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# (54) A METHOD OF PRODUCING DUAL-PHASE HIGH-STRENGTH STEEL SHEETS HAVING HIGH IMPACT ENERGY ABSORPTION PROPERTIES

VERFAHREN ZUR HERSTELLUNG VON ZWEIPHASEN HOCHFESTEN STAHLBLECHEN MIT ERHÖHTEN EIGENSCHAFTEN ZUR ABSORPTION VON AUFPRALLENERGIE

PROCEDE DE PREPARATION DES TOLES D’ACIER BIPHASEES A HAUTE RESISTANCE MÉCANIQUE ET A HAUTE CAPACITÉ D’ABSORPTION D’ENERGIE DE CHOCK

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(73) Proprietor: **Nippon Steel & Sumitomo Metal Corporation**
**Tokyo 100-8071 (JP)**

(72) Inventors:
- **UENISHI, Akihiro**
  **c/o Nippon Steel Corporation**
  **Futtsu City,**
  **Chiba 293-0011 (JP)**
- **TAKAHASHI, Manabu**
  **c/o Nippon Steel Corporation**
  **Futtsu City,**
  **Chiba 293-0011 (JP)**
- **KURIYAMA, Yukihisa**
  **c/o Nippon Steel Corporation**
  **Futtsu City,**
  **Chiba 293-0011 (JP)**
- **SAKUMA, Yasuharu**
  **c/o Nippon Steel Corp. Kimitsu Works**
  **Kimitsu City,**
  **Chiba 299-1193 (JP)**
- **KAWANO, Osamu**
  **c/o Nippon Steel Corp. Oita Works**
  **Oita City,**
  **Oita 870-8566 (JP)**
- **WAKITA, Junichi**
  **c/o Nippon Steel Corp. Oita Works**
  **Oita City,**
  **Oita 870-8566 (JP)**
- **MABUCHI, Hidesato**
  **c/o Nippon Steel Corp. Oita Works**
  **Oita City,**
  **Oita 870-8566 (JP)**

(74) Representative: **Vossius & Partner**
**Patentanwälte Rechtsanwälte mbB**
**Siebertstrasse 3**
**81675 München (DE)**

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- **PATENT ABSTRACTS OF JAPAN vol. 1995, no. 07, 31 August 1995 (1995-08-31) & JP 07 090482 A (KAWASAKI STEEL CORP), 4 April 1995 (1995-04-04)**

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**(Cont. next page)**

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- **G. BÉRANGER ET AL.: 'The Book of Steel', vol. 59, 1996, LAVOISIER PUBLISHERS, PARIS pages 1208 - 1211**
- **S. MASATOSCHI ET AL.: 'Influence of Microstructure on Yielding Behavior in Continuous-Annealed Multi-Phase Sheet Steels', 1985, THE METALLURGICAL SOCIETY OF AIME, PENNSYLVANIA pages 341 - 360**

## Description

**[0001]** The present invention relates to a method of producing dual-phase type high-strength steel sheets, for automobiles use, which have excellent dynamic deformation properties and exhibit excellent impact absorption properties, and are intended to be used as structural members and reinforcing materials primarily for automobiles them.

**[0002]** The applications of high-strength steels have been increasing for the purpose of achieving lighter weight vehicle bodies in consideration of fuel consumption restrictions on automobiles and even more applications for high-strength steel are expected as domestic and foreign restrictions, relating to estimated impact absorption properties in automobile accidents, become rapidly more broad and strict. For example, for frontal collisions of passenger cars, the use of materials with high impact absorption properties for members known as "front side members" can allow impact energy to be absorbed through collapse of the member, thus lessening the impact experienced by passengers.

**[0003]** However, conventional high-strength steels have been developed with a main view toward improving press formability, and doubts exist as to their application in terms of impact absorption properties. Prior art techniques relating to automobile steel with excellent impact absorption properties and methods of producing it have been developed which result in increased yield strength of steel sheets under high deformation speeds as an indicator of impact absorption properties, as disclosed in JP-A-7-18372, but because the members undergo deformation during the shaping process or during collision deformation, it is necessary to include a work-hardening aspect to the yield strength as an indicator of impact resistance, and this is inadequate in terms of anti-collision safety in the prior art described above.

**[0004]** In addition, since the strain rate undergone by each location upon automobile collision reaches about $10^3$ ($s^{-1}$), consideration of the impact absorption properties of the materials requires an understanding of the dynamic deformation properties in such a high strain rate range. Also, high-strength steel sheets with excellent dynamic deformation properties are understood to be important for achieving both lighter weight and improved impact absorption properties for automobiles, and recent reports have highlighted this fact. For example, the present inventors have reported on the high strain rate properties and impact energy absorption properties of high-strength thin steel sheets in CAMP-ISIJ Vol.9 (1966), pp.1112-1115, wherein they explain that the dynamic strength at a high strain rate of $10^3$ ($s^{-1}$) increases dramatically compared to the static strength at a low strain rate speed of $10^{-3}$ ($s^{-1}$), that absorption energy during crashes is increased by greater steel material strengths, that the strain rate dependency of materials depends on the structure of the steel, and that TRIP type steel (Transformation induced plasticity type steel) and dual-phase (hereunder, "DP") type steel exhibit both excellent press formability and high impact absorption properties. Also, the present inventors have already filed Japanese Patent Applications No.8-98000JP-A-2287050 and No.8-109224JP-A-10291016 relating to such a DP-type steel, among which there are proposed high-strength steel sheets with higher dynamic strength than static strength, which are suitable for achieving both lighter weights and improved impact absorption properties for automobiles, and a process for their production.

**[0005]** As mentioned above, although the dynamic deformation properties of high-strength steel sheets are understood at the high strain rates of automobile collisions, it is still unclear what properties should be maximized for automobile members with impact energy absorption properties, and on what criteria the selection of materials should be based. In addition, the automobile members are produced by press forming of steel sheets, and collision impacts are applied to these press formed members. However, high-strength steel sheets with excellent dynamic deformation properties as actual members, based on an understanding of the impact energy absorption properties after such press forming, are still unknown.

**[0006]** For press forming of members for collision safety, a combination of excellent shape fixability, excellent stretchability (tensile strength x total elongation $\geq$ 18,000) and excellent flangeability (hole expansion ratio $\leq$ 1.2) is desirable, but at the current time no material has provided both excellent impact absorption properties and excellent press formability.

**[0007]** JP-A-07-90482 discloses a cold-rolled thin steel sheet excellent in impact resistance and its production, in which a steel sheet is hot rolled preferably with a finishing hot rolling temperature of 850°C or higher, then the hot-rolled steel sheet is coiled at a temperature of 650°C or higher, and the hot-rolled steel sheet is cold-rolled, annealed at a temperature in the temperature range of 780 to 900°C, cooled to 500°C with a cooling rate of 15 to 50°C/sec and further cooled to 300°C with a cooling rate of 5 to 35°C/sec.

**[0008]** EP-A-0 719 868 discloses a steel sheet for automobiles having excellent impact resistance and method of manufacturing the steel sheet, in which a hot-rolled steel sheet is produced by the steps: hot rolling with a finishing temperature of 780 to 850°C, starting to cool the hot-rolled steel sheet within 0.5 seconds with a cooling rate of 30°C/sec or more to a temperature range of 750 to 650°C, subsequently holding the hot-rolled steel sheet in the temperature range of 750 to 600°C for 4 to 60 seconds, further cooling the hot-rolled steel sheet with a cooling rate of 30°C/sec or more and coiling in the temperature range of 500 to 100°C, and a cold-rolled steel sheet is produced by the steps: annealing a hot-rolled and cold-rolled steel sheet in the temperature range of 780 to 950°C, cooling the annealed steel sheet to 400°C at a cooling rate of 15 to 60°C/sec and further cooling the steel sheet to 150°C with a cooling rate of 3 to 15°C/sec.

**[0009]** The present invention has been proposed as a means of overcoming the problems described above, and provides a method of producing dual-phase type high-strength steel sheets for automobiles use, which have excellent impact absorption properties and excellent dynamic deformation properties.

**[0010]** The invention further provides a method of producing dual-phase type high-strength steel sheets, for automobiles, with excellent dynamic deformation properties, which are high-strength steel sheets used for automotive parts, such as front side members, and which are selected based on exact properties and standards for impact energy absorption during collisions and can reliably provide guaranteed safety.

**[0011]** The invention still further provides a method of producing dual-phase type high-strength steel sheets for automobiles with excellent dynamic deformation properties, which exhibit all the properties suitable for press forming of members, including excellent shape fixability, excellent stretchability and excellent flangeability. The object above can be achieved by the features specified in the claims.

**[0012]** The invention in described in detail in conjunction with the drawings, in which:

Fig. 1 is a graph showing the relationship between the absorption energy (Eab) of a shaped member during collision and the material strength (S), according to the invention,
Fig. 2 is a perspective view of a shaped member for measurement of impact absorption energy for Fig. 1,
Fig. 3 is a graph showing the relationship between the work hardening coefficient and dynamic energy absorption for a steel sheet,
Fig. 4 is a graph showing the relationship between the yield strength x work hardening coefficient and the dynamic energy absorption for a steel sheet,
Fig. 5 is a general view of a "hat model" used in the impact crush test method relating to Figs. 3 and 4,
Fig. 6 is a cross-sectional view of the shape of the test piece of Fig. 5,
Fig. 7 is a schematic view of the impact crush test method relating to Figs. 3-6,
Fig. 8 is a graph showing the relationship between TS and the difference between the average value odyn of the deformation stress in the range of 3~10% of equivalent strain when deformed in a strain rate range of 5 x $10^2$ - 5 x $10^3$ (1/S) and TS, as an index of the impact energy absorption property upon collision, according to the invention,
Fig. 9 is a graph showing the change in the static/dynamic ratio with tempered rolling for an example of the invention and a comparative example,
Fig. 10 is a graph showing the relationship between $\Delta T$ and the metallurgy parameter A for a hot-rolling step according to the invention,
Fig. 11 is a graph showing the relationship between the coiling temperature and the metallurgy parameter A for a hot-rolling step according to the invention, and
Fig. 12 is a graph showing the annealing cycle for continuous annealing according to the invention.

**[0013]** Impact absorbing members such as front side members of automobiles are produced by bending and press forming of steel sheets. Because impacts during automobile collisions are absorbed by such members which have undergone press forming, they must have high impact absorption properties even after having undergone the pre-deformation corresponding to the press forming. At the current time, however, no attempt has been made to obtain high-strength steel sheets with excellent impact absorption properties as actual members, with consideration of both the increase in the deformation stress by press forming and the increase in deformation stress due to a higher strain rate, as was mentioned above.

**[0014]** As a result of much experimentation and research with the aim of achieving this purpose, the present inventors have found that steel sheets with a dual-phase (DP) structure are ideal as high-strength steel sheets with excellent impact absorption properties for actual members which are press formed as described above. It was demonstrated that such steel sheets with a dual-phase microstructure, which is a composite microstructure wherein the dominating phase is a ferrite phase responsible for the increase in deformation resistance by an increased strain rate, and the second phase includes a hard martensite phase, have excellent dynamic deformation properties. That is, it was found that high dynamic deformation properties are exhibited when the microstructure of the final steel sheets is a composite structure wherein the dominating phase is ferrite and another low temperature product phase includes a hard martensite phase at a volume fraction of 3~50% after deformation at 5% equivalent strain of the steel sheet.

**[0015]** Concerning the volume fraction of 3~50% for the hard martensite phase, since high-strength steel sheets and even steel sheets with high dynamic deformation properties cannot be obtained if the martensite phase is less than 3%, the volume fraction of the martensite phase must be at least 3%. Also, if the martensite phase exceeds 50%, this results in a smaller volume fraction of the ferrite phase responsible for greater deformation resistance due to increased deformation speed, making it impossible to obtain steel sheets with excellent dynamic deformation properties compared to static deformation strength while also hindering press formability, and therefore it was found that the volume fraction of the martensite phase must be 3~50%.

**[0016]** The present inventors then pursued experimentation and research based on these findings and, as a result, found that although the degree of pre-deformation corresponding to press forming of impact absorbing members such as front side members sometimes reaches a maximum of over 20%, depending on the location, the majority are locations with 0%~10% of equivalent strain, and that by understanding the effect of pre-deformation in this range, it is possible to estimate the behavior of the member as a whole after pre-deformation. Consequently, according to the invention, a deformation of from 0% to 10% of equivalent strain was selected as the amount of pre-deformation applied to members during press forming.

**[0017]** Fig. 1 is a graph showing the relationship between the absorption energy (Eab) of a press formed member during collision and the material strength (S), for the different steel types shown in Table 5, according to an example to be described later. The material strength S is the tensile strength (TS) according to the common tensile test. The member absorption energy (Eab) is the absorption energy in the lengthwise direction (direction of the arrow) along a press formed member such as shown in Fig. 2, upon collision with a 400 kg mass weight at a speed of 15 m/sec, to a crushing degree of 100 mm. The shaped member in Fig. 2 consists of a 2.0 mm-thick steel sheet formed into a hat-shaped section 1 with a steel sheet 2 of the same thickness and the same type of steel, joined together by spot welding, the hat-shaped section 1 having a corner radius of 2 mm, and with spot welding points indicated by 3.

**[0018]** From Fig. 1 it is seen that the member absorption energy (Eab) tends to increase with the strength of materials under normal tensile testing, though with considerable variation. Here, the materials in Fig. 1 were subjected to pre-deformation of more than 0% and less than or equal to 10% of equivalent strain, and then the static deformation strength $\sigma s$when deformed in a strain rate range of $5 \times 10^{-4}$ - $5 \times 10^{-3}$ ($s^{-1}$) and the dynamic deformation strength $\sigma d$ when deformed in a strain rate range of $5 \times 10^{2}$ - $5 \times 10^{3}$ ($s^{-1}$) after the pre-deformation, were measured. As a result, a classification was possible based on ($\sigma d - \sigma s$). The symbols plotted in Fig. 1 were as follows:

○: ($\sigma d - \sigma s$) < 60 MPa with any pre-deformation of more than 0% and less than or equal to 10%;
●: 60 MPa ≤ ($\sigma d - \sigma s$) with any pre-deformation in the above range, and 60 MPa ≤ ($\sigma d - \sigma s$) < 80 MPa with pre-deformation of 5%;
■: 60 MFa < ($\sigma d - \sigma s$) with any pre-deformation in the above range, and 80 MPa ≤ ($\sigma d - \sigma s$) < 100 MPa with pre-deformation of 5%;
▲: 60 MPa ≤ ($\sigma d - \sigma s$) with any pre-deformation in the above range, and 100 MPa ≤ ($\sigma d - \sigma s$) with pre-deformation of 5%.

**[0019]** Also, when 60 MPa ≤ ($\sigma d - \sigma s$) with any pre-deformation in the range of more than 0% and less than or equal to 10% of equivalent strain, the values for member absorption energy (Eab) during collision was equal to or greater than the values predicted from the material strength S, thus indicating steel sheets with excellent dynamic deformation properties as impact absorbing members for collision. These predicted values are those shown in the curve in Fig. 1, represented by $Eab = 0.062S^{-0.8}$. Consequently, ($\sigma d - \sigma s$) must be at least 60 MPa.

**[0020]** For improved impact absorption properties, it is basically important to increase the work hardening coefficient, specifically to at least 0.13, and preferably at least 0.16; by controlling the yield strength and the work hardening coefficient to specified ranges it is possible to achieve excellent impact absorption properties, and for improved press formability it is effective to design the volume percentage and particle size of the martensite to within a specified range.

**[0021]** Fig. 3 shows the relationship between the work hardening coefficient of a steel sheet and the dynamic energy absorption which indicates the member impact absorption properties, for a class of materials with the same yield strength. Here it is shown that increased work hardening coefficients of the steel sheets result in improved member impact absorption properties (dynamic energy absorption), and that the work hardening coefficient of a steel sheet can properly indicate the member impact absorption properties so long as the yield strength class is the same. Also, when the yield strengths differ, as shown in Fig. 4, the yield strength x work hardening coefficient can be an indicator of the member impact absorption properties. While the work hardening coefficient was expressed in terms of an n value of 5%~10% strain in consideration of the strain undergone by members during press forming, from the viewpoint of improving the dynamic energy absorption, work hardening coefficients of under 5% strain or work hardening coefficients of even more than 10% strain may be preferred.

**[0022]** The dynamic energy absorptions for members shown in Fig. 3 and Fig. 4 were determined in the following manner. Specifically, the steel sheet was shaped into the member shape shown in Fig. 6 (corner R = 5 mm) and spot welded at 35 mm pitch using an electrode with a tip radius of 5.5 mm at a current of 0.9 times the expulsion current, and then after baking and painting treatment at 170°C x 20 minutes, an approximately 150 Kg falling weight was dropped from a height of about 10 m to crush the member in its lengthwise direction, and the displacement work where displacement = 0-150 mm is calculated from the area of the corresponding load displacement diagram to determine the dynamic energy absorption. A schematic illustration of this test method is shown in Fig. 7. In Fig. 5, 4 is a worktop, 5 is a test piece and 6 is a spot welding section.

**[0023]** In Fig. 6, 7 is a hat-shaped test piece and 8 is a spot welding section. In Fig. 7, 9 is a worktop, 10 is a test piece, 11 is a falling weight (150 kg), 12 is a frame, and 13 is a shock absorber. The work hardening coefficient and yield strength of each steel sheet was determined in the following manner. The steel sheet was shaped into a JIS-#5 test piece (gauge length: 50 mm, parallel width: 25 mm), subjected to tensile test at a strain rate of 0.001 ($s^{-1}$) to determine the yield strength and work hardening coefficient (n value at 5%~10% strain). The steel sheet used had a sheet thickness of 1.2 mm and the steel sheet composition contained C at 0.02-0.25 wt%, either or both Mn and Cr at a total of 0.15~3.5 wt% and one or more of Si, Al and P at a total of 0.02-4.0 wt%, with the remainder Fe as the main component.

**[0024]** Fig. 8 is a graph showing the relationship between the average value σdyn of the deformation stress in the range of 3~10% of equivalent strain when deformed in a strain rate range of $5 \times 10^2$ - $5 \times 10^3$ ($s^{-1}$) and the static material strength (TS), as an index of the impact energy absorption property upon collision, according to the invention, where the static material strength (TS) is the tensile strength (TS: MPa) in the static tensile test as measured in a strain rate range of $5 \times 10^{-4}$ - $5 \times 10^{-3}$ ($s^{-1}$).

**[0025]** As mentioned above, impact absorbing members such as front side members have a hat-shaped cross-sectional shape, and as a result of analysis of deformation of such members upon crushing by high-speed collision, the present inventors have found that despite deformation proceeding up to a high maximum strain of over 40%, at least 70% of the total absorption energy is absorbed in a strain range of 10% or lower in a high-speed stress-strain diagram. Therefore, the dynamic deformation resistance with high-speed deformation at 10% or lower was used as the index of the high-speed collision energy absorption property. In particular, since the amount of strain in the range of 3~10% is most important, the index used for the impact energy absorption property was the average stress: σdyn in the range of 3~10% of equivalent strain when deformed in a strain rate range of $5 \times 10^2$ - $5 \times 10^3$ ($s^{-1}$) high-speed tensile deformation.

**[0026]** The average stress: σdyn of 3~10% upon high-speed deformation generally increases with increasing static tensile strength {maximum stress (TS: MPa) in a static tensile test measured in a stress rate range of $5 \times 10^{-4}$ - $5 \times 10^{-3}$ ($s^{-1}$)} of the steel material prior to pre-deformation or baking treatment. Consequently, increasing the static tensile strength (which is synonymous with the static material strength) of the steel material directly contributes to an improved impact energy absorption property of the member. However, increased strength of the steel results in poorer press formability into members, making it difficult to obtain members with the necessary shapes. Consequently, steels having a high σdyn with the same tensile strength TS are preferred. It was found that, based on this relationship, steel sheets wherein the average value σdyn (MPa) of the deformation stress in the range of 3~10% of equivalent strain when deformed in a strain rate range of $5 \times 10^2$ - $5 \times 10^{-3}$ ($s^{-1}$), after pre-deformation of more than 0% and less than or equal to 10% of equivalent strain satisfies the inequality: $\sigma dyn \geq 0.766 \times TS + 250$ as expressed in terms of the tensile strength (TS: MPa) in the static tensile test as measured in a strain rate range of $5 \times 10^{-4}$ - $5 \times 10^{-3}$ ($s^{-1}$) prior to pre-deformation, have higher impact energy absorption properties as actual members compared to other steels, and that the impact energy absorption property is improved without increasing the overall weight of the member, making it possible to provide high-strength steel sheets with high dynamic deformation resistance.

**[0027]** Also, although the details are still unclear, it has been discovered that steel sheets with excellent dynamic deformation properties can be obtained when, as shown in Fig. 9, YS(0)/TS'(5) is no greater than 0.7, which amount is dependent on the initial microstructure, the amount of solid solution elements in the low temperature product phase other than the martensite phase and the main ferrite phase, and the deposited state of carbides, nitrides and carbonitrides. Here, YS(0) is the yield strength, and TS' (5) is the tensile strength (TS') in the static tensile test with pre-deformation at 5% of equivalent strain or after further bake hardening treatment (BH treatment). It was also demonstrated that steel sheets with even more excellent dynamic deformation properties can be obtained when the yield strength: YS(0) x work hardening coefficient is at least 70.

**[0028]** Furthermore, it is known that dynamic deformation strength is usually expressed in the form of the power of the static tensile strength, and as the static tensile strength increases, the difference between the dynamic deformation strength and the static deformation strength decreases. However, a small difference between the dynamic deformation strength and the static deformation strength will mean that no greater improvement in the impact absorption properties can be expected. From this standpoint, it is preferred for the value of (σd - σs) to be in a range which satisfies the following inequality, $(\sigma d - \sigma s) \geq 4.1 \times \sigma s^{0.8} - \sigma s$.

**[0029]** The microstructure of a steel sheet according to the invention will now be described in detail. As already mentioned, the martensite is at a volume fraction of 3-50%, and preferably 3~30%. The average grain size of the martensite is preferably no greater than 5 μm, and the average grain size of the ferrite is preferably no greater than 10 μm. That is, the martensite is hard, and contributes to a decrease in the yield ratio and an improvement in the work hardening coefficient, by producing a mobile dislocations primarily in adjacent ferrite grains; however, by satisfying the restrictions mentioned above it is possible to disperse fine martensite in the steel, so that the improvement in the properties spreads throughout the entire steel sheet. In addition, this dispersion of fine martensite in the steel can help to avoid deterioration in the hole expansion ratio and tensile strength x total elongation, which is an adverse effect of the hard martensite. Also, because it is possible to reliably achieve work hardening coefficient ≥ 0.130, tensile strength x total elongation ≥ 18,000 and hole expansion ratio ≥ 1.2, it is thereby possible to improve the impact absorption properties and press formability.

**[0030]** With a martensite volume fraction of less than 3%, the yield ratio becomes larger while the press formed member cannot exhibit an excellent work hardening property (work hardening coefficient ≥ 0.130) after it has undergone collision deformation, and since the deformation resistance (load) stays at a low level, and the dynamic energy absorption is low preventing improvement in the impact absorption properties. On the other hand, with a martensite volume fraction of greater than 50%, the yield ratio becomes larger while work hardening coefficient is reduced, and deterioration also occurs in the tensile strength x total elongation and the hole expansion ratio. From the standpoint of press formability, the volume fraction of the martensite is preferred to be no greater than 30%.

**[0031]** Also, the ferrite is present at a volume fraction of preferably at least 50%, and more preferably at least 70%, and its average grain size (mean circle equivalent diameter) is preferably no greater than 10 μm, and more preferably no greater than 5 μm, with the martensite preferably adjacent to the ferrite. This aids the fine dispersion of the martensite in the ferrite matrix, while effectively extending the property-improving effect, beyond simply a local effect, to the entire steel sheet, favorably acting to prevent the adverse effects of the martensite. The structure of the remainder present with the martensite and ferrite may be a mixed structure comprising a combination of one or more from among pearlite, bainite, retained $\gamma$, etc., and although primarily bainite is preferred in cases which require hole expansion properties, since retained $\gamma$ undergoes work-induced transformation into martensite by press forming, experimental results have shown that including retained austenite prior to press forming has an effect even in preferred small amounts (5% or less).

**[0032]** Also, from the standpoint of impact absorption properties and press formability it is preferred for the ratio of the martensite and ferrite particle sizes to be no greater than 0.6, and the ratio of the hardnesses to be at least 1.5.

**[0033]** The restrictions on the values for the chemical components of dual-phase type high-strength steel sheets with excellent dynamic deformation properties according to the invention, and the reasons for those restrictions, will now be explained.

**[0034]** Dual-phase type high-strength steel sheets with excellent dynamic deformation properties which are used according to the invention are steel sheets containing the following chemical compositions, in terms of weight percentage: C at 0.02~0.25%, either or both Mn and Cr at a total of 0.15~3.5%, one or more from among Si, Al and P at a total of 0.02~4.0%, if necessary also one or more from among Ni, Cu and Mo at a total of no more than 3.5%, one or more from among Nb, Ti and V at no more than 0.30%, and either or both Ca and REM at 0.0005~0.01% for Ca and 0.005~0.05% for REM, with the remainder Fe as the primary component. They are also dual-phase type high strength steel sheets with excellent dynamic deformation properties which contain, if necessary, one or more from among B (≤0.01), S (≤0.01%) and N (≤0.02%). These chemical components and their contents (percent by weight) will now be discussed.

**[0035]** C: C is the element which most strongly affects the microstructure of the steel sheet, and if its content is too low it will become difficult to obtain martensite with the desired amount and strength. Addition in too great an amount leads to unwanted carbide precipitation, inhibited increase in deformation resistance at higher strain rates and overly high strength, as well as poor press formability and weldability; the content is therefore 0.02-0.25 wt%.

**[0036]** Mn, Cr: Mn and Cr have an effect of stabilizing austenite and guaranteeing sufficient martensite, and are also solid solution hardening elements; they must therefore be added in a minimum amount of 0.15 wt%, but if added in too much the aforementioned effect becomes saturated thus producing adverse effects such as preventing ferrite transformation, and thus they are added in the maximum amount of 3.5 wt%.

**[0037]** Si, Al, P: Si and Al are useful elements for producing martensite, and they promote production of ferrite and suppress precipitation of carbides, thus having the effect of guaranteeing sufficient martensite, as well as a solid solution hardening effect and a deoxidization effect. P can also promote martensite formation and solid solution hardening, similar to Al and Si. From this standpoint, the minimum amount of Si + Al + P added must be at least 0.02 wt%. On the other hand, excessive addition will saturate this effect and result instead in brittleness, and therefore the maximum amount of addition is no more than 4.0 wt%. In particular, when an excellent surface condition is required, Si scales can be avoided by adding Si at no greater than 0.1 wt%, and conversely by adding it at 1.0 wt% or greater Si scales can be produced over the entire surface so that they are not conspicuous. Also, when excellent secondary workability, toughness, spot weldability and recycling properties are required, the P content may be kept at no greater than 0.05%, and preferably no greater than 0.02%.

**[0038]** Ni, Cu, Mo: These elements are added when necessary, and are austenite-stabilizing elements similar to Mn, which increase the hardenability of the steel, and are effective for adjustment of the strength. From the standpoint of weldability and chemical treatment, they can be used when the amounts of C, Si, Al and Mn are restricted, but if the total amount of these elements added exceeds 3.5 wt% the dominant ferrite phase will tend to be hardened, thus inhibiting the increase in deformation resistance by a greater strain rate, as well as raising the cost of the steel sheet; the amount of these elements added is therefore 3.50 wt% or lower.

**[0039]** Nb, Ti, V: These elements are added when necessary, and are effective for strengthening the steel sheet through formation of carbides, nitrides and carbonitrides. However, when added at greater than 0.3 wt% they are deposited in large amounts in the dominant ferrite phase or at the grain boundaries as carbides, nitrides and carbonitrides, becoming a source of the mobile dislocation during high speed deformation, and inhibiting the increase in deformation resistance by greater strain rates. In addition, the deformation resistance of the dominant phase becomes higher than necessary, thus wasting the C and leading to higher costs; the maximum amount to be added is therefore 0.3 wt%.

**[0040]** B: B is an element which is effective for strengthening since it improves the hardenability of the steel by suppressing production of ferrite, but if it is added at greater than 0.01 wt% its effect will be saturated, and therefore B is added at a maximum of 0.01 wt%.

**[0041]** Ca, REM: Ca is added to at least 0.0005 wt% for improved press formability (especially hole expansion ratio) by shape control (spheroidization) of sulfide-based inclusions, and the maximum amount thereof to be added is 0.01 wt% in consideration of effect saturation and the adverse effect due to increase in the aforementioned inclusions (reduced hole expansion ratio). For the same reasons, REM is added in an amount of from 0.005% to 0.05 wt%.

**[0042]** S: The amount of S is no greater than 0.01 wt%, and preferably no greater than 0.003 wt%, from the standpoint of press formability (especially hole expansion ratio) by sulfide-based inclusions, and reduced spot weldability.

**[0043]** The method of applying the pre-deformation according to the invention will now be explained. The pre-deformation is working with a tempering rolling or tension leveler which is applied to the steel sheet material prior to its press forming. In this case, either or both a tempering roller and tension leveler may be used. That is, the means used may include a tempering rolling, a tension leveler, or a tempering roller and tension leveler. The steel sheet material may also be subjected to press forming after being worked with a tempering rolling or tension leveler. The amount of pre-deformation applied with the tempering rolling and/or tension leveler, i.e. the degree of plastic deformation (T), will differ depending on the initial dislocation density, and T should be small if the initial density is large. Also, with few solid solution elements the introduced dislocations cannot be fixed, and high dynamic deformation properties cannot be guaranteed. Consequently, it was found that the plastic deformation (T) is determined based on the ratio between the yield strength YS(0) and the tensile strength TS'(5) in the static tensile test with pre-deformation at 5% of equivalent strain or after further bake hardening treatment (BH treatment), or YS(0)/TS'(5). That is, YS(0)/TS'(5) is an indicator of the sum of the initial dislocation density and the dislocation density introduced by 5% deformation, and the amount of the solid solution elements; it may be concluded that a smaller YS(0)/TS'(5) means a higher initial dislocation density and more of the solid solution elements. YS(0)/TS'(5) is therefore no greater than 0.7, and is preferably provided according to the following equation:

$$2.5\ \{YS(0)/TS'(5) - 0.5\} + 15 \geq T \geq 2.5\ \{YS(0)/TS'(5) - 0.5\} + 0.5$$

wherein the upper limit for T is determined from the standpoint of press formability including impact absorption property and flexibility.

**[0044]** A method of producing a dual-phase type high strength hot rolled steel sheet and a cold rolled steel sheet with excellent dynamic deformation properties according to the invention will now be explained. In this production method, a continuous cast slab is fed directly from casting to a hot rolling step, or is hot rolled upon reheating after momentary cooling. Thin gauge continuous casting and continuous hot rolling techniques (endless hot rolling) may be applied for the hot rolling in addition to normal continuous casting, but in order to avoid a lower ferrite volume fraction and a coarser average grain size of the thin steel sheet microstructure, the bar (cast strip) thickness at the hot rolling approach side (the initial steel bar thickness) is preferred to be at least 25 mm. At less than 25 mm, the mean circle equivalent size of ferrite of the steel sheet is made coarser, while it is also a disadvantage against obtaining the desired martensite. The final pass rolling speed for the hot rolling is preferred to be at least 500 mpm and more preferably at least 600 mpm, in light of the problems described above. At less than 500 mpm, the mean circle equivalent diameter of ferrite of the steel sheet is made coarser, while it is also a disadvantage against obtaining the desired martensite.

**[0045]** The finishing temperature for the hot rolling is from $Ar_3$ - 50°C to $Ar_3$ + 120°C. At lower than $Ar_3$ - 50°C, deformed ferrite is produced, with inferior work hardening property and press formability. At higher than $Ar_3$ + 120°C, and the mean circle equivalent size of ferrite of the steel sheet is made coarser, while it is also becomes difficult to obtain the desired martensite.

**[0046]** The average cooling rate for cooling in the run-out table is least 5°C/sec. At less than 5°C/sec it becomes difficult to obtain the desired martensite.

**[0047]** The coiling temperature is no higher than 350°C. At higher than 350°C it becomes difficult to obtain the desired martensite.

**[0048]** According to the invention, it was found particularly that a correlation exists between the finishing temperature in the hot rolling step, the finishing approach temperature and the coiling temperature. That is, as shown in Fig. 10 and Fig. 11, specific conditions exist which are determined primarily between the finishing temperature, finishing approach temperature and the coiling temperature. Specifically, the hot rolling is carried out so that when the finishing temperature for hot rolling is in the range of $Ar_3$ - 50°C to $Ar_3$ + 120°C, the metallurgy parameter A satisfies inequalities (1) and (2). The above-mentioned metallurgy parameter A may be expressed by the following equation.

$$A = \varepsilon^{*} \times \exp\{(75282 - 42745 \times C_{eq})/[1.978 \times (FT + 273)]\}$$

where

FT: finishing temperature (°C)
Ceq: carbon equivalents = C + $Mn_{eq}$/6 (%)
$Mn_{eq}$: manganese equivalents = Mn + (Ni + Cr + Cu + Mo)/2 (%)
$\varepsilon^{*}$ : final pass strain rate ($s^{-1}$)

$$\varepsilon^{*} = (v/\sqrt{R \times h_1}) \times (1/\sqrt{r}) \times \ln\{1/(1-r)\}$$

$h_1$: final pass approach sheet thickness
$h_2$: final pass exit sheet thickness
r: ($h_1$ - $h_2$)/$h_1$
R : roll radius
v : final pass exit speed

$$\Delta T\text{: finishing temperature (finishing final pass exit temperature) - finishing approach temperature (finishing first pass approach temperature)}$$

$$Ar_3\text{: } 901 - 325\ C\% + 33\ Si\% - 92\ Mn_{eq}$$

**[0049]** Thereafter, it is preferred for the average cooling rate on the run-out table to be at least 5°C/sec, and the coiling to be carried out under conditions such that the relationship between the metallurgy parameter A and the coiling temperature (CT) satisfies inequality (3).

$$9 \leq \log A \leq 18 \qquad (1)$$

$$\Delta T \leq 21 \times \log A - 61 \qquad (2)$$

$$CT \leq 6 \times \log A + 242 \qquad (3)$$

**[0050]** In inequality (1) above, a log A of less than 9 is unacceptable from the viewpoint of production of retained martensite and refinement of the microstructure, while it will also result in an inferior dynamic deformation resistance σdyn and 5~10% work hardening property. Also, if log A is to be greater than 18, massive equipment will be required to achieve it. With inequality (2), if the condition of inequality (2) is not satisfied it will be impossible to obtain the desired martensite, and the dynamic deformation resistance σdyn and 5~10% work hardening property, etc. will be inferior. The lower limit for ΔT is more flexible with a lower log A as indicated by inequality (2). Furthermore, if the relationship with the coiling temperature in inequality (3) is not satisfied, there will be an adverse effect on ensuring the amount of martensite, while the retained γ will be excessively stable even if retained γ can be obtained, it will be impossible to obtain the desired martensite during deformation, and the dynamic deformation resistance σdyn and 5~10% work hardening property, etc. will be inferior. The limit for the coiling temperature is more flexible with a higher log A.

**[0051]** The cold rolled sheet according to the invention is then subjected to the different steps following hot-rolling and coiling and is cold rolled and subjected to annealing. The annealing is ideally continuous annealing through an annealing cycle such as shown in Fig. 12, and during the annealing of the continuous annealing step, it must be kept for at least

10 seconds in the temperature range of $Ac_1$ - $Ac_3$. At less than $Ac_1$ austenite will not be produced and it will therefore be impossible to obtain martensite thereafter, while at greater than $Ac_3$ the austenite monophase structure will be coarse, and it will therefore be impossible to obtain the desired average grain size for the martensite. Also, at less than 10 seconds the austenite production will be insufficient, making it impossible to obtain the desired martensite thereafter. The maximum residence time is preferably no greater than 200 seconds, from the standpoint of avoiding addition to the equipment and coarsening of the microstructure. The cooling after this annealing must be at an average cooling rate of at least 5°C/sec. At less than 5°C/sec the desired space factor for the martensite cannot be achieved. Although there is no particular upper limit here, it is preferably 300°C/sec when considering temperature control during the cooling.

**[0052]** According to the invention, the cooled steel sheet is heated to a temperature To from $Ac_1$ - $Ac_3$ in the continuous annealing cycle shown in Fig. 12, and cooled under cooling conditions provided by a method wherein cooling to a secondary cooling start temperature Tq in the range of 550°C-To at the primary cooling rate of 1~10°C/sec is followed by cooling to a secondary cooling end temperature Te which is no higher than a temperature Tem which is determined by the chemical compositions of the steel and annealing temperature To, at a secondary cooling rate of 10~200°C/sec. This is a method whereby the cooling end temperature Te in the continuous annealing cycle shown in Fig.12 is represented as a function of the chemical compositions and annealing temperature, and is kept under a given critical value. After cooling to Te, the temperature is preferably held in a range of Te - 50°C to 400°C for up to 20 minutes prior to cooling to room temperature.

**[0053]** Here, Tem is the martensite transformation start temperature for the retained austenite at the quenching start point Tq. That is, Tem is defined by Tem = T1 -

**[0054]** T2, or the difference between the value excluding the effect of the C concentration in the austenite (T1) and the value indicating the effect of the C concentration (T2). Here, T1 is the temperature calculated from the solid solution element concentration excluding C, and T2 is the temperature calculated from the C concentration in the retained austenite at $Ac_1$ and $Ac_3$ determined by the chemical compositions of the steel and Tq determined by the annealing temperature To. Ceq represents the carbon equivalents in the retained austenite at the annealing temperature To. Thus, T1 is expressed as:

$$T1 = 561 - 33 \times \{Mn\% + (Ni + Cr + Cu + Mo)/2\}$$

and T2 is expressed in terms of:

$$Ac_1 = 723 - 0.7 \times Mn\% - 16.9 \times Ni\% + 29.1 \times Si\% + 16.9 \times Cr\%,$$

$$Ac_3 = 910 - 203 \times (C\%)^{1/2} - 15.2 \times Ni\% + 44.7 \times Si\% + 104 \times V\% + 31.5 \times Mo\% - 30 \times Mn\% - 11 \times Cr\% - 20 \times Cu\% + 70 \times P\% + 40 \times Al\% + 400 \times Ti\%,$$

and the annealing temperature To, and when

$$Ceq^{*} = (Ac_3 - Ac_1) \times C/(To - Ac_1) + (Mn + Si/4 + Ni/7 + Cr + Cu + 1.5\ Mo)/6$$

is greater than 0.6, T2 = 474 x ($Ac_3$ - $Ac_1$) x C/(To - $Ac_1$),
and when it is 0.6 or less, T2 = 474 x ($Ac_3$ - $Ac_1$) x C/{3 x ($Ac_3$ - $Ac_1$) x C + [(Mn + Si/4 + Ni/7 + Cr + Cu + 1.5 Mo)/2 - 0.85] x (To - $Ac_1$)}.

**[0055]** In other words, when Te is equal to or greater than Tem, the desired martensite cannot be obtained. Also, if Toa is 400°C or higher, the martensite obtained by cooling is tempered, making it impossible to achieve satisfactory dynamic properties and press formability. On the other hand, if Toa is less than Te - 50°C, additional cooling equipment is necessary, and greater variation will result in the material due to the difference between the temperature of the continuous annealing furnace and the temperature of the steel sheet; this temperature was therefore determined as the lower limit. Also, the upper limit for the holding time was determined to be 20 minutes, because when it is longer than 20 minutes it becomes necessary to expand the equipment.

**[0056]** By employing the chemical composition and production method described above, it is possible to produce a dual-phase type high-strength steel sheet with excellent dynamic deformation properties, wherein the microstructure of the steel sheet is a composite microstructure wherein the dominating phase is ferrite, and the second phase is another low temperature product phase containing martensite at a volume fraction from 3%~50% after shaping and working at 5% equivalent strain, and wherein the difference between the quasi-static deformation strength σs when deformed in a strain rate range of $5 \times 10^{-4}$ - $5 \times 10^{-3}$ (1/s) after pre-deformation of more than 0% and less than or equal to 10% of equivalent strain, and the dynamic deformation strength σd measured in a strain rate range of $5 \times 10^{2}$ - $5 \times 10^{3}$ (1/s) after the aforementioned pre-deformation, i.e. (σd - σs), is at least 60 MPa, and the work hardening coefficient at 5~10% strain is at least 0.13. The steel sheets according to the invention may be made into any desired product by annealing, tempering rolling, electronic coating or hot-dip coating.

Examples

**[0057]** The present invention will now be explained by way of examples.

(Example 1)

**[0058]** The 26 steel materials listed in Table 1 (steel nos. 1~26) were heated to 1050~1250°C and subjected to hot rolling, cooling and coiling under the production conditions listed in Table 2, to produce hot rolled steel sheets. As shown in Table 3, the steel sheets satisfying the chemical composition conditions and production conditions according to the invention have a dual-phase structure with a martensite volume fraction of at least 3% and no greater than 50%, and as shown in Fig. 4, the mechanical properties of the hot rolled steel sheets indicated excellent impact absorption properties as represented by a work hardening coefficient of at least 0.13 at 5~10% strain, $\sigma d - \sigma s \geq 60$ MPa, and $\sigma dyn \geq 0.766 \times TS + 250$, while also having suitable press formability and weldability.

Table 1 Chemical compositions of steels

| Steel No. | Chemical compositions (wt%) | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C | Si | Mn | P | S | Al | N | Si+Al+P | Ni | Cr | Cu | Mo | Nb | Ti | V | B | Ca | REM | Mn+Cr | Ceq | Mneq |
| 1 | 0.08 | 1.01 | 1.20 | 0.02 | 0.003 | 0.03 | 0.003 | 1.06 | | 0.10 | | | | | | | | | 1.30 | 0.29 | 1.25 |
| 2 | 0.08 | 1.01 | 1.20 | 0.02 | 0.003 | 0.03 | 0.002 | 1.06 | | 0.10 | | | | | | | 0.004 | | 1.30 | 0.29 | 1.25 |
| 3 | 0.05 | 1.20 | 1.30 | 0.01 | 0.001 | 0.01 | 0.003 | 1.22 | | | | | | | | | | | 1.30 | 0.27 | 1.30 |
| 4 | 0.15 | 1.51 | 1.01 | 0.02 | 0.002 | 0.02 | 0.002 | 1.55 | | | | | | | | | | | 1.01 | 0.32 | 1.01 |
| 5 | 0.08 | 0.01 | 1.30 | 0.02 | 0.003 | 1.20 | 0.003 | 1.23 | | | | | | | | | | | 1.30 | 0.30 | 1.30 |
| 6 | 0.07 | 0.01 | 1.60 | 0.08 | 0.003 | 0.03 | 0.003 | 0.12 | | | | | | | | | | | 1.60 | 0.34 | 1.60 |
| 7 | 0.07 | 0.50 | 1.10 | 0.07 | 0.002 | 0.01 | 0.002 | 0.58 | | | | | | | | | | | 1.10 | 0.25 | 1.10 |
| 8 | 0.08 | 0.80 | 1.20 | 0.02 | 0.003 | 0.50 | 0.003 | 1.32 | | | | | | | | | | | 1.20 | 0.28 | 1.20 |
| 9 | 0.08 | 0.01 | 1.10 | 0.08 | 0.002 | 0.20 | 0.003 | 0.29 | | | | | | | | | | | 1.10 | 0.26 | 1.10 |
| 10 | 0.07 | 0.02 | 0.80 | 0.01 | 0.001 | 0.02 | 0.002 | 0.05 | | 0.40 | | | | | | | | | 1.20 | 0.24 | 1.00 |
| 11 | 0.10 | 1.00 | 1.80 | 0.02 | 0.001 | 0.02 | 0.002 | 1.04 | | | | | | | | | | | 1.80 | 0.40 | 1.80 |
| 12 | 0.08 | 1.01 | 1.20 | 0.02 | 0.002 | 0.03 | 0.002 | 1.06 | | 0.10 | | | | | | | | 0.005 | 1.30 | 0.29 | 1.25 |
| 13 | 0.08 | 1.01 | 1.40 | 0.02 | 0.002 | 0.03 | 0.003 | 1.06 | | 0.10 | | | | | | | | | 1.50 | 0.32 | 1.45 |
| 14 | 0.08 | 1.01 | 1.20 | 0.02 | 0.002 | 0.03 | 0.003 | 1.06 | | 0.10 | | | | | | | | | 1.30 | 0.29 | 1.25 |
| 15 | 0.01 | 0.01 | 1.00 | 0.01 | 0.002 | 0.01 | 0.005 | 0.03 | | | | | | | | | | | 1.00 | 0.18 | 1.00 |
| 16 | 0.06 | 0.90 | 1.20 | 0.02 | 0.001 | 0.01 | 0.002 | 0.93 | 0.5 | | 1.0 | | | | | | | | 1.20 | 0.39 | 1.95 |
| 17 | 0.07 | 0.90 | 0.90 | 0.02 | 0.001 | 0.01 | 0.003 | 0.93 | | | | 0.5 | | | | | | | 0.90 | 0.26 | 1.15 |
| 18 | 0.09 | 2.16 | 1.91 | 0.01 | 0.003 | 0.03 | 0.003 | 2.20 | | 0.09 | | | 0.02 | | | | | | 2.00 | 0.42 | 1.96 |
| 19 | 0.06 | 0.80 | 1.10 | 0.02 | 0.002 | 0.01 | 0.002 | 0.83 | | | | | | | 0.05 | | | | 1.10 | 0.24 | 1.10 |
| 20 | 0.07 | 0.90 | 1.20 | 0.01 | 0.001 | 0.01 | 0.003 | 0.92 | | | | | | | | 0.003 | | | 1.20 | 0.27 | 1.20 |
| 21 | 0.05 | 1.00 | 1.36 | 0.01 | 0.003 | 0.02 | 0.003 | 1.03 | | 0.90 | | | | | | | | | 2.26 | 0.35 | 1.81 |
| 22 | 0.07 | 0.02 | 1.80 | 0.08 | 0.003 | 0.02 | 0.002 | 0.12 | | | | | | | | | | | 1.80 | 0.37 | 1.80 |
| 23 | 0.10 | 0.20 | 0.81 | 0.08 | 0.003 | 0.02 | 0.002 | 0.30 | | | | | | | | | | | 0.81 | 0.24 | 0.81 |
| 24 | 0.09 | 0.20 | 1.15 | 0.01 | 0.005 | 0.05 | 0.003 | 0.26 | | | | | | | | | | | 1.15 | 0.28 | 1.15 |
| 25 | 0.08 | 1.61 | 1.71 | 0.01 | 0.003 | 0.03 | 0.003 | 1.65 | | | | | | 0.12 | | | | | 1.71 | 0.37 | 1.71 |
| 26 | 0.40 | 0.002 | 0.10 | 0.005 | 0.010 | 0.01 | 0.003 | 0.017 | | | | | | | | | | | 0.10 | 0.42 | 0.10 |

Underlined data indicate values outside of the range of the invention.

Table 1 (cont.) Chemical compositions of steels

| Steel No. | Transformation temperature °C | | | Type |
|---|---|---|---|---|
| | Ac1 | Ac3 | Ar3 | |
| 1 | 741 | 863 | 793 | present invention |
| 2 | 741 | 863 | 793 | present invention |
| 3 | 744 | 880 | 805 | present invention |
| 4 | 756 | 871 | 809 | present invention |
| 5 | 709 | 863 | 756 | present invention |
| 6 | 706 | 816 | 731 | present invention |
| 7 | 726 | 851 | 794 | present invention |
| 8 | 733 | 874 | 791 | present invention |
| 9 | 712 | 834 | 774 | present invention |
| 10 | 722 | 830 | 787 | present invention |
| 11 | 733 | 839 | 736 | present invention |
| 12 | 741 | 863 | 793 | present invention |
| 13 | 739 | 857 | 775 | comparative example |
| 14 | 741 | 863 | 793 | comparative example |
| 15 | 713 | 861 | 806 | comparative example |
| 16 | 728 | 839 | 732 | present invention |
| 17 | 740 | 887 | 802 | present invention |
| 18 | 767 | 889 | 763 | present invention |
| 19 | 735 | 870 | 807 | present invention |
| 20 | 736 | 862 | 798 | present invention |
| 21 | 753 | 860 | 751 | present invention |
| 22 | 704 | 810 | 713 | present invention |
| 23 | 720 | 837 | 801 | present invention |
| 24 | 717 | 826 | 773 | present invention |
| 25 | 752 | 923 | 771 | present invention |
| 26 | 722 | 779 | 762 | comparative example |

Table 2 Production conditions

| Steel No. | Hot rolling conditions | | | | | | | | Cooling conditions | | Coiling conditions | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Finishing temp. °C | Initial steel strip thickness (mm) | Final pass rolling speed (mpm) | Final sheet thickness (mm) | Strain rate (/sec) | log A calculated | ΔT °C | Inequality (2) | Aver. cooling rate (°C/sec) | Note | Coiling temp. °C | Inequality (3) |
| 1 | 880 | 50 | 1000 | 1.2 | 300 | 14.4 | 140 | o | 120 | #1 | 100 | o |
| 2 | 780 | 26 | 500 | 2.9 | 90 | 15.0 | 150 | o | 30 | #1 | 300 | o |
| 3 | 830 | 30 | 600 | 2.9 | 140 | 14.8 | 160 | o | 60 | | 200 | o |
| 4 | 820 | 28 | 700 | 1.4 | 190 | 14.6 | 155 | o | 70 | | 310 | o |
| 5 | 840 | 35 | 500 | 2.3 | 95 | 14.3 | 120 | o | 50 | | 150 | o |
| 6 | 845 | 40 | 600 | 2.3 | 145 | 14.1 | 140 | o | 60 | | 150 | o |
| 7 | 830 | 35 | 650 | 2.3 | 150 | 14.9 | 150 | o | 50 | | 150 | o |
| 8 | 825 | 38 | 750 | 1.6 | 190 | 14.9 | 60 | o | 60 | | 150 | o |
| 9 | 850 | 36 | 600 | 1.8 | 150 | 14.6 | 170 | o | 40 | | 150 | o |
| 10 | 840 | 40 | 600 | 1.8 | 150 | 15.0 | 130 | o | 50 | | 150 | o |
| 11 | 800 | 26 | 550 | 1.8 | 145 | 14.0 | 110 | o | 40 | | 200 | o |
| 12 | 845 | 32 | 600 | 1.8 | 150 | 14.5 | 135 | o | 50 | | 100 | o |
| 13 | 930 | 20 | 500 | 1.8 | 135 | 13.3 | 100 | o | 15 | | 500 | x |
| 14 | 700 | 26 | 300 | 1.8 | 100 | 16.1 | 125 | o | 15 | | 320 | o |
| 15 | 850 | 30 | 600 | 1.8 | 150 | 15.4 | 150 | o | 4 | | 310 | o |
| 16 | 840 | 28 | 500 | 1.4 | 150 | 13.7 | 80 | o | 30 | | 150 | o |
| 17 | 830 | 28 | 500 | 1.4 | 145 | 14.9 | 100 | o | 30 | | 150 | o |
| 18 | 860 | 30 | 700 | 1.4 | 190 | 13.4 | 50 | o | 35 | | 100 | o |
| 19 | 840 | 30 | 700 | 1.4 | 180 | 15.0 | 180 | o | 30 | | 200 | o |
| 20 | 830 | 30 | 700 | 1.4 | 190 | 14.9 | 130 | o | 30 | | 200 | o |
| 21 | 840 | 30 | 700 | 1.4 | 190 | 14.1 | 140 | o | 30 | | 200 | o |
| 22 | 780 | 30 | 700 | 1.4 | 190 | 14.6 | 90 | o | 25 | | 200 | o |

(continued)

| Steel No. | Hot rolling conditions | | | | | | | | Cooling conditions | | Coiling conditions | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Finishing temp. °C | Initial steel strip thickness (mm) | Final pass rolling speed (mpm) | Final sheet thickness (mm) | Strain rate (/sec) | log A calculated | ΔT °C | Inequality (2) | Aver. cooling rate (°C/sec) | Note | Coiling temp. °C | Inequality (3) |
| 23 | 800 | 30 | 700 | 1.4 | 190 | 15.6 | 110 | o | 25 | | 200 | o |
| 24 | 810 | 30 | 700 | 1.4 | 190 | 15.0 | 120 | o | 25 | | 200 | o |
| 25 | 820 | 30 | 700 | 1.4 | 190 | 14.2 | 40 | o | 25 | | 200 | o |
| 26 | 880 | 30 | 700 | 1.4 | 190 | 13.2 | 220 | x | 15 | | 320 | o |
| Underlined data indicate values outside of the range of the invention. *1: 750° C~100 C at 15°C/sec. | | | | | | | | | | | | |

Table 3 Microstructure of steels

| Steel No. | Dominant phase | | Ferrite | Martensite | |
|---|---|---|---|---|---|
| | Phase | Circle equivalent diameter (μm) | Volume fraction (%) | Circle equivalent diameter (μm) | Volume fraction after 5% working (%) |
| 1 | ferrite | 5.5 | 80 | 2.5 | 15 |
| 2 | ferrite | 4.0 | 90 | 1.8 | 8 |
| 3 | ferrite | 5.0 | 85 | 2.2 | 10 |
| 4 | ferrite | 4.0 | 80 | 1.8 | 4 |
| 5 | ferrite | 4.5 | 80 | 2.0 | 20 |
| 6 | ferrite | 5.0 | 85 | 2.2. | 15 |
| 7 | ferrite | 4.5 | 90 | 2 | 10 |
| 8 | ferrite | 4.5 | 90 | 2 | 10 |
| 9 | ferrite | 5.0 | 90 | 2.2 | 10 |
| 10 | ferrite | 5.0 | 90 | 2.2 | 10 |
| 11 | ferrite | 4.0 | 80 | 1.7 | 20 |
| 12 | ferrite | 5.0 | 90 | 2.2 | 10 |
| 13 | ferrite | 11.0 | 50 | - | 0 |
| 14 | ferrite | Worked structure | 90 | - | 0 |
| 15 | ferrite | 10.0 | 95 | - | 0 |
| 16 | ferrite | 4.4 | 90 | 1.9 | 10 |
| 17 | ferrite | 4.5 | 91 | 2 | 9 |
| 18 | ferrite | 3.4 | 78 | 1.4 | 22 |
| 19 | ferrite | 4.4 | 91 | 1.9 | 9 |
| 20 | ferrite | 4.3 | 88 | 1.8 | 12 |
| 21 | ferrite | 4.5 | 85 | 2 | 13 |
| 22 | ferrite | 4.4 | 84 | 1.9 | 11 |
| 23 | ferrite | 4.4 | 85 | 1.9 | 8 |
| 24 | ferrite | 4.4 | 85 | 1.8 | 12 |
| 25 | ferrite | 2.4 | 80 | 1 | 10 |
| 26 | bainite | 10.5 | 30 | - | 0 |

Underlined data indicate values outside of the range of the invention.

Table 4 Mechanical properties of steels

| Steel No. | Static tension (strain rate = 0.001/s) | | | | | | | | Pre-deformation and BH treatment | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | TS Mpa | YS Mpa | T.El % | TS' (5) Mpa | 5-10% n value | YS x n | YS/TS' (5) | TS x T.El Mpa·% | Form of pre-deformation | Equivalent strain % | BH treatment |
| 1 | 680 | 475 | 27 | 720 | 0.17 | 81 | 0.66 | 18360 | C-directional uniaxial tension | 5% | yes |
| 2 | 630 | 440 | 35 | 665 | 0.19 | 84 | 0.66 | 22050 | C-directional uniaxial tension | 5% | no |
| 3 | 580 | 405 | 32 | 610 | 0.18 | 73 | 0.66 | 18560 | L-directional uniaxial tension | 5% | yes |
| 4 | 780 | 545 | 28 | 815 | 0.19 | 104 | 0.67 | 21840 | C-directional uniaxial tension | 2% | yes |
| 5 | 700 | 455 | 29 | 740 | 0.20 | 91 | 0.61 | 20300 | C-directional uniaxial tension | 5% | yes |
| 6 | 660 | 430 | 30 | 695 | 0.19 | 82 | 0.62 | 19800 | C-directional uniaxial tension | 10% | yes |
| 7 | 650 | 420 | 31 | 685 | 0.21 | 88 | 0.61 | 20150 | C-directional uniaxial tension | 5% | yes |
| 8 | 620 | 400 | 32 | 645 | 0.21 | 84 | 0.62 | 19840 | C-directional uniaxial tension | 5% | yes |
| 9 | 640 | 415 | 31 | 675 | 0.18 | 75 | 0.61 | 19840 | C-directional uniaxial tension | 5% | yes |
| 10 | 670 | 435 | 30 | 710 | 0.19 | 83 | 0.61 | 20100 | C-directional uniaxial tension | 5% | yes |
| 11 | 850 | 510 | 24 | 885 | 0.21 | 107 | 0.58 | 20400 | C-directional uniaxial tension | 5% | yes |
| 12 | 650 | 420 | 31 | 685 | 0.20 | 84 | 0.61 | 20150 | Equal biaxial tension | 5% | yes |
| 13 | 520 | 494 | 31 | 530 | 0.12 | 59 | 0.93 | 16120 | C-directional uniaxial tension | 5% | yes |
| 14 | 500 | 375 | 28 | 515 | 0.10 | 38 | 0.73 | 14000 | Equal biaxial tension | 5% | yes |
| 15 | 420 | 310 | 36 | 430 | 0.12 | 37 | 0.72 | 15120 | L-directional uniaxial tension | 5% | yes |
| 16 | 650 | 390 | 31 | 685 | 0.20 | 78 | 0.57 | 20150 | L-directional uniaxial tension | 5% | yes |
| 17 | 640 | 380 | 30 | 670 | 0.21 | 80 | 0.57 | 19200 | L-directional uniaxial tension | 5% | yes |
| 18 | 840 | 505 | 27 | 870 | 0.16 | 81 | 0.58 | 22680 | L-directional uniaxial tension | 5% | yes |
| 19 | 660 | 405 | 28 | 695 | 0.20 | 81 | 0.58 | 18480 | L-directional uniaxial tension | 5% | yes |
| 20 | 660 | 400 | 29 | 690 | 0.20 | 80 | 0.58 | 19140 | L-directional uniaxial tension | 5% | yes |
| 21 | 660 | 480 | 28 | 695 | 0.15 | 72 | 0.69 | 18480 | L-directional uniaxial tension | 5% | yes |
| 22 | 620 | 290 | 31 | 650 | 0.25 | 73 | 0.45 | 19220 | L-directional uniaxial tension | 5% | yes |
| 23 | 640 | 420 | 29 | 670 | 0.18 | 76 | 0.63 | 18560 | L-directional uniaxial tension | 5% | yes |
| 24 | 640 | 380 | 29 | 675 | 0.19 | 72 | 0.56 | 18560 | L-directional uniaxial tension | 5% | yes |
| 25 | 820 | 615 | 23 | 875 | 0.15 | 92 | 0.70 | 18860 | L-directional uniaxial tension | 5% | yes |
| 26 | 400 | 290 | 30 | 410 | 0.10 | 29 | 0.71 | 12000 | L-directional uniaxial tension | 5% | yes |

Underlined data indicate values outside of the range of the invention.

*3 $\sigma dyn - (0.766 \times TS + 250)$

*4 $2.5(YS/TS'(5)-0.5) + 15 \geq$ plastic deformation $T \geq 2.5(YS/TS'(5)-0.5) + 0.5$

Table 4 (cont.) Mechanical properties of steels

| Steel No. | Static/dynamic tension after pre-deformation·BH treatment (strain rate = 1000/s) | | | | | | | Plastic deformation | | Other properties | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5% WH*1 Mpa | ΔYS*2 Mpa | σs Mpa | σd Mpa | σd-σs Mpa | σdyn Mpa | Inequality *3 | T % | Inequality *4 satisfied | Weldability | $d/d_0$ |
| 1 | 140 | 205 | 720 | 841 | 121 | 825 | 54.1 | 1.0 | o | OK | 1.31 |
| 2 | 150 | 215 | 665 | 788 | 123 | 771 | 38.4 | 1.0 | o | OK | 1.45 |
| 3 | 145 | 210 | 610 | 732 | 122 | 718 | 23.7 | 1.0 | o | OK | 1.54 |
| 4 | 80 | 150 | 800 | 923 | 123 | 903 | 55.5 | 1.0 | o | OK | 1.21 |
| 5 | 140 | 210 | 740 | 864 | 124 | 847 | 60.8 | 0.9 | o | OK | 1.27 |
| 6 | 155 | 260 | 710 | 833 | 123 | 830 | 74.4 | 0.9 | o | OK | 1.35 |
| 7 | 145 | 215 | 685 | 810 | 125 | 794 | 46.1 | 0.9 | o | OK | 1.37 |
| 8 | 140 | 215 | 645 | 770 | 125 | 755 | 30.1 | 0.9 | o | OK | 1.44 |
| 9 | 140 | 210 | 675 | 797 | 122 | 781 | 40.8 | 0.9 | o | OK | 1.39 |
| 10 | 140 | 210 | 710 | 833 | 123 | 818 | 54.8 | 0.9 | o | OK | 1.33 |
| 11 | 150 | 220 | 885 | 1010 | 125 | 992 | 90.9 | 0.8 | o | OK | 1.20 |
| 12 | 140 | 210 | 685 | 809 | 124 | 793 | 45.1 | 0.9 | o | OK | 1.40 |
| 13 | 15 | 20 | 530 | 575 | 45 | 565 | -83.3 | 1.6 | o | OK | 1.71 |
| 14 | 20 | 25 | 515 | 565 | 50 | 555 | -78.0 | 0.1 | x | OK | 1.18 |
| 15 | 25 | 35 | 430 | 485 | 55 | 476 | -95.7 | 1.2 | o | OK | 1.90 |
| 16 | 140 | 210 | 685 | 809 | 124 | 793 | 45.1 | 0.7 | o | OK | 1.37 |
| 17 | 140 | 215 | 670 | 795 | 125 | 780 | 39.8 | 0.7 | o | OK | 1.39 |
| 18 | 145 | 210 | 870 | 989 | 119 | 972 | 78.6 | 0.8 | o | OK | 1.20 |
| 19 | 140 | 210 | 695 | 819 | 124 | 804 | 48.4 | 0.8 | o | OK | 1.35 |
| 20 | 140 | 210 | 690 | 814 | 124 | 798 | 42.4 | 0.8 | o | OK | 1.35 |
| 21 | 125 | 195 | 695 | 813 | 118 | 799 | 43.4 | 1.0 | o | OK | 1.35 |
| 22 | 145 | 215 | 650 | 779 | 129 | 765 | 40.1 | 0.4 | o | OK | 1.44 |
| 23 | 130 | 200 | 670 | 792 | 122 | 777 | 36.8 | 0.9 | o | OK | 1.39 |
| 24 | 140 | 210 | 675 | 798 | 123 | 784 | 43.8 | 0.7 | o | OK | 1.35 |
| 25 | 120 | 190 | 875 | 993 | 118 | 977 | 98.9 | 1.1 | o | OK | 1.20 |
| 26 | 25 | 35 | 410 | 445 | 35 | 437 | -119.4 | 1.1 | o | poor | 1.50 |

Underlined data indicate values outside of the range of the invention.

*3: σdyn - (0.766 x TS + 250) *4: 2.5(YS/TS' (5)-0.5) + 15 ≥ plastic deformation T ≥ 2.5(YS/TS' (5)-0.5) + 0.5

(Example 2)

**[0059]** The 22 steel materials listed in Table 5 (steel nos. 27-48) were heated to 1050~1250°C and subjected to hot rolling, cooling and coiling, followed by acid pickling and then cold rolling under the conditions listed in Table 6 to produce cold rolled steel sheets. Temperatures $Ac_1$ and $Ac_3$ were then calculated from the chemical compositions for each steel, and the sheets were subjected to heating, cooling and holding under the annealing conditions listed in Table 6, prior to cooling to room temperature. As shown in Table 7, the steel sheets satisfying the chemical composition conditions and production conditions according to the invention have a dual-phase structure with a martensite volume fraction of at least 3% and no greater than 50% and, as shown in Fig. 8, the mechanical properties of the hot-rolled steel sheets indicated excellent impact absorption properties as represented by a work hardening coefficient of at least 0.13 at 5~10% strain, $\sigma d - \sigma s \geq 60$ MPa, and $\sigma dyn \geq 0.766 \times TS + 250$, while also having suitable press formability and weldability.

Table 5 Chemical compositions of steel

| Steel No. | Chemical compositions (wt%) | | | | | | | | | | | | | | | | | | | Transformation temperature °C | | | Type |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C | Si | Mn | P | S | Al | N | Al+Si +P | Ni | Cr | Cu | Mo | Nb | Ti | V | B | Mn+Cr | Ceq | Mneq | Ac1 | Ac3 | Ar3 | |
| 27 | 0.01 | 1.00 | 0.10 | 0.01 | 0.003 | 0.04 | 0.003 | 1.05 | | | | | | | | | 0.10 | 0.03 | 0.10 | 751 | 934 | 922 | comp. ex. |
| 28 | 0.05 | 0.90 | 1.20 | 0.01 | 0.005 | 0.05 | 0.002 | 0.96 | | | | | | | | | 1.20 | 0.25 | 1.20 | 736 | 872 | 804 | invention |
| 29 | 0.05 | 0.90 | 1.20 | 0.01 | 0.005 | 0.05 | 0.002 | 0.96 | | | | | | | | | 1.20 | 0.25 | 1.20 | 736 | 872 | 804 | comp. ex. |
| 30 | 0.05 | 0.90 | 1.20 | 0.01 | 0.005 | 0.05 | 0.002 | 0.96 | | | | | | | | | 1.20 | 0.25 | 1.20 | 736 | 872 | 804 | comp. ex. |
| 31 | 0.05 | 1.30 | 1.20 | 0.01 | 0.002 | 0.04 | 0.003 | 1.35 | | | | | | | | | 1.20 | 0.25 | 1.20 | 748 | 889 | 817 | invention |
| 32 | 0.08 | 1.00 | 1.20 | 0.01 | 0.003 | 0.05 | 0.002 | 1.06 | | | | | | | | | 1.20 | 0.28 | 1.20 | 739 | 864 | 798 | invention |
| 33 | 0.08 | 0.20 | 0.70 | 0.01 | 0.003 | 0.04 | 0.003 | 0.25 | | | | | | | | | 0.70 | 0.20 | 0.70 | 721 | 843 | 817 | invention |
| 34 | 0.10 | 0.02 | 2.10 | 0.01 | 0.002 | 0.03 | 0.003 | 0.06 | | | | | | | | | 2.10 | 0.45 | 2.10 | 701 | 785 | 676 | invention |
| 35 | 0.08 | 0.80 | 1.00 | 0.01 | 0.003 | 1.20 | 0.002 | 2.01 | | | | | | | | | 1.00 | 0.25 | 1.00 | 736 | 907 | 809 | invention |
| 36 | 0.05 | 0.50 | 1.00 | 0.01 | 0.005 | 0.80 | 0.003 | 1.31 | | | | | | | | | 1.00 | 0.22 | 1.00 | 727 | 890 | 809 | invention |
| 37 | 0.05 | 1.00 | 1.00 | 0.01 | 0.003 | 0.05 | 0.002 | 1.06 | 0.9 | | | | | | | | 1.00 | 0.29 | 1.45 | 726 | 869 | 784 | invention |
| 38 | 0.05 | 1.00 | 1.00 | 0.01 | 0.005 | 0.04 | 0.003 | 1.05 | | | 1.0 | | | | | | 1.00 | 0.30 | 1.50 | 741 | 862 | 780 | invention |
| 39 | 0.05 | 1.00 | 1.00 | 0.01 | 0.003 | 0.04 | 0.003 | 1.05 | | | | 0.1 | | | | | 1.00 | 0.23 | 1.05 | 741 | 885 | 821 | invention |
| 40 | 0.05 | 1.00 | 1.50 | 0.01 | 0.005 | 0.05 | 0.002 | 1.06 | | 1.0 | | | | | | | 2.50 | 0.38 | 2.00 | 753 | 856 | 734 | invention |
| 41 | 0.10 | 1.00 | 1.50 | 0.01 | 0.003 | 0.46 | 0.002 | 1.47 | | | | | 0.04 | | | | 1.50 | 0.35 | 1.50 | 736 | 865 | 764 | invention |
| 42 | 0.10 | 1.00 | 1.50 | 0.01 | 0.005 | 0.04 | 0.002 | 1.05 | | | | | | 0.04 | | | 1.50 | 0.35 | 1.50 | 736 | 864 | 764 | invention |
| 43 | 0.10 | 1.00 | 1.50 | 0.10 | 0.003 | 0.05 | 0.003 | 1.15 | | | | | | 0.01 | 0.04 | | 1.50 | 0.35 | 1.50 | 736 | 863 | 764 | invention |
| 44 | 0.10 | 1.00 | 1.50 | 0.01 | 0.003 | 0.04 | 0.003 | 1.05 | | | | | 0.02 | | | 0.002 | 1.50 | 0.35 | 1.50 | 736 | 848 | 764 | invention |
| 45 | 0.10 | 0.01 | 1.50 | 0.003 | 0.003 | 0.002 | 0.003 | 0.015 | | | | | | | | | 1.50 | 0.35 | 1.50 | 707 | 802 | 731 | comp. ex. |
| 46 | 0.35 | 1.00 | 1.20 | 0.01 | 0.002 | 0.05 | 0.003 | 1.06 | | | | | | | | | 1.20 | 0.55 | 1.20 | 739 | 801 | 710 | comp. ex. |
| 47 | 0.05 | 0.80 | 2.50 | 0.01 | 0.003 | 0.04 | 0.002 | 0.85 | | 2.0 | | | | | | | 4.50 | 0.63 | 3.50 | 753 | 806 | 589 | comp. ex. |
| 48 | 0.08 | 3.50 | 1.50 | 0.25 | 0.003 | 0.80 | 0.003 | 4.55 | | | | | | | | | 1.50 | 0.33 | 1.50 | 809 | 1014 | 853 | comp. ex. |

Underlined data indicate values outside of the range of the invention.

Table 7 Microstructure of steels

| Steel No. | Dominant phase | | Ferrite | Martensite | |
|---|---|---|---|---|---|
| | Phase | Circle equivalent diameter (μm) | Volume fraction (%) | Circle equivalent diameter (μm) | Volume fraction after 5% working (%) |
| 27 | ferrite | 9.8 | 100 | -- | 0 |
| 28 | ferrite | 6.4 | 86 | 3.2 | 12 |
| 29 | ferrite | 6.4 | 95 | -- | 1 |
| 30 | ferrite | 6.4 | 94 | -- | 0 |
| 31 | ferrite | 5.3 | 89 | 3.1 | 11 |
| 32 | ferrite | 4.8 | 82 | 2.8 | 15 |
| 33 | ferrite | 5.1 | 84 | 2.9 | 12 |
| 34 | ferrite | 4.8 | 75 | 2.2 | 18 |
| 35 | ferrite | 5.1 | 90 | 2.3 | 10 |
| 36 | ferrite | 5.5 | 90 | 2.8 | 8 |
| 37 | ferrite | 6.2 | 89 | 3.1 | 11 |
| 38 | ferrite | 5.8 | 81 | 3.0 | 16 |
| 39 | ferrite | 5.6 | 78 | 3.2 | 18 |
| 40 | ferrite | 5.6 | 87 | 3.2 | 13 |
| 41 | ferrite | 4.2 | 80 | 1.7 | 16 |
| 42 | ferrite | 4.5 | 78 | 2.1 | 18 |
| 43 | ferrite | 4.3 | 79 | 2.2 | 19 |
| 44 | ferrite | 5.0 | 79 | 2.3 | 13 |
| 45 | ferrite | 4.9 | 81 | 2.1 | 1 |
| 46 | ferrite | 4.1 | 42 | 2.4 | 35 |
| 47 | ferrite | 4.6 | 51 | 2.6 | 25 |
| 48 | ferrite | 5.6 | 88 | 2.6 | 12 |
| Underlined data indicate values outside of the range of the invention. | | | | | |

Table 8 Mechanical properties c steels

| Steel No. | Static tension (strain rate = 0.001/s) | | | | | | | | Pre-deformation and BH treatment | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | TS Mpa | YS Mpa | T.El % | TS' (5) Mpa | 5-10% n value | YS x n | YS/TS' (5) | TS x T.El Mpa·% | Form of pre-deformation | Equivalent strain % | BH treatment |
| 27 | 357 | 243 | 48 | 357 | 0.28 | 68 | 0.68 | 17136 | C-directional uniaxial tension | 5 | yes |
| 28 | 592 | 349 | 34 | 630 | 0.24 | 84 | 0.55 | 20128 | C-directional uniaxial tension | 5 | no |
| 29 | 603 | 457 | 32 | 612 | 0.20 | 91 | 0.75 | 19296 | C-directional uniaxial tension | 5 | no |
| 30 | 583 | 472 | 26 | 591 | 0.15 | 71 | 0.80 | 15158 | C-directional uniaxial tension | 5 | no |
| 31 | 599 | 341 | 33 | 621 | 0.23 | 79 | 0.55 | 19767 | L-directional uniaxial tension | 10 | yes |
| 32 | 641 | 359 | 34 | 690 | 0.23 | 83 | 0.52 | 21794 | C-directional uniaxial tension | 5 | yes |
| 33 | 558 | 340 | 36 | 597 | 0.26 | 88 | 0.57 | 20088 | C-directional uniaxial tension | 5 | yes |
| 34 | 640 | 397 | 33 | 650 | 0.22 | 87 | 0.61 | 21120 | C-directional surface strain tension | 3 | yes |
| 35 | 611 | 354 | 35 | 633 | 0.23 | 82 | 0.56 | 21385 | C-directional uniaxial tension | 5 | yes |
| 36 | 589 | 324 | 36 | 600 | 0.24 | 78 | 0.54 | 21204 | C-directional uniaxial tension | 5 | yes |
| 37 | 634 | 361 | 33 | 657 | 0.21 | 76 | 0.55 | 20922 | Equal biaxial tension | 10 | yes |
| 38 | 625 | 388 | 31 | 668 | 0.19 | 74 | 0.58 | 19375 | C-directional uniaxial tension | 5 | yes |
| 39 | 689 | 434 | 29 | 712 | 0.18 | 78 | 0.61 | 19981 | L-directional uniaxial tension | 1 | no |
| 40 | 623 | 368 | 32 | 623 | 0.20 | 74 | 0.59 | 19936 | C-directional uniaxial tension | 1 | yes |
| 41 | 709 | 425 | 26 | 721 | 0.17 | 72 | 0.59 | 18434 | C-directional uniaxial tension | 5 | yes |
| 42 | 722 | 448 | 25 | 734 | 0.17 | 76 | 0.61 | 18050 | C-directional uniaxial tension | 5 | no |
| 43 | 731 | 468 | 25 | 755 | 0.16 | 75 | 0.62 | 18275 | Equal biaxial tension | 5 | yes |
| 44 | 715 | 465 | 26 | 726 | 0.16 | 74 | 0.64 | 18590 | C-directional uniaxial tension | 5 | yes |
| 45 | 648 | 531 | 25 | 681 | 0.12 | 64 | 0.78 | 16200 | C-directional uniaxial tension | 5 | yes |
| 46 | 1075 | 742 | 10 | 1075 | 0.08 | 59 | 0.69 | 10750 | C-directional uniaxial tension | 5 | yes |
| 47 | 712 | 484 | 21 | 712 | 0.11 | 53 | 0.68 | 14952 | C-directional uniaxial tension | 5 | yes |
| 48 | 792 | 475 | 22 | 792 | 0.14 | 67 | 0.60 | 17424 | C-directional uniaxial tension | 5 | yes |

Underlined data indicate values outside of the range of the invention.

Table 8 (cont.) Mechanical properties of steels

| Steel No. | Static/dynamic tension after pre-deformation·BH treatment (strain rate = 1000/s) | | | | | | | Plastic deformation | | Weldability |
|---|---|---|---|---|---|---|---|---|---|---|
| | 5% WH*1 Mpa | ΔYS*2 Mpa | $\sigma$s Mpa | $\sigma$d Mpa | $\sigma$d-$\sigma$s Mpa | $\sigma$dyn Mpa | Inequality *3 | T % | Inequality *4 satisfied | |
| 27 | 90 | 116 | 390 | 438 | 48 | 412 | -111.5 | 1.0 | o | OK |
| 28 | 182 | 260 | 630 | 734 | 104 | 721 | 17.5 | 1.0 | o | OK |
| 29 | 102 | 127 | 620 | 662 | 42 | 645 | -66.9 | 1.5 | o | OK |
| 30 | 97 | 115 | 593 | 626 | 33 | 599 | -97.6 | 1.5 | o | OK |
| 31 | 240 | 297 | 740 | 846 | 106 | 798 | 89.2 | 1.0 | o | OK |
| 32 | 212 | 294 | 757 | 818 | 61 | 786 | 45.0 | 1.0 | o | OK |
| 33 | 143 | 212 | 607 | 686 | 79 | 680 | 2.6 | 1.0 | o | OK |
| 34 | 191 | 229 | 660 | 748 | 88 | 745 | 4.8 | 1.0 | o | OK |
| 35 | 201 | 275 | 658 | 756 | 98 | 742 | 24.0 | 1.0 | o | OK |
| 36 | 212 | 289 | 612 | 733 | 121 | 722 | 20.8 | 1.0 | o | OK |
| 37 | 257 | 318 | 703 | 790 | 87 | 776 | 40.4 | 1.0 | o | OK |
| 38 | 182 | 244 | 678 | 762 | 84 | 748 | 19.3 | 1.0 | o | OK |
| 39 | 199 | 239 | 712 | 798 | 86 | 789 | 11.2 | 4.0 | o | OK |
| 40 | 201 | 181 | 625 | 748 | 123 | 740 | 12.8 | 1.0 | x | OK |
| 41 | 209 | 280 | 729 | 824 | 95 | 819 | 25.9 | 1.0 | o | OK |
| 42 | 201 | 260 | 734 | 833 | 99 | 818 | 14.9 | 1.0 | o | OK |
| 43 | 182 | 246 | 767 | 829 | 62 | 820 | 10.1 | 1.0 | o | OK |
| 44 | 177 | 253 | 739 | 835 | 96 | 824 | 26.3 | 1.0 | o | OK |
| 45 | 58 | 92 | 696 | 744 | 48 | 712 | -34.4 | 1.0 | x | OK |
| 46 | 299 | 341 | 1076 | 1088 | 12 | 1052 | -21.5 | 1.0 | o | poor |
| 47 | 181 | 229 | 715 | 757 | 42 | 740 | -55.4 | 1.0 | o | poor |
| 48 | 265 | 332 | 806 | 856 | 50 | 832 | -24.7 | 1.0 | o | OK |

Underlined data indicate values outside of the range of the invention.

*1: WH represents increase in YS with 5% pre-deformation at equivalent strain listed in the table.

*2: ΔYS represents increase in YS after pre-deformation in the table and heat treatment as paint baking treatment at 170°C x 20 min.

*3 $\sigma$dyn - (0.766 x TS + 250)

*4 $2.5(YS/TS'(5)-0.5) + 15 \geq$ plastic deformation $T \geq 2.5(YS/TS'(5)-0.5) + 0.5$

**[0060]** The microstructure was evaluated by the following method.

**[0061]** Identification of the ferrite, bainite, martensite and residual structure, observation of the location and measurement of the average grain size (mean circle equivalent diameter) was accomplished using a 1000 magnification optical micrograph with the thin steel sheet rolling direction cross-section etched with a nital and the reagent disclosed in

Japanese Unexamined Patent Publication No. 59-219473.

**[0062]** The properties were evaluated by the following methods.

**[0063]** A tensile test was conducted according to JIS5 (gauge mark distance: 50 mm, parallel part width: 25 mm) with a strain rate of 0.001/s and, upon determining the tensile strength (TS), yield strength (YS), total elongation (T. El) and work hardening coefficient (n value for 1%~5% strain), the YS x work hardening coefficient and TS x T. El. were calculated.

**[0064]** The stretch flanging property was measured by expanding a 20 mm punched hole from the burrless side with a 30° cone punch, and determining the hole expansion ratio ($d/d_0$) between the hole diameter (d) at the moment at which the crack penetrated the plate thickness and the original hollow diameter (do, 20 mm).

**[0065]** The spot weldability was judged to be unsuitable if a spot welding test piece bonded at a current of 0.9 times the expulsion current using an electrode with a tip radius of 5 times the square root of the steel sheet thickness underwent peel fracture when ruptured with a chisel.

**[0066]** As explained above, the present invention makes it possible to provide, in an economical and stable manner, high-strength hot rolled steel sheets and cold rolled steel sheets for automobiles which provide previously unobtainable excellent impact absorption properties and press formability and thus offers a markedly wider range of objects and conditions for uses of high-strength steel sheets.

## Claims

**1.** A method of producing a dual-phase high-strength hot-rolled steel sheet having high impact energy absorption properties, **characterized in that**

a continuous cast slab containing, in terms of weight percentage, C: 0.02-0.25%, either or both Mn and Cr in a total amount of 0.15-3.5%, one or more selected from Si, Al and P in a total amount of 0.02-4.0%, optionally one or more selected from Ni, Cu and Mo in a total amount of no more than 3.5%, optionally one or more selected from Nb, Ti and V in an amount of no more than 0.30%, and optionally either or both Ca and REM in an amount of 0.0005-0.0 1 % for Ca and 0.005-0.05% for REM, further optionally one or more selected from B of no more than 0.01%, S of no more than 0.01% and N of no more than 0.02%, with the remainder being Fe and unavoidable impurities, is fed directly from casting to a hot rolling step, or is hot rolled upon reheating after momentary cooling,

it is subjected to hot rolling at a finishing temperature of $Ar_3$-50°C to $Ar_3$+120°C,

the hot rolling is carried out so that the metallurgy parameter A satisfies inequalities (1) and (2) below, the subsequent average cooling rate in the run-out table is at least 5°C/sec, and the coiling is accomplished so that the relationship between said metallurgy parameter A and the coiling temperature (CT) satisfies inequality (3) below:

$$9 \leq \log A \leq 18 \qquad (1)$$

$$\Delta T \leq 21 \times \log A - 61 \qquad (2)$$

$$CT \leq 6 \times \log A + 242 \qquad (3)$$

wherein, metallurgy parameter A is expressed by the following equation:

$$A = \varepsilon^* \times \exp\{(75282 - 42745 \times Ceq) / [1.978 \times (FT + 273)]\}$$

wherein:

FT: finishing temperature (°C)
Ceq: carbon equivalents = C + Mneq / 6 (%)
Mneq: manganese equivalents = Mn + (Ni + Cr + Cu + Mo) / 2 (%)
$\varepsilon^*$: final pass strain rate ($s^{-1}$)

$$\varepsilon^* = (v / \sqrt{R \times h1}) \times (1 / \sqrt{r}) \times \ln\{1/(1 - r)\}$$

h1: final pass approach sheet thickness
h2: final pass exit sheet thickness

r: (h1-h2)/h1
R: roll radius
v: final pass exit speed
$\Delta T$: finishing temperature (finishing final pass exit temperature) - finishing approach temperature (finishing first pass approach temperature)
$Ar_3$: 901 - 325 C% + 33 Si% - 92 Mneq, and
working with a tempering rolling and/or tension leveler is accomplished so that the degree of plastic deformation (T) applied with the tempering rolling and/or tension leveler satisfies inequality (4) below:

$$2.5 \times \{YS(0)/TS'(5)-0.5\}+15 \geq T \geq 2.5 \times \{YS(0)/TS'(5)-0.5\}+0.5 \qquad (4)$$

wherein:

YS(0): yield strength
TS'(5): tensile strength in static tensile test with pre-deformation at 5% of equivalent strain or after further BH treatment and YS(0)/TS' (5) is no greater than 0.7.

**2.** A method of producing a dual-phase type high-strength cold-rolled steel sheet having high impact energy absorption properties, **characterized in that**
a continuous cast slab containing, in terms of weight percentage, C: 0.02-0.25%, either or both Mn and Cr in a total amount of 0.15-3.5%, one or more selected from Si, Al and P in a total amount of 0.02-4.0%, optionally one or more selected from Ni, Cu and Mo in a total amount of no more than 3.5%, optionally one or more selected from Nb, Ti and V in an amount of no more than 0.30%, and optionally either or both Ca and REM in an amount of 0.0005-0.01% for Ca and 0.005-0.05% for REM, further optionally one or more selected from B of no more than 0.01 %, S of no more than 0.01 % and N of no more than 0.02%, with the remainder being Fe and unavoidable impurities, is fed directly from casting to a hot rolling step, or is hot rolled upon reheating after momentary cooling,
it is hot rolled, the hot rolled and subsequently coiled steel sheet is cold rolled after acid pickling, and
during annealing in a continuous annealing step for preparation of the final product, the cold rolled steel sheet is heated to an annealing temperature (To) between $Ac_1$ and $Ac_3$ and subjected to the annealing while held in this temperature range for at least 10 seconds,
subsequently it is cooled with a primary cooling rate of 1-10°C/sec to a secondary cooling start temperature (Tq) in the range of 550-720°C and then cooled with a secondary cooling rate of 10-200°C/sec to a secondary cooling end temperature (Te) which is no higher than a temperature (Tem),
wherein Tem is the martensite transformation start temperature for the retained austenite at the secondary cooling start temperature Tq and defined by Tem = T1 - T2, wherein:

T1 = 561-33 x {Mn% + (Ni + Cr + Cu + Mo)/2},
T2 = 474 x ($Ac_3$ - $Ac_1$) x C/(To - $Ac_1$) when Ceq*= ($Ac_3$ - $Ac_1$) x C/(To - $Ac_1$) + (Mn + Si/4 + Ni/7 + Cr + Cu + 1.5Mo)/6 is greater than 0.6, and
T2 = 474 x ($Ac_3$ - $Ac_1$) x C/{3 x ($Ac_3$ - $Ac_1$) x C + [(Mn + Si/4 + Ni/7 + Cr + Cu + 1.5Mo)/2 - 0.85] x (To - $Ac_1$)} when Ceq* is 0. 6 or less,

wherein:

$Ac_1$ = 723 - 0.7 x Mn% - 16.9 x Ni% + 29.1 x Si% + 16.9 x Cr%,
$Ac_3$ = 910 - 203 x $(C\%)^{1/2}$ - 15.2 x Ni% + 44.7 x Si% + 104 x V% + 31.5 x Mo% - 30 x Mn% - 11 x Cr% - 20 x Cu% + 70 x P% + 40 x Al% + 400 x Ti%, and

working with a tempering rolling and/or tension leveler is accomplished so that the degree of plastic deformation (T) applied with the tempering rolling and/or tension leveler satisfies inequality (4) below:

$$2.5 \times \{YS(0)/TS'(5)-0.5\}+15 \geq T \geq 2.5 \times \{YS(0)/TS'(5)-0.5\}+0.5 \qquad (4)$$

wherein:

YS(0): yield strength
TS'(5): tensile strength in static tensile test with pre-deformation at 5% of equivalent strain or after further BH treatment and YS(0)/TS'(5) is no greater than 0. 7.

## Patentansprüche

1. Verfahren zur Herstellung eines hochfesten warmgewalzten Dualphasen-Stahlblechs mit hohen Aufprallenergie-Absorptionseigenschaften, **dadurch gekennzeichnet, dass** eine Stranggussbramme, die in Gewichtsprozent 0,02-0,25 % C, eine Gesamtmenge von 0,15-3,5 % Mn und/oder Cr, eine Gesamtmenge von 0,02-4,0 % Si und/oder Al und/oder P, optional eine Gesamtmenge von höchstens 3,5 % Ni und/oder Cu und/oder Mo, optional eine Menge von höchstens 0,30 % Nb und/oder Ti und/oder V sowie optional Ca und/oder SEM in einer Menge von 0,0005-0,01 % für Ca und 0,005-0,05 % für SEM, ferner optional höchstens 0,01 % B und/oder höchstens 0,01 % S und/oder höchstens 0,02 % N sowie als Rest Fe und unvermeidliche Verunreinigungen enthält, direkt vom Gießen einem Warmwalzschritt zugeführt oder nach Nachwärmen nach vorübergehender Abkühlung warmgewalzt wird, wobei das Warmwalzen bei einer Endtemperatur von $Ar_3$ - 50 °C bis $Ar_3$ + 120 °C erfolgt und so durchgeführt wird, dass der Metallurgieparameter A die nachstehenden Ungleichungen (1) und (2) erfüllt, die anschließende mittlere Abkühlungsgeschwindigkeit im Auslaufrollgang mindestens 5 °C/s beträgt und das Wickeln so realisiert wird, dass die Beziehung zwischen dem Metallurgieparameter A und der Wickeltemperatur (CT) die nachstehende Ungleichung (3) erfüllt:

$$9 \leq \log A \leq 18 \qquad (1),$$

$$\Delta T \leq 21 \times \log A - 61 \qquad (2),$$

$$CT \leq 6 \times \log A + 242 \qquad (3),$$

wobei der Metallurgieparameter A durch die folgende Gleichung ausgedrückt ist:

$$A = \varepsilon^* \times \exp\{(75282 - 42745 \times C_{eq})/[1,978 \times (FT + 273)]\},$$

wobei:

FT: Endtemperatur (°C),
$C_{eq}$: Kohlenstoffäquivalente = C + $Mn_{eq}$/6 (%),
$Mn_{eq}$: Manganäquivalente = Mn + (Ni + Cr + Cu + Mo)/2 (%),
$\varepsilon^*$: Verformungsgeschwindigkeit im Schlichtstich ($s^{-1}$),

$$\varepsilon^* = (v/\sqrt{R \times h_1}) \times (1/\sqrt{r}) \times \ln\{1/(1 - r)\},$$

$h_1$: Blechdicke am Schlichtsticheinlauf,
$h_2$: Blechdicke am Schlichtstichauslauf,
r: $(h_1 - h_2)/h_1$,
R: Walzenradius,
v: Geschwindigkeit am Schlichtstichauslauf,
$\Delta T$: Endtemperatur (Endtemperatur am Schlichtstichauslauf) - Endtemperatur am Einlauf (Endtemperatur am ersten Ansticheinlauf),
$Ar_3$: 901 - 325 C% + 33 Si% - 92 $Mn_{eq}$ und

eine Bearbeitung durch Nachwalzen und/oder einen Spannungsnivellierer durchgeführt wird, so dass der Grad der plastischen Verformung (T) durch das Nachwalzen und/oder den Spannungsnivellierer die folgende Ungleichung (4) erfüllt:

$$2{,}5 \times \{YS(0)/TS'(5) - 0{,}5\} + 15 \geq T \geq 2{,}5 \times \{YS(0)/TS'(5) - 0{,}5\} + 0{,}5 \qquad (4),$$

wobei:

YS(0): Fließgrenze
TS'(5): Zugfestigkeit im statischen Zugversuch mit einer Vorverformung von 5% einer Vergleichsformänderung oder nach einer weiteren Bake-Hardening-Behandlung (BH-Behandlung) und wobei YS(0)/TS'(5) bei höchstens 0,7 liegt.

**2.** Verfahren zur Herstellung eines hochfesten kaltgewalzten Stahlblechs vom Dualphasentyp mit hohen Aufprallenergie-Absorptionseigenschaften, **dadurch gekennzeichnet, dass** eine Stranggussbramme, die in Gewichtsprozent 0,02-0,25 % C, eine Gesamtmenge von 0,15-3,5 % Mn und/oder Cr, eine Gesamtmenge von 0,02-4,0 % Si und/oder Al und/oder P, optional eine Gesamtmenge von höchstens 3,5 % Ni und/oder Cu und/oder Mo, optional eine Menge von höchstens 0,30 % Nb und/oder Ti und/oder V sowie optional Ca und/oder SEM in einer Menge von 0,0005-0,01 % für Ca und 0,005-0,05 % für SEM, ferner optional höchstens 0,01 % B und/oder höchstens 0,01 % S und/oder höchstens 0,02 % N sowie als Rest Fe und unvermeidliche Verunreinigungen enthält, direkt vom Gießen einem Warmwalzschritt zugeführt oder nach Nachwärmen nach vorübergehender Abkühlung warmgewalzt wird, nach dem Warmwalzen das warmgewalzte und anschließend gewickelte Stahlblech nach Säurebeizen kaltgewalzt wird und beim Glühen in einem Durchlaufglühschritt zur Herstellung des Endprodukts das kaltgewalzte Stahlblech auf eine Glühtemperatur (To) zwischen $Ac_1$ und $Ac_3$ erwärmt und beim Glühen mindestens 10 Sekunden in diesem Temperaturbereich gehalten wird, und es anschließend mit einer primären Abkühlungsgeschwindigkeit von 1 - 10 °C/s auf eine sekundäre Abkühlungsanfangstemperatur (Tq) im Bereich von 550 - 720 °C abgekühlt und dann mit einer sekundären Abkühlungsgeschwindigkeit von 10 - 200 °C/s auf eine sekundäre Abkühlungsendtemperatur (Te) abgekühlt wird, die nicht höher als eine Temperatur (Tem) ist,
wobei Tem die Martensitumwandlungs-Anfangstemperatur für den Restaustenit bei der sekundären Abkühlungsanfangstemperatur Tq und durch Tem = T1 - T2 definiert ist, wobei:

T1 = 561 - 33 x {Mn% + (Ni + Cr + Cu + Mo)/2},
T2 = 474 x ($Ac_3$ - $Ac_1$) x C/(To - $Ac_1$), wenn Ceq* = ($Ac_3$ - $Ac_1$) x C/(To - $Ac_1$) + (Mn + Si/4 + Ni/7 + Cr + Cu + 1,5Mo)/6 größer als 0,6 ist, und
T2 = 474 x ($Ac_3$ - $Ac_1$) x C/{3 x ($Ac_3$ - $Ac_1$) x C + [(Mn + Si/4 + Ni/7 + Cr + Cu + 1,5Mo)/2 - 0,85] x (To - $Ac_1$)}, wenn Ceq* 0,6 oder kleiner ist,

wobei:

$Ac_1$ = 723 - 0,7 x Mn% - 16,9 x Ni% + 29,1 x Si% + 16,9 x Cr%,
$Ac_3$ = 910 - 203 x $(C\%)^{1/2}$ - 15,2 x Ni% + 44,7 x Si% + 104 x V% + 31,5 x Mo% - 30 x Mn% - 11 x Cr% - 20 x Cu% + 70 x P% + 40 x Al% + 400 x Ti%,

und eine Bearbeitung durch Nachwalzen und/oder einen Spannungsnivellierer durchgeführt wird, so dass der Grad der plastischen Verformung (T) durch das Nachwalzen und den Spannungsnivellierer die folgende Ungleichung (4) erfüllt:

$$2{,}5 \times \{YS(0)/TS'(5) - 0{,}5\} + 15 \geq T \geq 2{,}5 \times \{YS(0)/TS'(5) - 0{,}5\} + 0{,}5 \qquad (4),$$

wobei:

YS(0): Fließgrenze
TS'(5): Zugfestigkeit im statischen Zugversuch mit einer Vorverformung von 5% einer Vergleichsformänderung oder nach einer weiteren Bake-Hardening-Behandlung (BH-Behandlung) und wobei YS(0)/TS'(5) bei höchstens 0,7 liegt.

## Revendications

1. Procédé pour produire une tôle d'acier laminé à chaud haute résistance biphasique ayant des propriétés de forte absorption de l'énergie d'impact, **caractérisé en ce que**
un lingot coulé en continu contenant, en pourcentages en poids, C : 0,02 à 0,25 %, l'un ou l'autre ou les deux de Mn et Cr en une quantité totale de 0,15 à 3,5 %, un ou plusieurs choisi(s) parmi Si, Al et P en une quantité totale de 0,02 à 4,0 %, éventuellement un ou plusieurs choisi(s) parmi Ni, Cu et Mo en une quantité totale ne dépassant pas 3,5 %, éventuellement un ou plusieurs choisi(s) parmi Nb, Ti et V en une quantité ne dépassant pas 0,30 %, et éventuellement l'un ou l'autre ou les deux de Ca et REM en une quantité de 0,0005 à 0,01 % pour Ca et de 0,005 à 0,05 % pour REM, en outre éventuellement un ou plusieurs choisi(s) parmi B à raison d'au plus 0,01 %, S à raison d'au plus 0,01 % et N à raison d'au plus 0,02 %, le reste étant Fe et des impuretés inévitables, est introduit directement depuis la coulée vers une étape de laminage à chaud, ou est laminé à chaud lors du réchauffage après refroidissement momentané,
est soumis à un laminage à chaud à une température de finissage d'$Ar_3$ - 50°C à $Ar_3$ + 120°C,
le laminage à chaud est effectué de façon que le paramètre métallurgique A satisfasse aux inégalités (1) et (2) ci-dessous, la vitesse de refroidissement moyenne subséquente dans la table de sortie est d'au moins 5°C/s, et le bobinage est accompli de façon que la relation entre ledit paramètre métallurgique A et la température de bobinage (CT) satisfasse à l'inégalité (3) ci-dessous :

$$9 \leq \log A \leq 18 \qquad (1)$$

$$\Delta T \leq 21 \times \log A - 61 \qquad (2)$$

$$CT \leq 6 \times \log A + 242 \qquad (3)$$

où le paramètre métallurgique A est exprimé par l'équation suivante :

$$A = \varepsilon^* \times \exp\{(75282 - 42745 \times C_{eq})/[1{,}978 \times (FT + 273)]\}$$

dans laquelle :

FT : température de finissage (°C)
$C_{eq}$ : équivalents carbone = C + $Mn_{eq}/6$ (%)
$Mn_{eq}$ : équivalents manganèse = Mn + (Ni + Cr + Cu + Mo)/2 (%)
$\varepsilon^*$ : vitesse de déformation au passage final ($s^{-1}$)

$$\varepsilon^* = (v / \sqrt{R \times h_1}) \times (1/\sqrt{r}) \times \ln\{1 / (1 - r)\}$$

$h_1$ : épaisseur de tôle à l'approche du passage final
$h_2$ : épaisseur de tôle à la sortie du passage final
r : $(h_1 - h_2)/h_1$
R : rayon du cylindre
v : vitesse à la sortie du passage final
$\Delta \cdot T$ : température de finissage (température à la sortie du passage final de finissage) - température à l'approche du finissage (température à l'approche du premier passage de finissage)
$Ar_3$ : 901 - 325 C% + 33 Si% - 92 $Mn_{eq}$, et

l'usinage avec un laminage de revenu et/ou un niveleur de tension est réalisé de sorte que le degré de déformation plastique (T) appliquée au laminage de revenu et/ou au niveleur de tension satisfait à l'inégalité (4) ci-dessous :

$$2{,}5 \times \{YS(0)/TS'(5)-0{,}5\} + 15 \geq T \geq 2{,}5 \times \{YS(0)/TS'(5)-0{,}5\} + 0{,}5 \quad (4)$$

dans laquelle :

YS(0) : limite élastique
TS'(5) : résistance à la traction dans un test de traction statique avec une pré-déformation à 5 % de déformation équivalente ou après de plus un traitement BH et YS(0)/TS'(5) n'est pas supérieur à 0,7.

**2.** Procédé pour produire une tôle d'acier laminé à froid haute résistance biphasique ayant des propriétés de forte absorption de l'énergie d'impact, **caractérisé en ce que**
un lingot coulé en continu contenant, en pourcentage en poids, C : 0,02 à 0,25 %, l'un ou l'autre ou les deux de Mn et Cr en une quantité totale de 0,15 à 3,5 %, un ou plusieurs choisi(s) parmi Si, Al et P en une quantité totale de 0,02 à 4,0 %, éventuellement un ou plusieurs choisi(s) parmi Ni, Cu et Mo en une quantité totale ne dépassant pas 3,5 %, éventuellement un ou plusieurs choisi(s) parmi Nb, Ti et V en une quantité ne dépassant pas 0,30 %, et éventuellement l'un ou l'autre ou les deux de Ca et REM en une quantité de 0,0005 à 0,01 % pour Ca et de 0,005 à 0,05 % pour REM, en outre éventuellement un ou plusieurs choisi(s) parmi B à raison d'au plus 0,01 %, S à raison d'au plus 0,01 % et N à raison d'au plus 0,02 %, le reste étant Fe et des impuretés inévitables, est introduit directement depuis la coulée vers une étape de laminage à chaud, ou est laminé à chaud lors du réchauffage après refroidissement momentané,
est laminé à chaud, la tôle d'acier laminée à chaud et ensuite bobinée est laminée à froid après décapage acide et, durant le recuit dans une étape de recuit en continu pour la préparation du produit final, la tôle d'acier laminé à froid est chauffée à une température de recuit (To) comprise entre $Ac_1$ et $Ac_3$ et soumise au recuit tout en étant maintenue dans cette plage de température pendant au moins 10 secondes, et
ensuite est refroidie à une vitesse de refroidissement primaire de 1 à 10°C/s jusqu'à une température de début de refroidissement secondaire (Tq) située dans la plage allant de 550 à 720°C et puis refroidie à une vitesse de refroidissement secondaire de 10 à 200°C/s jusqu'à une température de fin de refroidissement secondaire (Te) qui n'est pas supérieure à une température (Tem),
où Tem est la température de début de transformation en martensite pour l'austénite résiduelle à la température de début de refroidissement secondaire Tq et est définie par Tem = T1 - T2, où :

T1 = 561 - 33 x {Mn% + (Ni + Cr + Cu + Mo) / 2},
T2 = 474 x ($Ac_3$ - $Ac_1$) x C / (To - $Ac_1$) quand Ceq* = ($Ac_3$ - $Ac_1$) x C / (To - $Ac_1$) + (Mn + Si/4 + Ni/7 + Cr + Cu + 1,5Mo) / 6 est supérieur à 0,6, et T2 = 474 x ($Ac_3$ - $Ac_1$) x C /{3 x ($Ac_3$ - $Ac_1$) x C + [(Mn + Si/4 + Ni/7 + Cr + Cu + 1,5Mo) / 2 - 0,85] x (To - $Ac_1$)} quand Ceq* vaut 0,6 ou moins,

où :

$Ac_1$ = 723 x 0,7 x Mn% - 16,9 x Ni% + 29,1 x Si% + 16,9 x Cr%,
Ac3 = 910 - 203 x $(C\%)^{1/2}$ - 15,2 x Ni% + 44,7 x Si% + 104 x V% + 31,5 x Mo% + 30 x Mn% - 11 x Cr% - 20 x Cu% + 70 x P% + 40 x Al% + 400 x Ti%,

et l'usinage avec un laminage de revenu et/ou un niveleur de tension est réalisé de sorte que le degré de déformation plastique (T) appliquée au laminage de revenu et/ou au niveleur de tension satisfait à l'inégalité (4) ci-dessous :

$$2{,}5 \times \{YS(0)/TS'(5)-0{,}5\} + 15 \geq T \geq 2{,}5 \times \{YS(0)/TS'(5)-0{,}5\} + 0{,}5 \quad (4)$$

dans laquelle :

YS(0) : limite élastique
TS'(5) : résistance à la traction dans un test de traction statique avec une pré-déformation à 5 % de déformation équivalente ou après de plus un traitement BH et YS(0)/TS'(5) n'est pas supérieur à 0,7.

Fig.1

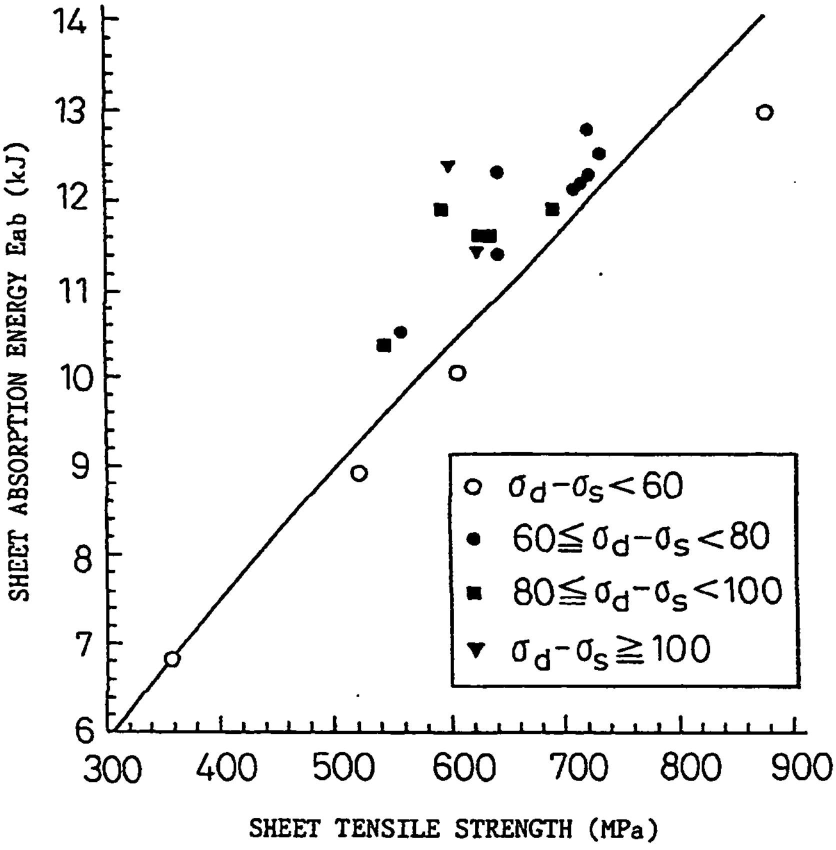

14
13
12
11
10
9
8
7
6
SHEET ABSORPTION ENERGY Eab (kJ)
300
400
500
600
700
800
900
SHEET TENSILE STRENGTH (MPa)
○ $\sigma_d-\sigma_s<60$
● $60\leqq\sigma_d-\sigma_s<80$
■ $80\leqq\sigma_d-\sigma_s<100$
▼ $\sigma_d-\sigma_s\geqq100$

Fig.2

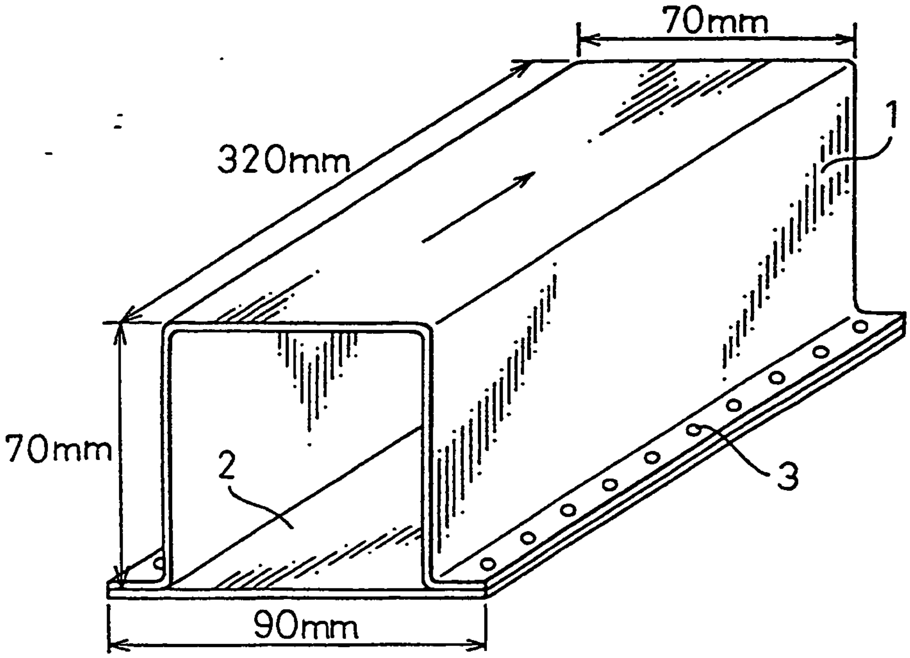


Fig.3

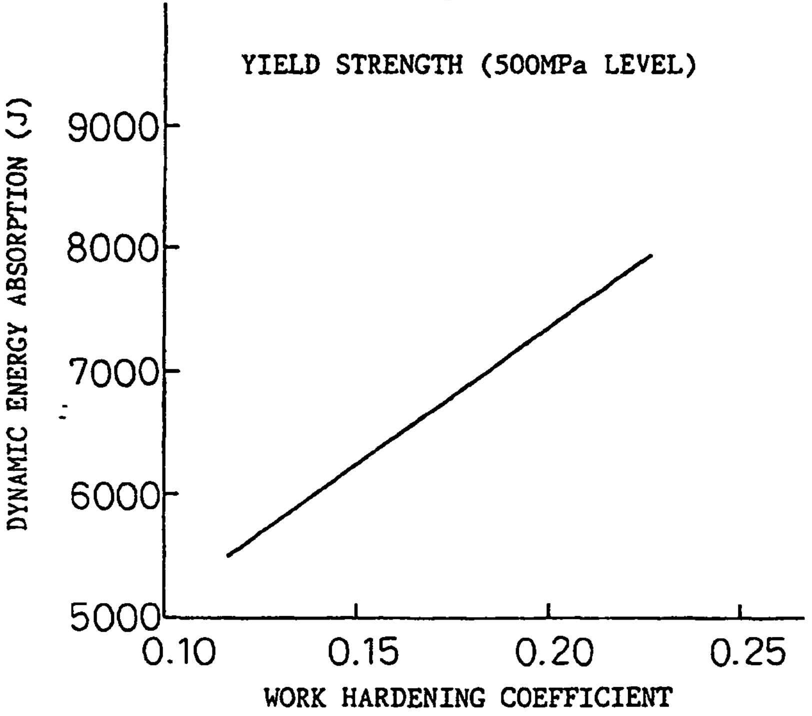

YIELD STRENGTH (500MPa LEVEL)
DYNAMIC ENERGY ABSORPTION (J)
9000
8000
7000
6000
5000
0.10
0.15
0.20
0.25
WORK HARDENING COEFFICIENT

Fig.4

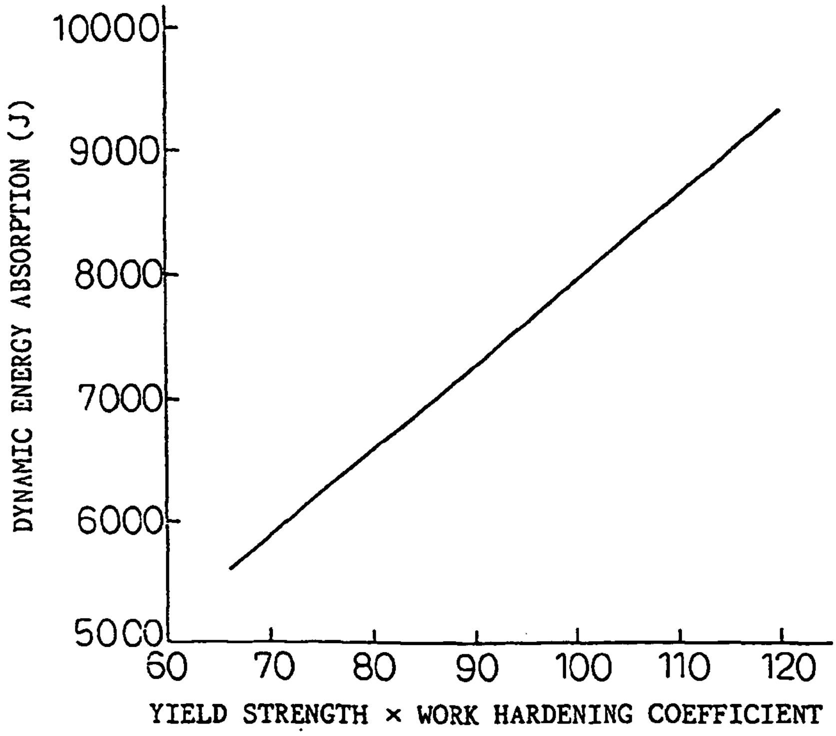

DYNAMIC ENERGY ABSORPTION (J)
10000
9000
8000
7000
6000
5000
60
70
80
90
100
110
120
YIELD STRENGTH × WORK HARDENING COEFFICIENT

Fig.5

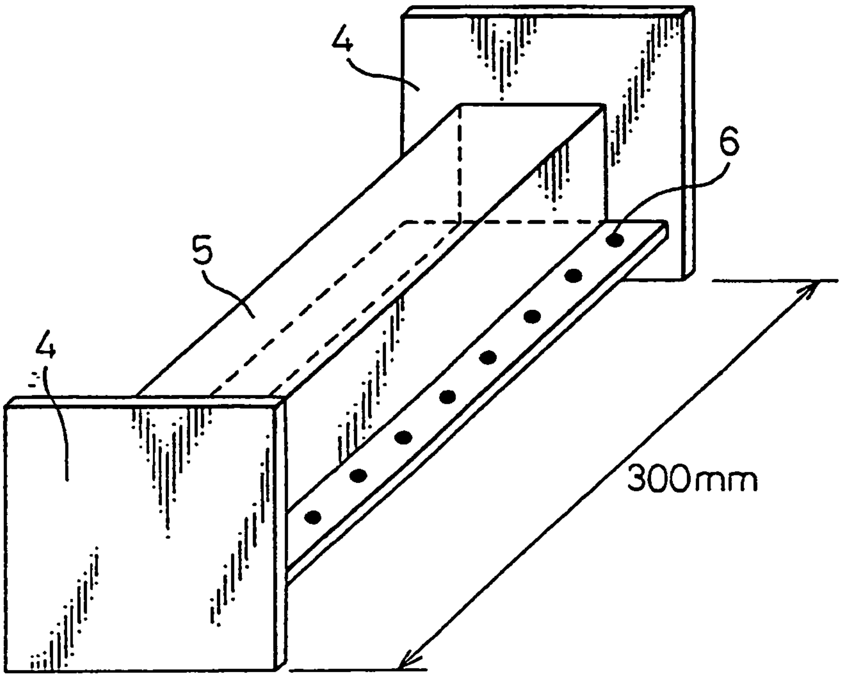


Fig.6

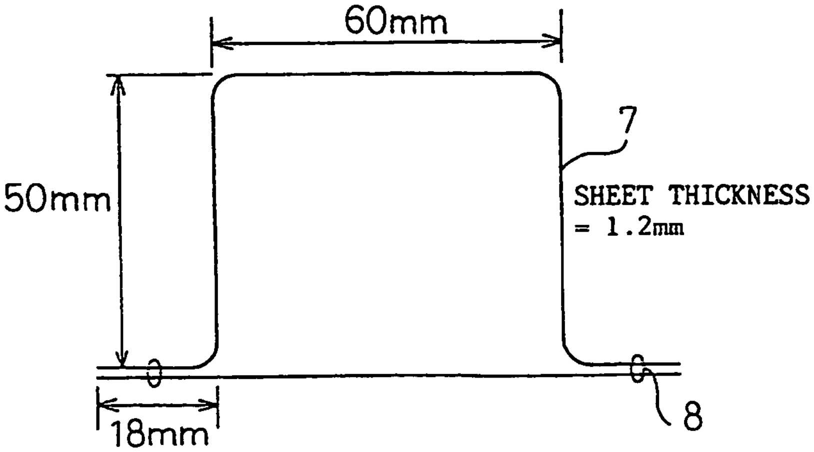


Fig. 7

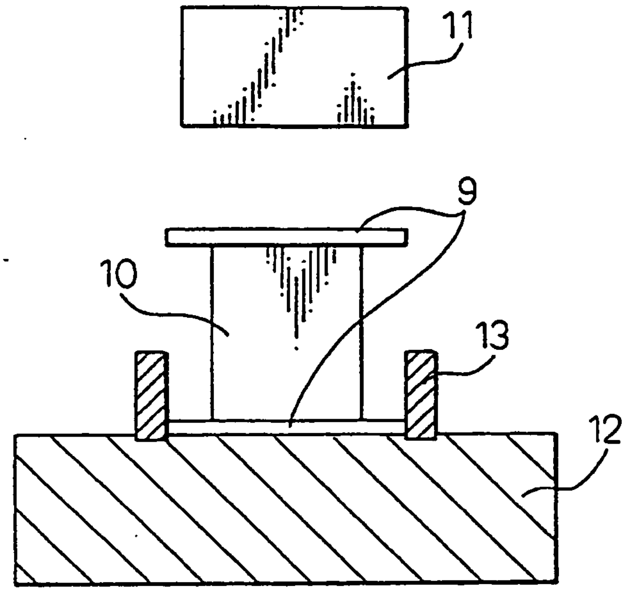

11
9
10
13
12

Fig. 8

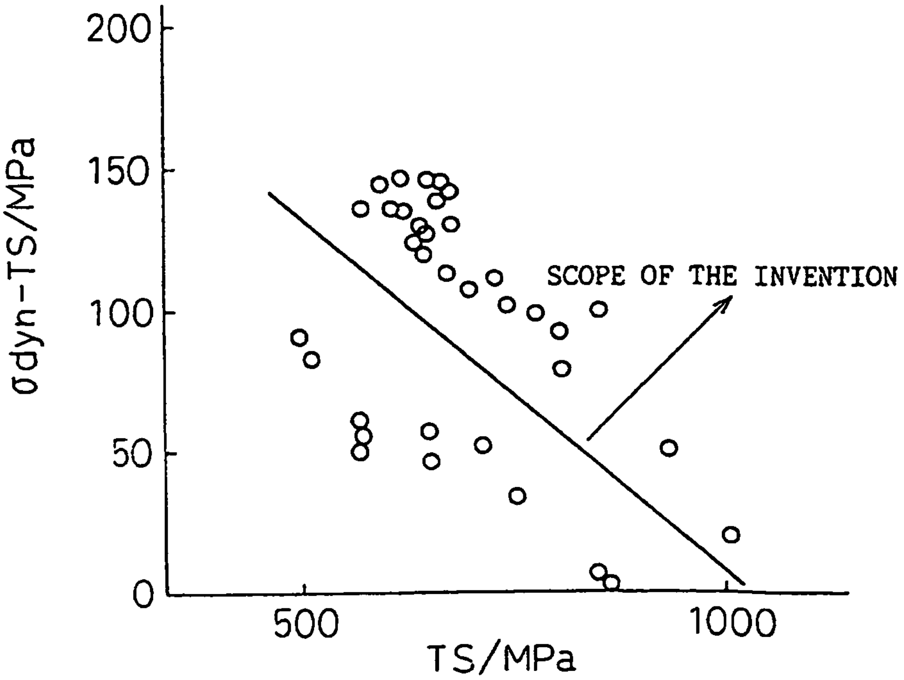

σdyn-TS/MPa
200
150
100
50
0
500
1000
TS/MPa
SCOPE OF THE INVENTION

Fig.9

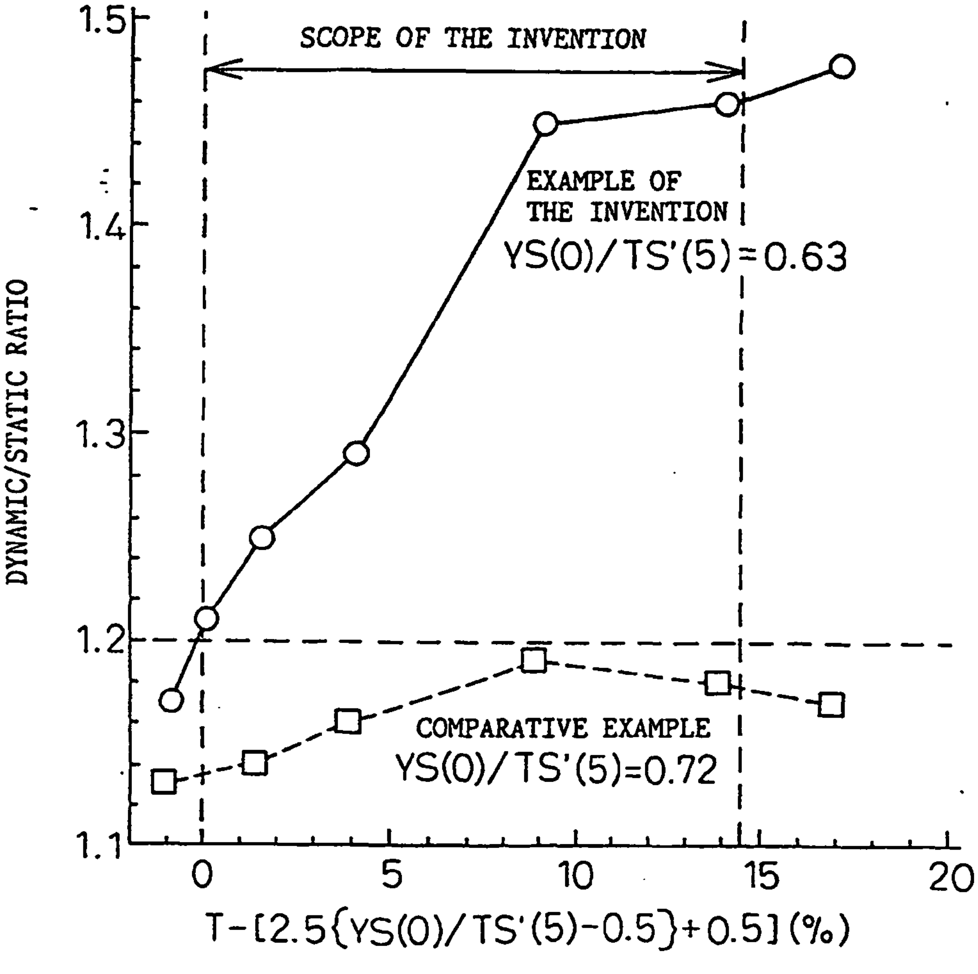

1.5
1.4
1.3
1.2
1.1
DYNAMIC/STATIC RATIO
SCOPE OF THE INVENTION
EXAMPLE OF THE INVENTION
YS(0)/TS'(5)=0.63
COMPARATIVE EXAMPLE
YS(0)/TS'(5)=0.72
0
5
10
15
20
T-[2.5{YS(0)/TS'(5)-0.5}+0.5] (%)

Fig.10

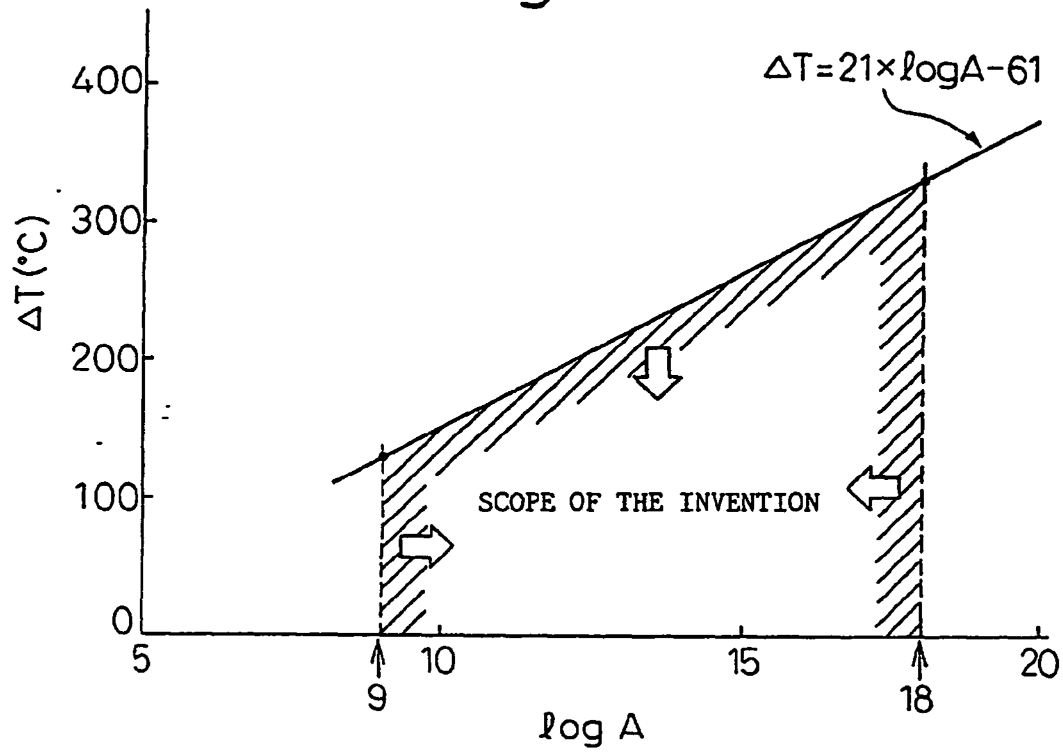

ΔT=21×ℓogA−61
400
300
200
100
0
ΔT(°C)
SCOPE OF THE INVENTION
5
10
15
20
9
18
ℓog A

Fig.11

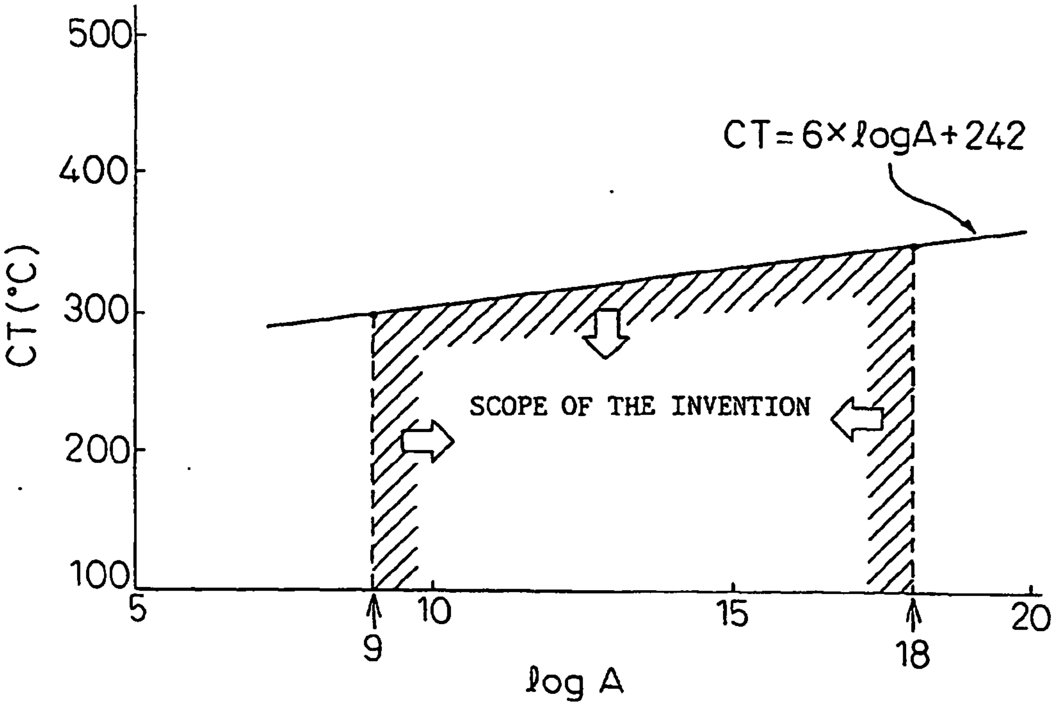
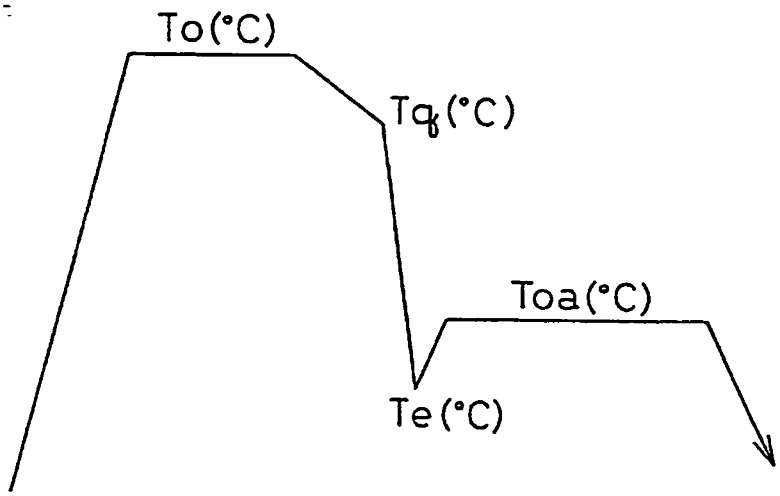

CT=6×ℓogA+242
500
400
300
200
100
CT(°C)
SCOPE OF THE INVENTION
5
10
15
20
9
18
ℓog A

Fig.12



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