property can be provided. Further, in the case of a plated steel sheet, since carbon in a solid solution form becomes absent at grain boundaries in the hot-dip galvanizing, Zn penetrates into the grain boundaries, which deteriorates the plating properties. The upper limit of the cooling rate is about 300 °C/sec from the viewpoint of the capacity of facilities.

Properties of the recrystallized aggregate structure in soft and high strength cold-rolled steel sheets will now be described with reference to experimental examples.

(1) Soft Cold-Rolled Steel Sheet:

A slab having a chemical composition comprising 0.0010 % of C, 0.13 % of Mn, 0.004 % of P, 0.003 % of S, 0.025 % of acid soluble Al, 0.0003 % of B, 0.007 % of Ti, 0.009 % of Nb and 0.0016 % of N with the balance consisting of Fe and unavoidable impurities was hot-rolled into a steel sheet having a finish thickness of 6.5 mm which was then coiled at about 700 °C and cold-rolled into a steel sheet having a finish thickness of 1.6 mm. The cold-rolled sheet was subjected to recrystallization annealing at a temperature of about 850 °C to provide a soft cold-rolled steel sheet. In this case, in one example, rapid cooling was effected within 0.5 sec after the completion of hot rolling at a cooling rate of 60 °C/sec to attain a temperature fall of 100 °C, while in another example, such quenching was not effected. The relationship between the average r value and the natural logarithm ratio (log(I{222}/I{200})) of the X-ray diffraction intensity with respect to the above-described two examples is shown in Fig. 1. In the Figure, ● represents data with respect to the example wherein quenching was effected, and ○ represents data with respect to the example wherein quenching was not effected.

From the Figure, the average r value improves with increasing log(I{222}/I{200}). In particular, when quenching was effected immediately after the completion of finish rolling, the log(I{222}/I{200}) value was so high that the average r value was also high. Further, from the Figure, it is apparent that, in order to provide an average r value of 2.0 or more necessary for soft materials, it is necessary for the log-(I{222}/I{200}) value to be 2.8 or more. With respect to the X-ray diffraction intensity, I{222} and I{200} mean X-ray reflection intensity ratios for random samples of {222} plane and {200} plane determined by the inverse method.

According to the present invention, it is possible to provide soft cold-rolled steel sheets having a very good workability which exhibits a log(I{222}/I{200}) value of 2.8 or more.

(2) High-Strength Cold-Rolled Steel Sheet:

A slab having a chemical composition comprising 0.0013 % of C, 0.15 % of Si, 1.00 % of Mn, 0.051 % of P, 0.0010 % of S, 0.03 % of acid soluble Al, 0.004 % of Ti, 0.028 % of Nb and 0.0018 % of N with the balance consisting of Fe and unavoidable impurities was heated to a temperature of 1100 to 1150 °C, hot-rolled at a finish temperature of 900 to 935 °C, coiled at a temperature of 705 to 725 °C, cold-rolled with a reduction ratio of 78 % and subjected to recrystallization annealing under conditions of an annealing temperature of 850 °C and a holding time of 40 sec to provide a high-strength cold-rolled steel sheet. In this case, in one example, quenching was effected within 2 sec (0.3 to 0.5 sec) after the completion of hot rolling, while in another example, quenching was effected after more than 2 sec (3 to 5 sec) elapsed after the completion of hot rolling. The relationship between the average r value and the logarithm ratio (log-(I{222}/I{200})) of the X-ray diffraction intensity with respect to the above-described two examples is shown in Fig. 2. In the drawing, ● represents data for the former, and ○ represents data for the latter. From the drawing, it is apparent that, when quenching is initiated within 2 sec after the completion of hot rolling, the average r value is improved, and, in order to attain an average r value of 1.9 or more necessary for high-strength materials, it is necessary for the log(I{222}/I{200}) value to be 2.7 or more.

Thus, the cold-rolled steel sheet according to the present invention comprises a recrystallized aggregate structure capable of providing a high average r value, so that, in the present invention, it is possible to improve the {111} orientation and the size of the crystal grains.

Galvanized steel sheets will now be described.

As described above, after a cold-rolled steel sheet is produced, at least one surface of the steel sheet is subjected to galvanizing. In this case, after the above-described recrystallization annealing and cooling are effected with a continuous annealing apparatus, plating may be effected at a coverage of 15 g/m^2 or more through an electrogalvanizing line. Alternatively, after cold rolling, the steel sheet may be passed through a hot-dip galvanizing line to effect recrystallization annealing, cooling and plating.

In the latter case, although the line usually comprises a non-oxidizing heating zone, a reduction zone, a cooling zone, a zinc pot, an alloying furnace and a cooling zone, since it does not have a holding zone, it is necessary that annealing be effected at a temperature (830 to 890 °C) somewhat higher than the above-described continuous annealing condition (820 to 880 °C) and the steel sheet be travelled in such a manner that 40 sec or longer elapse during which time the temperature of the steel sheet is 800 °C or above. After annealing, the steel sheet is cooled at a rate of 3 °C/sec or more and dipped in a zinc pot having a temperature in the range of from 440 to 460 °C so that at least one surface of the steel sheet is subjected to hot-dip galvanizing at a coverage of 15 g/m^2 or more. Immediately after that, the steel sheet is pulled up from the zinc pot, and the plating layer is subjected to an alloying treatment at a temperature of 550 to 600 °C. The temperature of the melted zinc in the zinc pot is determined by the state of melting of zinc, and the alloying temperature is a temperature for providing a proper alloy layer structure. When the alloying temperature is below 550 °C, alloying does not satisfactorily proceed. On the other hand, when the alloying temperature exceeds 600 °C, alloying excessively proceeds, so that the proportion of a hard γ phase increases, which gives rise to peeling during molding, i.e., deteriorates the so-called "powdering property".

After the alloying treatment, the steel sheet was cooled and then subjected to temper rolling. The reduction ratio in the temper rolling should be as low as 0.5 % or less.

[Examples]

Example 1

Steels having chemical compositions specified in Table 1 were produced by a melt process and subjected to continuous casting to provide slabs. In Table 1, steels A to F and steels P and Q fall within the scope of the present invention, and the other steels are comparative steels. In steels G and H, the C content is outside the scope of the present invention. In steels I to L, the content of any of Mn, Nb, N and B is higher than that specified in the present invention. In steels M and N, the Nb content is less than 93/12C which is excessively small relative to the C content of the steel. In steel O, the Ti content is excessively high relative to the N content of the steel. These slabs were then heated to 1060 to 1120 °C. In all the steels, the finish termination temperature was Ar_3 or above. Thereafter, the materials were quenched under conditions specified in Table 2 to about 800 °C to attain a temperature fall of 100 to 150 °C. The finish thickness was 4 mm. Then, the steel sheets were pickled and cold-rolled into sheets having a thickness of 0.8 mm. Then, the cold-rolled steel sheets were continuously annealed and subjected to temper rolling with a reduction ratio of 0.5 %. Hot rolling and annealing conditions and mechanical properties are given in Table 2. The mechanical test was effected using a No. 5 specimen specified in JISZ2201 by a method specified in JISZ2241. In Table 2, α(AA) is the sum of the work hardening and the hardening by BH. The higher this value, the better the dent resistance. YP-E1 is an elongation at yield point after artificial aging at 100 °C for one hr. This value is preferably 0.2 % or less from the viewpoint of necessary delayed aging. The transition temperature in a fabrication embrittlement test was given as a measure of the fabrication resistance. The lower the transition temperature, the better the fabrication resistance.

Table 1

(mass %)

Steel	C	Mn	P	S	Al	Ti	Nb	B	N	Remarks
A	0.0024	0.08	0.007	0.0007	0.029	0.004	0.022	-	0.0013	Invention
B	0.0019	0.14	0.006	0.0018	0.020	0.003	0.015	-	0.0014	Invention
C	0.0015	0.15	0.005	0.0018	0.019	0.002	0.015	-	0.0012	Invention
D	0.0019	0.09	0.006	0.0007	0.023	0.005	0.017	0.0003	0.0011	Invention
E	0.0022	0.13	0.006	0.0009	0.020	0.005	0.018	0.0005	0.0017	Invention
F	0.0017	0.14	0.008	0.0009	0.024	0.004	0.015	0.0001	0.0010	Invention
G	0.0006	0.06	0.007	0.0013	0.013	0.004	0.006	-	0.0011	Comp.
H	0.0053	0.12	0.005	0.0012	0.029	0.005	0.043	0.0001	0.0012	Comp.
I	0.0023	0.74	0.005	0.0019	0.027	0.005	0.022	-	0.0013	Comp.
J	0.0016	0.11	0.005	0.0007	0.029	0.005	0.076	-	0.0014	Comp.
K	0.0023	0.09	0.005	0.0013	0.018	0.020	0.019	0.0002	0.0051	Comp.
L	0.0020	0.12	0.006	0.0010	0.024	0.004	0.016	0.0035	0.0014	Comp.
M	0.0037	0.11	0.005	0.0006	0.022	0.003	0.023	-	0.0016	Comp.
N	0.0029	0.13	0.007	0.0018	0.026	0.002	0.013	-	0.0009	Comp.
O	0.0016	0.09	0.005	0.0012	0.021	0.015	0.013	-	0.0014	Comp.
P	0.0015	0.05	0.008	0.0007	0.027	0.002	0.013	-	0.0011	Invention
Q	0.0023	0.06	0.007	0.0013	0.028	0.003	0.022	-	0.0011	Invention

Note: Si≤0.04%

Nos. 1, 2, 5, 7, 12, 13, 14, 24 and 25 listed in Table 2 are sheets produced according to the present invention. They have an excellent r value, E1 value and n value and have satisfactory strength at yield point (YP), BH property and fabrication quality resistance (transition temperature) values as contemplated in the present invention. The other Nos. are steel sheets wherein production conditions are outside the scope of the present invention. In these steel sheets, at least one of the above-described properties is unsatisfactory. In No. 3, since the time between the completion of finish annealing in the hot rolling and the initiation of quenching is excessively long, the structure of the hot-rolled sheet becomes coarsened, so that the r value and n value of the product are poor. In No. 4, since the coiling temperature is excessively low, the scavenging effect is unsatisfactory, so that the YP value is high and the E1 and n values are poor. On the other hand, in No. 6, since the coiling temperature is excessively high, the structure of the hot-rolled sheet becomes so coarse that the r value is poor. In No. 8, the annealing temperature is so low that not only the workability is poor but also the BH property is unsatisfactory. On the other hand, in No. 9, the annealing temperature is so high that the r value and n value are poor due to a change in the aggregate structure attributable to excessive coarsening of grains and partial austenitizing. In. No. 10, since the heat holding time in the annealing is excessively short, the development of the aggregate structure and redissolution of C in a solid solution form are unsatisfactory, so that the r value, n value and BH property are poor. In No. 11, the BH property cannot be ensured because the rate of cooling after annealing is so low that C precipitates during cooling, while in No. 15, the BH property cannot be ensured because the C content of the steel is excessively low. No. 15 is poor also in fabrication resistance. In Nos. 16, 17 and 19, since the respective C, Mn and N contents of the steels are so high that the YP value is high and the n value is poor. In No. 18, the Nb content is so high that not only the BH property but also the fabrication resistance (transition temperature) is poor. In No. 20, the B content is so high that the r value is poor. In Nos. 21 and 22, since the Nb content is excessively low, C in a solid solution form remains in the stage before annealing, so that not only the workability (n value, r value and E1 value) but also the aging property are poor. In No. 23, since the Ti content is excessively high, a number of fine TiC grains precipitate in the hot-steel sheet and the YP value is high and the n value is poor.

Table 2

No.	Steel	Hot Rolling Conditions				Annealing Conditions			Mechanical Properties									Remarks
		Finish termination temp. (°C)	Time taken up to rapid cooling (sec)	Rapid cooling rate (°C/sec)	Coiling temp. (°C)	Annealing temp. (°C)	Holding time (sec)	Cooling rate (°C/sec)	YP (N/mm^2)	TS (N/mm^2)	El (%)	n	r	BH (N/mm^2)	σ (AA) (N/mm^2)	YP-El (%)	Transition temp. (°C)	
1	A	915	0.8	60	730	875	60	20	131	312	55.7	0.256	2.15	37	68	0.15	-85	Invention
2	A	900	0.8	60	730	875	60	20	159	301	52.9	0.277	2.45	43	81	0.05	<-100	Invention
3	A	910	2.5	60	730	875	60	20	140	290	55.3	0.242	1.89	30	79	0.10	<-100	Comp.
4	A	905	1.0	70	580	870	50	50	180	335	47.7	0.212	2.08	45	72	0.10	<-100	Comp.
5	B	910	0.6	70	700	880	60	20	136	284	53.2	0.267	2.38	39	82	0.10	<-100	Invention
6	B	925	0.8	60	810	850	50	50	138	315	51.2	0.216	1.90	56	81	0.05	-85	Comp.
7	C	900	1.5	30	750	840	60	20	142	286	53.1	0.279	2.21	47	66	0.15	-80	Invention
8	C	915	1.5	50	750	800	50	50	162	311	46.9	0.215	2.05	22	49	0.20	-80	Comp.
9	C	900	0.8	50	750	910	70	30	144	303	54.0	0.235	1.78	63	79	0.15	-90	Comp.
10	C	910	0.8	50	750	860	5	10	165	324	51.3	0.228	1.91	16	41	0.05	<-100	Comp.
11	C	910	0.8	50	730	860	30	1.5	134	282	51.3	0.258	2.18	18	59	0.05	-80	Comp.
12	D	910	0.6	50	760	880	60	30	134	282	55.6	0.251	2.48	40	65	0.15	<-100	Invention
13	E	915	0.8	50	740	860	60	30	154	298	52.5	0.266	2.23	41	74	0.20	<-100	Invention

Table 2 (continued)

No.	Steel	Hot Rolling Conditions				Annealing Conditions			Mechanical Properties									Remarks
		Finish termination temp. (°C)	Time taken up to rapid cooling (sec)	Rapid cooling rate (°C/sec)	Coiling temp. (°C)	Annealing temp. (°C)	Holding time (sec)	Cooling rate (°C/sec)	YP (N/mm^2)	TS (N/mm^2)	El (%)	n	r	BH (N/mm^2)	σ (AA) (N/mm^2)	YP-El (%)	Transition temp. (°C)	
14	F	905	0.8	50	740	860	60	30	146	318	54.8	0.255	2.31	39	64	0.20	-90	Invention
15	G	905	0.8	60	690	850	60	50	131	299	55.9	0.271	2.58	15	52	0.15	-50	Comp.
16	H	905	0.6	60	740	850	80	40	175	320	51.0	0.231	2.04	38	48	0.20	-90	Comp.
17	I	910	1.0	40	730	850	50	80	171	318	50.5	0.228	2.10	30	46	0.20	-90	Comp.
18	J	905	0.8	50	730	860	80	50	162	302	52.3	0.241	2.41	14	37	0.15	-35	Comp.
19	K	900	1.1	70	730	860	30	50	181	324	50.5	0.222	2.17	51	72	0.20	<-100	Comp.
20	L	920	0.8	70	700	850	30	90	174	310	52.1	0.247	1.94	32	68	0.15	<-100	Comp.
21	M	915	0.9	60	740	860	70	100	156	323	49.0	0.239	1.88	53	42	0.40	<-100	Comp.
22	N	910	0.8	50	720	880	60	60	154	324	50.5	0.221	1.71	55	54	0.30	<-100	Comp.
23	O	910	1.1	60	730	850	50	90	170	318	50.0	0.226	2.17	38	48	0.10	-90	Comp.
24	P	915	0.8	30	750	850	50	80	150	280	51.1	0.276	2.50	56	71	0.05	-90	Invention
25	Q	915	1.0	60	720	860	70	30	136	302	55.8	0.255	2.15	56	66	0.05	-90	Invention

Example 2

Steels having chemical compositions specified in Table 3 were subjected to refining in a converter and produced by a melt process. In all the steels, the carbon content was rendered extra low by RH vacuum

degassing. Among these steels, steels A to E fall within the scope of the present invention, and the other steels are different from the steels of the present invention with respect to an item(s) enclosed in a thick frame. In particular, steel N is an excess carbon type steel having Nb/C < 1 (atomic weight) and, so to speak, a steel provided by a process commonly used in the art. These steels were continuously cast into slabs and then hot-rolled. The hot-rolled steel sheets were pickled, cold-rolled and then passed through a continuous annealing line to provide products. Hot rolling and annealing conditions are given in Table 4. The heating temperature in the hot rolling was 1110 to 1150 °C, and the temperature fall in quenching after hot rolling was 100 to 120 °C. The thickness of the hot-rolled steel sheets was 4.0 mm, and these hot-rolled steel sheets were cold-rolled with a reduction ratio of 80 %, into cold-rolled coils having a thickness of 0.8 mm. Finally, the cold-rolled coils were subjected to temper rolling with a reduction ratio of 0.3 to 0.4 %. The mechanical test values and chemical conversion treatment property for these steel sheets are also given in Table 4.

The mechanical test was effected using a No. 5 specimen specified in JISZ2201 by a method specified in JISZ2241 to determine the strength YP at yield point, tensile strength TS and elongation E1 at break. The n value was calculated from (10 %-20 %) strain. The painting-baking property was expressed in terms of the BH property and the sum (σ(AA)) of the 2 % work hardening and the hardening by BH as described above. In order to evaluate the cold aging resistance, the recovery of elongation at yield point after the sample was allowed to stand at 40 °C for 30 days was expressed in terms of YP-E1. YP-E1 is an quantity corresponding to a stretcher strain defect, and this defect occurs unless the YP-E1 value is 0.2 % or less. The fabrication embrittlement resistance was expressed in terms of the ductility-embrittlement temperature. This value is the transition temperature at which cracking occurs when a cup prepared by molding with a draw ratio of 2.2 is subjected to 10 % flaring at varied temperatures.

As is apparent from Table 4, steel sheets (Nos. 1, 2, 6, 10, 14, 15 and 17) according to the present invention had a tensile strength of about 350 to about 400 N/mm^2, and, despite being high-strength high-dent-resistant steel sheets having a BH value of 40 N/mm^2 or more and an σAA value of 60 N/mm^2 or more, have a sufficiently low YP value (i.e., a sufficient face strain resistance), and good elongation, r value and n value (i.e., a high moldability). Further, with respect to the aging property, they had substantially no recovery of YP-E1 in cold aging and exhibited either no cold aging or delayed aging, and, with respect to the fabrication embrittlement, the transition temperature was so low that no problem occurred. Further, the chemical conversion was also good. In the steel sheets according to the present invention, the natural logarithm ratio (log(I{222}/ I{200})) of the diffraction intensity in the X-ray diffraction was 2.7 or more.

By contrast, none of the comparative steel sheets satisfied all the above-described property requirements. In particular, it is apparent that, with respect to steel sheet No. 26, which is of excess carbon type, and steel sheet No. 4, which is different from the process of the present invention in the treatment of NbC although C < Nb (atomic ratio), the level of the workability is far from that contemplated in the present invention.

Although steel sheet No. 21 had a relatively good workability, it was poor in the chemical conversion.

Table 3

(mass %)

Steel	C	Si	Mn	P	Cr	S	Al	Ti	Nb	B	N	Nb-93/12C	Ti/N*	Remarks
A	0.0013	0.16	1.01	0.067	-	0.0018	0.026	0.005	0.027	—	0.0011	0.017	1.33	Invention
B	0.0021	0.44	0.63	0.030	-	0.0007	0.017	0.004	0.018	0.0004	0.0016	0.002	0.73	Invention
C	0.0025	0.25	0.96	0.030	0.81	0.0013	0.014	0.007	0.038	—	0.0017	0.019	1.20	Invention
D	0.0027	0.02	0.46	0.072	0.66	0.0020	0.053	0.008	0.042	0.0002	0.0020	0.021	1.17	Invention
E	0.0018	0.02	0.75	0.045	1.00	0.0020	0.045	0.005	0.035	0.0003	0.0019	0.021	0.77	Invention
F	0.0020	0.10	1.00	0.044	0.76	0.0015	0.030	0.018	0.033	0.0002	0.0015	0.018	3.51	Comp.
G	0.0007	0.02	0.98	0.065	—	0.0020	0.025	0.008	0.027	—	0.0020	0.022	1.17	Comp.
H	0.0060	0.12	1.15	0.040	0.45	0.0010	0.019	0.005	0.048	—	0.0013	0.002	1.12	Comp.
I	0.0020	0.72	0.66	0.038	0.51	0.0014	0.037	0.008	0.028	0.0002	0.0018	0.013	1.30	Comp.
J	0.0016	0.22	0.58	0.031	—	0.0017	0.015	0.005	0.048	—	0.0017	0.036	0.86	Comp.
K	0.0020	0.25	1.08	0.049	—	0.0013	0.021	0.004	0.065	0.0004	0.0016	0.050	0.73	Comp.
L	0.0018	0.20	0.71	0.035	0.50	0.0006	0.022	0.009	0.017	—	0.0051	0.003	0.52	Comp.
M	0.0015	0.01	1.01	0.070	—	0.0018	0.035	0.005	0.027	0.0035	0.0017	0.015	0.86	Comp.
N	0.0039	0.02	0.86	0.058	—	0.0010	0.028	0.006	0.019	—	0.0017	-0.011	1.03	Comp.

*Atomic weight ratio

Table 4

No.	Steel	Hot Rolling Conditions				Annealing Conditions			Mechanical Properties										Chemical Conversion	Remarks
		Finish termination temp. (°C)	Time taken up to rapid cooling (sec)	Rapid cooling rate (°C/sec)	Coiling temp. (°C)	Annealing temp. (°C)	Holding time (sec)	Cooling rate (°C/sec)	YP (N/mm^2)	TS (N/mm^2)	El (%)	n	r	BH (N/mm^2)	σ (AA) (N/mm^2)	YP-El (%)	Transition temp. (°C)		
1	A	905	0.8	55	705	875	30	10	238	420	40.0	0.255	2.00	45	78	0.05	-80	Good	Invention
2	A	920	0.5	60	730	855	300	100	240	425	39.5	0.266	2.05	55	89	0.10	-80	Good	Invention
3	A	900	3.0	60	730	860	40	100	236	420	39.0	0.250	1.72	50	80	0.10	-80	Good	Comp.
4	A	910	1.0	60	565	865	40	100	240	424	38.0	0.233	1.50	52	76	0.05	-80	Good	Comp.
5	A	910	0.5	55	710	855	85	1.5	235	409	40.5	0.277	2.01	16	44	0.05	-35	Good	Comp.
6	B	915	1.0	65	705	865	185	70	219	385	41.5	0.277	2.01	50	80	0.05	-90	Good	Invention
7	B	925	0.8	70	825	860	180	105	221	390	40.0	0.244	1.75	50	65	0.10	-75	Good	Comp.
8	B	920	0.6	65	720	805	180	100	240	410	39.6	0.210	1.59	14	36	0.00	-75	Good	Comp.
9	B	930	1.0	65	710	860	5	100	220	391	40.3	0.240	1.88	10	33	0.05	-75	Good	Comp.
10	C	885	1.0	55	710	860	65	55	205	415	40.5	0.288	2.10	55	80	0.10	-90	Good	Invention
11	C	900	0.8	50	710	910	40	100	175	377	37.0	0.276	1.76	40	66	0.15	-80	Good	Comp.
12	C	890	4.5	65	700	860	90	100	210	420	40.0	0.280	1.80	51	76	0.10	-80	Good	Comp.
13	C	915	0.6	55	715	860	40	1.5	195	418	41.0	0.280	2.09	19	45	0.10	-45	Good	Comp.

Table 4 (continued)

No.	Steel	Hot Rolling Conditions				Annealing Conditions			Mechanical Properties									Chemical Conversion	Remarks
		Finish termination temp. (°C)	Time taken up to rapid cooling (sec)	Rapid cooling rate (°C/sec)	Coiling temp. (°C)	Annealing temp. (°C)	Holding time (sec)	Cooling rate (°C/sec)	YP (N/mm²)	TS (N/mm²)	El (%)	n	r	BH (N/mm²)	σ (AA) (N/mm²)	YP-El (%)	Transition temp. (°C)		
14	D	920	0.3	60	750	855	30	100	203	405	43.0	0.279	2.00	50	75	0.05	-90	Good	Invention
15	D	915	1.0	100	720	865	385	75	200	402	43.4	0.275	2.00	55	86	0.05	-90	Good	Invention
16	D	920	0.6	60	735	860	8	95	196	396	43.5	0.267	1.90	17	44	0.05	-75	Good	Comp.
17	E	890	0.8	50	705	855	45	55	190	399	42.0	0.275	2.10	44	80	0.05	-90	Good	Invention
18	F	900	0.8	50	740	860	60	100	241	412	39.0	0.260	1.80	15	38	0.00	-60	Good	Comp.
19	G	915	0.6	70	710	870	60	105	245	400	41.0	0.280	2.10	16	45	0.00	-30	Good	Comp.
20	H	910	0.8	75	750	860	85	95	265	421	36.5	0.200	1.60	65	77	0.30	-90	Good	Comp.
21	I	935	0.6	75	735	870	45	100	251	436	38.0	0.263	1.91	43	75	0.05	-90	Poor	Comp.
22	J	925	0.8	55	720	860	60	110	187	373	42.5	0.286	2.10	19	55	0.00	-35	Good	Comp.
23	K	910	0.8	70	710	860	80	100	260	430	39.2	0.260	1.98	10	40	0.00	-75	Good	Comp.
24	L	910	1.0	65	710	870	50	105	225	395	39.9	0.215	1.75	55	75	0.25	-80	Good	Comp.
25	M	905	0.6	75	740	860	50	95	255	422	37.0	0.208	1.60	50	65	0.05	<-100	Good	Comp.
26	N	920	0.6	70	720	860	75	100	212	400	37.5	0.200	1.65	70	88	0.40	-80	Good	Comp.

Example 3

Steels having chemical compositions specified in Table 5 were subjected to refining in a converter and produced by a melt process. In all the steels, the carbon content was rendered extra low by RH vacuum

degassing. Among these steels, steels A to F, Q and R fall within the scope of the present invention, and the other steels are outside the scope of the present invention with respect to the C content for steels G and H, Mn content for steel I, Nb content/or (Nb-93/12C) content for steels J and K, N content for steel L, B content for steel M and Ti/N value for steel P. Further, steels N and O are of an excess carbon type steel having Nb/C < 1 which is different from the steels according to the present invention.

These steels were continuously cast into slabs and then hot-rolled. The hot-rolled sheet sheets were pickled, cold-rolled and then passed through a hot-dip galvanizing line to provide products. Hot rolling, cold rolling and hot-dip galvanizing conditions are given in Table 6. The heating temperature in the hot rolling was 1110 to 1160°C, and the temperature fall in quenching after hot rolling was 100 to 120°C. The thickness of the hot-rolled steel sheets was 4.0 mm, and these hot-rolled sheets were cold-rolled with a reduction ratio of 80 % into cold-rolled coils having a thickness of 0.8 mm. Finally, the cold-rolled coils were subjected to temper rolling with a reduction ratio of 0.3 to 0.4 %. The mechanical test values and plating properties for these steel sheets are also given in Table 6.

The mechanical test was effected using a No. 5 specimen specified in JISZ2201 by a method specified in JISZ2241 to determine the strength YP at yield point, tensile strength TS and elongation E1 at break. The n value was calculated from (10 %-20 %) strain. The painting-baking property was expressed in terms of the BH property and the sum (σ(AA)) of the 2 % work hardening and the hardening by BH as described above. In order to evaluate the cold aging resistance, the recovery of elongation at yield point after the sample was allowed to stand at 40°C for 30 days was expressed in terms of YP-E1. YP-E1 is an quantity corresponding to a stretcher strain defect, and this defect occurs unless the YP-E1 value is 0.2 % or less. The fabrication embrittlement resistance was expressed in terms of the ductility-embrittlement temperature. This value is the transition temperature at which cracking occurs when a cup prepared by molding with a draw ratio of 2.2 is subjected to 10 % flaring at varied temperatures.

Further, the plating properties were evaluated in terms of the iron content and powdering property of the alloyed layer. The powdering property was determined by effecting deep drawing of a cylinder with a draw ratio of 2.2 and determining the proportion of peeling according to the following equation:

P (measure of powdering) = (A - B)/(A - C) x 100 (%)

wherein A is the weight of a blank before molding;

B is the weight of a cup after the inner and outer surfaces of the side face of the cup as molded are subjected to peeling with a pressure-sensitive tape (= state peeled by powdering); and

C is the weight of the cup which has been pickled after molding.

The lower the P value, the better the powdering property. When the P value is 40 % or less, the powdering property is very good. In the case of alloyed hot-dip galvanizing commonly used for automobiles, when the coverage of zinc is 40 to 50 g/m^2, the P value and iron content are 30 to 50 % and 8 to 12 %, respectively.

As is apparent from Table 6, steel sheets (Nos. 1, 2, 5, 7, 12 to 14, 25 and 26) according to the present invention had a sufficiently low YP value (i.e., a sufficient face strain resistance), good elongation, r value and n value (i.e., a high moldability) and, with respect to the aging property, had substantially no recovery of YP-E1 in cold aging (either no cold aging or delayed aging), and a high painting-baking hardening (a high dent resistance), and, with respect to the fabrication embrittlement, the transition temperature was so low that no problem occurred. Further, also with respect to plating properties, both the iron content as a measure of the degree of alloying and the P value as a measure of the evaluation of powdering were very good.

By contrast, none of the comparative steel sheets satisfied all the above-described property requirements. In particular, it is apparent that, with respect to steel sheet Nos. 22 and 23, which are of excess carbon type, and steel sheet No. 4, which is different from the process of the present invention in the treatment of NbC although C < Nb (atomic ratio), the level of the workability is relatively high but still far from that contemplated in the present invention.

Table 5

(mass %)

Steel	C	Mn	P	S	Al	Ti	Nb	B	N	Nb-93/12C	Ti/N*	Remarks
A	0.0029	0.07	0.004	0.0007	0.028	0.002	0.031	–	0.0010	0.009	0.66	Invention
B	0.0019	0.10	0.005	0.0017	0.014	0.007	0.022	–	0.0016	0.007	1.25	
C	0.0023	0.11	0.005	0.0007	0.018	0.005	0.035	–	0.0014	0.017	1.02	
D	0.0023	0.07	0.005	0.0013	0.011	0.007	0.032	0.0002	0.0014	0.014	1.37	
E	0.0017	0.10	0.005	0.0019	0.028	0.004	0.031	0.0004	0.0012	0.018	0.95	
F	0.0022	0.11	0.007	0.0008	0.021	0.004	0.030	0.0004	0.0009	0.013	1.10	
G	0.0008	0.14	0.006	0.0012	0.023	0.006	0.019	–	0.0017	0.015	1.06	Comp.
H	0.0053	0.06	0.007	0.0005	0.029	0.005	0.059	0.0003	0.0016	0.018	0.84	
I	0.0017	0.74	0.007	0.0012	0.018	0.003	0.028	–	0.0017	0.015	0.53	
J	0.0015	0.11	0.007	0.0012	0.012	0.004	0.052	–	0.0014	0.040	0.79	
K	0.0018	0.12	0.006	0.0020	0.029	0.003	0.049	0.0004	0.0012	0.035	0.62	
L	0.0016	0.12	0.007	0.0015	0.015	0.022	0.014	0.0002	0.0051	0.002	1.28	
M	0.0016	0.11	0.006	0.0014	0.012	0.005	0.015	0.0035	0.0011	0.002	1.40	
N	0.0037	0.06	0.007	0.0018	0.012	0.003	0.019	–	0.0011	-0.010	0.77	
O	0.0029	0.11	0.004	0.0009	0.024	0.005	0.013	–	0.0013	-0.010	1.09	
P	0.0016	0.11	0.005	0.0015	0.015	0.015	0.024	–	0.0016	0.011	2.59	
Q	0.0015	0.15	0.003	0.0012	0.027	0.004	0.019	–	0.0010	0.007	1.32	Invention
R	0.0018	0.10	0.003	0.0013	0.029	0.003	0.031	–	0.0014	0.017	0.69	

*Atomic weight ratio

Table 6

No.	Steel	Hot Rolling Conditions				Annealing Conditions		Mechanical Properties									Plating Properties			Remarks
		Finish termination temp. (°C)	Time taken up to rapid cooling (sec)	Rapid cooling rate (°C/sec)	Coiling temp. (°C)	Annealing temp. (°C)	Cooling rate (°C/sec)	YP (N/mm^2)	TS (N/mm^2)	El (%)	n	r	BH (N/mm^2)	σ (AA) (N/mm^2)	YP-El (%)	Transition temp. (°C)	Amt. of plating (g/mm^2)	Iron content (%)	P value (%)	
1	A	915	0.8	60	730	875	10	150	299	52.9	0.255	2.15	59	65	0.05	-85	45	9.7	24	Invention
2	A	915	0.8	60	730	875	10	154	302	50.7	0.260	2.25	45	71	0.15	-80	45	10.9	33	
3	A	915	2.5	60	730	875	10	175	320	49.2	0.254	1.81	35	82	0.10	-80	45	8.9	28	Comp.
4	A	905	1.0	70	580	870	10	185	352	44.5	0.213	1.93	40	64	0.20	-85	45	9.0	26	
5	B	915	0.6	70	700	880	10	159	334	51.0	0.272	2.28	50	85	0.15	-80	30	10.3	34	Invention
6	B	915	0.8	60	810	850	10	147	319	47.9	0.237	1.91	56	84	0.15	-75	30	10.2	34	Comp.
7	C	920	1.5	30	750	840	10	157	297	51.2	0.253	2.19	56	70	0.15	-80	30	10.8	33	Invention
8	C	910	1.5	50	750	800	10	186	332	45.7	0.225	1.98	11	35	0.05	-50	45	12.1	48	Comp.
9	C	900	0.8	50	750	910	10	164	305	53.7	0.234	1.60	51	75	0.00	-90	45	9.4	28	
10	C	910	0.8	50	750	810	10	183	330	46.3	0.235	1.71	9	35	0.05	-40	45	13.3	52	
11	C	910	0.8	50	730	860	1.5	149	305	49.4	0.273	2.26	18	59	0.10	-50	45	12.5	49	
12	D	915	0.6	50	760	880	20	174	321	49.5	0.254	2.19	52	60	0.05	<-100	45	11.1	27	Invention
13	E	915	0.8	50	740	860	20	163	314	50.3	0.265	2.26	44	67	0.20	<-100	45	9.3	35	
14	F	910	0.8	50	740	860	10	165	313	51.5	0.258	2.40	40	83	0.15	<-100	45	11.3	31	

Table 6 (continued)

No.	Steel	Hot Rolling Conditions				Annealing Conditions		Mechanical Properties									Plating Properties			Remarks
		Finish termination temp. (°C)	Time taken up to rapid cooling (sec)	Rapid cooling rate (°C/sec)	Coiling temp. (°C)	Annealing temp. (°C)	Cooling rate (°C/sec)	YP (N/mm²)	TS (N/mm²)	El (%)	n	r	BH (N/mm²)	σ (AA) (N/mm²)	YP-El (%)	Transition temp. (°C)	Amt. of plating (g/mm²)	Iron content (%)	P value (%)	
15	G	900	0.8	40	750	870	10	136	294	54.9	0.273	2.48	15	52	0.15	-50	45	13.0	45	Comp.
16	H	900	1.0	60	680	870	10	187	333	49.0	0.231	1.95	38	48	0.05	-90	45	10.7	26	
17	I	915	0.7	40	700	850	10	184	331	48.5	0.228	2.02	19	46	0.20	-90	45	12.8	58	
18	J	920	1.1	60	720	860	10	174	315	50.3	0.241	2.33	14	37	0.05	-35	45	13.2	53	
19	K	915	0.8	50	740	880	10	166	319	51.8	0.245	2.32	16	31	0.00	-27	45	13.4	55	
20	L	910	0.6	60	700	870	10	197	330	48.0	0.222	2.09	51	72	0.20	<-100	45	9.0	21	
21	M	900	0.7	50	740	880	10	188	325	50	0.247	1.82	45	59	0.05	<-100	45	10.8	26	
22	N	905	0.8	40	720	860	10	179	350	46.2	0.228	1.64	31	50	0.35	<-100	45	9.4	34	
23	O	910	1.0	50	720	860	10	185	315	49.9	0.248	1.67	46	53	0.30	<-100	45	11.0	25	
24	P	910	0.7	50	730	880	10	189	324	48.1	0.228	2.06	38	48	0.15	-90	45	13.0	55	
25	Q	915	0.8	40	700	860	10	171	332	53.9	0.253	2.38	45	87	0.15	-90	45	10.7	20	Invention
26	R	905	0.8	30	700	850	10	167	334	52.4	0.275	2.13	58	74	0.10	-90	45	10.3	34	

Example 4

Steels having chemical compositions specified in Table 7 were subjected to refining in a converter and produced by a melt process. In all the steels, the carbon content was rendered extra low by RH vacuum

degassing. Among these steels, steels A to F fall within the scope of the present invention, and the other steels are different from the steels of the present invention with respect to an item(s) enclosed in a thick frame. In particular, steels N and O are an excess carbon type steel having Nb/C < 1 (atomic weight) and, so to speak, a steel provided by a process commonly used in the art. These steels were continuously cast into slabs and hot-rolled. The hot-rolled steel sheets were pickled, cold-rolled and then travelled through a hot-dip galvanizing line to provide products. Hot rolling, cold rolling and hot-dip galvanizing conditions are given in Table 8. The heating temperature in the hot rolling was 1110 to 1150 °C, and the temperature fall in quenching after hot rolling was 100 to 120 °C. The thickness of the hot-rolled steel sheets was 4.0 mm, and these hot-rolled sheets were cold-rolled with a reduction ratio of 80 % into cold-rolled coils having a thickness of 0.8 mm. Finally, the cold-rolled coils were subjected to temper rolling with a reduction ratio of 0.3 to 0.4 %. The mechanical test values and plating properties for these steel sheets are also given in Table 8.

The mechanical test was effected using a No. 5 specimen specified in JISZ2201 by a method specified in JISZ2241 to determine the strength YP at yield point, tensile strength TS and elongation E1 at break. The n value was calculated from 10%-20% strain. The painting-baking property was expressed in terms of the BH property and the sum (σ(AA)) of the 2 % work hardening and the hardening by BH as described above. In order to evaluate the cold aging resistance, the recovery of elongation at yield point after the sample was allowed to stand at 40 °C for 30 days was expressed in terms of YP-E1. YP-E1 is an quantity corresponding to a stretcher strain defect, and this defect occurs unless the YP-E1 value is 0.2 % or less. The fabrication embrittlement resistance was expressed in terms of the ductility-embrittlement temperature. This value is the transition temperature at which cracking occurs when a cup prepared by molding with a draw ratio of 2.2 is subjected to 10 % flaring at varied temperatures.

Further, the plating properties were evaluated in terms of the iron content, degree of alloying and powdering property of the alloyed layer. The iron content was determined by analysis, and the degree of alloying was evaluated with the naked eye. The powdering property was determined by effecting deep drawing of a cylinder with a draw ratio of 2.2 and determining the proportion of peeling according to the following equation:

$$\text{P (measure of powdering)} = \frac{A - B}{A - C} \times 100 \ (\%)$$

wherein A is the weight of a blank before molding;

B is the weight of a cup after the inner and outer surfaces of the side face of the cup as molded are subjected to peeling with a pressure-sensitive tape (= state peeled by powdering); and

C is the weight of the cup which has been pickled after molding.

The lower the P value, the better the powdering property. When the P value is 40 % or less, the powdering property is very good. In the case of alloyed hot-dip galvanizing commonly used for automobiles, when the coverage of zinc is 40 to 50 g/m^2, the P value and iron content are 30 to 50 % and 8 to 12 %, respectively.

As is apparent from Table 8, steel sheets (Nos. 1, 2, 5, 7 and 12 to 14) according to the present invention had a tensile strength of about 350 to about 400 N/mm^2, and, despite being a high-strength high-dent-resistant steel sheet having a BH value of 40 N/mm^2 or more and an σAA value of 60 N/mm^2 or more, had a sufficiently low YP value (i.e., a high face strain resistance), good elongation, r value and n value (i.e., a high moldability), and, with respect to the aging property, had substantially no recovery of YP-E1 in cold aging (cold non-aging or delayed aging), and a high paining-baking hardening (a high dent resistance), and, with respect to the fabrication embrittlement, the transition temperature was so low that no problem occurred. Further, also with respect to plating properties, both the iron content as a measure of the degree of alloying and the P value as a measure of the evaluation of powdering were very good.

By contrast, none of the comparative steel sheets satisfied all the above-described property requirements. In particular, it is apparent that, with respect to steel sheet Nos. 22 and 23, which are of excess carbon type, and steel sheet No. 4, which is different from the process of the present invention in the treatment of NbC although C < Nb (atomic ratio), the level of the workability is relatively high but still far from that contemplated in the present invention.

Table 7

(mass %)

Steel	C	Si	Mn	P	Cr	S	Al	Ti	Nb	B	N	Nb-93/12C	Ti/N*	Mn/(Si+10P)	Remarks
A	0.0025	0.23	1.27	0.062	–	0.0011	0.018	0.006	0.035	–	0.0016	0.016	1.14	1.49	Invention
B	0.0015	0.15	1.06	0.051	–	0.0012	0.017	0.005	0.023	–	0.0010	0.011	1.43	1.60	Invention
C	0.0024	0.13	0.92	0.044	–	0.0017	0.028	0.002	0.030	0.0008	0.0010	0.012	0.71	1.58	Invention
D	0.0017	0.25	1.06	0.064	0.81	0.0020	0.019	0.003	0.034	0.0004	0.0009	0.021	0.95	1.20	Invention
E	0.0021	0.22	0.88	0.052	0.59	0.0017	0.012	0.006	0.021	0.0005	0.0014	0.004	1.26	1.21	Invention
F	0.0023	0.26	0.91	0.033	1.10	0.0012	0.012	0.007	0.032	0.0005	0.0017	0.014	1.22	1.54	Invention
G	0.0006	0.10	0.45	0.029	–	0.0012	0.028	0.005	0.009	–	0.0017	0.004	0.81	1.16	Comp.
H	0.0053	0.16	0.83	0.054	–	0.0016	0.024	0.003	0.043	0.0004	0.0015	0.002	0.54	1.18	Comp.
I	0.0018	0.67	1.26	0.035	–	0.0006	0.029	0.004	0.032	–	0.0009	0.018	1.16	1.24	Comp.
J	0.0023	0.22	1.37	0.063	–	0.0017	0.028	0.005	0.052	–	0.0012	0.035	1.23	1.61	Comp.
K	0.0021	0.12	1.20	0.061	–	0.0012	0.029	0.003	0.049	0.0004	0.0012	0.033	0.72	1.65	Comp.
L	0.0021	0.24	0.61	0.024	–	0.0009	0.022	0.011	0.017	0.0004	0.0051	0.001	0.64	1.27	Comp.
M	0.0017	0.16	0.57	0.020	–	0.0013	0.016	0.004	0.022	0.0035	0.0008	0.009	1.35	1.56	Comp.
N	0.0037	0.12	1.41	0.068	–	0.0017	0.026	0.006	0.021	–	0.0018	-0.008	0.96	1.78	Comp.
O	0.0029	0.20	1.03	0.040	–	0.0009	0.010	0.009	0.013	–	0.0018	-0.010	1.42	1.72	Comp.
P	0.0019	0.15	0.85	0.040	–	0.0006	0.017	0.010	0.021	–	0.0013	0.006	2.08	1.53	Comp.
Q	0.0025	0.16	0.34	0.028	–	0.0014	0.013	0.006	0.033	0.0008	0.0012	0.014	1.42	0.81	Comp
R	0.0015	0.47	0.74	0.058	0.65	0.0013	0.021	0.003	0.028	–	0.0016	0.016	0.64	0.70	Comp

*Atomic weight ratio

Table 8

No.	Steel	Hot Rolling Conditions				Annealing Conditions		Mechanical Properties									Plating Properties				Remarks
		Finish termination temp. (°C)	Time taken up to rapid cooling (sec)	Rapid cooling rate (°C/sec)	Coiling temp. (°C)	Annealing temp. (°C)	Cooling rate (°C/sec)	YP (N/mm^2)	TS (N/mm^2)	El (%)	n	r	BH (N/mm^2)	σ (AA) (N/mm^2)	YP-El (%)	Transition temp. (°C)	Amt. of plating (g/mm^2)	Alloying	Iron content (%)	P value (%)	
1	A	920	0.8	60	730	875	10	222	390	40.9	0.273	2.10	54	80	0.10	-85	45	Good	11.3	27	Invention
2	A	905	0.8	60	730	875	10	221	396	38.6	0.258	2.11	41	89	0.10	-80	45	Good	10.5	21	Invention
3	A	900	2.5	60	730	875	10	229	395	39.6	0.270	1.98	41	68	0.20	-80	45	Good	9.4	27	Comp.
4	A	915	1.0	70	580	870	10	274	399	33.7	0.207	1.46	57	83	0.06	-85	45	Good	10.9	29	Comp.
5	B	910	0.6	70	700	880	10	221	369	41.2	0.279	2.01	51	88	0.05	-80	30	Good	10.7	26	Invention
6	B	905	0.8	60	810	850	10	170	355	39.9	0.233	1.80	45	67	0.10	-45	30	Good	10.9	21	Comp.
7	C	900	1.5	30	750	840	10	210	377	40.5	0.269	1.92	55	68	0.15	-80	30	Good	9.9	21	Invention
8	C	910	1.5	50	750	800	10	246	393	36.4	0.220	1.52	26	52	0.10	-50	45	Good	12.1	48	Comp.
9	C	905	0.8	50	750	910	10	202	362	43.3	0.288	1.73	40	67	0.15	-90	45	Good	10.3	23	Comp.
10	C	920	0.8	50	750	810	10	248	358	42.4	0.289	1.62	9	32	0.15	-40	45	Unplating: medium	13.3	52	Comp.
11	C	915	0.8	50	730	860	1.5	208	362	43.1	0.275	2.09	19	45	0.10	-50	45	Unplating: low	12.5	49	Comp.
12	D	920	0.6	50	760	880	20	247	419	37.2	0.245	1.93	53	73	0.00	<-100	45	Good	10.6	27	Invention
13	E	915	0.8	50	740	860	20	238	399	39.7	0.257	2.09	45	81	0.15	<-100	45	Good	9.7	32	Invention

Table 8 (continued)

No.	Steel	Hot Rolling Conditions: Finish termination temp. (°C)	Hot Rolling Conditions: Time taken up to rapid cooling (sec)	Hot Rolling Conditions: Rapid cooling rate (°C/sec)	Hot Rolling Conditions: Coiling temp. (°C)	Annealing Conditions: Annealing temp. (°C)	Annealing Conditions: Cooling rate (°C/sec)	Mechanical Properties: YP (N/mm²)	Mechanical Properties: TS (N/mm²)	Mechanical Properties: El (%)	Mechanical Properties: n	Mechanical Properties: r	Mechanical Properties: BH (N/mm²)	Mechanical Properties: σ (AA) (N/mm²)	Mechanical Properties: YP-El (%)	Mechanical Properties: Transition temp. (°C)	Plating Properties: Amt. of plating (g/m²)	Plating Properties: Alloying	Plating Properties: Iron content (%)	Plating Properties: P value (%)	Remarks
14	F	910	0.8	50	740	860	10	217	362	43.4	0.275	2.23	59	65	0.20	<-100	45	Good	8.9	35	Invention
15	G	915	0.9	70	690	870	10	214	364	42.8	0.284	2.10	15	52	0.05	-50	45	Good	13.0	45	Comp.
16	H	905	0.9	50	730	860	10	210	370	37.7	0.229	1.68	50	48	0.20	-90	45	Good	11.2	34	Comp.
17	I	910	0.8	50	700	840	10	247	434	36.6	0.245	1.81	19	46	0.05	-90	45	Unplating: high	12.8	58	Comp.
18	J	910	0.7	40	710	860	10	250	417	36.5	0.249	1.67	14	37	0.10	-35	45	Unplating: medium	13.2	53	Comp.
19	K	905	0.8	60	690	840	10	219	368	40.3	0.260	1.88	21	39	0.00	-27	45	Unplating: medium	13.4	55	Comp.
20	L	900	1.0	60	680	860	10	198	334	40.8	0.236	2.19	56	83	0.00	<-100	45	Good	9.8	25	Comp.
21	M	910	0.9	50	740	850	10	195	335	44.5	0.296	1.84	56	83	0.00	<-100	45	Good	11.5	25	Comp.
22	N	920	0.9	60	740	830	10	285	424	33.3	0.197	1.62	57	81	0.40	<-100	45	Good	8.8	31	Comp.
23	O	905	0.9	60	710	820	10	250	381	36.6	0.225	1.85	23	48	0.40	<-100	45	Good	11.5	25	Comp.
24	P	910	0.8	60	730	840	10	220	376	39.9	0.228	1.77	29	48	0.00	-90	45	Unplating: medium	13.0	55	Comp.
25	Q	915	0.6	40	720	870	10	206	355	43.2	0.281	2.15	58	69	0.15	-90	45	Unplating: high	13.7	45	Comp.
26	R	910	0.8	70	740	850	10	242	406	39.3	0.257	1.88	52	68	0.05	-90	45	Unplating: high	14.1	51	Comp.

[Industrial Applicability]

Automobiles are related to an environmental problem, and an attempt to reduce the body weight of automobiles has been made for the purpose of reducing fuel consumption. Panels for automobiles are not an exception to object materials for a reduction in the body weight of automobiles, and since they occupy a large proportion of the weight of an automobile, importance is attached to the reduction in the weight thereof. Further, since the panels attract much attention in connection with the quality of automobiles, the importance of design of panels has increased. This has led to an ever-increasing demand for panels having a complicated shape. Under these circumstances, the present invention is very important because it can provide a cold-rolled steel sheet having a combination of high workability and strength with a good dent resistance which can satisfy the above-described demand. Further, even when such a steel sheet is galvanized, the above-described demand can be satisfied, which renders the effect of the present invention very valuable now that importance has become attached to a high corrosion resistance.

Claims

1. A cold-rolled steel sheet, for an automobile, having excellent moldability and painting-baking hardenability, comprising, in terms of % by mass, 0.0010 to 0.0040 % of C, 0.0030 % or less of N, 0.5 % or less of Si, 0.02 to 1.5 % of Mn, 0.08 % or less of P, 0.01 % or less of S, 0.005 to 0.07 % of acid soluble Al, 0.05 % or less of Nb satisfying a requirement of a {Nb % - 93/12•C %) value of more than zero to 0.025 % and 24/14•N % to 72/14•N % of Ti with the balance consisting of Fe and unavoidable impurities and further having carbon in a solid solution form provided through dissolution of a precipitated carbide by recrystallization annealing and an aggregate structure such that, in X-ray diffraction, the natural logarithm ratio (log(I{222}/I{200})) of the diffraction intensity I {222} of a {222} plane to the diffraction intensity I {200} of a {200} plane is 2.7 or more.

2. A mild cold-rolled steel sheet, for an automobile, having excellent moldability and painting-baking hardenability, comprising, in terms of % by mass, 0.0010 to 0.0040 % of C, 0.0030 % or less of N, less than 0.1 % of Si, 0.02 to less than 0.3 % of Mn, less than 0.03 % of P, 0.01 % or less of S, 0.005 to 0.07 % of acid soluble Al, 0.05 % or less of Nb satisfying a requirement of a {Nb % - 93/12•C %} value of more than zero to 0.025 % and 24/14•N % to 72/14•C % of Ti with the balance consisting of Fe and unavoidable impurities and further having carbon in a solid solution form provided through dissolution of a precipitated carbide by recrystallization annealing and an aggregate structure such that, in X-ray diffraction, the natural logarithm ratio (log(I{222}/I{200})) of the diffraction intensity I {222} of a {222} plane to the diffraction intensity I {200} of a {200} plane is 2.8 or more.

3. The soft cold-rolled steel sheet according to claim 2, which further comprises 0.0001 to 0.0020 % by mass of B.

4. A high-strength cold-rolled steel sheet, for an automobile, having excellent moldability and painting-baking hardenability, comprising, in terms of % by mass, 0.0010 to 0.0040 % of C, 0.0030 % or less of N, 0.1 to 0.5 % of Si, 0.3 to 1.5 % of Mn, 0.03 to 0.08 % of P, 0.01 % or less of S, 0.005 to 0.07 % of acid soluble Al, 0.05 % or less of Nb satisfying a requirement of a {Nb % - 93/12•C %}value of more than zero to 0.025 % and 24/14•N % to 72/14•N % of Ti with the balance consisting of Fe and unavoidable impurities and further having carbon in a solid solution form provided through dissolution of a precipitated carbide by recrystallization annealing and an aggregate structure such that, in X-ray diffraction, the natural logarithm ratio (log(I{222}/I{200})) of the diffraction intensity I {222} of a {222} plane to the diffraction intensity I {200} of a {200} plane is 2.7 or more.

5. The high-strength cold-rolled steel sheet according to claim 4, which further comprises at least one member selected from the group consisting of 0.0001 to 0.0020 % by mass of B and 0.02 to 1.2 % by mass of Cr.

6. The mild cold-rolled steel sheet, for an automobile, according to claim 2, which has at least one surface galvanized at a coverage of 15 g/m^2 or more.

7. The mild cold-rolled steel sheet, for an automobile, according to claim 2, which further comprises 0.0001 to 0.0020 % by mass of B and has at least one surface galvanized at a coverage of 15 g/m^2 or more.

8. The high-strength cold-rolled steel sheet, for an automobile, according to claim 4, which has a value of Mn%/(Si + 10P)% in terms of % by mass of 1.0 or more and at least one surface galvanized at a coverage of 15 g/m^2 or more.

9. The high-strength cold-rolled steel sheet, for an automobile, according to claim 4, which further comprises at least one member selected from the group consisting of 0.0001 to 0.0020 % by mass of B and 0.02 to 1.2 % by mass of Cr and has a value of Mn%/(Si + 10P)% in terms of by mass of 1.0 or more and at least one surface galvanized at a coverage of 15 g/m^2 or more.

10. A process for producing a cold-rolled steel sheet, for an automobile, having excellent moldability and painting-baking hardenability, characterized by comprising hot-rolling a steel composed of, in terms of % by mass, 0.0010 to 0.0040 % of C, 0.0030 % or less of N, 0.5 % or less of Si, 0.02 to 1.5 % of Mn, 0.08 % or less of P, 0.01 % or less of S, 0.005 to 0.07 % of acid soluble Al, 0.05 % or less of Nb satisfying a requirement of a {Nb % - 93/12•C %} value of more than zero to 0.025 % and 24/14•N % to 72/14•N % of Ti with the balance consisting of Fe and unavoidable impurities at a finish termination temperature of an Ar_3 transformation point or above, quenching the hot-rolled steel sheet within 2 sec after the completion of the hot-rolling at a rate of 30 °C/sec or more to attain a temperature fall of 100 °C or above, coiling the cooled steel sheet at a temperature of 650 to 770 °C, subsequently cold-rolling the coiled steel sheet with a reduction ratio of 72 to 92 %, subjecting the cold-rolled steel sheet to annealing in a temperature range of from 820 to 880 °C for 20 sec or more and cooling the annealed steel sheet from that temperature to room temperature at a cooling rate of 3 °C/sec or more.

11. A process for producing a mild cold-rolled steel sheet, for an automobile, having excellent moldability and painting-baking hardenability, characterized by comprising hot-rolling a steel composed of, in terms of % by mass, 0.0010 to 0.0040 % of C, 0.0030 % or less of N, less than 0.1 % of Si, 0.02 to less than 0.3 % of Mn, less than 0.03 % of P, 0.01 % or less of S, 0.005 to 0.07 % of acid soluble Al, 0.05 % or less of Nb satisfying a requirement of a {Nb % - 93/12•C %} value of more than zero to 0.025 % and 24/14•N % to 72/14•N % of Ti with the balance consisting of Fe and unavoidable impurities at a finish termination temperature of an Ar_3 transformation point or above, quenching the hot-rolled steel sheet within 2 sec after the completion of the hot-rolling at a rate of 30 to 300 °C/sec or more to attain a temperature fall of 100 °C or above, coiling the cooled steel sheet at a temperature of 650 to 770 °C, subsequently cold-rolling the coiled steel sheet with a reduction ratio of 72 to 92 %, subjecting the cold-rolled steel sheet to annealing in a temperature range of from 820 to 880 °C for 20 sec or more and cooling the annealed steel sheet from that temperature to room temperature at a cooling rate of 3 °C/sec or more.

12. A process for producing a high-strength cold-rolled steel sheet, for an automobile, having excellent moldability and painting-baking hardenability, characterized by comprising hot-rolling a steel composed of, in terms of % by mass, 0.0010 to 0.0040 % of C, 0.0030 % or less of N, 0.1 to 0.5 % of Si, 0.3 to 1.5 % of Mn, 0.03 to 0.08 % of P, 0.01 % or less of S, 0.005 to 0.07 % of acid soluble Al, 0.05 % or less of Nb satisfying a requirement of a {Nb % - 93/12•C %} value of more than zero to 0.025 % and 24/14•N % to 72/14•N % of Ti with the balance consisting of Fe and unavoidable impurities at a finish termination temperature of an Ar_3 transformation point or above, quenching the hot-rolled steel sheet within 2 sec after the completion of the hot-rolling at a rate of 30 to 300 °C/sec or more to attain a temperature fall of 100 °C or above, coiling the cooled steel sheet at a temperature of 650 to 770 °C, subsequently cold-rolling the coiled steel sheet with a reduction ratio of 72 to 92 %, subjecting the cold-rolled steel sheet to annealing in a temperature range of from 820 to 880 °C for 20 sec or more and cooling the annealed steel sheet from that temperature to room temperature at a cooling rate of 3 °C/sec or more.

13. The process for producing a soft cold-rolled steel sheet, for an automobile, according to claim 11, wherein said sheet further comprises 0.0001 to 0.0020 % by mass of B.

14. The process for producing a high-strength cold-rolled steel sheet, for an automobile, according to claim 12, wherein said steel further comprises at least one member selected from the group consisting of 0.0001 to 0.0020 % by mass of B and 0.02 to 1.2 % by mass of Cr.

15. A process for producing a galvanized high-strength cold-rolled steel sheet, for an automobile, according to claim 11, wherein said cold-rolled steel sheet is transferred to a plating tank where at least one surface of said steel sheet is galvanized at a coverage of 15 g/m^2 or more.

16. A process for producing a galvanized high-strength cold-rolled steel sheet, for an automobile, according to claim 12, wherein said steel sheet has a composition further regulated to have a Mn%/(Si + 10P)% in terms of % by mass of 1.0 or more and is transferred to a plating tank where at least one surface of said steel sheet is galvanized at a coverage of 15 g/m^2 or more.

17. A process for producing a galvanized high-strength cold-rolled steel sheet, for an automobile, according to claim 11, wherein said steel sheet further comprises 0.0001 to 0.0020 % by mass of B and is transferred to a plating tank where at least one surface of said steel sheet is galvanized at a coverage of 15 g/m^2 or more.

18. A process for producing a galvanized high-strength cold-rolled steel sheet, for an automobile, according to claim 12, wherein said steel sheet further comprises at least one member selected from the group consisting of 0.0001 to 0.0020 % by mass of B and 0.02 to 1.2 % by mass of Cr and is further regulated to have a Mn%/(Si + 10P)% in terms of % by mass of 1.0 or more and is transferred to a plating tank where at least one surface of said steel sheet is galvanized at a coverage of 15 g/m^2 or more.

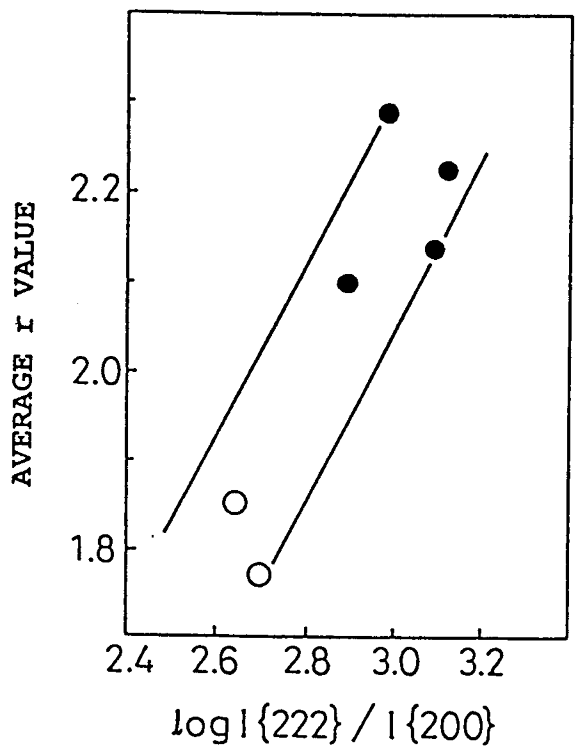
19. A process for producing an alloyed and galvanized mild cold-rolled steel sheet, for an automobile, having excellent moldability and painting-baking hardenability, characterized by comprising hot-rolling a steel composed of, in terms of % by mass, 0.0010 to 0.0040 % of C, 0.0030 % or less of N, less than 0.1 % of Si, 0.02 to less than 0.3 % of Mn, less than 0.03 % of P, 0.01 % or less of S, 0.005 to 0.07 % of acid soluble Al, 0.05 % or less of Nb satisfying a requirement of a {Nb % - 93/12•C %} value of more than zero to 0.025 % and 24/14•N % to 72/14•N % of Ti with the balance consisting of Fe and unavoidable impurities at a finish termination temperature of an Ar_3 transformation point or above, quenching the hot-rolled steel sheet within 2 sec after the completion of the hot-rolling at a rate of 30 to 300 °C/sec or more to attain a temperature fall of 100 °C or above, coiling the cooled steel sheet at a temperature of 650 to 770 °C, subsequently cold-rolling the coiled steel sheet with a reduction ratio of 72 to 92 %, then passing said steel sheet through a hot-dip galvanizing line, subjecting the galvanized steel sheet to annealing in a temperature range of from 830 to 890 °C, cooling the annealed steel sheet from said temperature range to 440 to 460 °C at a cooling rate of 3 °C/sec or more, subjecting said cooled steel sheet to hot-dip galvanizing at said temperature and subjecting said galvanized steel sheet to an alloying treatment in a temperature range of from 550 to 600 °C.

20. A process for producing an alloyed and galvanized high-strength cold-rolled steel sheet, for an automobile, having excellent moldability and painting-baking hardenability, characterized by comprising hot-rolling a steel composed of, in terms of % by mass, 0.0010 to 0.0040 % of C, 0.0030 % or less of N, 0.1 to 0.5 % of Si, 0.3 to 1.5 % of Mn, 0.3 to 0.08 % of P satisfying a requirement of a Mn%/-(Si + 10P)% value of 1.0 or more, 0.01 % or less of S, 0.005 to 0.07 % of acid soluble Al, 0.05 % or less of Nb satisfying a requirement of a {Nb % - 93/12•C %} value of more than zero to 0.025 % and 24/14•N % to 72/14•N % of Ti with the balance consisting of Fe and unavoidable impurities at a finish termination temperature of an Ar_3 transformation point or above, quenching the hot-rolled steel sheet within 2 sec after the completion of the hot-rolling at a rate of 30 to 300 °C/sec or more to attain a temperature fall of 100 °C or above, coiling the cooled steel sheet at a temperature of 650 to 770 °C, subsequently cold-rolling the coiled steel sheet with a reduction ratio of 72 to 92 %, then passing said steel sheet through a hot-dip galvanizing line, subjecting the galvanized steel sheet to annealing in a temperature range of from 830 to 890 °C, cooling the annealed steel sheet from said temperature range to 440 to 460 °C at a cooling rate of 3 °C/sec or more, subjecting said cooled steel sheet to hot-dip galvanizing at said temperature and subjecting said galvanized steel sheet to an allying treatment in a temperature range of from 550 to 600 °C.

21. A process for producing an alloyed and galvanized mild cold-rolled steel sheet according to claim 19, which further comprises 0.0001 to 0.0020 % by mass of B.

22. A process for producing an alloyed and galvanized high-strength cold-rolled steel sheet, for an automobile, according to claim 20, which further comprises at least one member selected from the group consisting of 0.0001 to 0.0020 % by mass of B and 0.02 to 1.2 % by mass of Cr.

Fig. 1


AVERAGE r VALUE
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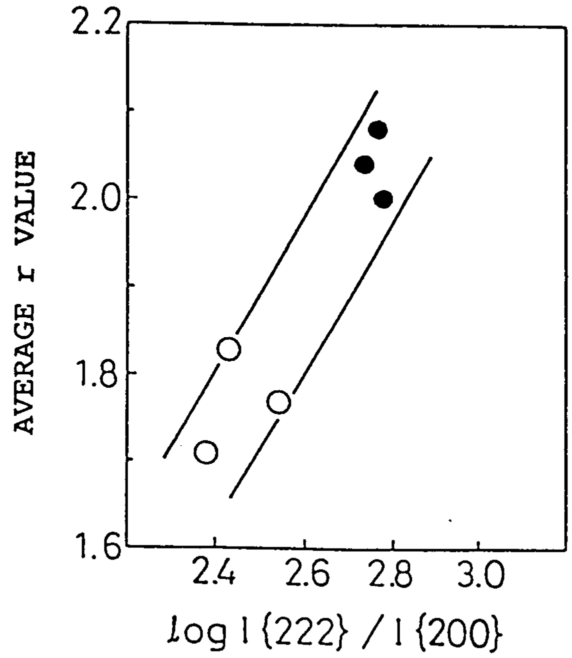
2.0
1.8
2.4
2.6
2.8
3.0
3.2
log I {222} / I {200}

Fig. 2


AVERAGE r VALUE
2.2
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3.0
log I {222} / I {200}

INTERNATIONAL SEARCH REPORT

International Application No PCT/JP92/00181

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

Int. Cl^5 C22C38/14, C21D8/04, C21D9/48, C23C2/06, 2/28, C25D5/26

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
IPC	C22C38/00-38/14, C21D8/04, C21D9/48, C23C2/06, 2/28, C25D5/26

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category *	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
A	JP, B2, 54-3131 (Nippon Steel Corp.), February 19, 1979 (19. 02. 79), Column 1 & US, A, 3897280	1-22
A	JP, A, 56-166331 (Nippon Steel Corp.), December 21, 1981 (21. 12. 81), Lower left column, page 1, lowere right column, page 2 (Family: none)	1-22
A	JP, A, 59-226149 (Nippon Steel Corp.), December 19, 1984 (19. 12. 84), Page 1 (Family: none)	1-22
A	JP, A, 1-123058 (Kawasaki Steel Corp.), May 16, 1989 (16. 05. 89), Pages 1 to 2 (Family: none)	1-22

* Special categories of cited documents: [10]

"A" document defining the general state of the art which is not considered to be of particular relevance

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
May 6, 1992 (06. 05. 92)	May 26, 1992 (26. 05. 92)
International Searching Authority	**Signature of Authorized Officer**
Japanese Patent Office	