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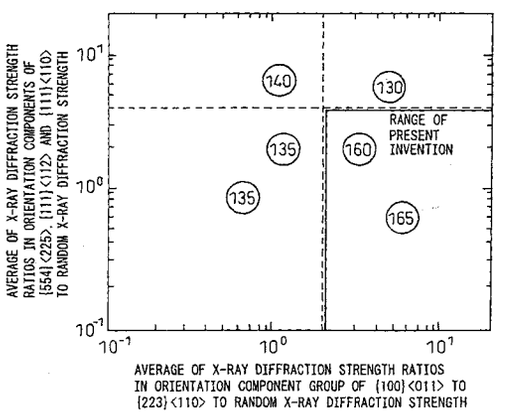
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(54) THIN STEEL SHEET FOR AUTOMOBILE EXCELLENT IN NOTCH FATIGUE STRENGTH AND METHOD FOR PRODUCTION THEREOF

(57) The present invention provides a thin steel sheet, for automobile use, excellent in notch-fatigue strength, and a method for producing said steel sheet. Specifically, the present invention is a thin steel sheet for automobile use excellent in notch-fatigue strength, said steel sheet containing, in mass, 0.01 to 0.3% C, 0.01 to 2% Si, 0.05 to 3% Mn, 0.1% or less P, 0.01% or less S and 0.005 to 1% Al, with the balance consisting of Fe and unavoidable impurities, characterized in that, on a plane at an arbitrary depth within 0.5 mm from the surface of said steel sheet in the thickness direction thereof, the average of the ratios of the X-ray diffraction strength in the orientation component group of {100}<011> to {223}<110> to random X-ray diffraction strength is 2 or more and the average of the ratios of the X-ray diffraction strength in the three orientation components of {554}<225>, {111}<112> and {111}<110> to random X-ray diffraction strength is 4 or less and that the thickness of said steel sheet is in the range from 0.5 to 12 mm, and a method for producing said steel sheet by subjecting a steel slab containing aforementioned chemical components to rolling at a total reduction ratio of 25% or more in a temperature range of the Ar_3 transformation temperature + 100°C or lower.

Fig.2



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Description

Technical Field

[0001] The present invention relates to a thin steel sheet for automobile use excellent in notch-fatigue strength, and a method for producing the steel sheet, and, more specifically, to a thin steel sheet for automobile use excellent in notch-fatigue strength and suitable as the material for undercarriage components of an automobile and the like to overcome the problem of the propagation of a fatigue crack from a site of stress concentration such as a blanked or welded portion, and a method for producing the steel sheet.

Background Art

[0002] The application of light metals such as aluminum alloys and high-strength steel sheets to automobile members has expanded recently for the purposes of reducing automobile weight and thereby reducing the fuel consumption and the like. However, while light metals such as aluminum alloys have an advantage of high specific strength, their application is limited to special uses because they are far more costly than steel. For further reducing the automobile weight, therefore, a wider application of low-cost high-strength steel sheets is required.

[0003] In response to the requirement for such high-strength steel materials, in the field of cold-rolled steel sheets used for a white body and panels which account for about one fourth of the weight of an automobile, a steel sheet having both high strength and deep drawability, a steel sheet having bake-hardenability and the like, have so far been developed and have contributed to the weight reduction of an automobile body. However, the focus of the efforts for reducing the weight of an automobile has shifted lately to structural and undercarriage members which account for roughly 20% of the automobile body weight. As a consequence, the development of a high-strength steel sheet applicable to those members has come to be required as a matter of urgency.

[0004] However, as the strengthening of a steel material usually leads to the deterioration of formability (workability) and so on, a key issue in the development of a high-strength steel sheet for those applications is how to realize a high strength without sacrificing those material properties. The important properties required especially of a steel sheet for the structural and undercarriage members of an automobile include shearing and blanking workability, burring workability, fatigue resistance, corrosion resistance and so forth, not to mention elongation; it is essential to balance a high strength with these properties at high levels.

[0005] For instance, an undercarriage component such as a suspension arm is produced through the processes of blanking and boring by shearing and punching, thereafter press forming and, in some cases, welding. It is often the case with such a component that a crack propagates from a point near a sheared end face or a weld and causes fatigue fracture. In other words, a sheared end face or a weld acts as a stress concentration site like a notch and a fatigue crack propagates therefrom.

[0006] Meanwhile, in general, the fatigue limit of a material is lowered as a notch becomes acute. When the acuteness of a notch surpasses a certain extent, however, a fatigue limit does not lower any further. This is because a fatigue limit shifts from being dominated by a crack initiation limit toward being dominated by a crack propagation limit as the acuteness of a notch increases. When the strength of a material increases, while a crack initiation limit increases, a crack propagation limit does not, and therefore the acuteness of a notch, at which a fatigue limit shifts from being dominated by a crack initiation limit toward being dominated by a crack propagation limit, moves toward an acuter side. As a result, when a material has an acute notch, even if the strength of the material is increased, the decrease in the fatigue limit resulting from the acuteness of the notch becomes significant and thus the advantages of the high strength are not secured. In other words, when the strength of a material is increased, the sensitivity thereof to a notch increases.

[0007] Thin steel sheets having strength of the 340 to 440 MPa class are presently used for the undercarriage members of an automobile. However, the level of strength required of the steel sheets for those members is rising toward the 590 to 780 MPa class. Therefore, to satisfactorily respond to such a requirement, it is essential to develop a steel sheet with which the advantages of high strength can be secured even when an acute notch exists.

[0008] There are basically two methods for enhancing the fatigue strength of a steel sheet having an end face formed by blanking or shearing: one is to remove an acute notch such as a burr formed at a blanking or shearing end face, and the other is to enhance the resistance to the propagation of a crack even when such an acute notch exists.

[0009] There are the following methods as examples of inventions based on the former method. Japanese Unexamined Patent Publication No. H5-51695 discloses a technology wherein the occurrence of a burr is suppressed by reducing the addition amount of Si and forming precipitates of Ti, Nb and V for lowering breaking elongation and thereby the fatigue strength of an as-blanked or as-sheared steel sheet is enhanced. Japanese Unexamined Patent Publication No. H5-179346 discloses a technology wherein the upper limit of the volume percentage of bainite is regulated by defining an upper limit of a finish rolling temperature and, thereby, the fatigue strength of an as-blanked or as-sheared steel sheet is enhanced. Japanese Unexamined Patent Publication No. H8-13033 discloses a technology wherein the

formation of martensite is suppressed by defining a cooling rate after rolling and, thereby, the fatigue strength of an as-blanked or as-sheared steel sheet is enhanced.

[0010] Further, Japanese Unexamined Patent Publication No. H8-302446 discloses a technology wherein strain energy during blanking or shearing is reduced by regulating the hardness of the second phase of a dual phase steel to at least 1.3 times that of ferrite and, thereby, the fatigue strength of an as-blanked or as-sheared steel sheet is enhanced. Japanese Unexamined Patent Publication No. H9-170048 discloses a technology wherein the occurrence of a burr during blanking or shearing is suppressed by regulating the length of intergranular cementite and thereby the fatigue strength of an as-blanked or as-sheared steel sheet is enhanced. Furthermore, Japanese Unexamined Patent Publication No. H9-202940 discloses a technology wherein blanking performance is improved by regulating a parameter based on the addition amounts of Ti, Nb and Cr and thereby the fatigue strength of an as-blanked steel sheet is enhanced.

[0011] Meanwhile, there are the following methods as the examples of the inventions based on the latter method. Japanese Unexamined Patent Publication No. H6-88161 discloses a technology wherein the X-ray diffraction strength ratio of a (100) plane parallel to the rolling surfaces in the texture at a steel sheet surface layer is regulated to 1.5 or more and, thereby, a fatigue crack propagation speed is lowered. Further, Japanese Unexamined Patent Publications No. H8-199286 and No. H10-147846 disclose technologies wherein the area percentage of recovered or recrystallized ferrite is controlled in the range from 15 to 40% by regulating the X-ray diffraction strength ratio of a (200) plane in the thickness direction in the range from 2.0 to 15.0 and, thereby, a fatigue crack propagation speed is lowered.

[0012] However, in the cases of the technologies of suppressing an acute notch such as a burr generated at a blanked or sheared end face as disclosed in the above Japanese Unexamined Patent Publications No. H5-51695, No. H5-179346, No. H8-13033, No. H8-302446, No. H9-170048, No. H9-202940 and so forth, as the degree of a generated burr largely varies with the clearance of tools at blanking or shearing, the technologies are not ones that can be employed under any conditions. Therefore, it must be said that the technologies are insufficient when be applied to a steel sheet excellent in notch-fatigue strength.

[0013] On the other hand, technologies of enhancing the resistance to crack propagation by controlling the texture of a steel sheet as disclosed in the above Japanese Unexamined Patent Publications No. H6-88161, No. H8-199286 and No. H10-147846 are the inventions mainly intended for steels used for large structures such as construction machines, ships and bridges and are not intended for a thin steel sheet, used for automobiles, for which the present invention is intended.

[0014] In addition, the aforementioned technologies are ones wherein a fatigue crack propagation speed is controlled in a PARIS zone that is referred to in the fracture mechanics of a fatigue crack mainly propagating from a weld toe portion and therefore are insufficient as technologies to be employed in such a case as a thin steel sheet, for automobile use, where a crack propagation zone is not included in the PARIS zone because of the thickness of the steel sheet.

[0015] Besides the above, no invention has been proposed up to now wherein notch-fatigue properties are evaluated using a test piece, as shown in Fig. 1(b), in a plane bending fatigue test method applied to a thin steel sheet.

Disclosure of the Invention

[0016] In view of the above situation, the present invention relates to a technology wherein the notch-fatigue strength of a thin steel sheet for automobile use is improved by controlling the texture of the steel sheet and thus enhancing the resistance to a fatigue crack propagating from a notch such as an end face formed after blanking or shearing, regardless of the conditions such as the clearance of tools during blanking or shearing. In other words, the object of the present invention is to provide a thin steel sheet for automobile use excellent in notch-fatigue strength and a method for producing the steel sheet economically and stably.

[0017] The present inventors, in consideration of the production processes of thin steel sheets presently produced on an industrial scale using generally employed production facilities, earnestly studied methods for enhancing the notch-fatigue strength of a thin steel sheet for automobile use. As a result, the present invention has been established on the basis of a new discovery that the following conditions are very effective for enhancing notch-fatigue strength: that, on a plane at an arbitrary depth within 0.5 mm from the surface of a steel sheet in the thickness direction thereof, the average of the ratios of the X-ray diffraction strength in the orientation component group of {100}<011> to {223}<110> to random X-ray diffraction strength is 2 or more and the average of the ratios of the X-ray diffraction strength in the three orientation components of {554}<225>, {111}<112> and <111}<110> to random X-ray diffraction strength is 4 or less; and that the thickness of the steel sheet is in the range from 0.5 to 12 mm.

[0018] The gist of the present invention, therefore, is as follows:

(1) A thin steel sheet for automobile use excellent in notch-fatigue strength, characterized in: that, on a plane at an arbitrary depth within 0.5 mm from the surface of the steel sheet in the thickness direction thereof, the average of the ratios of the X-ray diffraction strength in the orientation component group of {100}<011> to {223}<110> to

random X-ray diffraction strength is 2 or more and the average of the ratios of the X-ray diffraction strength in the three orientation components of {554}<225>, {111}<112> and {111}<110> to random X-ray diffraction strength is 4 or less; and that the thickness of the steel sheet is in the range from 0.5 to 12 mm.

(2) A thin steel sheet for automobile use excellent in notch-fatigue strength according to the item (1), characterized in that the microstructure of the steel sheet is a compound structure containing bainite or ferrite and bainite as the phase accounting for the largest volume percentage.

(3) A thin steel sheet for automobile use excellent in notch-fatigue strength according to the item (1), characterized in that the microstructure of the steel sheet is a compound structure containing retained austenite by 5 to 25% in terms of volume percentage and having the balance mainly consisting of ferrite and bainite.

(4) A thin steel sheet for automobile use excellent in notch-fatigue strength according to the item (1), characterized in that the microstructure of the steel sheet is a compound structure containing ferrite as the phase accounting for the largest volume percentage and martensite as the second phase.

(5) A thin steel sheet for automobile use excellent in notch-fatigue strength, the steel sheet containing, in mass, 0.01 to 0.3% C, 0.01 to 2% Si, 0.05 to 3% Mn, 0.1% or less P, 0.01% or less S and 0.005 to 1% Al, with the balance consisting of Fe and unavoidable impurities, characterized in: that, on a plane at an arbitrary depth within 0.5 mm from the surface of the steel sheet in the thickness direction thereof, the average of the ratios of the X-ray diffraction strength in the orientation component group of {100}<011> to {223}<110> to random X-ray diffraction strength is 2 or more and the average of the ratios of the X-ray diffraction strength in the three orientation components of {554}<225>, {111} <112> and {111}<110> to random X-ray diffraction strength is 4 or less; and that the thickness of the steel sheet is in the range from 0.5 to 12 mm.

(6) A thin steel sheet for automobile use excellent in notch-fatigue strength according to the item (5), characterized by further containing, in mass, one or more of 0.2 to 2% Cu, 0.0002 to 0.002% B, 0.1 to 1% Ni, 0.0005 to 0.002% Ca, 0.0005 to 0.02% REM, 0.05 to 0.5% Ti, 0.01 to 0.5% Nb, 0.05 to 1% Mo, 0.02 to 0.2% V, 0.01 to 1% Cr and 0.02 to 0.2% Zr.

(7) A thin steel sheet for automobile use excellent in notch-fatigue strength according to the item (5) or (6), characterized in that the microstructure of the steel sheet is any one of 1) a compound structure containing bainite or ferrite and bainite as the phase accounting for the largest volume percentage, 2) a compound structure containing retained austenite by 5 to 25% in terms of volume percentage and having the balance mainly consisting of ferrite and bainite, and 3) a compound structure containing ferrite as the phase accounting for the largest volume percentage and martensite as the second phase.

(8) A thin steel sheet for automobile use excellent in notch-fatigue strength, characterized in that the steel sheet is produced by applying galvanizing to a thin steel sheet for automobile use according to any one of the items (1) to (7).

(9) A method for producing a thin steel sheet for automobile use excellent in notch-fatigue strength characterized in: that a steel slab containing, in mass, 0.01 to 0.3% C, 0.01 to 2% Si, 0.05 to 3% Mn, 0.1% or less P, 0.01% or less S and 0.005 to 1% Al, with the balance consisting of Fe and unavoidable impurities, is subjected, in a hot rolling process, to rough rolling and then to finish rolling at a total reduction ratio of 25% or more in terms of steel sheet thickness in the temperature range of the Ar_3 transformation temperature + 100°C or lower; that, on a plane at an arbitrary depth within 0.5 mm from the surface of the steel sheet in the thickness direction thereof, the average of the ratios of the X-ray diffraction strength in the orientation component group of {100}<011> to {223}<110> to random X-ray diffraction strength is 2 or more and the average of the ratios of the X-ray diffraction strength in the three orientation components of {554}<225>, {111}<112> and {111}<110> to random X-ray diffraction strength is 4 or less; and that the thickness of the steel sheet is in the range from 0.5 to 12 mm.

(10) A method for producing a thin steel sheet for automobile use excellent in notch-fatigue strength according to the item (9), characterized by: cooling the steel sheet at a cooling rate of 20°C/sec. or higher after the finish rolling; and then coiling it at a coiling temperature of 450°C or higher.

(11) A method for producing a thin steel sheet for automobile use excellent in notch-fatigue strength according to the item (9), characterized by: retaining the steel sheet for 1 to 20 sec. in the temperature range from the Ar_1

transformation temperature to the Ar_3 transformation temperature after the finish rolling; then cooling it at a cooling rate of 20°C/sec. or higher; and coiling it at a coiling temperature in the range from higher than 350°C to lower than 450°C.

(12) A method for producing a thin steel sheet for automobile use excellent in notch-fatigue strength according to the item (11), characterized by coiling the steel sheet at a coiling temperature of 350°C or lower after the cooling.

(13) A method for producing a thin steel sheet for automobile use excellent in notch-fatigue strength according to any one of the items (9) to (12), characterized by applying lubrication rolling to the steel sheet in the hot rolling.

(14) A method for producing a thin steel sheet for automobile use excellent in notch-fatigue strength according to any one of the items (9) to (13), characterized by applying descaling to the steel sheet after the completion of the rough rolling in the hot rolling.

(15) A method for producing a thin steel sheet for automobile use excellent in notch-fatigue strength, characterized in: that a steel slab containing, in mass, 0.01 to 0.3% C, 0.01 to 2% Si, 0.05 to 3% Mn, 0.1% or less P, 0.01% or less S and 0.005 to 1% Al, with the balance consisting of Fe and unavoidable impurities, is subjected to rough rolling, then finish rolling at a total reduction ratio of 25% or more in terms of steel sheet thickness in the temperature range of the Ar_3 transformation temperature + 100°C or lower, pickling, cold rolling at a reduction ratio of less than 80% in terms of steel sheet thickness, and then annealing for recovery or recrystallization comprising the processes of retaining the cold-rolled steel sheet for 5 to 150 sec. in the temperature range from the recovering temperature to the Ac_3 transformation temperature + 100°C and then cooling it; that, on a plane at an arbitrary depth within 0.5 mm from the surface of the steel sheet in the thickness direction thereof, the average of the ratios of the X-ray diffraction strength in the orientation component group of {100}<011> to {223}<110> to random X-ray diffraction strength is 2 or more and the average of the ratios of the X-ray diffraction strength in the three orientation components of {554}<225>, {111}<112> and {111}<110> to random X-ray diffraction strength is 4 or less; and that the thickness of the steel sheet is in the range from 0.5 to 12 mm.

(16) A method for producing a thin steel sheet for automobile use excellent in notch-fatigue strength according to the item (15), characterized by subjecting the steel sheet after the cold rolling to a heat treatment comprising the processes of retaining the cold-rolled steel sheet for 5 to 150 sec. in the temperature range from the Ac_1 transformation temperature to the Ac_3 transformation temperature + 100°C and then cooling it.

(17) A method for producing a thin steel sheet for automobile use excellent in notch-fatigue strength according to the item (15), characterized by subjecting the steel sheet to a heat treatment comprising the processes of, in sequence, retaining the cold-rolled steel sheet for 5 to 150 sec. in said temperature range, cooling it at a cooling rate of 20°C/sec. or higher to the temperature range from higher than 350°C to lower than 450°C, retaining it for 5 to 600 sec. in said temperature range, and then cooling it at a cooling rate of 5°C/sec. or higher to the temperature range of 200°C or lower.

(18) A method for producing a thin steel sheet for automobile use excellent in notch-fatigue strength according to the item (15), characterized by subjecting the steel sheet to a heat treatment comprising the processes of retaining the cold-rolled steel sheet for 5 to 150 sec. in said temperature range and then cooling it at a cooling rate of 20°C/sec. or higher to the temperature range of 350°C or lower.

(19) A method for producing a thin steel sheet for automobile use excellent in notch-fatigue strength, characterized in that the steel sheet produced by the method according to any one of the items (11) to (18) further contains, in mass, one or more of 0.2 to 2% Cu, 0.0002 to 0.002% B, 0.1 to 1% Ni, 0.0005 to 0.002% Ca, 0.0005 to 0.02% REM, 0.05 to 0.5% Ti, 0.01 to 0.5% Nb, 0.05 to 1% Mo, 0.02 to 0.2% V, 0.01 to 1% Cr and 0.02 to 0.2% Zr.

(20) A method for producing a thin steel sheet for automobile use excellent in notch-fatigue strength according to the item (10) or (16), characterized in that the microstructure of the steel sheet is a compound structure containing bainite or ferrite and bainite as the phase accounting for the largest volume percentage.

(21) A method for producing a thin steel sheet for automobile use excellent in notch-fatigue strength according to the item (11) or (17), characterized in that the microstructure of the steel sheet is a compound structure containing retained austenite at 5 to 25% in terms of volume percentage and having the balance mainly consisting of ferrite and bainite.

(22) A method for producing a thin steel sheet for automobile use excellent in notch-fatigue strength according to the item (12) or (18), characterized in that the microstructure of the steel sheet is a compound structure containing ferrite as the phase accounting for the largest volume percentage and martensite as the second phase.

(23) A method for producing a thin steel sheet for automobile use excellent in notch-fatigue strength characterized by, after producing a hot-rolled steel sheet or a steel sheet annealed for recovery or recrystallization according to any one of the items (9) to (22), further applying galvanizing to the surfaces of the steel sheet by dipping the steel sheet in a zinc plating both.

(24) A method for producing a thin steel sheet for automobile use excellent in notch-fatigue strength according to the item (23), characterized by subjecting the steel sheet further to an alloying treatment after the galvanizing.

Brief Description of the Drawings

[0019]

Fig. 1 consists of illustrations showing the shapes of test pieces for fatigue test: Fig. 1(a) shows an unnotched test piece for fatigue test, and Fig. 1(b) a notched test piece for fatigue test.
Fig. 2 is a graph showing the result of a preliminary test that leads to the present invention in terms of the relationship among: the average of the ratios of the X-ray diffraction strength in the orientation component group of {100}<011> to {223}<110> to random X-ray diffraction strength; the average of the ratios of the X-ray diffraction strength in the three orientation components of {554}<225>, {111}<112> and {111}<110> to random X-ray diffraction strength; and notch-fatigue strength (the fatigue strength for finite life after 10^7 cycles of repetition, namely the fatigue limit).

Best Mode for Carrying out the Invention

[0020] In the first place, the results of preliminary studies that lead to the present invention are explained hereafter.

[0021] Generally speaking, a fatigue crack of a steel sheet starts from the surface thereof; this is true also with the case where a stress concentration site such as a notch exists. In the case where an end face formed by blanking or shearing exists, it is often observed that, under a repeated load including a loading mode in the out-of-plane bending direction, a fatigue crack starts and propagates from an end of a steel sheet surface. It is clear from this that, even in such a case, it is effective for enhancing notch-fatigue strength to increase resistance to crack propagation at the surface of a steel sheet or in the layer from the surface to a depth of several crystal grains or so. On the other hand, even though resistance to crack propagation is increased at the thickness center of a steel sheet, it is difficult to arrest an already formed crack. For this reason, in the present invention, the range of a steel sheet texture effective in enhancing fatigue strength is limited to the range from the surface to a depth of 0.5 mm in the thickness direction. The range is, more adequately, to a depth of 0.1 mm.

[0022] The present inventors investigated the influences of the average of the ratios of the X-ray diffraction strength in the orientation component group of {100}<011> to {223}<110> to random X-ray diffraction strength and the average of the ratios of the X-ray diffraction strength in the three orientation components of {554}<225>, {111}<112> and {111}<110> to random X-ray diffraction strength on a plane at an arbitrary depth in the range from the surface of a steel sheet to a depth of 0.5 mm in the thickness direction thereof over notch-fatigue strength. The specimens for the investigation were prepared by melting a steel and adjusting the chemical components thereof so that the steel contained 0.08% C, 0.9% Si, 1.2% Mn, 0.01% P, 0.001% S, and 0.03% Al, casting it into a slab, hot rolling the slab to a thickness of 3.5 mm so that the finish rolling was completed at a temperature of not lower than the Ar_3 transformation temperature, and then coiling the hot-rolled steel sheet.

[0023] For the purpose of measuring the average of the ratios of the X-ray diffraction strength in the orientation component group of {100}<011> to {223}<110> to random X-ray diffraction strength and the average of the ratios of the X-ray diffraction strength in the three orientation components of {554}<225>, {111}<112> and {111}<110> to random X-ray diffraction strength on a plane at an arbitrary depth within 0.5 mm from the surface of a steel sheet obtained as above in the thickness direction thereof, a test piece was prepared by cutting out a specimen sheet 30 mm in diameter from a position of 1/4 or 3/4 of the width of a steel sheet, grinding the surface of the specimen sheet to a depth of about 0.05 mm from the surface so that the surface might have the second finest finish, and then removing strain by chemical polishing or electrolytic polishing.

[0024] Note that a crystal orientation component expressed as {hkl}<uvw> means that the direction of a normal to the plane of a steel sheet is parallel to <hkl> and the rolling direction of the steel sheet is parallel to <uvw>. The measurement of a crystal orientation with X-rays is conducted, for example, in accordance with the method described in pages 274 to 296 of the Japanese translation of Elements of X-ray Diffraction by B. D. Cullity (published in 1986 by

AGNE Gijutsu Center, translated by Gentaro Matsumura).

[0025] Here, the average of the ratios of the X-ray diffraction strength in the orientation component group of {100}<011> to {223}<110> to random X-ray diffraction strength is obtained from the X-ray diffraction strengths in the principal orientation components included in said orientation component group, namely {100}<011>, {116}<110>, {114}<110>, {113}<110>, {112}<110>, {335}<110> and {223}<110>, in the three-dimensional texture calculated either by the vector method based on the pole figure of {110} or by the series expansion method using two or more (desirably, three or more) pole figures out of the pole figures of {110}, {100}, {211} and {310}.

[0026] For example, in the case of obtaining the ratios of the X-ray diffraction strength in the above crystal orientation components to random X-ray diffraction strength by the latter method, the strengths of (001)[1-10], (116) [1-10), (114) [1-10], (113)[1-10], (112)[1-10], (335)[1-10] and (223) [1-10] at a $\phi 2 = 45^\circ$ cross section in a three-dimensional texture may be used without modification. Note that the average of the ratios of the X-ray diffraction strength in the orientation component group of {100}<011> to {223}<110> to random X-ray diffraction strength is the arithmetic average of the ratios in all the above orientation components.

[0027] When it is impossible to obtain the strengths in all these orientation components, the arithmetic average of the strengths in the orientation components of {100}<011>, {116}<110>, {114}<110>, {112}<110> and {223}<110> may be used as a substitute.

[0028] Likewise, the average of the ratios of the X-ray diffraction strength in the three orientation components of {554}<225>, {111}<112> and {111}<110> to random X-ray diffraction strength can be obtained from the three-dimensional texture calculated in the same manner as explained above.

[0029] Next, for the purpose of investigating the notch-fatigue strength of the above steel sheet, a test piece for fatigue test having the shape shown in Fig. 1(b) was cut out from a position of 1/4 or 3/4 of the width of the steel sheet so that the longitudinal direction of the test piece coincided with the rolling direction of the steel sheet, and was subjected to a fatigue test. It has to be noted here that, whereas a test piece for fatigue test shown in Fig. 1(a) is a common unnotched test piece for evaluating the fatigue strength of a steel material, a test piece for fatigue test shown in Fig. 1(b) is a notched test piece prepared for evaluating notch-fatigue strength. A test piece for fatigue test was ground to a depth of about 0.05 mm from the surface so that the surface might have the second finest finish, and a fatigue test was carried out using an electro-hydraulic servo type fatigue tester and the methods conforming to JIS Z 2273-1978 and JIS Z 2275-1978.

[0030] Fig. 2 shows the results of an investigation of the influences of the average of the ratios of the X-ray diffraction strength in the orientation component group of {100}<011> to {223}<110> to random X-ray diffraction strength and the average of the ratios of the X-ray diffraction strength in the three orientation components of {554}<225>, {111}<112> and {111}<110> to random X-ray diffraction strength over notch-fatigue strength. The numeral in a circle in the figure indicates the fatigue limit (the fatigue strength for finite life after 10^7 cycles of repetition) obtained through a fatigue test using a notched test piece having the shape shown in Fig. 1(b); the numeral is hereinafter referred to as a notch-fatigue strength.

[0031] It has been clarified that there is a strong correlation among: the average of the ratios of the X-ray diffraction strength in the orientation component group of {100}<011> to {223}<110> to random X-ray diffraction strength; the average of the ratios of the X-ray diffraction strength in the three orientation components of {554}<225>, {111}<112> and {111}<110> to random X-ray diffraction strength; and notch-fatigue strength, and that notch-fatigue strength is remarkably enhanced when the above average figures are 2 or more and 4 or less, respectively.

[0032] As a result of closely examining the results of those tests, the present inventors have newly found that it is very important, for enhancing notch-fatigue strength, that, on a plane at an arbitrary depth within 0.5 mm from the surface of a steel sheet in the thickness direction thereof, the average of the ratios of the X-ray diffraction strength in the orientation component group of {100}<011> to {223}<110> to random X-ray diffraction strength is 2 or more and the average of the ratios of the X-ray diffraction strength in the three orientation components of {554}<225>, {111}<112> and {111}<110> to random X-ray diffraction strength is 4 or less.

[0033] Further, for enhancing the resistance to the occurrence of a fatigue crack not only in a notched test piece but also in an unnotched test piece, it is desirable that, on a plane at an arbitrary depth within 0.5 mm from the surface of a steel sheet in the thickness direction thereof, the average of the ratios of the X-ray diffraction strength in the orientation component group of {100}<011> to {223}<110> to random X-ray diffraction strength is 4 or more and the average of the ratios of the X-ray diffraction strength in the three orientation components of {554}<225>, {111}<112> and {111}<110> to random X-ray diffraction strength is 2.5 or less.

[0034] The reason for the above is not altogether clear, but it is presumed to be as follows.

[0035] Generally speaking, in the case where an acute notch exists, the fatigue limit of a material is determined by the crack propagation limit of the material, namely the degree of the resistance to the propagation of a crack for arresting the crack. The propagation of a fatigue crack is caused by the repetition of small plastic deformation at the bottom of a notch or a stress concentration site, and it is presumed that, when a crack length is comparatively small and plastic deformation occurs within a range comparable to the size of a crystal grain, the crack propagation is significantly

influenced by crystallographic slip planes and slip directions. Therefore, if the proportion of the crystal grains having slip planes and slip directions that show a high resistance to crack propagation is large in the crack propagation direction and on the plane of a crack, then the propagation of the fatigue crack is suppressed.

[0036] Next, the reasons for limiting the thickness of a steel sheet in the present invention are explained.

[0037] When the thickness of a steel sheet is less than 0.5 mm, the conditions of allowing the occurrence of a small-scale yield are not satisfied regardless of the extent of stress concentration and therefore there is a danger that monotonic ductile fracture is caused. In addition, as the sufficient constraint of plastic deformation is required from the viewpoint of arresting a crack, it is desirable that the thickness of a steel sheet is 1.2 mm or more for maintaining the state of plane strain.

[0038] When the thickness of a steel sheet exceeds 12 mm, on the other hand, the deterioration of fatigue strength resulting from thickness effect (size effect) becomes significant. Further, when the thickness of a steel sheet exceeds 8 mm, an excessive load may be required to be imposed on production facilities for achieving the conditions of hot or cold rolling that allow a texture effective for enhancing notch-fatigue strength to be obtained. For that reason, a desirable thickness is 8 mm or less. As a conclusion, the thickness of a steel sheet is limited to 0.5 to 12 mm, or desirably 1.2 to 8 mm, in the present invention.

[0039] The microstructure of a steel sheet according to the present invention is explained hereafter.

[0040] In the present invention, it is not necessary to specify the microstructure of a steel sheet for the purpose of enhancing the notch-fatigue strength of the steel sheet. The effect of enhancing notch-fatigue strength in the present invention is obtained as far as a texture falls in the range specified in the present invention (a texture showing the ratios of the X-ray diffraction strength in specific orientation components to random X-ray diffraction strength falling in the ranges specified in the present invention) in the structures of ferrite, bainite, pearlite and martensite forming in a commonly used steel material. Therefore, it is desirable to regulate the microstructure of a steel sheet in consideration of other required material properties. It has to be noted, however, that the above effect is further enhanced when a microstructure is a specific microstructure, for example, a compound structure containing retained austenite by 5 to 25% in terms of volume percentage and having the balance mainly consisting of ferrite and bainite, a compound structure containing ferrite as the phase accounting for the largest volume percentage and mainly martensite as the second phase, or the like.

[0041] Note that the ferrite mentioned here includes bainitic ferrite and acicular ferrite. Note also that, when a structure which is not a bcc crystal structure, such as retained austenite, is included in a compound structure composed of two or more phases, such a compound structure does not pose any problem insofar as the ratios of the X-ray diffraction strength in the orientation components and orientation component groups to random X-ray diffraction strength converted by the volume percentage of the other structures are within the relevant ranges according to the present invention. Besides, as pearlite containing coarse carbides may act as a starting point of a fatigue crack and remarkably deteriorate fatigue strength, it is desirable that the volume percentage of the pearlite containing coarse carbides is 15% or less. When still better fatigue properties are required, it is desirable that the volume percentage of the pearlite containing coarse carbides is 5% or less.

[0042] Here, the volume percentage of ferrite, bainite, pearlite, martensite or retained austenite is defined as the area percentage thereof in a microstructure observed with an optical microscope under a magnification of 200 to 500 at a position in the depth of 1/4 of the steel sheet thickness on a section surface along the rolling direction of a specimen which is cut out from a position of 1/4 or 3/4 of the width of the steel sheet, the section surface being polished and etched with a nitral reagent and/or the reagent disclosed in Japanese Unexamined Patent Publication No. H5-163590. As it is sometimes difficult to identify retained austenite by the etching with the above reagents, the volume percentage may also be calculated in the following manner.

[0043] Because the crystal structure of austenite is different from that of ferrite, they can be easily distinguished from each other crystallographically. Therefore, the volume percentage of retained austenite can be obtained experimentally by the X-ray diffraction method too, namely by the simplified method wherein the volume percentage thereof is calculated with the following equation on the basis of the difference between austenite and ferrite in the reflection intensity of the Kα ray of Mo on their lattice planes:

$$V\gamma = (2/3)\{100/(0.7 \times \alpha(211)/\gamma(220) + 1)\} +$$

$$(1/3)\{100/(0.78 \times \alpha(211)/\gamma(311) + 1)\},$$

where, $\alpha(211)$, $\gamma(220)$ and $\gamma(311)$ are the X-ray reflection intensities of the indicated lattice planes of ferrite (α) and austenite (γ), respectively.

[0044] For the purpose of obtaining a good burring workability in addition to enhancing notch-fatigue strength in the present invention, it is necessary that the microstructure of a steel sheet is a compound structure containing bainite

or ferrite and bainite as the phase accounting for the largest volume percentage. Here, in this case, the present invention allows the compound structure to contain unavoidably included martensite, retained austenite and pearlite. For the purpose of obtaining a good burring workability (a hole expansion ratio), it is desirable that the total volume percentage of hard retained austenite and martensite is less than 5%. It is also desirable that the volume percentage of bainite is 30% or more. Further, for realizing a good ductility, it is desirable that the volume percentage of bainite is 70% or less.

[0045] Further, for the purpose of obtaining a good ductility in addition to enhancing notch-fatigue strength in the present invention, it is necessary that the microstructure of a steel sheet is a compound structure containing retained austenite by 5 to 25% in terms of volume percentage and having the balance mainly consisting of ferrite and bainite. Here, in this case, the present invention allows the compound structure to contain unavoidably included martensite and pearlite as far as their total volume percentage is less than 5%.

[0046] Furthermore, for the purpose of obtaining a low yield ratio for realizing a good shape-fixation property in addition to enhancing notch-fatigue strength in the present invention, it is necessary that the microstructure of a steel sheet is a compound structure containing ferrite as the phase accounting for the largest volume percentage and mainly martensite as the second phase. Here, in this case, the present invention allows the compound structure to contain unavoidably included bainite, retained austenite and pearlite as far as their total volume percentage is less than 5%. Note that, for securing a low yield ratio of 70% or less, it is desirable that the volume percentage of ferrite is 50% or more.

[0047] Next, the reasons for limiting the chemical components in the present invention are explained.

[0048] C is an indispensable element for obtaining a desired microstructure. When a C content exceeds 0.3%, however, workability deteriorates and, for this reason, a C content is limited to 0.3% or less. Additionally, when a C content exceeds 0.2%, weldability tends to deteriorate and, for this reason, it is desirable that a C content is 0.2% or less. On the other hand, when a C content is less than 0.01%, steel strength decreases and, therefore, a C content is limited to 0.01% or more. Further, for the purpose of obtaining retained austenite stably in an amount sufficient for realizing a good ductility, it is desirable that a C content is 0.05% or more.

[0049] Si is a solute-strengthening element and, as such, it is effective for enhancing strength. An Si content has to be 0.01% or more for obtaining a desired strength, but, when an Si content exceeds 2%, workability deteriorates. Therefore, an Si content is limited in the range from 0.01 to 2%.

[0050] Mn is also a solute-strengthening element and, as such, it is effective for enhancing strength. An Mn content has to be 0.05% or more for obtaining a desired strength. In the case where elements such as Ti, which suppress hot cracking induced by S, are not added in a sufficient amount in addition to Mn, it is desirable to add Mn so that the expression $Mn/S \geqq 20$ is satisfied in terms of mass percentage. Further, Mn is an element that stabilizes austenite and, therefore, in order to stably obtain a sufficient amount of retained austenite in an attempt to secure a good ductility, it is desirable that an Mn addition amount is 0.1% or more. When Mn is added in excess of 3%, on the other hand, cracks occur to a slab. For this reason, an Mn content is limited to 3% or less.

[0051] P is an undesirable impurity, and the lower the P content, the better. When a P content exceeds 0.1%, workability and weldability are adversely affected, and so are fatigue properties. Therefore, a P content is limited to 0.1% or less.

[0052] S is also an undesirable impurity, and the lower the S content, the better. When an S content is too high, the A type inclusions detrimental to local ductility and burring workability are formed and, for this reason, an S content has to be minimized. A permissible content of S is 0.01% or less.

[0053] Al must be added by 0.005% or more for deoxidizing molten steel, but its upper limit is set at 1.0% to avoid a cost increase. Al increases the formation of non-metallic inclusions and deteriorates elongation when added excessively and, for this reason, a desirable content of Al is 0.5% or less.

[0054] Cu is added as occasion demands, since Cu has an effect of improving fatigue properties when it is in the state of solid solution. No tangible effect is obtained when a Cu addition amount is less than 0.2%, but the effect is saturated when a Cu content exceeds 2%. Thus, the range of a Cu content is determined to be from 0.2 to 2%. It has to be noted that, when a coiling temperature is 450°C or higher and Cu is added in excess of 1.2%, Cu may precipitate after coiling, drastically deteriorating workability. For this reason, it is desirable to limit a Cu content to 1.2% or less.

[0055] B is added as occasion demands, as B has an effect of raising fatigue limit when added in combination with Cu. An addition of B by less than 0.0002% is not enough for obtaining the effect, but, when B is added in excess of 0.002%, cracks occur in a slab. For this reason, the addition amount of B is limited to 0.0002 to 0.002%.

[0056] Ni is added as occasion demands for preventing hot shortness caused by the presence of Cu. An Ni addition amount of less than 0.1% is not enough for obtaining the effect, but, even when it is added in excess of 1%, the effect is saturated. For this reason, an Ni content is limited in the range from 0.1 to 1%.

[0057] Ca and REM are the elements that modify the shape of non-metallic inclusions, which serve as the starting points of fractures and/or deteriorate workability, and, by so doing, render them harmless. But no tangible effect is obtained when either of them is added at less than 0.0005%. When Ca is added in excess of 0.002% or REM in excess of 0.02%, the effect is saturated. Thus, it is desirable to add Ca by 0.0005 to 0.002% and REM by 0.0005 to 0.02%.

[0058] Additionally, one or more of precipitation-strengthening and solute-strengthening elements, namely Ti, Nb,

Mo, V, Cr and Zr, may be added for enhancing strength. However, when they are added at less than 0.05%, 0.01%, 0.05%, 0.02%, 0.01% and 0.02%, respectively, no tangible effects are obtained and, when they are added in excess of 0.5, 0.5%, 1%, 0.2%, 1% and 0.2%, respectively, their effects are saturated.

[0059] Note that Sn, Co, Zn, W and/or Mg may be added at 1% or less in total to a steel containing aforementioned elements as the main components. However, as Sn may cause surface defects during hot rolling, it is desirable to limit an Sn content to 0.05% or less.

[0060] Now, the reasons for limiting the conditions of the production method according to the present invention are explained in detail hereafter.

[0061] A steel sheet according to the present invention can be produced through any of the following process routes: casting, hot rolling and cooling; casting, hot rolling, cooling, pickling, cold rolling and annealing; heat treatment of a hot-rolled or cold-rolled steel sheet in a hot dip plating line; or, further, surface treatment applied separately to a steel sheet produced through any of the above process routes.

[0062] The present invention does not specify production methods prior to hot rolling. That is, a steel may be melted and refined in a blast furnace, an electric arc furnace or the like, then the chemical components may be adjusted in one or more of various secondary refining processes so that the steel may contain desired amounts of the components, and then the steel may be cast into a slab through a casting process such as an ordinary continuous casting process, an ingot casting process and a thin slab casting process. Steel scraps may be used as a raw material. Further, in the case of a slab cast through a continuous casting process, the slab may be fed to a hot-rolling mill directly while it is hot, or it may be hot rolled after being cooled to room temperature and then heated in a reheating furnace.

[0063] No limit is particularly set to the temperatures of reheating, but it is desirable that a reheating temperature is lower than 1,400°C, since, when it is 1,400°C or higher, the descale amount becomes large and the product yield decreases. It is also desirable that a reheating temperature is 1,000°C or higher, since a reheating temperature lower than 1,000°C remarkably deteriorates the operation efficiency of a rolling mill in terms of rolling schedule.

[0064] In a hot rolling process, a slab undergoes finish rolling after completing rough rolling. When descaling is applied after completing the rough rolling, it is desirable to satisfy the following condition:

$$P\ (MPa) \times L\ (l/cm^2) \geqq 0.0025,$$

where, P (MPa) is an impact pressure of high-pressure water on a steel sheet surface, andL (l/cm^2) a flow rate of descaling water.

[0065] An impact pressure P of high-pressure water on a steel sheet surface is expressed as follows (see Tetsu-to-Hagané, 1991, Vol. 77, No. 9, p.1450):

$$P\ (MPa) = 5.64 \times P_0 \times V/H^2,$$

where, P_0 (MPa) is a pressure of liquid, V (l/min.) a liquid flow rate of a nozzle, and H (cm) a distance between a nozzle and the surface of a steel sheet.

[0066] The flow rate L (l/cm^2) is expressed as follows:

$$L\ (l/cm^2) = V/(W \times v),$$

where, V (l/min.) is a liquid flow rate of a nozzle, W (cm) the width of liquid when the liquid blown from a nozzle hits a steel sheet surface, and v (cm/min.) a traveling speed of a steel sheet.

[0067] It is not necessary to specify an upper limit of the product of the impact pressure P and the flow rate L for the purpose of obtaining the effects of the present invention. However, it is preferable that the product is 0.02 or less because, when the liquid flow rate of a nozzle is raised, problems such as violent nozzle wear occur.

[0068] It is preferable, further, that the maximum roughness height Ry of a steel sheet after finish rolling is 15 μm (15 μm Ry, ℓ 2.5 mm, ℓn 12.5 mm) or less. The reason for this is clear from the fact that the fatigue strength of an as-hot-rolled or as-pickled steel sheet correlates with the maximum roughness height Ry of the steel sheet surface, as stated, for example, in page 84 of Metal Material Fatigue Design Handbook edited by the Society of Materials Science, Japan. Further, it is preferable that the subsequent finish hot rolling is done within 5 sec. after high-pressure descaling so that scales may be prevented from forming again.

[0069] Besides the above, finish rolling may be carried out continuously by welding sheet bars together after rough rolling or the subsequent descaling. In this case, the rough-rolled sheet bars may be welded together after being coiled temporarily, held inside a cover having a heat retention function as occasion demands, and then uncoiled.

[0070] When a hot-rolled steel sheet is used as a final product, it is necessary that the finish rolling is done at a total reduction ratio of 25% or more in the temperature range of the Ar_3 transformation temperature + 100°C or lower during the latter half of the finish rolling. Here, the Ar_3 transformation temperature can be expressed, in a simplified manner, in relation to steel chemical components, for instance, by the following equation:

$$Ar_3 = 910 - 310 \times \%C + 25 \times \%Si - 80 \times \%Mn.$$

[0071] When the total reduction ratio in the temperature range of the Ar_3 transformation temperature + 100°C or lower is less than 25%, the rolled texture of austenite does not develop sufficiently and, as a result, the effects of the present invention are not obtained, no matter how the steel sheet is cooled thereafter. For obtaining the specified texture, it is desirable that the total reduction ratio in the temperature range of the Ar_3 transformation temperature + 100°C or lower is 35% or more.

[0072] The present invention does not specify a lower limit of the temperature range in which rolling at a total reduction ratio of 25% or more is carried out. However, when the rolling is done at a temperature lower than the Ar_3 transformation temperature, a work-induced structure remains in ferrite having precipitated during the rolling, and, as a result, ductility falls and workability deteriorates. For this reason, it is desirable that a lower limit of the temperature range in which rolling at a total reduction ratio of 25% or more is carried out is not lower than the Ar_3 transformation temperature. However, when recovery or recrystallization advances to some extent during the subsequent coiling process or a heat treatment after the coiling process, a rolling temperature lower than the Ar_3 transformation temperature is acceptable.

[0073] The present invention does not specify an upper limit of the total reduction ratio in the temperature range of the Ar_3 transformation temperature + 100°C or lower. However, when a total reduction ratio exceeds 97.5%, the rolling load becomes too high and it becomes necessary to increase the rigidity of a rolling mill excessively, resulting in economical disadvantage. For this reason, the total reduction ratio is, desirably, 97.5% or less.

[0074] Here, when the friction between a hot-rolling roll and a steel sheet is large during hot rolling in the temperature range of the Ar_3 transformation temperature + 100°C or lower, crystal orientations mainly composed of {110} planes develop at planes near the surfaces of the steel sheet, causing the deterioration of notch-fatigue strength. As a countermeasure, lubrication may be applied for reducing the friction between a hot-rolling roll and a steel sheet as occasion demands.

[0075] The present invention does not specify an upper limit of the friction coefficient between a hot-rolling roll and a steel sheet. However, when a friction coefficient exceeds 0.2, crystal orientations mainly composed of {110} planes develop conspicuously, deteriorating notch-fatigue strength. For this reason, it is desirable to control a friction coefficient between a hot-rolling roll and a steel sheet to 0.2 or less at least at one of the passes of the hot rolling in the temperature range of the Ar_3 transformation temperature + 100°C or lower. It is more desirable to control a friction coefficient between a hot-rolling roll and a steel sheet to 0.15 or less at all the passes of the hot rolling in the temperature range of the Ar_3 transformation temperature + 100°C or lower.

[0076] Here, a friction coefficient between a hot-rolling roll and a steel sheet is the value calculated from a forward slip ratio, a rolling load, a rolling torque and so on on the basis of the rolling theory.

[0077] The present invention does not specify a temperature at the final pass (FT) of finish rolling, but it is desirable that the final pass is completed at a temperature not lower than the Ar_3 transformation temperature. This is because, if a rolling temperature is lower than the Ar_3 transformation temperature during hot rolling, a work-induced structure remains in ferrite having precipitated before or during the rolling, and, as a result, ductility lowers and workability deteriorates. However, when a heat treatment for recovery or recrystallization is applied during or after the subsequent coiling process, a temperature at the final pass (FT) of finish rolling is allowed to be lower than the Ar_3 transformation temperature.

[0078] The present invention does not specify an upper limit of a finishing temperature, but, if a finishing temperature exceeds the Ar_3 transformation temperature + 100°C, it becomes practically impossible to carry out rolling at a total reduction ratio of 25% or more in the temperature range of the Ar_3 transformation temperature + 100°C or lower. For this reason, it is desirable that an upper limit of a finishing temperature is the Ar_3 transformation temperature + 100°C or lower.

[0079] In the present invention, it is not necessary to specify the microstructure of a steel sheet for only the purpose of enhancing the notch-fatigue strength thereof and, therefore, no specific limitation is set forth regarding the cooling process after the completion of finish rolling until the coiling at a prescribed coiling temperature. Nevertheless, a steel sheet is cooled, as occasion demands, for the purpose of securing a prescribed coiling temperature or controlling the microstructure. The present invention does not specify an upper limit of a cooling rate, but, as thermal strain may cause a steel sheet to warp, it is desirable to control a cooling rate to 300°C/sec. or lower. In addition, when a cooling rate is too high, it becomes impossible to accurately control the cooling end temperature and an over-cooling may happen as a result of overshooting to a temperature lower than a prescribed coiling temperature. For this reason, a cooling

rate here is, desirably, 150°C/sec. or lower. No lower limit of a cooling rate is specifically set forth, either. For reference, the cooling rate in the case where a steel sheet is left to cool by air without any intentional cooling is 5°C/sec. or higher.

[0080] For the purpose of obtaining a good burring workability in addition to enhancing notch-fatigue strength in the present invention, it is necessary that the microstructure of a steel sheet is a compound structure containing bainite or ferrite and bainite as the phase accounting for the largest volume percentage. In that case, the present invention does not specify the conditions of the process after the completion of finish rolling until the coiling at a prescribed coiling temperature, except for the cooling rate applied during the process. However, in the case where a steel sheet is required to have both a good burring workability and a high ductility without sacrificing the burring workability too much, a hot-rolled steel sheet may be retained for 1 to 20 sec. in the temperature range from the Ar_3 transformation temperature to the Ar_1 transformation temperature (the ferrite-austenite two-phase zone). Here, the retention of a hot-rolled steel sheet is carried out for accelerating ferrite transformation in the two-phase zone. When a retention time is less than 1 sec., ferrite transformation in the two-phase zone is insufficient and a sufficient ductility is not obtained. However, when a retention time exceeds 20 sec., pearlite forms and an intended microstructure having a compound structure containing bainite or ferrite and bainite as the phase accounting for the largest volume percentage is not obtained.

[0081] In addition, in order to facilitate the acceleration of ferrite transformation, it is desirable that the temperature range in which a steel sheet is retained for 1 to 20 sec. is from the Ar_1 transformation temperature to 800°C. Further, in order not to lower productivity drastically, it is desirable that the retention time, which has been defined earlier as in the range from 1 to 20 sec., is 1 to 10 sec. For satisfying all those requirements, it is necessary to reach said temperature range rapidly at a cooling rate of 20°C/sec. or higher after completing finish rolling.

[0082] The present invention does not specify an upper limit of a cooling rate, but, in consideration of the capacity of cooling equipment, a reasonable cooling rate is 300°C/sec. or lower. In addition, when a cooling rate is too high, it becomes impossible to accurately control the cooling end temperature and over-cooling may occur as a result of over-shooting to the Ar_1 transformation temperature or lower, losing the ductility improvement effect. For this reason, a cooling rate here is, desirably, 150°C/sec. or lower.

[0083] Subsequently, a steel sheet is cooled at a cooling rate of 20°C/sec. or higher from the above temperature range to a coiling temperature (CT). When a cooling rate is lower than 20°C/sec., pearlite or bainite containing carbides forms and an intended microstructure having a compound structure containing bainite or ferrite and bainite as the phase accounting for the largest volume percentage is not obtained. The effects of the present invention can be enjoyed without specifying an upper limit of the cooling rate down to the coiling temperature but, to avoid warping caused by thermal strain, it is desirable to control a cooling rate to 300°C/sec. or lower.

[0084] For the purpose of obtaining a good ductility in addition to enhancing notch-fatigue strength in the present invention, it is necessary that the microstructure of a steel sheet is a compound structure containing retained austenite at 5 to 25% in terms of volume percentage and having the balance mainly consisting of ferrite and bainite. For obtaining such a compound structure, a hot-rolled steel sheet has to be retained for 1 to 20 sec. in the temperature range from the Ar_3 transformation temperature to the Ar_1 transformation temperature (the ferrite-austenite two-phase zone) in the first process after completing finish rolling. Here, the retention of a hot-rolled steel sheet is carried out for accelerating ferrite transformation in the two-phase zone. When a retention time is less than 1 sec., ferrite transformation in the two-phase zone is insufficient and a sufficient ductility is not obtained. However, when a retention time exceeds 20 sec., pearlite forms and an intended microstructure containing retained austenite by 5 to 25% in terms of volume percentage and having the balance mainly consisting of ferrite and bainite is not obtained.

[0085] In addition, in order to facilitate the acceleration of ferrite transformation, it is desirable that the temperature range in which a steel sheet is retained for 1 to 20 sec. is from the Ar_1 transformation temperature to 800°C. Further, in order not to lower productivity drastically, it is desirable that the retention time, which has been defined earlier as in the range from 1 to 20 sec., is 1 to 10 sec. To satisfy all those requirements, it is necessary to reach said temperature range rapidly at a cooling rate of 20°C/sec. or higher after completing finish rolling. The present invention does not specify an upper limit of a cooling rate, but, in consideration of the capacity of cooling equipment, a reasonable cooling rate is 300°C/sec. or lower. In addition, when a cooling rate is too high, it becomes impossible to accurately control the cooling end temperature and over-cooling may happen as a result of overshooting to the Ar_1 transformation temperature or lower. For this reason, a cooling rate here is, desirably, 150°C/sec. or lower.

[0086] Subsequently, a steel sheet is cooled at a cooling rate of 20°C/sec. or higher from the above temperature range to a coiling temperature (CT). When a cooling rate is lower than 20°C/sec., pearlite or bainite containing carbides forms and a sufficient amount of retained austenite is not secured and, as a result, an intended microstructure containing retained austenite at 5 to 25% in terms of volume percentage and having the balance mainly consisting of ferrite and bainite is not obtained. The effects of the present invention can be enjoyed without bothering to specify an upper limit of the cooling rate down to the coiling temperature but, to avoid warping caused by thermal strain, it is desirable to control a cooling rate to 300°C/sec. or lower.

[0087] Further, for the purpose of obtaining a low yield ratio for realizing a good shape-fixation property in addition to enhancing notch-fatigue strength in the present invention, it is necessary that the microstructure of a steel sheet is

a compound structure containing ferrite as the phase accounting for the largest volume percentage and mainly martensite as the second phase. For obtaining such a compound structure, a hot-rolled steel sheet has to be retained for 1 to 20 sec. in the temperature range from the Ar_3 transformation temperature to the Ar_1 transformation temperature (the ferrite-austenite two-phase zone) in the first process after completing finish rolling. Here, the retention of a hot-rolled steel sheet is carried out for accelerating ferrite transformation in the two-phase zone. When a retention time is less than 1 sec., ferrite transformation in the two-phase zone is insufficient and a sufficient ductility is not obtained. However, when a retention time exceeds 20 sec., pearlite forms and an intended compound structure containing ferrite as the phase accounting for the largest volume percentage and mainly martensite as the second phase is not obtained.

[0088] In addition, in order to facilitate the acceleration of ferrite transformation, it is desirable that the temperature range in which a steel sheet is retained for 1 to 20 sec. is from the Ar_1 transformation temperature to 800°C. Further, in order not to lower productivity drastically, it is desirable that the retention time, which has been defined earlier as in the range from 1 to 20 sec., is 1 to 10 sec. To satisfy all those requirements, it is necessary to reach said temperature range rapidly at a cooling rate of 20°C/sec. or higher after completing finish rolling. The present invention does not specify an upper limit of a cooling rate, but, in consideration of the capacity of cooling equipment, a reasonable cooling rate is 300°C/sec. or lower. In addition, when a cooling rate is too high, it becomes impossible to accurately control the cooling end temperature and over-cooling may happen as a result of overshooting to the Ar_1 transformation temperature or lower. For this reason, a cooling rate here is, desirably, 150°C/sec. or lower.

[0089] Subsequently, a steel sheet is cooled at a cooling rate of 20°C/sec. or higher from the above temperature range to a coiling temperature (CT). When a cooling rate is lower than 20°C/sec., pearlite or bainite forms and a sufficient amount of martensite is not secured and, as a result, an intended microstructure containing ferrite as the phase accounting for the largest volume percentage and martensite as the second phase is not obtained.

[0090] The effects of the present invention can be enjoyed without specifying an upper limit of the cooling rate down to the coiling temperature but, to avoid distortion caused by thermal strain, it is desirable to control the cooling rate to 300°C/sec. or lower.

[0091] In the present invention, it is not necessary to specify the microstructure of a steel sheet only for the purpose of enhancing the notch-fatigue strength thereof and, therefore, the present invention does not specify an upper limit of a coiling temperature. However, in order to carry over the texture of austenite obtained by finish rolling at a total reduction ratio of 25% or more in the temperature range of the Ar_3 transformation temperature + 100°C or lower, it is desirable to coil a steel sheet at the coiling temperature T_0 shown below or lower. Note that it is unnecessary to set the temperature T_0 to room temperature or lower. T_0 is the temperature defined thermodynamically as that at which austenite and ferrite having the same chemical components as the austenite have the same free energy. It can be calculated in a simplified manner by the following equation, taking the influences of components other than C into consideration:

$$T_0 = -650.4 \times \%C + B,$$

where, B is determined as follows:

$$B = -50.6 \times Mneq + 894.3,$$

where, Mneq is determined from the mass percentages of the component elements as shown below:

$$Mneq = \%Mn + 0.24 \times \%Ni + 0.13 \times \%Si + 0.38 \times \%Mo +$$

$$0.55 \times \%Cr + 0.16 \times \%Cu - 0.50 \times \%Al - 0.45 \times \%Co + 0.90$$

$$\times \%V.$$

[0092] Note that the influences on T_0 of the mass percentages of the other components specified in the present invention than those included in the above equation are insignificant, and are negligible here.

[0093] Since it is not necessary to specify the microstructure of a steel sheet only for the purpose of enhancing the notch-fatigue strength thereof, it is not necessary to specify the lower limit of a coiling temperature. However, to avoid a poor appearance caused by rust when a coil is kept wet with water for a long period of time, it is desirable that a coiling temperature is not lower than 50°C.

[0094] For the purpose of obtaining a good burring workability in addition to enhancing notch-fatigue strength in the

present invention, it is necessary that the microstructure of a steel sheet is a compound structure containing bainite or ferrite and bainite as the phase accounting for the largest volume percentage. To obtain such a compound structure, the coiling temperature has to be restricted to 450°C or higher. This is because, when a coiling temperature is lower than 450°C, retained austenite or martensite considered detrimental to burring workability may form in a great amount and, as a consequence, an intended microstructure having a compound structure containing bainite or ferrite and bainite as the phase accounting for the largest volume percentage is not obtained.

[0095] Further, although the present invention does not specify a cooling rate to be applied after coiling, it is desirable that a cooling rate after coiling is 30°C/sec. or higher to a temperature of 200°C. Otherwise, when Cu is added by 1.2% or more, it precipitates after coiling and, as a result, not only workability is deteriorated but also solute Cu effective for improving fatigue properties may be lost.

[0096] Further, for the purpose of obtaining a good ductility in addition to enhancing notch-fatigue strength in the present invention, it is necessary that the microstructure of a steel sheet is a compound structure containing retained austenite at 5 to 25% in terms of volume percentage and having the balance mainly consisting of ferrite and bainite. To obtain such a compound structure, the coiling temperature is restricted to lower than 450°C. This is because, when a coiling temperature is 450°C or higher, bainite containing carbides forms and a sufficient amount of retained austenite is not secured and, as a result, an intended microstructure containing retained austenite at 5 to 25% in terms of volume percentage, and having the balance mainly consisting of ferrite and bainite, is not obtained. When a coiling temperature is not higher than 350°C, on the other hand, a great amount of martensite forms and a sufficient amount of retained austenite is not secured and, as a result, an intended microstructure containing retained austenite by 5 to 25% in terms of volume percentage and having the balance mainly consisting of ferrite and bainite is not obtained. For this reason, a coiling temperature is limited to higher than 350°C.

[0097] Further, although the present invention does not specify a cooling rate to be applied after coiling, it is desirable that a cooling rate after coiling is 30°C/sec. or higher up to a temperature of 200°C. Otherwise, when Cu is added at 1% or more, it precipitates after coiling and, as a result, not only is the workability deteriorated but also solute Cu effective for improving fatigue properties may be lost.

[0098] Further, for the purpose of obtaining a low yield ratio for realizing a good shape-fixation property in addition to enhancing notch-fatigue strength in the present invention, it is necessary that the microstructure of a steel sheet is a compound structure containing ferrite as the phase accounting for the largest volume percentage and mainly martensite as the second phase. For obtaining such a compound structure, a coiling temperature has to be restricted to 350°C or lower. This is because, when a coiling temperature exceeds 350°C, bainite forms and a sufficient amount of martensite is not secured and, as a result, an intended microstructure containing ferrite as the phase accounting for the largest volume percentage and martensite as the second phase is not obtained. It is not necessary to specify a lower limit of a coiling temperature but, to avoid a poor appearance caused by rust when a coil is kept wet with water for a long period of time, it is desirable that a coiling temperature is not lower than 50°C.

[0099] After completing a hot rolling process, as occasion demands, a steel sheet may be subjected to pickling and then skin pass rolling at a reduction ratio of 10% or less or cold rolling at a reduction ratio up to 40% or so, either on-line or off-line.

[0100] Next, in the case where a cold-rolled steel sheet is used as a final product, the present invention does not specify the conditions of finish hot rolling. However, in order to obtain a better notch-fatigue strength, it is desirable that a total reduction ratio, in the temperature range of the Ar_3 transformation temperature + 100°C or lower, is 25% or more. Further, while the temperature at the final pass (FT) of finish rolling is allowed to be lower than the Ar_3 transformation temperature, in such a case, since an intensively work-induced structure remains in ferrite having precipitated before or during the rolling, it is desirable that the work-induced structure is recovered and recrystallized through the subsequent coiling process or a heat treatment.

[0101] A total reduction ratio at subsequent cold rolling after pickling must be less than 80%. This is because, when a total reduction ratio at cold rolling is 80% or more, the ratios of the integrated X-ray diffraction strengths in {111} and {554} crystallographic planes parallel to the plane of a steel sheet, the crystallographic planes having a texture usually obtained through cold rolling and recrystallization, tend to rise. A preferable total reduction ratio at cold rolling is 70% or less. The effects of the present invention can be enjoyed without specifying a lower limit of a cold reduction ratio but, for controlling the X-ray diffraction strengths in specific crystal orientation components within appropriate ranges, it is desirable to set a lower limit of a cold reduction ratio at 3% or more.

[0102] The discussion here is based on the premise that the heat treatment of a steel sheet cold rolled as specified above is carried out in a continuous annealing process.

[0103] In the first place, a steel sheet is subjected to a heat treatment for 5 to 150 sec. in the temperature range of the Ac_3 transformation temperature + 100°C or lower. When an upper limit of a heat treatment temperature exceeds the Ac_3 transformation temperature + 100°C, ferrite having formed through recrystallization transforms into austenite, the texture formed by the growth of austenite grains is randomized, and the texture of ferrite finally obtained is also randomized. For this reason, an upper limit of a heat treatment temperature is set at the Ac_3 transformation temperature

+ 100°C or lower.

[0104] The Ac_1 and Ac_3 transformation temperatures mentioned herein can be expressed in relation to steel chemical components using, for example, the expressions according to p. 273 of the Japanese translation of The Physical Metallurgy of Steels by W. C. Leslie (published by Maruzen in 1985, translated by Hiroshi Kumai and Tatsuhiko Noda).

[0105] With regard to a lower limit of a heat treatment temperature, it is acceptable if the temperature is equal to or higher than the recovery temperature, because it is not necessary to specify the microstructure of a steel sheet for the purpose of enhancing the notch-fatigue strength thereof. When a heat treatment temperature is lower than the recovery temperature, however, a work-induced structure is retained and formability is significantly deteriorated. For this reason, a lower limit of a heat treatment temperature is set to be equal to or higher than the recovery temperature. Further, with regard to a retention time in the above temperature range, when a retention time is shorter than 5 sec., it is insufficient for having cementite completely dissolve again. However, when a retention time exceeds 150 sec., the effect of the heat treatment is saturated and, what is worse, productivity is lowered. For this reason, a retention time is determined to be in the range from 5 to 150 sec.

[0106] The present invention does not specify the conditions of cooling after a heat treatment. However, for the purpose of controlling the microstructure of a steel sheet, cooling or the combination of retention at an arbitrary temperature and cooling as explained later may be employed as deemed necessary.

[0107] For the purpose of obtaining a good burring workability in addition to enhancing notch-fatigue strength in the present invention, it is necessary that the microstructure of a steel sheet is a compound structure containing bainite or ferrite and bainite as the phase accounting for the largest volume percentage. To obtain such a compound structure, a lower limit of a heat treatment temperature is set at a temperature of the Ac_1 transformation temperature or higher. When a lower limit of a heat treatment temperature is lower than the Ac_1 transformation temperature, an intended compound structure containing bainite or ferrite and bainite as the phase accounting for the largest volume percentage, is not obtained. When it is intended to obtain both a good burring workability and a high ductility without sacrificing the burring workability too much, a heat treatment temperature must be in the range from the Ac_1 transformation temperature to the Ac_3 transformation temperature (the ferrite-austenite two-phase zone) in order to increase the volume percentage of ferrite. Further, for the purpose of obtaining a still better burring workability, it is desirable that the heat treatment temperature is in the range from the Ac_3 transformation temperature to the Ac_3 transformation temperature + 100°C in order to increase the volume percentage of bainite.

[0108] The present invention does not specify the conditions of a cooling process in heat treatment. However, when a heat treatment temperature is in the range from the Ac_1 transformation temperature to the Ac_3 transformation temperature, it is desirable to cool a steel sheet at a cooling rate of 20°C/sec. or higher to the temperature range from higher than 350°C to the temperature T_0 specified herein earlier. This is because, when a cooling rate is lower than 20°C/sec., the temperature history of steel is likely to pass through the transformation nose of bainite or pearlite containing much carbide. Further, when a cooling end temperature is 350°C or lower, martensite, which is considered detrimental to burring properties, may form in a great amount and, as a result, an intended microstructure having a compound structure containing bainite or ferrite and bainite as the phase accounting for the largest volume percentage is not obtained. For this reason, it is desirable that a cooling end temperature is higher than 350°C. In addition, in order to carry over the texture obtained to the previous process, it is desirable that a cooling end temperature is not higher than T_0.

[0109] Finally, when a cooling rate to the cooling end temperature is 20°C/sec. or higher, martensite, which is considered detrimental to burring properties, may form in a great amount during the cooling and, as a result, an intended microstructure having a compound structure containing bainite or ferrite and bainite as the phase accounting for the largest volume percentage may not be obtained. For this reason, it is desirable that a cooling rate is lower than 20°C/sec. Further, when a cooling end temperature is higher than 200°C, aging properties may deteriorate, and, for this reason, it is desirable that a cooling end temperature is 200°C or lower. If water cooling or mist cooling is applied and a coil is kept wet with water for a long period of time, it is desirable, to avoid a poor appearance caused by rust, that a cooling end temperature is not lower than 50°C.

[0110] On the other hand, in the case where above mentioned heat treatment temperature is in the range from higher than the Ac_3 transformation temperature to the Ac_3 transformation temperature + 100°C, it is desirable to cool a steel sheet at a cooling rate of 20°C/sec. or higher to a temperature of 200°C or lower. This is because, when a cooling rate is lower than 20°C/sec., the temperature history of steel is likely to pass through the transformation nose of bainite or pearlite containing much carbide. In addition, when a cooling end temperature exceeds 200°C, aging properties may deteriorate. For this reason, it is desirable that a cooling end temperature is 200°C or lower. If water cooling or mist cooling is applied and a coil is kept wet with water for a long period of time, it is desirable, to avoid a poor appearance caused by rust, that a cooling end temperature is not lower than 50°C.

[0111] Further, for the purpose of obtaining a good ductility in addition to enhancing notch-fatigue strength in the present invention, it is necessary that the microstructure of a steel sheet is a compound structure containing retained austenite at 5 to 25% in terms of volume percentage and having the balance mainly consisting of ferrite and bainite.

To obtain such a compound structure, a steel sheet must be subjected to a heat treatment for 5 to 150 sec. in the temperature range from the Ac_1 transformation temperature to the Ac_3 transformation temperature + 100°C, as described earlier. In this case, when a temperature is too low within the above temperature range and when cementite has precipitated in an as-hot-rolled state, it takes too long for the cementite to dissolve again. When a temperature is too high, on the other hand, the volume percentage of austenite increases excessively and the concentration of C in austenite decreases, and, as a consequence, the temperature history of steel is likely to pass through the transformation nose of bainite or pearlite containing much carbide. For this reason, it is desirable to heat a steel sheet to a temperature in the range from 780°C to 850°C. When a cooling rate after retention is lower than 20°C/sec., the temperature history of steel is likely to pass through the transformation nose of bainite or pearlite containing much carbide, and, for this reason, a cooling rate must be 20°C/sec. or higher.

[0112] Next, with respect to the process to accelerate bainite transformation and stabilize a required amount of retained austenite, when a cooling end temperature is not lower than 450°C, retained austenite is decomposed into bainite or pearlite containing much carbide, and an intended microstructure containing retained austenite at 5 to 25% in terms of volume percentage and having the balance mainly consisting of ferrite and bainite is not obtained. When a cooling end temperature is not higher than 350°C, on the other hand, martensite may form in a great amount and a sufficient amount of retained austenite cannot be secured and, as a result, an intended microstructure containing retained austenite at 5 to 25% in terms of volume percentage and the balance mainly consisting of ferrite and bainite is not obtained. For this reason, the cooling must be continued to a temperature in the range from higher than 350°C to lower than 450°C.

[0113] Further, with respect to a retention time in the above temperature range, when a retention time is shorter than 5 sec., bainite transformation for stabilizing retained austenite is insufficient and, as a consequence, unstable retained austenite may transform into martensite at the end of the subsequent cooling, and, as a result, an intended microstructure containing retained austenite at 5 to 25% in terms of volume percentage and having the balance mainly consisting of ferrite and bainite is not obtained. When a retention time exceeds 600 sec., on the other hand, bainite transformation overshoots and a required amount of stable retained austenite is not formed, and, as a result, an intended microstructure containing retained austenite at 5 to 25% in terms of volume percentage and having the balance mainly consisting of ferrite and bainite is not obtained. For this reason, a retention time in the above temperature range must be from 5 to 600 sec.

[0114] Finally, when a cooling rate up to the end of cooling is lower than 5°C/sec., bainite transformation may overshoot during the cooling and a required amount of stable retained austenite is not formed, and, as a consequence, an intended microstructure containing retained austenite by 5 to 25% in terms of volume percentage and having the balance mainly consisting of ferrite and bainite may not be obtained. For this reason, a cooling rate is set at 5°C/sec. or higher.

[0115] In addition, when a cooling end temperature is higher than 200°C, aging properties may deteriorate and, for this reason, a cooling end temperature must be 200°C or lower. The present invention does not specify a lower limit for a cooling end temperature. However, if water cooling or mist cooling is applied and a coil is kept wet with water for a long period of time, it is desirable, to avoid a poor appearance caused by rust, that a cooling end temperature is not lower than 50°C.

[0116] Further, for the purpose of obtaining a low yield ratio for realizing a good shape-fixation property in addition to enhancing notch-fatigue strength in the present invention, it is necessary that the microstructure of a steel sheet is a compound structure containing ferrite as the phase accounting for the largest volume percentage and mainly martensite as the second phase. To obtain such a compound structure, a steel sheet must be subjected to a heat treatment for 5 to 150 sec. in the temperature range from the Ac_1 transformation temperature to the Ac_3 transformation temperature + 100°C as described before. In this case, when the temperature is too low within the above temperature range and when cementite has precipitated in an as-hot-rolled state, it takes too long for the cementite to dissolve again. When the temperature is too high, on the other hand, the volume percentage of austenite increases excessively and the concentration of C in austenite decreases, and, as a consequence, the temperature history of steel is likely to pass through the transformation nose of bainite or pearlite containing much carbide. For this reason, it is desirable to heat a steel sheet to a temperature in the range from 780°C to 850°C.

[0117] When a cooling rate after retention is lower than 20°C/sec., the temperature history of steel is likely to pass through the transformation nose of bainite or pearlite containing much carbide, and, for this reason, a cooling rate must be 20°C/sec. or higher. When a cooling end temperature is higher than 350°C, an intended microstructure containing ferrite as the phase accounting for the largest volume percentage and martensite as the second phase is not obtained. For this reason, the cooling must be continued down to a temperature of 350°C or lower. The present invention does not specify a lower limit of a cooling end temperature. However, if water cooling or mist cooling is applied and a coil is kept wet with water for a long period of time, it is desirable, to avoid a poor appearance caused by rust, that a cooling end temperature is not lower than 50°C.

[0118] Thereafter, skin pass rolling may be applied, if required.

[0119] When galvanizing is applied to a hot-rolled steel sheet after pickling or a cold-rolled steel sheet after completing the above annealing for recrystallization, the steel sheet is dipped in a zinc-plating bath. After that, it may be subjected to an alloying treatment, if required.

Example

(Example 1)

[0120] The present invention is further explained hereafter based on Example 1.

[0121] Steels A to L having the chemical components shown in Table 1 were melted and refined in a converter, cast continuously into slabs, reheated and then rolled through rough rolling and finish rolling into steel sheets 1.2 to 5.5 mm in thickness, and then coiled. Note that the chemical components in the table are expressed in terms of mass percentage.

[0122] Table 2 shows the details of the production conditions. In the table, "SRT" means the slab reheating temperature, "FT" the finish rolling temperature at the final pass, and "reduction ratio" the total reduction ratio in the temperature range of the Ar_3 transformation temperature + 100°C or lower. Note that, in the case where a hot-rolled steel sheet is cold rolled, it is not necessary to restrict the reduction ratio of hot rolling and, for this reason, the space of "reduction ratio" is filled with a dash meaning "not applicable." Further, "lubrication" indicates if or not lubrication is applied in the temperature range of the Ar_3 transformation temperature + 100°C or lower.

[0123] In the column of "coiling", ○ means that the coiling temperature (CT) is equal to or lower than T_0, and × that the coiling temperature is higher than T_0. Note that, in the case of a cold-rolled steel sheet, the space is filled with a dash meaning "not applicable," because it is not necessary to restrict the coiling temperature as one of the production conditions.

[0124] Some of the steel sheets were subjected to pickling, cold rolling and annealing after hot rolling. The thickness of the cold-rolled steel sheets ranged from 0.7 to 2.3 mm.

[0125] Also in the table, "cold reduction ratio" means the total reduction ratio of the cold rolling, and "time" the time of annealing. In the column of "annealing", ○ means that the annealing temperature is within the range from the recovery temperature to the Ar_3 transformation temperature + 100°C, and × that it is outside the range. Steel L was subjected to descaling under the conditions of an impact pressure of 2.7 MPa and a flow rate of 0.001 l/cm^2 after the rough rolling. Further, among the steels mentioned above, steels G and F-5 were subjected to zinc plating.

[0126] The hot-rolled steel sheets thus prepared were subjected to a tensile test in accordance with the test method specified in JIS Z 2241, after forming the specimens into No. 5 test pieces according to JIS Z 2201. The yield strength (σY), tensile strength (σB) and breaking elongation (El) of the steel sheets are shown also in Table 2.

[0127] Then, a test piece 30 mm in diameter was cut out from a position of 1/4 or 3/4 of the width of each of the steel sheets, the surfaces were ground to a depth of about 0.05 mm so that the surfaces might have the three-triangle grade finish (the second finest finish) and, subsequently, strain was removed by chemical polishing or electrolytic polishing. The test pieces thus prepared were subjected to X-ray diffraction strength measurement in accordance with the method described in pages 274 to 296 of the Japanese translation of Elements of X-ray Diffraction by B. D. Cullity (published in 1986 by AGNE Gijutsu Center, translated by Gentaro Matsumura).

[0128] Here, the average of the ratios of the X-ray diffraction strength in the orientation component group of {100}<011> to {223}<110> to random X-ray diffraction strength is obtained from the X-ray diffraction strengths in the principal orientation components included in the orientation component group, namely {100}<011>, {116}<110>, {114}<110>, {113}<110>, {112}<110>, {335}<110> and {223}<110>, in the three-dimensional texture calculated either by the vector method based on the pole figure of {110} or by the series expansion method using two or more (desirably, three or more) pole figures out of the pole figures of {110}, {100}, {211} and {310}.

[0129] For example, in the case of obtaining the ratios of the X-ray diffraction strength in the above crystal orientation components to random X-ray diffraction strength by the latter method, the strengths of (001)[1-10], (116)[1-10], (114)[1-10], (113)[1-10], (112)[1-10], (335)[1-10] and (223)[1-10] at a $\phi 2 = 45°$ cross section in a three-dimensional texture may be used without modification. Note that the average of the ratios of the X-ray diffraction strength in the orientation component group of {100}<011> to {223}<110> to random X-ray diffraction strength is the arithmetic average of the ratios in all the above orientation components.

[0130] When it is impossible to obtain the strengths in all these orientation components, the arithmetic average of the strengths in the orientation components of {100}<011>, {116}<110>, {114}<110>, {112}<110> and {223}<110> may be used as a substitute.

[0131] Likewise, the average of the ratios of the X-ray diffraction strength in the three orientation components of {554}<225>, {111}<112> and {111}<110> to random X-ray diffraction strength can be obtained from the three-dimensional texture calculated in the same manner as explained above.

[0132] In Table 2, "strength ratio 1" under "ratios of X-ray diffraction strength to random X-ray diffraction strength"

means the average of the ratios of the X-ray diffraction strength in the orientation component group of {100}<011> to {223}<110> to random X-ray diffraction strength, and "strength ratio 2" the average of the ratios of the X-ray diffraction strength in the above three orientation components of {554}<225>, {111}<112> and {111}<110> to random X-ray diffraction strength.

[0133] Next, for the purpose of investigating the notch-fatigue strength of the above steel sheets, a test piece for fatigue test having the shape shown in Fig. 1(b) was cut out from a position of 1/4 or 3/4 of the width of each of the steel sheets so that the longitudinal direction of the test piece coincided with the rolling direction of the steel sheet, and subjected to a fatigue test. The surfaces of the test pieces for fatigue test were ground to a depth of about 0.05 mm so that the surfaces might have the second finest finish, and the fatigue test was carried out using an electro-hydraulic servo type fatigue tester and methods conforming to JIS Z 2273-1978 and Z 2275-1978. The notch-fatigue limit (σWK) and notch-fatigue limit ratio (σWK/σB) of each of the steel sheets are shown also in Table 2.

[0134] The samples according to the present invention are 11 steels, namely steels A, E, F-1, F-2, F-5, G, H, I, J, K and L. In these samples, obtained are the thin steel sheets for automobile use excellent in notch-fatigue strength, each of the steel sheets being characterized in that: the steel sheet contains prescribed amounts of chemical components; on a plane at an arbitrary depth within 0.5 mm from the surface of the steel sheet in the thickness direction thereof, the average of the ratios of the X-ray diffraction strength in the orientation component group of {100}<011> to {223}<110> to random X-ray diffraction strength is 2 or more and the average of the ratios of the X-ray diffraction strength in the three orientation components of {554}<225>, {111}<112> and {111}<110> to random X-ray diffraction strength is 4 or less; and the thickness of the steel sheet is in the range from 0.5 to 12 mm. As a consequence, in the evaluations by the methods according to the present invention, the fatigue limit ratios of these steels were superior to those of conventional steels which ranged from 20 to 30%.

[0135] All the steels other, than those mentioned above, in the tables were outside the ranges of the present invention for the following reasons.

[0136] In steel B, the content of C was outside the range specified in the present invention and, as a consequence, a sufficient strength (σB) was not obtained. In steel C, the content of P was outside the range specified in the present invention and, as a consequence, a sufficient notch-fatigue strength ratio (σWK/σB) was not obtained. In steel D, the content of S was outside the range specified in the present invention and, as a consequence, a sufficient elongation (El) was not obtained. In steel F-3, as the total reduction ratio in the temperature range of the Ar_3 transformation temperature + 100°C or lower was outside the range specified in the present invention, the texture intended in the present invention was not obtained and, as a consequence, a sufficient notch-fatigue strength ratio (σWK/σB) was not obtained.

[0137] In steel F-4, as the finish rolling end temperature (FT) and the coiling temperature were outside the respective ranges specified in the present invention, the texture intended in the present invention was not obtained and, as a consequence, a sufficient notch-fatigue strength ratio (σWK/σB) was not obtained. In steel F-6, as the cold reduction ratio was outside the range specified in the present invention, the texture intended in the present invention was not obtained and, as a consequence, a sufficient notch-fatigue strength ratio (σWK/σB) was not obtained. In steel F-7, as the annealing temperature was outside the range specified in the present invention, the texture intended in the present invention was not obtained and, as a consequence, a sufficient notch-fatigue strength ratio (σWK/σB) was not obtained. In steel F-8, as the annealing time was outside the range specified in the present invention, the texture intended in the present invention was not obtained and, as a consequence, a sufficient notch-fatigue strength ratio (σWK/σB) was not obtained.

(Example 2)

[0138] The present invention is hereafter explained in more detail based on Example 2.

[0139] Slabs of two steels G and H having the chemical components shown in Table 1 were reheated to the reheating temperatures shown in Table 3, rolled through rough rolling and then finish rolling into steel sheets 1.5 to 5.5 mm in thickness, and then coiled. As shown in Table 3, some of the steel sheets were subjected to descaling under the conditions of an impact pressure of 2.7 MPa and a flow rate of 0.001 l/cm^2 after the rough rolling.

[0140] Table 3 shows the details of the production conditions. In the table, "SRT" means the slab reheating temperature, "FT" the finish rolling temperature at the final pass, and "reduction ratio" the total reduction ratio in the temperature range of the Ar_3 transformation temperature + 100°C or lower. Note that, in the case where a hot-rolled steel sheet is cold rolled, it is not necessary to restrict the reduction ratio of hot rolling and, for this reason, the space "reduction ratio" is filled with a dash meaning "not applicable." Further, "lubrication" indicates if or not lubrication is applied in the temperature range of the Ar_3 transformation temperature + 100°C or lower. Furthermore, "CT" indicates the coiling temperature. Note that, in the case of a cold-rolled steel sheet, the space is filled with a dash meaning "not applicable," because it is not necessary to restrict the coiling temperature as one of the production conditions. Some of the steel sheets were subjected to pickling, cold rolling and heat treatment after the hot rolling. The thickness of the cold-rolled

steel sheets ranged from 0.7 to 2.3 mm. Also in the table, "cold reduction ratio" means the total reduction ratio of the cold rolling, "ST" the temperature of the heat treatment and "time" the time thereof. Some of the steels were subjected to galvanizing .

[0141] The hot-rolled and cold-rolled steel sheets thus prepared were subjected to a tensile test in the same manner as described earlier.

[0142] The yield strength (σY), tensile strength (σB), breaking elongation (El), yield ratio (YR) and strength-ductility index (σB x El) of each of the steel sheets are shown in Table 4. Burring workability (hole expansibility) was evaluated following the hole expansion test method according to the Standard of the Japan Iron and Steel Federation JFS T 1001-1996. Table 4 also shows the hole expansion ratio (λ).

[0143] Table 4 shows the microstructures of the steel sheets, too. Here, "others" accounts for pearlite and any other phase than ferrite, bainite, retained austenite and martensite, which are listed individually in Table 4. The volume percentage of ferrite, bainite, retained austenite, pearlite or martensite is defined as the area percentage thereof in the microstructure of each of the steel sheets observed with an optical microscope under a magnification of 200 to 500 at a position in the depth of 1/4 of the steel sheet thickness on a section surface along the rolling direction of a specimen which is cut out from a position of 1/4 or 3/4 of the width of the steel sheet, the section surface being polished and etched with a nitral reagent and the reagent disclosed in Japanese Unexamined Patent Publication No. H5-163590.

[0144] Because the crystal structure of austenite is different from that of ferrite, they can be easily distinguished from each other crystallographically. Therefore, the volume percentage of retained austenite can be obtained experimentally by the X-ray diffraction method too, namely by the simplified method wherein the volume percentage thereof is calculated with the following equation on the basis of the difference between austenite and ferrite in the reflection intensity of the Kα ray of Mo on their lattice planes:

$$V\gamma = (2/3)\{100/(0.7 \times \alpha(211)/\gamma(220) + 1)\} + (1/3)\{100/(0.78 \times \alpha(211)/\gamma(311) + 1)\},$$

where, $\alpha(211)$, $\gamma(220)$ and $\gamma(311)$ are the X-ray reflection intensities of the indicated lattice planes of ferrite (α) and austenite (γ), respectively. The measurement result of the volume percentage of retained austenite was substantially the same either by the optical microscope observation or the X-ray diffraction method, and, thus, the measured values by any of the two methods may be used.

[0145] The X-ray diffraction strength was measured by the same method as described earlier.

[0146] The fatigue test was carried out also in the same manner as described earlier. The notch-fatigue limit (σWK) and notch-fatigue limit ratio ($\sigma WK/\sigma B$) of the steel sheets are shown also in Table 4.

[0147] The samples according to the present invention are 9 steels, namely steels g-1, g-2, g-3, g-5, g-6, g-7, h-1, h-2 and h-3. In these samples, obtained are thin steel sheets, for automobile use, excellent in notch-fatigue strength, each of the steel sheets being characterized in that: the steel sheet contains prescribed amounts of chemical components; on a plane at an arbitrary depth within 0.5 mm from the surface of the steel sheet in the thickness direction thereof, the average of the ratios of the x-ray diffraction strength in the orientation component group of {100}<011> to {223}<110> to random X-ray diffraction strength is 2 or more and the average of the ratios of the X-ray diffraction strength in the three orientation components of {554}<225>, {111}<112> and {111}<110> to random X-ray diffraction strength is 4 or less; the thickness of the steel sheet is in the range from 0.5 to 12 mm; and the microstructure is a compound structure containing bainite or ferrite and bainite as the phase accounting for the largest volume percentage, a compound structure containing retained austenite by 5 to 25% in terms of volume percentage and having the balance mainly consisting of ferrite and bainite, or a compound structure containing ferrite as the phase accounting for the largest volume percentage and mainly martensite as the second phase. As a consequence, in the evaluations by the methods according to the present invention, the fatigue limit ratios of these steels were significantly superior to those of conventional steels which ranged from 20 to 30%.

[0148] All the steels, other than those mentioned above, in the table were outside the ranges of the present invention for the following reasons.

[0149] In steel g-4, as the finish rolling end temperature (FT) and the total reduction ratio in the temperature range of the Ar_3 transformation temperature + 100°C or lower were outside the respective ranges specified in the present invention, the texture intended in the present invention was not obtained and, as a consequence, a sufficient notch-fatigue strength ratio ($\sigma WK/\sigma B$) was not obtained. In steel g-8, as the cold reduction ratio was outside the range specified in the present invention, the texture intended in the present invention was not obtained and, as a consequence, a sufficient notch-fatigue strength ratio ($\sigma WK/\sigma B$) was not obtained. In steel h-4, too, as the finish rolling end temperature (FT) and the total reduction ratio in the temperature range of the Ar_3 transformation temperature + 100°C or lower were outside the respective ranges specified in the present invention, the texture intended in the present invention was not obtained and, as a consequence, a sufficient notch-fatigue strength ratio ($\sigma WK/\sigma B$) was not obtained.

Table 1

Steel	Chemical composition (in mass %)							Remarks
	C	Si	Mn	P	S	Al	Others	
A	0.041	0.02	0.26	0.012	0.0011	0.033	REM: 0.0008	Invented steel
B	0.002	0.01	0.11	0.011	0.0070	0.044	Ti: 0.057	Comparative steel
C	0.022	0.02	0.22	0.300	0.0015	0.012		Comparative steel
D	0.018	0.04	0.55	0.090	0.0400	0.033		Comparative steel
E	0.058	0.92	1.16	0.008	0.0009	0.041	Cu: 0.48, B: 0.0002	Invented steel
F	0.081	0.88	1.24	0.007	0.0008	0.031		Invented steel
G	0.049	0.91	1.27	0.006	0.0011	0.025	Cu: 0.78, Ni: 0.33	Invented steel
H	0.094	1.89	1.87	0.008	0.0007	0.024	Ti: 0.071, Nb: 0.022	Invented steel
I	0.060	1.05	1.16	0.007	0.0008	0.033	Mo: 0.11	Invented steel
J	0.061	0.91	1.21	0.006	0.0011	0.030	V: 0.02, Cr: 0.08	Invented steel
K	0.055	1.21	1.10	0.008	0.0007	0.024	Zr: 0.03	Invented steel
L	0.050	1.14	1.00	0.007	0.0009	0.031	Ca: 0.0005	Invented steel

Table 2

Steel	Classification	Production conditions: Hot rolling process: SRT (°C)	FT (°C)	Reduction ratio (%)	Lubrication	Coiling	Cold rolling and annealing processes: Cold reduction ratio (%)	Annealing	Time (S)	Ratios of X-ray diffraction strength to random X-ray diffraction strength: Strength ratio 1	Strength ratio 2	Mechanical properties: δY (MPa)	δB (MPa)	El (%)	Fatigue properties: δWk (MPa)	δWk/σB (%)	Remarks
A	Hot-rolled	1250	880	42	Not applied	O	-	-	-	5.8	0.7	221	311	47	100	32	Invented steel
B	Hot-rolled	1250	890	30	Applied	O	-	-	-	1.3	6.1	161	281	56	75	27	Comparative steel
C	Hot-rolled	1200	880	30	Not applied	O	-	-	-	0.8	1.3	220	369	42	90	24	Comparative steel
D	Hot-rolled	1200	880	30	Not applied	O	-	-	-	1.2	0.9	195	306	44	75	25	Comparative steel
E	Hot-rolled	1150	870	42	Not applied	O	-	-	-	8.1	1.8	422	637	29	230	36	Invented steel
F-1	Hot-rolled	1200	870	42	Not applied	O	-	-	-	7.2	2.1	438	668	28	230	34	Invented steel
F-2	Hot-rolled	1200	870	42	Applied	O	-	-	-	8.3	1.4	423	655	29	240	37	Invented steel
F-3	Hot-rolled	1300	950	0	Not applied	O	-	-	-	1.8	1.5	431	660	28	150	23	Comparative steel
F-4	Hot-rolled	1300	970	0	Not applied	x	-	-	-	1.8	1.7	400	622	32	150	24	Comparative steel
F-5	Cold-rolled	1200	860	-	Applied	-	65	O	90	4.2	2.3	418	671	28	240	36	Invented steel
F-6	Cold-rolled	1200	860	-	Applied	-	80	O	90	2.8	4.2	433	667	28	150	22	Comparative steel
F-7	Cold-rolled	1200	860	-	Applied	-	65	x	90	1.7	2.6	552	721	20	150	21	Comparative steel
F-8	Cold-rolled	1200	860	-	Applied	-	65	O	2	1.8	2.2	570	710	21	150	21	Comparative steel
G	Hot-rolled	1150	870	71	Not applied	O	-	-	-	8.5	0.8	441	661	30	235	36	Invented steel
H	Hot-rolled	1250	870	30	Applied	O	-	-	-	8.7	0.9	776	986	16	340	34	Invented steel
I	Hot-rolled	1200	870	42	Not applied	O	-	-	-	6.7	2.0	404	638	27	220	34	Invented steel
J	Hot-rolled	1200	870	71	Not applied	O	-	-	-	5.9	2.1	431	623	26	220	35	Invented steel
K	Hot-rolled	1200	870	71	Not applied	O	-	-	-	7.8	1.0	425	627	30	220	35	Invented steel
L	Hot-rolled	1150	790	71	Not applied	O	-	-	-	11.0	1.4	401	588	25	210	36	Invented steel

Table 3

Steel	Classification	Production conditions: Hot rolling process: SRT (°C)	FT (°C)	Ar_3+100 (°C)	Reduction ratio (%)	Lubrication	CT (°C)	TO (°C)	Cold reduction ratio (%)	Cold rolling and annealing processes: Ac_1 (°C)	ST (°C)	Ac_3+100 (°C)	Time 1 (S)	OA (°C)	Time 2 (S)	CR (°C/S)	Ratios of X-ray diffraction strength to random X-ray diffraction strength: Strength ratio 1	Strength ratio 2
g-1	Hot-rolled	1150	870	916	71	Applied	50	782	-	-	-	-	-	-	-	-	8.2	1.1
g-2	Hot-rolled	1150	870	916	71	Applied	400	782	-	-	-	-	-	-	-	-	8.0	1.0
g-3	Hot-rolled	1150	890	916	42	Applied	600	782	-	-	-	-	-	-	-	-	8.4	0.9
g-4	Hot-rolled	1250	930	916	0	Not applied	600	782	-	-	-	-	-	-	-	-	1.8	1.5
g-5	Cold-rolled	1150	870	-	-	Applied	-	-	65	730	800	982	90	-	-	5	4.4	2.2
g-6	Cold-rolled	1150	870	-	-	Applied	-	-	65	730	800	982		400	180	30	4.6	2.4
g-7	Cold-rolled	1150	870	-	-	Applied	-	-	65	730	800	982	90	-	-	30	4.8	2.6
g-8	Cold-rolled	1150	870	-	-	Not applied	-	-	80	730	800	982	90	-	-	5	2.6	4.3
h-1	Hot-rolled	1230	860	879	30	Applied	50	727	-	-	-	-	-	-	-	-	8.6	1.2
h-2	Hot-rolled	1230	860	879	30	Applied	400	727	-	-	-	-	-	-	-	-	8.5	0.9
h-3	Hot-rolled	1230	860	879	30	Applied	600	727	-	-	-	-	-	-	-	-	8.4	1.3
h-4	Hot-rolled	1230	930	879	0	Not applied	730	727	-	-	-	-	-	-	-	-	1.8	2.1

Table 4

Microstructure					Fatigue properties						Fatigue properties		Remarks
Ferrite (%)	Bainite (%)	Martensite (%)	Retained austenite (%)	Others (%)	δY (MPa)	δB (MPa)	El (%)	λ (%)	δB×El (MPa*%)	YR (%)	δWk (MPa)	δWk/αB (%)	
85	0	13	2	0	470	772	26	52	20072	61	280	36	Invented steel
80	8	0	12	0	512	646	37	67	23902	79	220	34	Invented steel
67	30	0	0	3	478	576	27	130	15552	83	190	33	Invented steel
65	35	0	0	0	502	588	28	141	16464	85	120	20	Comparative steel
70	28	0	0	2	482	584	25	87	14600	83	190	33	Invented steel
79	10	0	11	0	480	660	36	50	23760	73	230	35	Invented steel
87	0	10	3	0	444	731	26	42	19006	61	270	37	Invented steel
50	45	0	2	3	495	591	25	76	14775	84	135	23	Comparative steel
67	5	21	4	3	613	991	21	18	20811	62	330	33	Invented steel
63	15	3	17	2	694	902	27	26	24354	77	285	32	Invented steel
35	55	3	4	3	670	823	18	76	14814	81	255	31	Invented steel
30	63	0	3	4	673	796	20	70	15920	85	180	23	Comparative steel

Effect of the Invention

[0150] As has been explained in detail, the present invention relates to a thin steel sheet, for automobile use, excellent in notch-fatigue strength, and a method for producing the steel sheet. The use of a thin steel sheet according to the present invention makes it possible to expect a significant improvement in notch-fatigue strength that is one of the essential properties of such a structural member including an undercarriage component of an automobile to overcome the problem of generating the propagation of a fatigue crack from a site of stress concentration including a blanked or welded portion and thus to require durability. For this reason, the present invention is of a high industrial value.

Claims

1. A thin steel sheet, for automobile use, excellent in notch-fatigue strength, **characterized in: that**, on a plane at an arbitrary depth within 0.5 mm from the surface of the steel sheet in the thickness direction thereof, the average of the ratios of the X-ray diffraction strength in the orientation component group of {100}<011> to {223}<110> to random X-ray diffraction strength is 2 or more and the average of the ratios of the X-ray diffraction strength in the three orientation components of {554}<225>, {111}<112> and {111}<110> to random X-ray diffraction strength is 4 or less; and that the thickness of the steel sheet is in the range from 0.5 to 12 mm.

2. A thin steel sheet, for automobile use, excellent in notch-fatigue strength according to claim 1, **characterized in that** the microstructure of the steel sheet is a compound structure containing bainite or ferrite and bainite as the phase accounting for the largest volume percentage.

3. A thin steel sheet, for automobile use, excellent in notch-fatigue strength according to claim 1, **characterized in that** the microstructure of the steel sheet is a compound structure containing retained austenite at 5 to 25% in terms of volume percentage and having the balance mainly consisting of ferrite and bainite.

4. A thin steel sheet for automobile use excellent in notch-fatigue strength according to claim 1, **characterized in that** the microstructure of the steel sheet is a compound structure containing ferrite as the phase accounting for the largest volume percentage and martensite as the second phase.

5. A thin steel sheet for automobile use excellent in notch-fatigue strength, the steel sheet containing, in mass, 0.01 to 0.3% C, 0.01 to 2% Si, 0.05 to 3% Mn, 0.1% or less P, 0.01% or less S and 0.005 to 1% Al, with the balance consisting of Fe and unavoidable impurities, **characterized in that**, on a plane at an arbitrary depth within 0.5 mm from the surface of the steel sheet in the thickness direction thereof, the average of the ratios of the X-ray diffraction strength in the orientation component group of {100}<011> to {223}<110> to random X-ray diffraction strength is 2 or more and the average of the ratios of the X-ray diffraction strength in the three orientation components of {554}<225>, {111}<112> and {111}<110> to random X-ray diffraction strength is 4 or less and that the thickness of the steel sheet is in the range from 0.5 to 12 mm.

6. A thin steel sheet for automobile use excellent in notch-fatigue strength according to claim 5, **characterized by** further containing, in mass, one or more of 0.2 to 2% Cu, 0.0002 to 0.002% B, 0.1 to 1% Ni, 0.0005 to 0.002% Ca, 0.0005 to 0.02% REM, 0.05 to 0.5% Ti, 0.01 to 0.5% Nb, 0.05 to 1% Mo, 0.02 to 0.2% V, 0.01 to 1% Cr and 0.02 to 0.2% Zr.

7. A thin steel sheet for automobile use excellent in notch-fatigue strength according to claim 5 or 6, **characterized in that** the microstructure of the steel sheet is any one of 1) a compound structure containing bainite or ferrite and bainite as the phase accounting for the largest volume percentage, 2) a compound structure containing retained austenite at 5 to 25% in terms of volume percentage and having the balance mainly consisting of ferrite and bainite, and 3) a compound structure containing ferrite as the phase accounting for the largest volume percentage and martensite as the second phase.

8. A thin steel sheet for automobile use excellent in notch-fatigue strength, **characterized in that** the steel sheet is produced by applying galvanizing to a thin steel sheet for automobile use according to any one of claims 1 to 7.

9. A method for producing a thin steel sheet for automobile use excellent in notch-fatigue strength **characterized in that** a steel slab containing, in mass, 0.01 to 0.3% C, 0.01 to 2% Si, 0.05 to 3% Mn, 0.1% or less P, 0.01% or less S and 0.005 to 1% Al, with the balance consisting of Fe and unavoidable impurities, is subjected, in a hot rolling

process, to rough rolling and then to finish rolling at a total reduction ratio of 25% or more in terms of steel sheet thickness in the temperature range of the Ar_3 transformation temperature + 100°C or lower, that, on a plane at an arbitrary depth within 0.5 mm from the surface of the steel sheet in the thickness direction thereof, the average of the ratios of the X-ray diffraction strength in the orientation component group of {100}<011> to {223}<110> to random X-ray diffraction strength is 2 or more and the average of the ratios of the X-ray diffraction strength in the three orientation components of {554}<225>, {111}<112> and {111}<110> to random X-ray diffraction strength is 4 or less and that the thickness of the steel sheet is in the range from 0.5 to 12 mm.

10. A method for producing a thin steel sheet, for automobile use, excellent in notch-fatigue strength according to claim 9, **characterized by** cooling the steel sheet at a cooling rate of 20°C/sec. or higher after the finish rolling and then coiling it at a coiling temperature of 450°C or higher.

11. A method for producing a thin steel sheet, for automobile use, excellent in notch-fatigue strength according to claim 9, **characterized by** retaining the steel sheet for 1 to 20 sec. in the temperature range from the Ar_1 transformation temperature to the Ar_3 transformation temperature after the finish rolling then cooling it at a cooling rate of 20°C/sec. or higher and then coiling it at a coiling temperature in the range from higher than 350°C to lower than 450°C.

12. A method for producing a thin steel sheet, for automobile use, excellent in notch-fatigue strength according to claim 11, **characterized by** coiling the steel sheet at a coiling temperature of 350°C or lower after the cooling.

13. A method for producing a thin steel sheet, for automobile use, excellent in notch-fatigue strength according to any one of claims 9 to 12, **characterized by** applying lubrication rolling to the steel sheet in the hot rolling.

14. A method for producing a thin steel sheet, for automobile use, excellent in notch-fatigue strength according to any one of claims 9 to 13, **characterized by** applying descaling to the steel sheet after the completion of the rough rolling in the hot rolling.

15. A method for producing a thin steel sheet, for automobile use, excellent in notch-fatigue strength, **characterized in that** a steel slab containing, in mass, 0.01 to 0.3% C, 0.01 to 2% Si, 0.05 to 3% Mn, 0.1% or less P, 0.01% or less S and 0.005 to 1% Al, with the balance consisting of Fe and unavoidable impurities, is subjected to rough rolling, then finish rolling at a total reduction ratio of 25% or more in terms of steel sheet thickness in the temperature range of the Ar_3 transformation temperature + 100°C or lower, pickling, cold rolling at a reduction ratio of less than 80% in terms of steel sheet thickness and then annealing for recovery or recrystallization comprising the processes of retaining the cold-rolled steel sheet for 5 to 150 sec. in the temperature range from the recovering temperature to the Ac_3 transformation temperature + 100°C and then cooling it, that, on a plane at an arbitrary depth within 0.5 mm from the surface of the steel sheet in the thickness direction thereof, the average of the ratios of the X-ray diffraction strength in the orientation component group of {100}<011> to {223}<110> to random X-ray diffraction strength is 2 or more and the average of the ratios of the X-ray diffraction strength in the three orientation components of {554}<225>, {111}<112> and {111}<110> to random X-ray diffraction strength is 4 or less and that the thickness of the steel sheet is in the range from 0.5 to 12 mm.

16. A method for producing a thin steel sheet, for automobile use, excellent in notch-fatigue strength according to claim 15, **characterized by** subjecting the steel sheet after the cold rolling to a heat treatment comprising the processes of retaining the cold-rolled steel sheet for 5 to 150 sec. in the temperature range from the AC_1 transformation temperature to the Ac_3 transformation temperature + 100°C and then cooling it.

17. A method for producing a thin steel sheet for automobile use excellent in notch-fatigue strength according to claim 15, **characterized by** subjecting the steel sheet to a heat treatment comprising the processes of, in sequence, retaining the cold-rolled steel sheet for 5 to 150 sec. in said temperature range, cooling it at a cooling rate of 20°C/sec. or higher to the temperature range from higher than 350°C to lower than 450°C, retaining it for 5 to 600 sec. in said temperature range, and then cooling it at a cooling rate of 5°C/sec. or higher to the temperature range of 200°C or lower.

18. A method for producing a thin steel sheet, for automobile use, excellent in notch-fatigue strength according to claim 15, **characterized in** subjecting the steel sheet to a heat treatment comprising the processes of retaining the cold-rolled steel sheet for 5 to 150 sec. in said temperature range and then cooling it at a cooling rate of 20°C/sec. or higher to the temperature range of 350°C or lower.

19. A method for producing a thin steel sheet, for automobile use, excellent in notch-fatigue strength, **characterized in that** the steel sheet produced by the method according to any one of claims 11 to 18 further contains, in mass, one or more of 0.2 to 2% Cu, 0.0002 to 0.002% B, 0.1 to 1% Ni, 0.0005 to 0.002% Ca, 0.0005 to 0.02% REM, 0.05 to 0.5% Ti, 0.01 to 0.5% Nb, 0.05 to 1% Mo, 0.02 to 0.2% V, 0.01 to 1% Cr and 0.02 to 0.2% Zr.

20. A method for producing a thin steel sheet, for automobile use, excellent in notch-fatigue strength according to claim 10 or 16, **characterized in that** the microstructure of the steel sheet is a compound structure containing bainite or ferrite and bainite as the phase accounting for the largest volume percentage.

21. A method for producing a thin steel sheet, for automobile use, excellent in notch-fatigue strength according to claim 11 or 17, **characterized in that** the microstructure of the steel sheet is a compound structure containing retained austenite at 5 to 25% in terms of volume percentage and having the balance mainly consisting of ferrite and bainite.

22. A method for producing a thin steel sheet, for automobile use, excellent in notch-fatigue strength according to claim 12 or 18, **characterized in that** the microstructure of the steel sheet is a compound structure containing ferrite as the phase accounting for the largest volume percentage and martensite as the second phase.

23. A method for producing a thin steel sheet, for automobile use, excellent in notch-fatigue strength **characterized by**, after producing a hot-rolled steel sheet or a steel sheet annealed for recovery or recrystallization according to any one of claims 9 to 22, further applying galvanizing to the surfaces of the steel sheet by dipping the steel sheet in a zinc plating bath.

24. A method for producing a thin steel sheet, for automobile use, excellent in notch-fatigue strength according to claim 23, **characterized by** further subjecting the steel sheet to an alloying treatment after the galvanizing.

Fig.1(a)

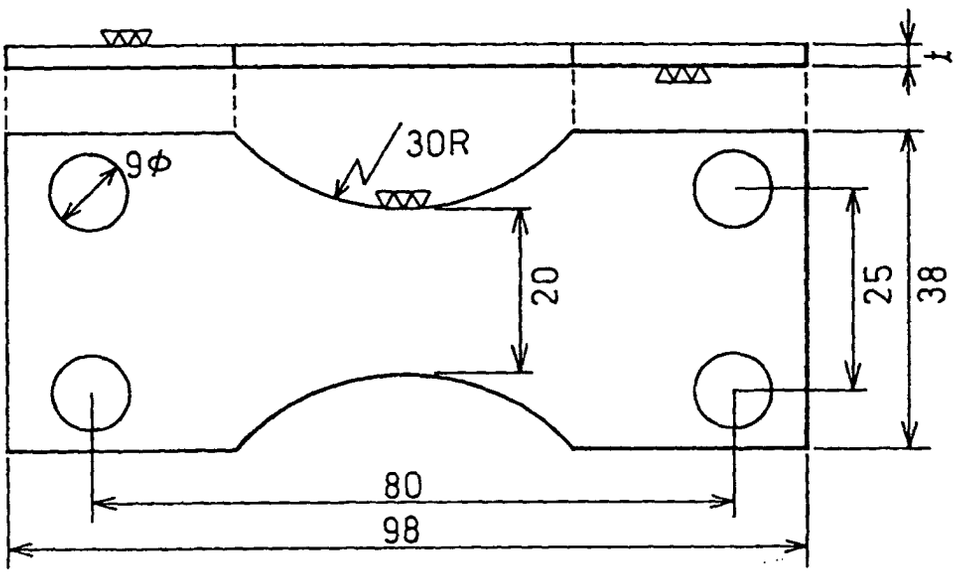


Fig.1(b)

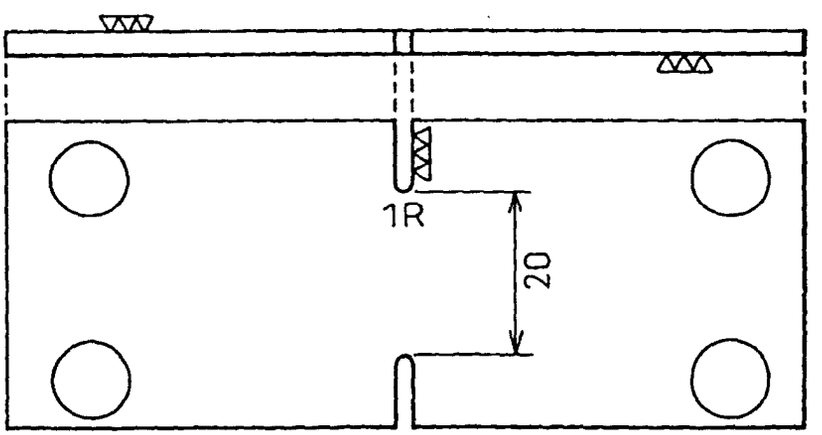
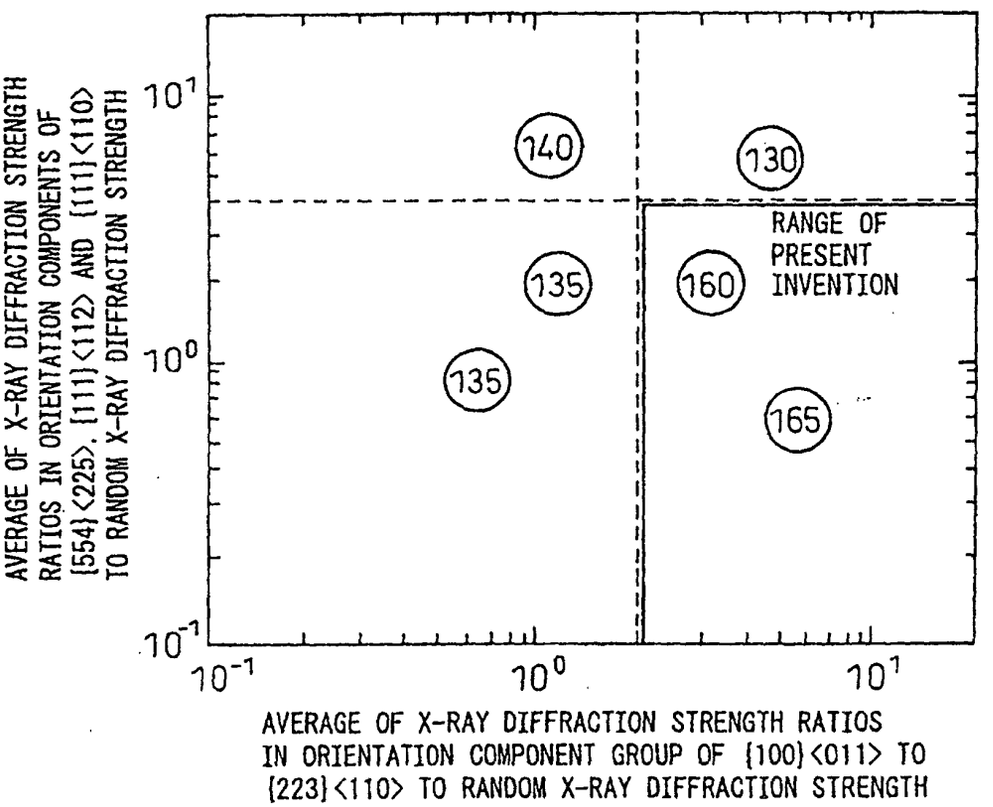


Fig.2


AVERAGE OF X-RAY DIFFRACTION STRENGTH RATIOS IN ORIENTATION COMPONENTS OF {554}<225>, {111}<112> AND {111}<110> TO RANDOM X-RAY DIFFRACTION STRENGTH
10^1
10^0
10^{-1}
10^{-1}
10^0
10^1
140
130
135
160
135
165
RANGE OF PRESENT INVENTION
AVERAGE OF X-RAY DIFFRACTION STRENGTH RATIOS IN ORIENTATION COMPONENT GROUP OF {100}<011> TO {223}<110> TO RANDOM X-RAY DIFFRACTION STRENGTH

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP02/01498

A. CLASSIFICATION OF SUBJECT MATTER
Int.Cl[7] C22C38/00, 301

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
Int.Cl[7] C22C38/00, 301

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho	1926-2002	Jitsuyo Shinan Toroku Koho	1996-2002
Kokai Jitsuyo Shinan Koho	1970-2002	Toroku Jitsuyo Shinan Koho	1994-2002

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 10-60527 A (Sumitomo Metal Industries, Ltd.), 03 March, 1998 (03.03.98), (Family: none)	1-24
A	JP 2001-64750 A (Nippon Steel Corp.), 13 March, 2001 (13.03.01), (Family: none)	1-24

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

* Special categories of cited documents:
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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
16 May, 2002 (16.05.02)	28 May, 2002 (28.05.02)
Name and mailing address of the ISA/ Japanese Patent Office	Authorized officer
Facsimile No.	Telephone No.

Form PCT/ISA/210 (second sheet) (July 1998)