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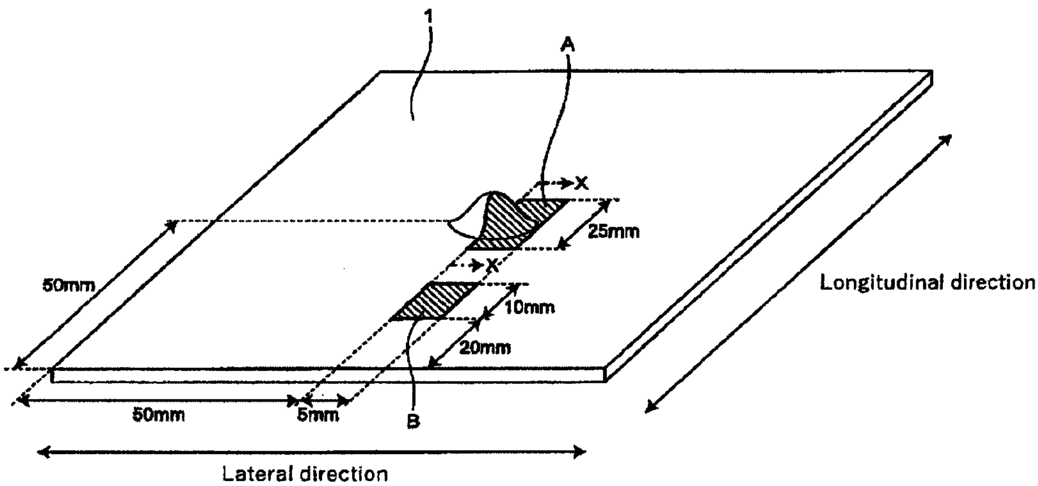
(54) **Titre : PROCEDE DE FABRICATION D'ELEMENT EN ACIER DOTE DE SECTION RAMOLLIE LOCALEMENT**
(54) **Title: METHOD FOR PRODUCING STEEL COMPONENT HAVING LOCALLY SOFTENED PART**



(57) **Abrégé/Abstract:**
Disclosed is a method for producing a steel component, which include the steps of: preparing a steel sheet having a chemical composition including: C: 0.05 to 0.40% by mass, Si: 0 to 2.0% by mass, Mn: 1.0 to 3.0% by mass, Al: 0.010 to 1.0% by mass, P: more than 0% by mass and 0.100% by mass or less, S: more than 0% by mass and 0.010% by mass or less, N: more than 0% by mass and 0.010% by mass or less, and B: 0.0005 to 0.010% by mass, with the balance being iron and inevitable impurities; heating the steel sheet to a temperature of Acl point (°C) or higher and lower than Ac3 point (°C) + 10°C); after the heating step, processing the steel sheet by applying a strain of 0.5% or more thereto at a temperature of 675°C or higher and lower than Ac3 point + 10°C; after the processing step, holding or gradually cooling the steel sheet at an average cooling rate of 0 to 15°C/sec for 1 second or more and 120 seconds or less; and after the holding or gradually cooling step, cooling the steel sheet to a temperature of Ms point (°C) - 50°C, wherein an average cooling rate from the temperature of the heating step to the Ms point (°C) - 50°C is controlled to be 10°C/sec or more.

ABSTRACT

Disclosed is a method for producing a steel component, which include the steps of: preparing a steel sheet having a chemical composition including: C: 0.05 to 0.40% by mass, Si: 0 to 2.0% by mass, Mn: 1.0 to 3.0% by mass, Al: 0.010 to 1.0% by mass, P: more than 0% by mass and 0.100% by mass or less, S: more than 0% by mass and 0.010% by mass or less, N: more than 0% by mass and 0.010% by mass or less, and B: 0.0005 to 0.010% by mass, with the balance being iron and inevitable impurities; heating the steel sheet to a temperature of Ac1 point (°C) or higher and lower than Ac3 point (°C) + 10°C); after the heating step, processing the steel sheet by applying a strain of 0.5% or more thereto at a temperature of 675°C or higher and lower than Ac3 point + 10°C; after the processing step, holding or gradually cooling the steel sheet at an average cooling rate of 0 to 15°C/sec for 1 second or more and 120 seconds or less; and after the holding or gradually cooling step, cooling the steel sheet to a temperature of Ms point (°C) - 50°C, wherein an average cooling rate from the temperature of the heating step to the Ms point (°C) - 50°C is controlled to be 10°C/sec or more.

DESCRIPTION

METHOD FOR PRODUCING STEEL COMPONENT HAVING LOCALLY SOFTENED PART

Technical Field

[0001]

The present disclosure relates to a method for producing a steel component having a locally softened part.

Background Art

[0002]

In recent years, there is a need for technology that allows a specific part to become deformed preferentially during an automobile collision while maintaining high strength of a whole automobile frame component in order to protect occupants during the collision. Therefore, a high-strength steel component usable in this technology, specifically, in which a specific part is locally softened, and/or a production method thereof are required.

[0003]

Patent Document 1 discloses a method of applying a heat shield cover to a part, which is to be intentionally softened thereafter, when heating a steel sheet to the austenite single-phase temperature range. Consequently, the temperature of the part applied with the heat shield cover remains under the austenite single-phase temperature range during heating, which suppresses martensitic transformation of the part after quenching, making this part softer than other parts not applied with the heat shield cover.

[0004]

Patent Document 2 discloses a method of providing a part where a steel sheet and a mold do not contact well when quenching the steel sheet from the austenite single-phase temperature range while being in contact with the mold. Consequently, a soft microstructure (ferrite and/or pearlite) precipitates in this part, and this part is softened.

Conventional Art Document

Patent Document

[0005]

Patent Document 1: JP 2017-78189 A

Patent Document 2: JP 2011-179028 A

Disclosure of the Invention

Problems to be Solved by the Invention

[0006]

In Patent Documents 1 and 2, it is not possible to selectively soften only the part to be intentionally softened due to heat transfer and the like in the steel sheet. For example, in Patent Document 1, although only the part applied with the heat shield cover is to be softened by being below the austenite single-phase temperature range, heat is transferred to the end of the part applied with the heat shield cover from an adjacent part not applied with the heat shield cover. As a result, the end of the part applied with the heat shield cover cannot be softened sufficiently. In Patent Document 2, although only the part that does not contact the mold well is to be intentionally softened without quenching, heat is transferred from this part to an adjacent part that contacts the mold well. As a result, this adjacent part in contact with the mold is susceptible to the softening effect. Therefore, it is difficult to selectively soften only the part to be intentionally softened by methods of softening a steel sheet through local temperature control such as the methods disclosed in Patent Documents 1 and 2.

[0007]

The embodiments of the present invention have been made in view of such a situation, and an object thereof is to provide a method for producing a high-strength steel component having a locally softened part without local temperature control.

Means for Solving the Problems

[0008]

The present invention according to a first aspect provides a method for producing a steel component, which includes the steps of:

preparing a steel sheet having a chemical composition including:

C: 0.05 to 0.40% by mass,

Si: 0 to 2.0% by mass,

Mn: 1.0 to 3.0% by mass,

Al: 0.010 to 1.0% by mass,

P: more than 0% by mass and 0.100% by mass or less,

S: more than 0% by mass and 0.010% by mass or less,

N: more than 0% by mass and 0.010% by mass or less, and

B: 0.0005 to 0.010% by mass, with the balance being iron and inevitable impurities;

heating the steel sheet to a temperature of Ac1 point (°C) or higher and lower than Ac3 point (°C) + 10°C;

after the heating step, processing the steel sheet by applying a strain of 0.5% or more thereto at a processing temperature of 675°C or higher and lower than Ac3 point (°C) + 10°C;

after the processing step, holding the steel sheet at the processing temperature for 1 second or more and 120 seconds or less, or gradually cooling the steel sheet at an average cooling rate of more than 0°C/sec and 15°C/sec or less for 1 second or more and 120 seconds or less; and

after the holding or gradually cooling step, cooling the steel sheet to a temperature of Ms point (°C) - 50°C,

wherein an average cooling rate from the temperature of the heating step to the Ms point (°C) - 50°C is controlled to be 10°C/sec or more.

[0009]

The prevent invention according to a second aspect provides a method for producing a steel component, which includes the steps of:

preparing a steel sheet having a chemical composition including:

C: 0.05 to 0.40% by mass,

Si: 0 to 2.0% by mass,

Mn: 1.0 to 3.0% by mass,

Al: 0.010 to 1.0% by mass,

P: more than 0% by mass and 0.100% by mass or less,

S: more than 0% by mass and 0.010% by mass or less,

N: more than 0% by mass and 0.010% by mass or less, and

B: 0.0005 to 0.010% by mass, with the balance being iron and inevitable impurities;

heating the steel sheet to a temperature of Ac3 point (°C) + 10°C or higher and 1,100°C or lower;

after the heating step, processing the steel sheet by applying a strain of 10% or more thereto at a processing temperature of Ms point (°C) + 50°C or higher and lower than Ac3 point (°C) + 10°C;

after the processing step, holding the steel sheet at the processing temperature for 1 second or more and 120 seconds or less, or gradually cooling the steel sheet at an average cooling rate of more than 0°C/sec and 15°C/sec or less for 1 second or more and 120 seconds or less; and

after the holding or gradually cooling step, cooling the steel sheet to a temperature of Ms point (°C) - 50°C,

wherein an average cooling rate from the temperature in the heating step to the Ms point (°C) - 50°C is controlled to be 10°C/sec or more.

[0010]

In a third aspect, the prevent invention provides the production method according to the first or second aspect, wherein the steel sheet further includes one or more selected from the group consisting of:

Cu: more than 0% by mass and 0.50% by mass or less, and

Ni: more than 0% by mass and 0.50% by mass or less.

[0011]

In a fourth aspect, the prevent invention provides the production method according to any one of the first to third aspects, wherein the steel sheet further includes one or more selected from the group consisting of:

Ti: more than 0% by mass and 0.10% by mass or less,

Cr: more than 0% by mass and 3.0% by mass or less, and

Nb: more than 0% by mass and 0.10% by mass or less.

[0012]

In a fifth aspect, the present invention provides the production method according to any one of the first to fourth aspects, further including applying the strain by stretch forming.

[0013]

In a sixth aspect, the present invention provides the production method according to any one of the first to fourth aspects, further including applying the strain by forging.

[0014]

In a seventh aspect, the present invention provides the production method according to any one of the first to fourth aspects, further including applying the strain by return bending during draw forming.

[0015]

In an eighth aspect, the present invention provides the production method according to any one of the first to fourth aspects, further including applying the strain by shearing.

[0016]

In a ninth aspect, the present invention provides the production method according to any one of the first to eighth aspects, further including applying the strain by a plurality of times of processing.

[0017]

In a tenth aspect, the present invention provides the production method according to the ninth aspect, wherein the plurality of times of processing includes processing for applying deformation and processing for restoring the deformation.

[0017a]

In yet another aspect, the present invention provides a method for producing a steel component, which comprises the steps of: preparing a steel sheet having a chemical composition comprising: C: 0.05 to 0.40% by mass, Si: 0 to 2.0% by mass, Mn: 1.0 to 3.0% by mass, Al: 0.010 to 1.0% by mass, P: more than 0% by mass and 0.100% by mass or less, S: more than 0% by mass and 0.010% by mass or less, N: more than 0% by mass and 0.010% by mass or less, and B: 0.0005 to 0.010% by mass, with the balance being iron and inevitable impurities; heating the steel sheet to a temperature of Ac3 point (°C) + 10°C or higher and 1,100°C or lower; after the heating step, processing a part of the steel sheet by applying a strain of 10% or more thereto at a processing temperature of Ms point (°C) + 50°C or higher and lower than Ac3 point (°C) + 10°C; after the processing step, holding the steel sheet at the processing temperature for 1 second or more and 120 seconds or less, or gradually cooling the steel sheet at an average cooling rate of more than 0°C/sec and 15°C/sec or less for 1 second or more and 120 seconds or less; and after the holding or gradually cooling step, cooling the steel sheet to a temperature of Ms point (°C) - 50°C, wherein an average cooling rate from the temperature in the heating step to the Ms point (°C) - 50°C is controlled to be 10°C/sec or more.

Effects of the Invention

[0018]

According to an embodiment of the present invention, it is possible to provide a method for producing a high-strength steel component having a locally softened part without local temperature control.

Brief Description of the Drawings

[0019]

FIG. 1 is a graph showing the relationship between the temperature and displacement of a steel sheet when heating the steel sheet from a low temperature in a formaster test.

FIG. 2 is a graph showing the relationship between the temperature and displacement of the steel sheet when cooling the steel sheet from high temperature in the formaster test, in addition to the relationship shown in FIG. 1.

FIG. 3 is a schematic diagram showing the locations of samples taken for evaluation in Examples.

FIG. 4 is a schematic cross-sectional view taken along the line X-X shown in FIG. 3.

Mode for Carrying Out the Invention

[0020]

The inventors of the present application have made various investigations in order to achieve a method for producing a high-strength steel component having a locally softened part without local temperature control.

[0021]

As a result, it has been found that by heating a steel sheet having a predetermined chemical composition to be in a state where austenite is relatively unstable, such as in a two-phase region composed of austenite and ferrite, a slight strain is applied to a part which is to be intentionally softened in the steel sheet, thus promoting nucleation of a soft microstructure (ferrite and/or pearlite) only in the part to be intentionally softened, and then the steel sheet is held or gradually cooled for a certain time, allowing the soft microstructure to grow in this part (hereinafter referred to as first embodiment of the present invention).

[0022]

As a result, it has also been found at the same time that even when heating a steel sheet in a state where austenite is relatively stable, such as in an austenite single-phase region, nucleation of a soft microstructure can be promoted only in the part to be intentionally softened by applying a relatively large strain to the part to be intentionally softened, in the same manner as in the first embodiment of the present invention (hereinafter referred to as second embodiment of the present invention).

[0023]

Hereinafter, the details of requirements specified by the first and second embodiments of the present invention will be described. As used herein, the term "steel component" refers to a steel sheet that has been processed into a predetermined shape by the processing step in the first and second embodiments of the present invention.

[0024]

<First Embodiment of The Present Invention>

A production method according to the first embodiment of the present invention includes the step of:
(a) preparing a steel sheet;
(b) after the step (a), heating;
(c) after the step (b), processing;
(d) after the step (c), holding or cooling gradually; and
(e) after the step (d), cooling.

Hereinafter, each step will be described.

[0025]

(a) Step of preparing steel sheet

The steel sheet according to the first embodiment of the present invention includes: C: 0.05 to 0.40% by mass, Si: 0 to 2.0% by mass, Mn: 1.0 to 3.0% by mass, Al: 0.010 to 1.0% by mass, P: more than 0% by mass and 0.100% by mass or less, S: more than 0% by mass and 0.010% by mass or less, N: more than 0% by mass and 0.010% by mass or less, and B: 0.0005 to 0.010% by mass, with the balance being iron and inevitable impurities.

Hereinafter, each element will be described in detail.

[0026]

(C: 0.05 to 0.40% by mass)

The C content determines the strength of a steel component. In order to obtain a sufficient strength of the steel component, the C content is set at 0.05% by mass or more, and is preferably 0.10% by mass or more, and more preferably 0.20% by mass or more.

[0027]

Meanwhile, the excessive C content remarkably reduce the toughness of a steel component and tends to cause delayed fracture of the steel component. Thus, the C content is set at 0.40% by mass or less, and is preferably 0.38% by mass or less, and more preferably 0.36% by mass or less.

[0028]

(Si: 0 to 2.0% by mass)

Si is an element optionally present in the steel sheet. Si contributes to the hardness stability of the steel sheet by increasing the resistance to temper softening. Thus, Si is preferably contained in an amount of more than 0% by mass in the steel sheet.

[0029]

Meanwhile, Si facilitates the formation of residual austenite (γ) and contributes to a decrease in the yield strength (YS) and to Mn segregation. Thus, the Si content is set at 2.0% by mass or less, and is preferably 1.8% by mass or less.

[0030]

(Mn: 1.0 to 3.0% by mass)

Mn contributes to an increase in the strength of a steel component by enhancing the hardenability of the steel sheet. To exhibit this effect, the Mn content is set at 1.0% by mass or more, and is preferably 1.2% by mass or more, and more preferably 1.4% by mass or more.

[0031]

Meanwhile, the excessive Mn content may cause coarse carbides to precipitate in a steel component. Thus, the Mn content is set at 3.0% by mass or less, and is preferably 2.8% by mass or less, and more preferably 2.6% by mass or less.

[0032]

(Al: 0.010 to 1.0% by mass)

Al is an element that serves as a deoxidizing agent. To exhibit this effect, the Al content is set at 0.010% by mass or more. The Al content is preferably 0.020% by mass or more, and more preferably 0.025% by mass or more. However, the excessive Al content leads to an increase in production costs and causes deterioration of surface quality (decarburization and thinning) due to an increased heating temperature of the material because Ac3 point is extremely increased. Thus, the Al content is set at 1.0% by mass or less. The Al content is preferably 0.80% by mass or less, and more preferably 0.70% by mass or less.

[0033]

(P: more than 0% by mass and 0.100% by mass or less)

P is an inevitable element that degrades the weldability of the steel sheet, but also has the effect of contributing to the solute strengthening of a ferrite phase. To prevent the degradation in the weldability of the steel sheet while exhibiting such an effect, the P content is set at 0.100% by mass or less. The P is preferably 0.050% by mass or less, and more preferably 0.020% by mass or less. P is an impurity trapped inevitably in steel, and it is impossible to suppress its content to 0% by mass in terms of industrial production. Thus, the P content can be usually more than 0% by mass, and can further be 0.00050% by mass or more.

[0034]

(S: more than 0% by mass and 0.010% by mass or less)

S is an inevitable element that degrades the weldability of the steel sheet. Therefore, the S content is set at 0.010% by mass or less. The S content is preferably 0.0080% by mass or less, and more preferably 0.0050% by mass or less.

Since the S content should be as low as possible, the lower limit of the S content is not particularly limited, but it is impossible to set the S content to 0% by mass in terms of industrial production, and the S content can usually be more than 0% by mass, and even 0.00010% by mass or more.

[0035]

(N: more than 0% by mass and 0.010% by mass or less)

N is an inevitable element, and an excess N content generates AlN, which reduces the deoxidizing effect of Al. Therefore, the N content is set at 0.010% by mass or less. The N content is preferably 0.0080% by mass or less, and more preferably 0.0050% by mass or less. Since the N content should be as low as possible, the lower limit of the N content is not particularly limited, but it is impossible to set the N content to 0% by mass in terms of industrial production, and the N content can usually be more than 0% by mass, and even 0.00010% by mass or more.

[0036]

(B: 0.0005 to 0.010% by mass)

B contributes to an increase in the strength of a steel component by enhancing the hardenability of the steel sheet. To exhibit this effect, the B content is set at 0.0005% by mass or more, preferably 0.0010% by mass or more, and more preferably 0.0015% by mass or more.

[0037]

Meanwhile, excessive B content results in the precipitation of coarse iron boron compounds, reducing the toughness of a steel component. Thus, the B content is set at 0.010% by mass or less, and is preferably 0.0080% by mass or less, and more preferably 0.0060% by mass or less.

[0038]

(Balance: iron and inevitable impurities)

In one preferred embodiment, the balance includes iron and inevitable impurities. The inevitable impurities include elements brought in steel material, depending on the circumstances including raw materials, source materials, production facilities, and the like.

There are some elements, such as P, S, and N, for example, which are inevitable impurities that are usually preferred in smaller amounts and whose composition range is separately specified as mentioned above. For this reason, "inevitable impurities" constituting the balance as used herein is the concept excluding an element, the composition range of which is separately specified.

[0039]

Further, the steel sheet according to the first embodiment of the present invention may optionally contain the following arbitrary elements as appropriate, and the properties of the steel component can be further improved depending on the contained element.

[0040]

(One or more selected from the group consisting of Cu: more than 0% by mass and 0.50% by mass or less, and Ni: more than 0% by mass and 0.50% by mass or less)

The inclusion of Cu improves the corrosion resistance of the steel sheet itself, thereby enabling suppression of hydrogen generation due to corrosion of the steel sheet and improvement in the delayed fracture resistance. Cu also has the effect of promoting the formation of iron oxide: α-FeOOH, which is said to be thermodynamically stable and protective among rusts formed in the atmosphere. By promoting the formation of the rust, it is possible to suppress the penetration of generated hydrogen into the steel sheet, thereby preventing hydrogen induced cracking under a severe corrosive environment. Thus, the Cu content is preferably more than 0% by mass, more preferably 0.05% by mass or more, and still more preferably 0.10% by mass or more. Meanwhile, the excessive Cu content degrades platability in a plating process during steel sheet production and chemical conversion processability after hot stamping. Thus, the Cu content is preferably set at 0.50% by mass or less.

Ni is known to have the same effects as Cu. Thus, the Ni content is preferably more than 0% by mass, more preferably 0.05% by mass or more, and still more preferably 0.10% by mass or more. Meanwhile, the Ni content is preferably 0.50% by mass or less.

[0041]

(One or more selected from the group consisting of Ti: more than 0% by mass and 0.10% by mass or less, Cr: more than 0% by mass and 3.0% by mass or less, and Nb: more than 0% by mass and 0.10% by mass or less)

Ti reduces the amount of BN formed in the steel sheet by forming TiN. This can increase the amount of a solid solution B in the steel sheet, thus enhancing the effect of improving the hardenability of B. To exhibit such an effect, the Ti content is preferably more than 0% by mass, more preferably 0.0005% by mass or more, and still more preferably 0.0250% by mass or more, or 0.050% by mass or more.

Meanwhile, the excessive Ti content in the steel sheet causes carbides to precipitate on the grain boundaries, which deteriorates the hardenability of the steel sheet. Thus, the Ti content is preferably set at 0.10% by mass or less, more preferably 0.080% by mass or less, and still more preferably 0.070% by mass or less.

[0042]

Cr contributes to ensuring hardness and suppressing the precipitation of coarse carbides during cooling. To exhibit these effects, the Cr content is preferably more than 0% by mass.

Meanwhile, the excessive Cr content in the steel sheet may cause cracking or the like of the steel sheet. The Cr content is preferably set at 3.0% by mass or less, more preferably 2.5% by mass or less, and still more preferably 2.0% by mass or less.

[0043]

Nb is a carbide-forming element that contributes to the microstructure refinement of the steel sheet. Thus, the Nb content is preferably more than 0% by mass, and more preferably 0.0050% by mass or more.

Meanwhile, by refinement of the microstructure of the steel sheet, reverse transformation during heat treatment is promoted, but ferrite formation is promoted during cooling, which may lead to a reduced strength of steel components. Such effects become greater as its content increases. In addition, an inconvenience such as deteriorated cold-rollability also occurs. From this aspect, the Nb content is preferably 0.10% by mass or less. It is preferably 0.070% by mass or less, and more preferably 0.050% by mass or less.

[0044]

(b) Heating step

In the first embodiment of the present invention, the above steel sheet is heated to the Ac1 point (°C) or higher and lower than the Ac3 point (°C) + 10°C.

At a temperature of lower than the Ac1 point, austenite transformation does not occur, making it difficult to produce a high-strength steel component after a cooling step (e) mentioned below. Meanwhile, by keeping the temperature of the steel sheet lower than the Ac3 point + 10°C, it is easier to promote the nucleation of ferrite and/or pearlite, which are soft microstructures, in the processing step (c) mentioned below.

[0045]

The Ac1 and Ac3 points can be determined by examining the temperatures of the steel sheet during heating and the displacement history thereof due to expansion and shrinkage of the steel as it is heated in the formaster test. FIG. 1 is a graph showing the relationship between the temperature and displacement of the steel sheet when heating the steel sheet from a low temperature in the formaster test. At low temperatures, steel can expand linearly with increasing temperature at an expansion rate corresponding to the crystalline structure of ferrite (bcc). As the temperature of steel further increases, austenite with a denser crystalline structure (fcc) is formed and may begin to shrink. The temperature at which the linearity starts not to be satisfied can be defined as Ac1 point. In a higher temperature range where the temperature of the steel is increased even further, all ferrite transforms to austenite, which can again expand linearly at an expansion rate according to the crystalline structure of the austenite. The temperature at which this expansion starts to occur along the linear line can be defined as Ac3 point.

[0046]

(c) Processing step

After the above heating step (b), the steel sheet is processed by applying a strain of 0.5% or more at a temperature of 675°C or higher and lower than Ac3 point + 10°C.

At the above temperatures, there can be lots of grain boundaries in the steel sheet that are nucleation sites for ferrite and/or pearlite, which are soft microstructures. In such an unstable state, by applying a slight strain (i.e., 0.5% or more), nucleation of ferrite and/or pearlite, which are soft microstructures, can be promoted remarkably in a part where the strain is applied. The applied strain is more preferably 5.0% or more, and still more preferably 9.0% or more.

The strain can be calculated by the following equation (1).

$$\text{Strain (\%)} = |(d_0 - d_1)/d_0 \times 100| \qquad (1)$$

where d_0 is the sheet thickness of the steel sheet before processing or the sheet thickness of a non-processed portion of the steel sheet after the processing, and d_1 is the sheet thickness of a processed part of the steel sheet after the processing. Both thicknesses are represented by using a unit of mm.

The strain may be, for example, equivalent plastic strain determined by FEM analysis. In other words, if the equivalent plastic strain determined by the FEM analysis is 0.5% or more, it can be softened in the same way.

[0047]

The Ms point can be determined by examining the temperatures of the steel sheet during cooling and the displacement history thereof due to expansion and shrinkage of the steel as it is cooled in the formaster test. FIG. 2 is a graph showing the relationship between the temperature and displacement of the steel sheet when cooling the steel sheet at a relatively high speed after heating, in addition to the relationship during the heating shown in FIG. 1. At medium and high temperatures, steel can shrink linearly with decreasing temperature at a shrinkage rate corresponding to the crystalline structure of austenite. As the temperature of the steel is decreased even further, it can be transformed into martensite and begin to expand. The temperature at which the linearity starts not to be satisfied can be defined as Ms point.

[0048]

When the heating temperature in the above heating step (b) is set at Ac1 point (°C) or higher and lower than Ac3 point (°C) + 10°C, and the processing temperature is set at lower than 675°C, the transformation to a soft microstructure becomes more active, so that the softening of a non-processed portion also becomes more pronounced, making it difficult to produce a steel component that is locally softened at the processed part only.

When the heating temperature in the above heating step (b) is set at Ac1 point (°C) or higher and lower than Ac3 point (°C) + 10°C, and the processing temperature is set at

Ac3 point + 10°C or higher, the areas of the grain boundaries, which are the nucleation sites of the soft microstructure, are reduced, and thus the nucleation of the soft microstructure cannot be promoted only by applying a slight strain.

[0049]

The above processing temperature may be the same as or different from the heating temperature of the heating step (b) above. When these are different, an additional step of heating and/or cooling may be included between the above steps (b) and (c). After the step (b) and before the step (c), a further step of holding the steel sheet at a certain temperature may be included.

[0050]

The above processing may be any arbitrary one, but pressing, stretch forming, forging, return bending during draw forming, shearing, etc., for example, are all suitable.

[0051]

(d) Step of holding or gradually cooling

After the processing step (c), the steel is held for 1 second or more and 120 seconds or less, or gradually cooled at an average cooling rate of 0 to 15°C/sec. Specifically, the steel sheet is held at the processing temperature for 1 second or more and 120 seconds or less, or gradually cooled at an average cooling rate of more than 0°C/sec and 15°C/sec or less for 1 second or more and 120 seconds or less. This allows the growth of ferrite and/or pearlite, nucleated in the step (c) above, which are soft microstructures.

[0052]

If the average cooling rate is more than 15°C/sec or if the holding or gradually cooling time is less than 1 second, ferrite and/or pearlite, which are soft microstructures, cannot be sufficiently precipitated and grown. The holding or gradually cooling time is preferably more than 1 second, more preferably 3 seconds or more, and still more preferably 6 seconds or more.

If the holding or gradually cooling time is more than 120 seconds, ferrite and/or pearlite, which are soft microstructures, precipitate and grow even in the non-processed portion, thus failing to obtain a high-strength steel component. This time is preferably 12 second or less.

[0053]

(e) Cooling step

After the holding or gradually cooling step (d) above, the steel sheet is cooled to Ms point (°C) - 50°C. At this time, the average cooling rate from the heating temperature in the heating step (b) (i.e., Ac1 point (°C) or higher and Ac3 point (°C) + 10°C or lower) to Ms point (°C) - 50°C is controlled to 10°C/sec or more. This allows martensitic transformation to occur at least in the non-processed portion, ensuring sufficient strength in the non-processed portion. If cooling at an average cooling rate of 10°C/sec or more is terminated at higher than Ms point (°C) - 50°C, martensitic transformation cannot occur sufficiently in the non-processed portion. Besides, if the average cooling rate is less than 10°C/sec, the martensitic transformation cannot occur sufficiently in the non-processed portion.

[0054]

After the cooling step (e) above, the steel sheet can be cooled to, for example, room temperature. The cooling rate from Ms point (°C) - 50°C to room temperature is not particularly limited.

[0055]

<Second Embodiment of the Invention>

A production method according to a second embodiment of the present invention differs from the production method according to the first embodiment of the present invention in the conditions of the heating step (b) and the processing step (c). Hereinafter, these steps which are different from those of the first embodiment of the present invention will be described as a heating step (b') and a processing step (c').

[0056]

(b') Heating step

In the second embodiment of the present invention, the above steel sheet is heated to the Ac3 point (°C) + 10°C or higher and 1,100°C or lower. Unlike the first embodiment of the present invention, even though the steel sheet is heated to a temperature of Ac3 point (°C) + 10°C or higher in the heating step, the nucleation of ferrite and/or pearlite, which are soft microstructures, can be remarkably promoted if a relatively large strain is applied in a processing step (c') to be mentioned later, similarly to the first embodiment of the present invention. Meanwhile, if the temperature of the steel sheet exceeds 1,100°C, decarburization on the steel surface becomes more pronounced, so that the desired strength cannot be obtained. In addition, there is a possibility that oxidation will progress, resulting in thinning. In a case where the steel sheet is plated, oxidation and alloying will occur, causing problems of which, for example, the hardness of the plating becomes extremely high, allowing the plating to be peeled off in the processing step (leading to oxidation of the steel sheet, and/or pressing scratches).

[0057]

(c') Processing step

After the above heating step (b'), the steel sheet is processed by applying a strain of 10% or more thereto at a temperature of Ms point (°C) + 50°C or higher and lower than Ac3 point (°C) + 10°C. At the temperature of Ms point (°C) + 50°C or higher and lower than Ac3 point (°C) + 10°C, austenite becomes relatively unstable. Thus, by applying a relatively large (10% or more) strain, the nucleation of ferrite and/or pearlite, which are soft microstructures, can be remarkably promoted in a part where the strain is applied. The strain applied is more preferably 15% or more, and still more preferably 40% or more. The strain can be calculated by the above equation (1). The strain may be, for example, equivalent plastic strain determined by FEM analysis. In other words, if the equivalent plastic strain determined by the FEM analysis is 10% or more, it can be softened in the same way.

[0058]

At temperatures of Ac3 point (°C) + 10°C or higher, austenite becomes relatively stable. Thus, even when a relatively large strain is applied, the nucleation of ferrite/or pearlite, which are soft microstructures, are difficult to promote. Meanwhile, at temperatures of lower than Ms point (°C) + 50°C, martensitic transformation may occur, making it difficult to promote nucleation of ferrite and/or pearlite, which are soft microstructures.

[0059]

The cooling from the temperature after the heating step (b') (i.e. Ac3 point (°C) + 10°C or higher to 1,100°C or lower) to the temperature in the processing step (c') (i.e. Ms point (°C) + 50°C or higher and lower than Ac3 point (°C) + 10°C) is not particularly limited, and may be performed at any average cooling rate. After the step (b') and before the step (c'), a further step of holding the steel sheet at a certain temperature may be included.

[0060]

The above processing step (c') may be any arbitrary one, but pressing, stretch forming, forging, bending back during draw forming, shearing, etc., for example, are all suitable.

[0061]

In the first and second embodiments of the present invention, the strain in the steps (c) and (c') may be applied through a plurality of times of processing.

When the strain is applied through the plurality of times of processing in the above steps (c) and (c'), the strain can be calculated by the following equation (2).

[0062]

[Equation 1]

$$\text{Strain } (\%) = \sum_{1}^{n} \left| (d_{n-1} - d_n) / d_{n-1} \times 100 \right| \quad \cdots (2)$$

where d_n is a sheet thickness of a processed part of the steel sheet obtained after the n-th processing, and the unit of d_n is mm.

It is noted that the strain determined by the above equation (2) may be, for example, the total of equivalent plastic strains determined by FEM analysis after each processing.

[0063]

For example, when the step (c) or (c′) is a single process, it may be difficult to apply the predetermined strain (0.5% or more in the first embodiment, 10% or more in the second embodiment). In such a case, it is advantageous to perform the above steps (c) and (c′) a plurality of times to accumulate the strain so that the strain is more likely to exceed the predetermined value.

[0064]

When the step (c) or (c′) is a single process, it may be difficult to set a delivery time from the above step (c) or (c′) to the above cooling step (e) to less than 1 second, or to make the time for the above holding or gradually cooling step (d) (i.e. for 1 second or more). In such a case, it is advantageous to perform the above steps (c) and (c′) a plurality of times because the delivery time between the plurality times of processing steps can be used as the time for the holding or gradually cooling step (d).

[0065]

The plurality of times of processing may include processing for applying deformation and processing for restoring the deformation. This allows the above strain to be applied to the initial steel sheet shape without changing the final steel component shape.

[0066]

When each of the above steps (c) and (c') includes a plurality of times of processing, the above holding or gradually cooling step (d) may be performed after each time of processing. For example, when the processing is performed twice, the first processing may be performed, followed by the first holding or gradually cooling step, the second processing and further the second holding or gradually cooling step. In this case, the total of the time for the first holding or gradually cooling step and the time for the second holding or gradually cooling step may be within a defined time of the step (d) specified by the first and second embodiments of the present invention, i.e., 1 second or more and 120 seconds or less.

[0067]

The temperatures in the above steps (a) to (e), (b') and (c') above are the surface temperature of the steel sheet (or steel component) and may be measured using a thermocouple or radiation thermometer. Alternatively, the correspondence between the ambient temperature of a heating line, etc., and the surface temperature of the steel sheet (or steel component) measured by the thermocouple or the like may be investigated in advance, and thereby the surface temperature of the steel sheet (or steel component) may be read off from the ambient temperature of the heating line, etc.

[0068]

According to the first and second embodiments of the present invention, it is possible to provide a method for producing a high-strength steel component in which only a part applied with a predetermined level or more of strain by the processing is locally softened, without any local temperature control.

EXAMPLES

[0069]

The embodiments of the present invention will be described in more detail by way of Examples. It is to be understood that the embodiments of the present invention are not limited to the following Examples, and various design variations made in accordance with the purports mentioned hereinbefore and hereinafter are also included in the scope of the embodiments of the present invention.

Example 1

[0070]

Steel having the chemical composition shown as steel type No. A in Table 1, (Ac1 point: 778°C, Ac3 point: 875°C, and Ms point: 385°C) was used to prepare a steel sheet with a sheet thickness of 1.6 mm and an area of 100 mm × 100 mm, and the prepared steel sheet was heated to 880°C. Thereafter, the steel sheet was cooled down to 750°C at about 12°C/sec, and subjected to stretch forming at 750°C. The stretch forming was performed by pressing a hemispherical punch with 10 mm diameter against the center of the steel sheet with a 100 mm × 100 mm from its back side. The height due to the stretch forming was set at 3.0 mm. After the stretch forming, the steel sheet was gradually cooled for 6 seconds at an average cooling rate of 10.8°C/sec. The steel sheet was then water-cooled to Ms point (°C) - 50°C (i.e., 335°C), so that the average cooling rate from 880°C to 335°C was 39.5°C/sec. Thereafter, the steel sheet was allowed to cool to room temperature. The above procedure is defined as Production Example 1-2.

The Ac1, Ac3 and Ms points above were determined by the formaster test. The formaster test was performed under the following conditions.

Formaster testing device: FTM-10, manufactured by Fuji Electronic Industrial Co., Ltd.

Specimen size: 2.0 mm thickness × 3.0 mm width × 10 mm length (note that two holes of 0.7 mm diameter × 2.0 mm depth for thermocouple insertion are formed)

Number of tests: 7 times (only cooling rate was changed, while other conditions were constant)

Heating rate: 10°C/s (room temperature to heating temperature)

Heating temperature: 950°C

Holding time at the heating temperature: 180 seconds.

Cooling rate: 2, 5, 10, 15, 20, 30, and 40°C/s (heating temperature to room temperature)

In Table 1, the Cu content of steel type No. A is listed as "-" because it was at the inevitable impurity level (less than 0.01% by mass).

[0071]

[Table 1]

Steel type No.	Chemical composition (% by mass) * Balance being iron and inevitable impurities										
	C	Si	Mn	Al	P	S	N	B	Ti	Cr	Cu
A	0.31	1.2	1.2	0.042	0.01	0.001	0.004	0.002	0.04	0.6	-
B	0.235	0.19	1.29	0.041	0.013	0.002	0.0054	0.0033	0.026	0.23	0.07

[0072]

To evaluate the strain and hardness of a steel component obtained by Production Example 1-2, evaluation samples were taken. The locations where the evaluation samples were taken are shown in Figure 3. As shown in FIG. 3, a stretch formed portion A (25 mm in the longitudinal direction × 5 mm in the lateral direction) at the center of the steel component and a non-processed portion B (10 mm in the longitudinal direction × 5 mm in the lateral direction) located longitudinally away from the stretch forming part A were taken.

[0073]

To evaluate the strain of the samples, the sheet thickness of the steel sheet was determined by cross-sectional observation with an optical microscope.

The sheet thickness of the stretch formed portion A was determined at the center of the steel component, at a distance of 3.75 mm longitudinally from the center (referred to as middle section), and at a distance of 7.5 mm longitudinally from the center (referred to as hem section). Then, by using the above equation (1), the strains at the center, the middle section, and the hem section of the steel component were determined by defining each of the sheet thicknesses of the center, the middle section, and the hem section of the steel component as the sheet thickness d1 of the processed part, and also by defining the sheet thickness of the non-processed portion B as the sheet thickness d0 of the steel sheet before the processing.

[0074]

Vickers hardnesses were measured at three locations (the center, middle section, and hem section) of the stretch formed portion A and the non-processed portion B. The measurement was performed using a Vickers hardness tester under conditions of a load of 1 kg and a holding time of 10 seconds. The measurement positions were set at three points that were located at d/4 from the surface of the steel component in the thickness direction where d is the sheet thickness. FIG. 4 is a schematic cross-sectional view taken along the line X-X shown in FIG. 3 and shows hardness measurement positions of the stretch formed portion A.

Although the hardness measurement positions of the non-processed portion B are not shown in the drawings, the measurement positions were set at three points that were located at the center of the non-processed portion B in the longitudinal and lateral directions and at d/4 from the surface of the steel component in the direction of the sheet thickness.

[0075]

An average value of Vickers hardnesses at three locations (the center, the middle section, and the hem section) of the stretch formed portion A, as well as an average value of Vickers hardnesses at three points of the non-processed portion B were adopted as the respective Vickers hardnesses.

[0076]

Steel components (hereinafter referred to as Production Examples 1-1 and 1-3 to 1-8) were produced by changing any of the following conditions of Production Example 1-2: temperature (°C) at which the stretch forming was performed (referred to as molding temperature), an height (mm) due to the stretch forming, a cooling rate (°C/sec) during gradually cooling, a gradually cooling time (sec), and an average cooling rate (°C/sec) from a heating temperature to the Ms point - 50°C. The strain and Vickers hardness of each steel component were evaluated in the same manner as the steel component obtained in Production Example 1-2. The results are shown in Table 2.

In Table 2, numerical values underlined indicate that they deviate from the scope of the first embodiment of the present invention.

[0077]

[Table 2]

Production Examples	(a) Step of preparing steel sheet	(b) Heating step	(c) Processing step					(d) Holding or gradually cooling step		Average cooling rate from heating temperature to Ms point - 50°C	Hardness						
	Steel type No.	Heating temperature	Molding temperature	Height due to the strain forming	Strain			Cooling rate	Gradually cooling time		Vickers hardness				Difference in Vickers hardness between center and non-processed portion		
					Center	Middle section	Hem section				Center	Middle section	Hem section	Non-processed portion	Center	Middle section	Hem section
		[°C]	[°C]	[mm]	[%]	[%]	[%]	[°C/sec]	[Sec]	[°C/sec]	[HV]	[HV]	[HV]	[HV]	[HV]	[HV]	[HV]
1-1	A	880	750	0.1	0.6	0.6	0.6	10.8	6	39.5	268	262	271	387	-119	-125	-116
1-2	A	880	750	3	9.7	18.2	4.8	10.8	6	39.5	288	290	385	412	-124	-122	-27
1-3	A	880	750	6	14.1	39.9	4.9	10.8	6	39.5	340	330	435	519	-179	-189	-84
1-4	A	880	750	6	14.0	37.2	4.9	9.6	12	27.5	267	281	337	403	-137	-123	-67
1-5	A	880	<u>650</u>	3	7.3	17.7	4.3	7.1	6	24.8	272	286	265	259	13	27	5
1-6	A	880	<u>650</u>	6	13.9	44.2	4.8	7.1	6	24.8	277	306	249	251	26	55	-2
1-7	A	880	<u>550</u>	3	9.1	16.4	3.6	4.7	6	16.0	280	302	235	215	65	87	20
1-8	A	880	<u>550</u>	6	14.1	47.9	6.1	4.7	6	16.0	303	345	233	224	79	121	9

[0078]

Among Production Examples 1-1 to 1-8, Production Example in which at least one of the center, the middle section, and the hem section had a Vickers hardness lower by 20 HV or more than the Vickers hardness of the non-processed portion while the hardness of the non-processed portion was 310 HV or higher was determined to satisfy the criteria of "locally softened high-strength steel component". A preferred Production Example as the "locally softened" steel component is one in which at least one of the center, the middle section, and the hem section had a Vickers hardness lower by 40 HV or more than the Vickers hardness of the non-processed portion. A further preferred Production Example is one in which at least one of the center, the middle section, and the hem section had a Vickers hardness lower by 100 HV or more than the Vickers hardness of the non-processed portion.

A more preferred Production Example as the "high-strength steel component" is one in which the Vickers hardness of the non-processed portion is 400 HV or more, and an still more preferred Production Example is one in which the Vickers hardness of the non-processed portion is 500 HV or more.

The same goes for Examples 2 and 3 to be mentioned later.

[0079]

From the results in Table 2, the following can be discussed. Production Examples 1-1 to 1-4 of Table 2 are examples satisfying all requirements specified by the first embodiment of the present invention, and were able to manufacture high-strength steel components in which only a part applied with a predetermined or more strain (0.5% or more in the first embodiment of the present invention) by the processing was locally softened without any local thermal control.

Meanwhile, Production Examples 1-5 to 1-8 of Table 2 are example not satisfy any of the requirements specified by the first embodiment of the present invention and were not able to manufacture high-strength steel components in which a part applied with a predetermined or more strain (0.5% or more in the first embodiment of the present invention) by the processing was locally softened.

[0080]

In Production Examples 1-5 to 1-8, since the forming temperature was 650°C or 550°C, and less than 675°C, the entire steel component including the non-processed portion was softened, and thus a high-strength steel component locally softened was not able to be produced.

Example 2

[0081]

Steel having the chemical composition shown as steel type No. A in Table 1 was used to prepare a steel sheet with a sheet thickness of 1.6 mm and an area of 100 mm × 100 mm, and the prepared steel sheet was heated to 880°C. Thereafter, the steel sheet was cooled down to 750°C at about 12°C/sec, and subjected to the first stretch forming at 750°C. The first stretch forming was performed by pressing a hemispherical punch with 10 mm diameter against the center of the steel sheet with a 100 mm × 100 mm from its back side. The height due to the first stretch forming was set at 3.0 mm. After the first stretch forming, the steel sheet was gradually cooled for 6 seconds at an average cooling rate of 10.8°C/sec. After the first gradually cooling step, the second stretch forming was performed. The second stretch forming was performed by pressing the hemispherical punch with 10 mm diameter against the locations of the steel sheet subjected to the first stretch forming in the opposite direction of the first stretch forming (i.e., from its front side). After the second stretch forming, the steel sheet was gradually cooled for 6 seconds at an average cooling rate of 6.7°C/sec. After the second gradually cooling step, the steel sheet was then water-cooled to Ms point (°C) - 50°C (i.e., 335°C) so that the average cooling rate from 880°C to 335°C was 26.2°C/sec. Thereafter, the steel sheet was allowed to cool to room temperature. The above procedure is defined as a Production Example 2-1.

[0082]

The strain and Vickers hardness of the steel component obtained in Production Example 2-1 were evaluated in the same manner as Example 1. The strain was calculated using the above equation (2). Since the first stretch forming was performed in the same way as in Production Example 1-2, the strain was calculated on the assumption that the sheet thickness after the first stretch forming was the same as that in Production Example 1-2. The results are shown in Table 3. The second stretch forming was performed in the opposite direction as the first stretch forming, and thus the height due to the second stretch forming was a negative value.

[0083]

[Table 3]

Production Example	(a) Step of preparing steel sheet	(b) Heating step	(c) Processing step						(d) Holding or gradually cooling step				Average cooling rate from heating temperature to Ms point - 50°C	Hardness						
	Steel type No.	Heating temperature	First molding temperature	Height due to the first stretch forming	Height due to the second stretch forming	Strain due to twice processing			First cooling rate	First gradually cooling time	Second cooling rate	Second gradually cooling time		Vickers hardness				Difference in Vickers hardness between center and non-processed portion		
						Center	Middle section	Hem section						Center	Middle section	Hem section	Non-processed portion	Center	Middle section	Hem section
		[°C]	[°C]	[mm]	[mm]	[%]	[%]	[%]	[°C/sec]	[Sec]	[°C/sec]	[Sec]	[°C/sec]	[HV]	[HV]	[HV]	[HV]	[HV]	[HV]	[HV]
2-1	A	880	750	3	-3	11.9	34.6	5.9	10.8	6	6.7	6	26.2	319	340	310	381	-62	-41	-71

[0084]

From the results in Table 3, the following can be discussed. Production Example 2-1 of Table 3 is an example satisfying all requirements specified by the first embodiment of the present invention, and was able to manufacture a high-strength steel component in which only a part applied with a predetermined or more strain (0.5% or more in the first embodiment of the present invention) by the processing was locally softened without any local thermal control.

Example 3

[0085]

Steel having the chemical composition shown as steel type No. A in Table 1 was used to prepare a steel sheet with a sheet thickness of 1.6 mm and an area of 100 mm × 100 mm, and the prepared steel sheet was heated to 950°C and held for 60 seconds. Thereafter, the steel sheet was cooled down to 550°C at about 12°C/sec, and subjected to stretch forming at 550°C. The stretch forming was performed by pressing a hemispherical punch with 10 mm diameter against the center of the steel sheet with a 100 mm × 100 mm from its back side. The height due to the stretch forming was set at 0.1 mm. After the stretch forming, the steel sheet was gradually cooled for 6 seconds at an average cooling rate of 4.7°C/sec. The steel sheet was then water-cooled to Ms point (°C) - 50°C (i.e., 335°C) so that the average cooling rate from 950°C to 335°C was 12.5°C/sec. Thereafter, the steel sheet was allowed to cool to room temperature. The above procedure is defined as Production Example 3-1.

[0086]

The strain and Vickers hardness of the steel component obtained in Production Example 3-1 were evaluated in the same manner as Example 1.

[0087]

Steel components (hereinafter referred to as Production Examples 3-2 to 3-19) were produced by changing any of the following conditions of Production Example 3-1: temperature (°C) at which the stretch forming was performed (referred to as molding temperature), a height due to the stretch forming (mm), a cooling rate (°C/sec) during gradually cooling, a gradually cooling time (sec), and an average cooling rate (°C/sec) from a heating temperature to the Ms point - 50°C. The strain and Vickers hardness of each steel component were evaluated in the same manner as in Production Example 3-1. The results are shown in Tables 4 and 5. The Ac1 point of the steel having the chemical composition shown in steel type No. B in Table 1 was 778°C, the Ac3 point was 875°C, and the Ms point was 385°C.

In Tables 4 and 5, numerical values underlined indicate that they deviate from the scope of the second embodiment of the present invention.

[0088]

[Table 4]

Production Examples	(a) Step of preparing steel sheet	(b) Heating step	(c) Processing step					(d) Holding or gradually cooling step		Average cooling rate from heating temperature to Ms point - 50°C	Hardness						
	Steel type No.	Heating temperature	Molding temperature	Height due to the stretch forming	Strain			Cooling rate	Gradually cooling time		Vickers hardness				Difference in Vickers hardness between center and non-processed portion		
					Center	Middle section	Hem section				Center	Middle section	Hem section	Non-processed portion	Center	Middle section	Hem section
		[°C]	[°C]	[mm]	[%]	[%]	[%]	[°C/sec]	[Sec]	[°C/sec]	[HV]	[HV]	[HV]	[HV]	[HV]	[HV]	[HV]
3-1	A	950	550	0.1	1	0	0	4.7	6	12.5	637	640	628	622	15	17	6
3-2	A	950	650	0.1	2	0	0	7.1	6	16.5	642	623	622	623	19	0	-1
3-3	A	950	750	0.1	2	0	0	10.8	6	21.2	636	630	625	625	11	5	0
3-4	A	950	550	6	26	41	9	4.7	6	12.5	564	490	629	645	-80	-154	-15
3-5	A	950	650	6	17	39	7	7.1	6	1.65	584	555	636	639	-55	-84	-4
3-6	A	950	750	6	21	41	6	10.8	6	21.2	542	427	627	633	-91	-206	-6
3-7	A	950	550	3	7	8	6	16.5	0	14.2	593	604	586	590	3	14	-4
3-8	A	950	550	3	7	5	2	4.7	6	12.5	632	628	627	627	5	1	0
3-9	A	950	550	3	9	14	6	4.7	12	11.1	617	573	613	607	10	-34	6
3-10	A	950	600	3	8	6	6	67	6	14.6	636	615	640	617	20	-1	24
3-11	A	950	600	3	8	13	7	6.7	12	12.8	608	566	618	613	-5	-46	5
3-12	A	950	650	3	9	13	7	26.0	0	19.7	593	603	587	589	4	14	-2
3-13	A	950	650	3	8	9	5	7.1	6	1.65	628	629	629	618	11	11	12
3-14	A	950	650	3	11	16	6	7.1	12	14.2	582	562	625	615	-33	-53	10
3-15	A	950	700	3	10	15	8	9.2	6	18.8	602	582	636	625	-23	-43	11
3-16	A	950	700	3	10	14	7	9.2	12	15.9	593	587	614	623	-30	-36	-9
3-17	A	950	750	3	11	6	4	35.5	0	26.7	590	590	589	590	0	0	-1
3-18	A	950	750	3	8	7	5	10.8	6	21.2	621	626	628	643	-22	-17	-14
3-19	A	950	750	3	8	4	5	10.8	12	17.6	635	634	639	638	-3	-4	2

[0089]

[Table 5]

Production Examples	(a) Step of preparing steel sheet	(b) Heating step	(c) Processing step					(d) Holding or gradually cooling step		Average cooling rate from heating temperature to Ms point - 50°C	Hardness						
	Steel type No.	Heating temperature	Molding temperature	Height due to the stretch forming	Strain			Cooling rate	Gradually cooling time		Vickers hardness				Difference in Vickers hardness between center and non-processed portion		
					Center	Middle section	Hem section				Center	Middle section	Hem section	Non-processed portion	Center	Middle section	Hem section
		[°C]	[°C]	[mm]	[%]	[%]	[%]	[°C/sec]	[Sec]	[°C/sec]	[HV]	[HV]	[HV]	[HV]	[HV]	[HV]	[HV]
3-20	A	950	700	3	11	19	2	7.9	6	18.6	567	521	584	594	-27	-73	-10
3-21	A	950	700	4	14	24	2	7.9	6	18.6	515	474	586	591	-77	-117	-5
3-22	A	950	700	5	17	34	1	7.9	6	18.6	497	411	589	603	-106	-192	-14
3-23	A	950	700	6	17	34	2	7.9	6	18.6	493	396	585	597	-103	-201	-12
3-24	A	950	700	7	17	39	3	7.9	6	18.6	522	413	592	606	-84	-193	-13
3-25	A	950	700	6	17	40	1	8.3	4	19.8	490	373	597	603	-112	-230	-6
3-26	A	950	700	6	20	36	3	7.7	9	17.1	506	400	587	599	-93	-199	-13
3-27	A	950	700	6	19	36	3	7.4	12	15.8	471	371	585	590	-119	-219	-5
3-28	A	950	700	6	18	37	1	30.8	0	22.8	595	602	587	589	6	13	-2
3-29	B	950	750	6	24	38	1	34.8	0	25	498	510	494	495	3	16	-1
3-30	B	950	750	6	24	46	1	8.7	12	16.7	350	295	441	449	-100	-154	-8
3-31	B	950	750	6	22	42	2	9.2	6	18.2	383	352	491	480	-97	-128	-11
3-32	B	950	750	6	22	39	3	9.7	6	20	418	397	488	497	-79	-100	-8
3-33	B	950	750	0.1	2	0	0	9.7	6	20	483	481	486	491	-8	-10	-5
3-34	B	950	750	3	11	17	1	9.7	6	20	438	429	477	492	-54	-63	-15
3-35	B	950	750	4	16	24	2	9.7	6	20	447	408	474	491	-44	-83	-17
3-36	B	950	750	5	19	31	1	9.7	6	20	418	384	484	486	-68	-102	-2
3-37	B	950	750	6	19	33	1	9.7	6	20	414	355	486	481	-67	-126	5
3-38	B	950	750	7	19	37	1	9.7	6	20	423	338	485	480	-57	-142	5

[0090]

From the results in Tables 4 and 5, the following can be discussed. Production Examples 3-4 to 3-6, 3-9, 3-11, and 3-14 to 3-16 of Table 4 and Production Examples 3-20 to 3-27, 3-30 to 3-32, and 3-34 to 3-38 of Table 5 are examples satisfying all requirements specified by the second embodiment of the present invention, and were able to manufacture high-strength steel components in which only a part applied with a predetermined or more strain (10% or more in the second embodiment of the present invention) by the processing was locally softened without any local thermal control.

[0091]

Meanwhile, Production Examples 3-1 to 3-3, 3-7 to 3-8, 3-10, 3-12 to 3-13, 3-17, and 3-19 of Table 4 and Production Examples 3-28, 3-29, and 3-33 of Table 5 are examples not satisfying any of the requirements specified by the second embodiment of the present invention, and were not able to manufacture high-strength steel components in which only a part applied with a predetermined or more strain (10% or more in the second embodiment of the present invention) by the processing was locally softened.

[0092]

In Production Examples 3-1 to 3-3, 3-8, 3-10, 3-13, and 3-19 of Table 4 and Production Example 3-33 of Table 5, the strains in all the center, the middle section, and the hem section were less than 10%, and thus the high-strength steel component locally softened was not able to be produced.

[0093]

In Production Example 3-7 of Table 4, the gradually cooling rate in the holding or gradually cooling step (d) was more than 15°C/sec (i.e., a gradually cooling time was less than 1 sec), and the strains in all the center, the middle section, and the hem section were less than 10%. As a result, the high-strength steel component locally softened was not able to be produced.

[0094]

In Production Examples to 3-12 and 3-17 of Table 4 and Production Examples 3-28 and 3-29 of Table 5, the gradually cooling rate in the holding or gradually cooling step (d) was more than 15°C/sec (i.e., gradually cooling time was less than 1 sec), and thus the high-strength steel component locally softened was not able to be produced.

[0095]

In Production Example 3-18 of Table 4, the strain applied to the center of the steel sheet by the processing was 8%, and did not satisfy the strain of 10% or more specified by the second embodiment of the present invention, but a difference in the hardness between the center and the non-processed portion was 20 HV or more. There is a possibility that at the center of the component No. 3-18, the production conditions other than the strain (heating temperature, cooling rate, and gradually cooling time, etc.) were preferable conditions, but the details thereof are unknown.

Example 4

[0096]

Steel having the chemical composition shown as steel type No. A in Table 1 was used to prepare a steel sheet with a sheet thickness of 1.6 mm and an area of 100 mm × 100 mm, and the prepared steel sheet was heated to 950°C. Thereafter, the steel sheet was cooled down to 750°C at about 12°C/sec, and subjected to the first stretch forming at 750°C. The first stretch forming was performed by pressing a hemispherical punch with 10 mm diameter against the center of the steel sheet with a 100 mm × 100 mm from its back side. The height due to the first stretch was set at 4.0 mm. After the first stretch forming, the steel sheet was gradually cooled for 6 seconds at an average cooling rate of 9.7°C/sec. After the first gradually cooling step, the second stretch forming was performed. The second stretch forming was performed by pressing the hemispherical punch with 10 mm diameter against the locations of the steel sheet subjected to the first stretch forming in the opposite direction of the first stretch forming (i.e., from its front side). After the second stretch forming, the steel sheet was gradually cooled for 6 seconds at an average cooling rate of 5.3°C/sec. After the second gradually cooling step, the steel sheet was then water-cooled to Ms point (°C) - 50°C (i.e., 335°C) so that the average cooling rate from 950°C to 335°C was 16.6°C/sec. Thereafter, the steel sheet was allowed to cool to room temperature. The above procedure is Production Example 4-1.

[0097]

The strain and Vickers hardness of the steel component obtained in Production Example 4-1 were evaluated in the same manner as Example 1. The strain was calculated using the above equation (2). It was confirmed that the thickness of the steel sheet at the center was 1.39 mm, its thickness at the middle section was 1.22 mm, and its thickness at the hem section was 1.58 mm when the second stretch forming was not performed in Production Example 4-1. These sheet thicknesses were used as the sheet thicknesses after the first stretch forming in Production Example 4-1 to calculate the strains. The results are shown in Table 6. The second stretch forming was performed in the opposite direction as the first stretch forming, and thus the height due to the second stretch forming was a negative value.

[0098]

[Table 6]

Production Example	(a) Step of preparing steel sheet	(b) Heating step	(c) Processing step						(d) Holding or gradually cooling step				Average cooling rate from heating temperature to Ms point - 50°C	Hardness						
	Steel type No.	Heating temperature	First molding temperature	Height due to the first stretch forming	Height due to the second stretch forming	Strain due to twice processing			First cooling rate	First gradually cooling time	Second cooling rate	Second gradually cooling time		Vickers hardness				Difference in Vickers hardness between center and non-processed portion		
						Center	Middle section	Hem section						Center	Middle section	Hem section	Non-processed portion	Center	Middle section	Hem section
		[°C]	[°C]	[mm]	[mm]	[%]	[%]	[%]	[°C/sec]	[Sec]	[°C/sec]	[Sec]	[°C/sec]	[HV]	[HV]	[HV]	[HV]	[HV]	[HV]	[HV]
4-1	A	950	750	4	-4	14	39	9	9.7	6	5.3	6	16.6	553	500	577	586	-33	-86	-9

[0099]

From the results in Table 6, the following can be discussed. Production Example 4-1 of Table 6 is an example satisfying all requirements specified by the second embodiment of the present invention, and was able to manufacture high-strength steel components in which only a part applied with a predetermined or more strain (10% or more in the second embodiment of the present invention) by the processing was locally softened without any local thermal control.

Industrial Applicability

[0100]

In the embodiments of the present invention, it is possible to provide a method for producing a high-strength steel component having a locally softened part without any local temperature control. Such high-strength steel component is suitable, for example, for materials of automobile frames.

[Description of Reference Numerals]

[0101]

1 Steel component

2 First location of hardness measurement at center

3 Second location of hardness measurement at center

4 Third location of hardness measurement at center

5 First location of hardness measurement at middle section

6 Second location of hardness measurement at middle section

7 Third location of hardness measurement at middle section

8 First location of hardness measurement at hem section

9 Second location of hardness measurement at hem section

10 Third location of hardness measurement at hem section

A Stretch formed portion

B Non-processed portion

CLAIMS

1. A method for producing a steel component, which comprises the steps of:

preparing a steel sheet having a chemical composition comprising:

C: 0.05 to 0.40% by mass,

Si: 0 to 2.0% by mass,

Mn: 1.0 to 3.0% by mass,

Al: 0.010 to 1.0% by mass,

P: more than 0% by mass and 0.100% by mass or less,

S: more than 0% by mass and 0.010% by mass or less,

N: more than 0% by mass and 0.010% by mass or less, and

B: 0.0005 to 0.010% by mass, with the balance being iron and inevitable impurities;

heating the steel sheet to a temperature of Ac1 point (°C) or higher and lower than Ac3 point (°C) + 10°C;

after the heating step, processing the steel sheet by applying a strain of 0.5% or more thereto at a processing temperature of 675°C or higher and lower than Ac3 point (°C) + 10°C;

after the processing step, holding the steel sheet at the processing temperature for 1 second or more and 120 seconds or less, or gradually cooling the steel sheet at an average cooling rate of more than 0°C/sec and 15°C/sec or less for 1 second or more and 120 seconds or less; and

after the holding or gradually cooling step, cooling the steel sheet to a temperature of Ms point (°C) - 50°C, wherein an average cooling rate from the temperature of the heating step to the Ms point (°C) - 50°C is controlled to be 10°C/sec or more.

2. A method for producing a steel component, which comprises the steps of:

preparing a steel sheet having a chemical composition comprising:

C: 0.05 to 0.40% by mass,

Si: 0 to 2.0% by mass,

Mn: 1.0 to 3.0% by mass,

Al: 0.010 to 1.0% by mass,

P: more than 0% by mass and 0.100% by mass or less,

S: more than 0% by mass and 0.010% by mass or less,

N: more than 0% by mass and 0.010% by mass or less, and

B: 0.0005 to 0.010% by mass, with the balance being iron and inevitable impurities;

heating the steel sheet to a temperature of Ac3 point (°C) + 10°C or higher and 1,100°C or lower;

after the heating step, processing a part of the steel sheet by applying a strain of 10% or more thereto at a processing temperature of Ms point (°C) + 50°C or higher and lower than Ac3 point (°C) + 10°C;

after the processing step, holding the steel sheet at the processing temperature for 1 second or more and 120 seconds or less, or gradually cooling the steel sheet at an average cooling rate of more than 0°C/sec and 15°C/sec or less for 1 second or more and 120 seconds or less; and

after the holding or gradually cooling step, cooling the steel sheet to a temperature of Ms point (°C) - 50°C, wherein an average cooling rate from the temperature in the heating step to the Ms point (°C) - 50°C is controlled to be 10°C/sec or more.

3. The production method according to claim 1, wherein the steel sheet further comprises at least one of the following (a) and (b):

(a) one or more selected from the group consisting of Cu: more than 0% by mass and 0.50% by mass or less, and Ni: more than 0% by mass and 0.50% by mass or less, and

(b) one or more selected from the group consisting of Ti: more than 0% by mass and 0.10% by mass or less, Cr: more than 0% by mass and 3.0% by mass or less, and Nb: more than 0% by mass and 0.10% by mass or less.

4. The production method according to claim 2, wherein the steel sheet further comprises at least one of the following (a) and (b):

(a) one or more selected from the group consisting of Cu: more than 0% by mass and 0.50% by mass or less, and Ni: more than 0% by mass and 0.50% by mass or less, and

(b) one or more selected from the group consisting of Ti: more than 0% by mass and 0.10% by mass or less, Cr: more than 0% by mass and 3.0% by mass or less, and Nb: more than 0% by mass and 0.10% by mass or less.

5. The production method according to any one of claims 1 to 4, further comprising applying the strain by stretch forming.

6. The production method according to any one of claims 1 to 4, further comprising applying the strain by forging.

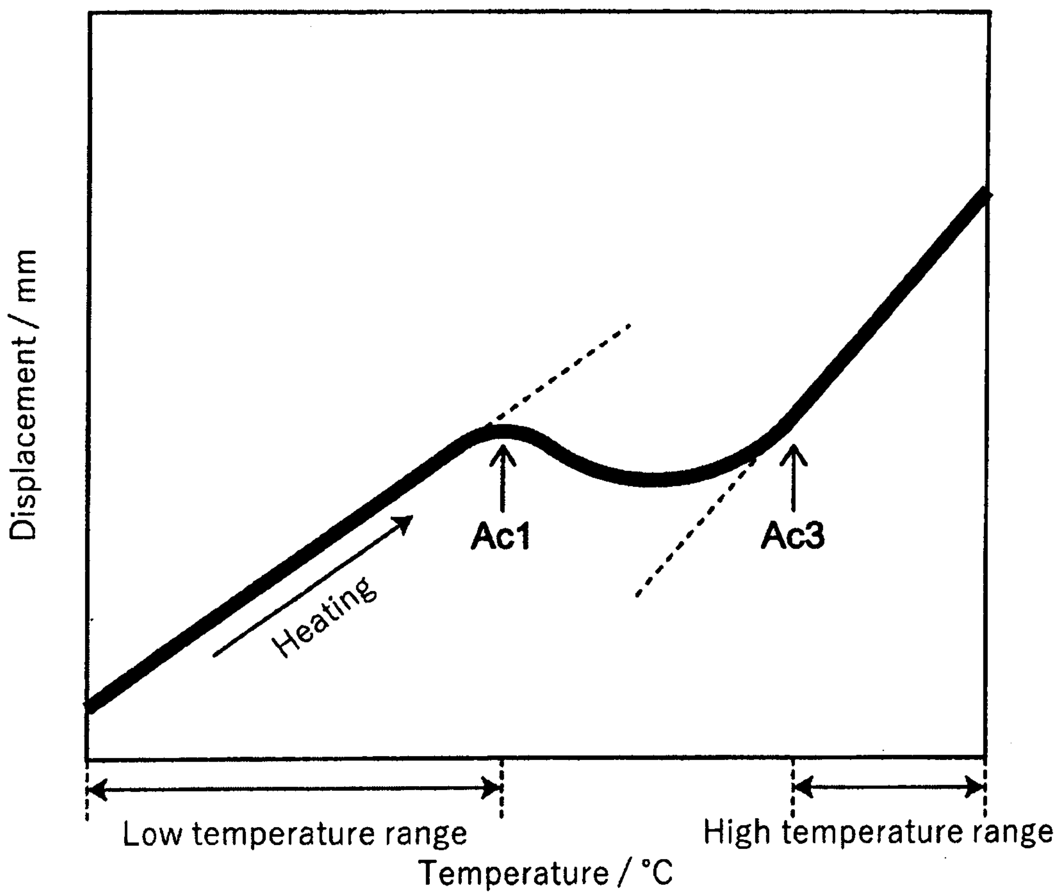
7. The production method according to any one of claims 1 to 4, further comprising applying the strain by return bending during draw forming.

8. The production method according to any one of claims 1 to 4, further comprising applying the strain by shearing.

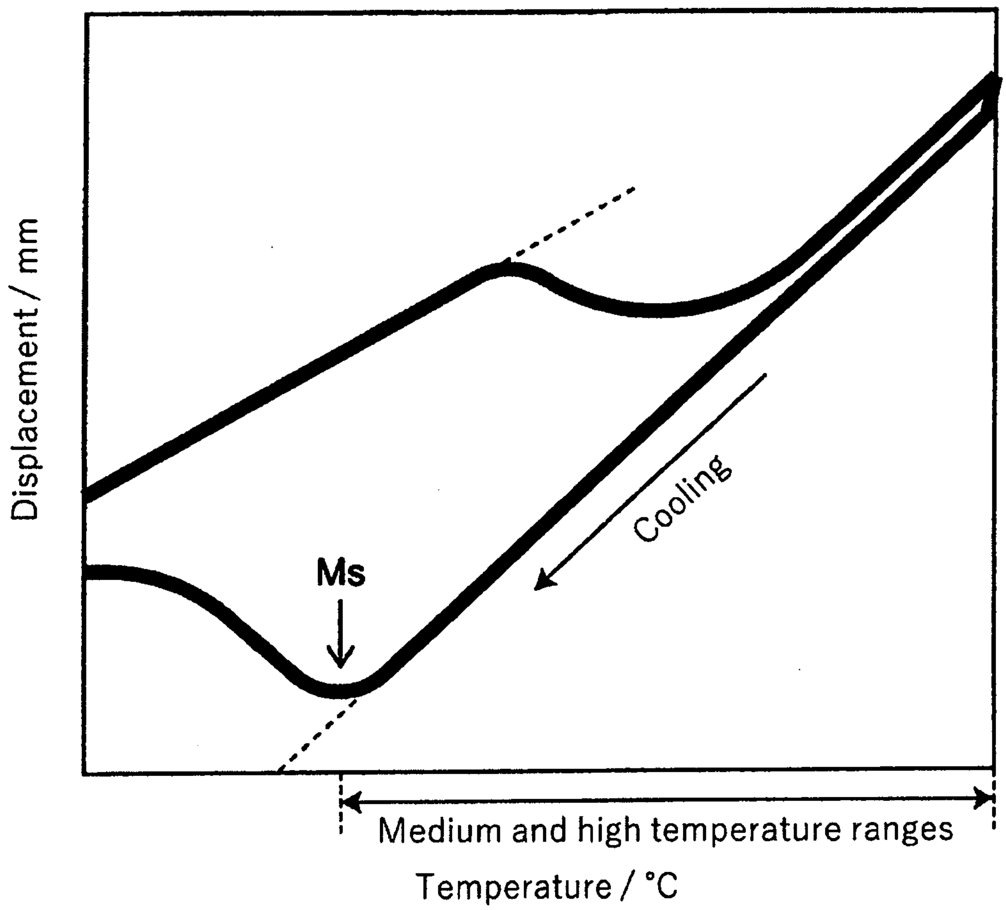
9. The production method according to any one of claims 1 to 4, further comprising applying the strain by a plurality of times of processing.

10. The production method according to claim 9, wherein the plurality of times of processing includes processing for applying deformation and processing for restoring the deformation.

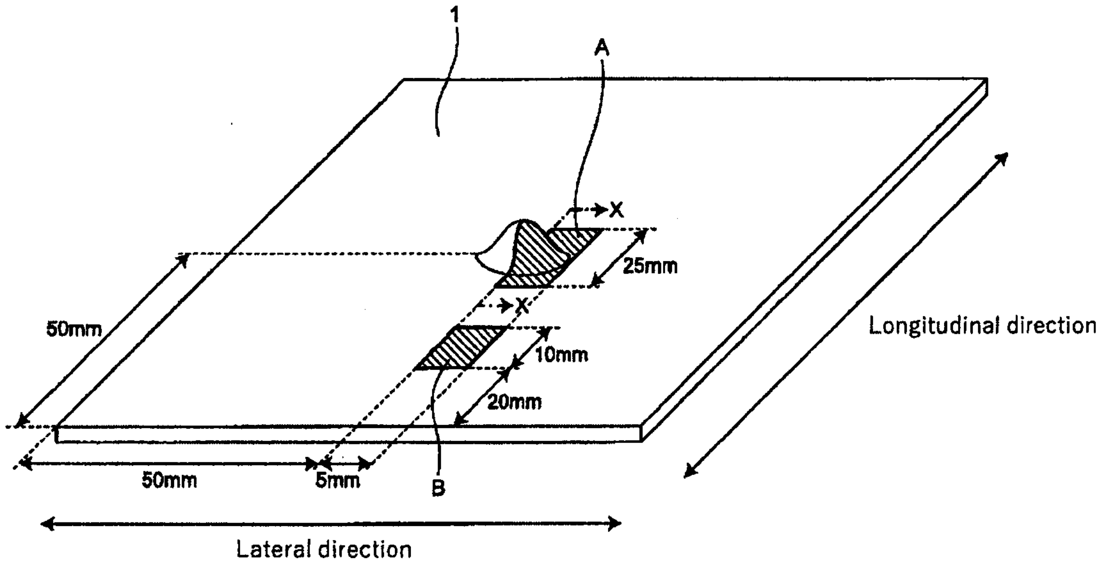
[FIG. 1]


Displacement / mm
Ac1
Ac3
Heating
Low temperature range
High temperature range
Temperature / °C

[FIG. 2]


Displacement / mm
Ms
Cooling
Medium and high temperature ranges
Temperature / °C

[FIG. 3]


1
A
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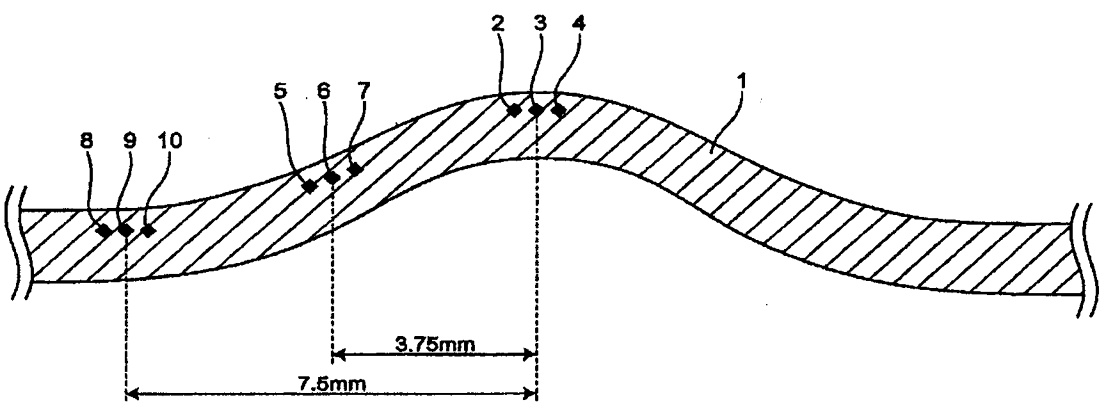
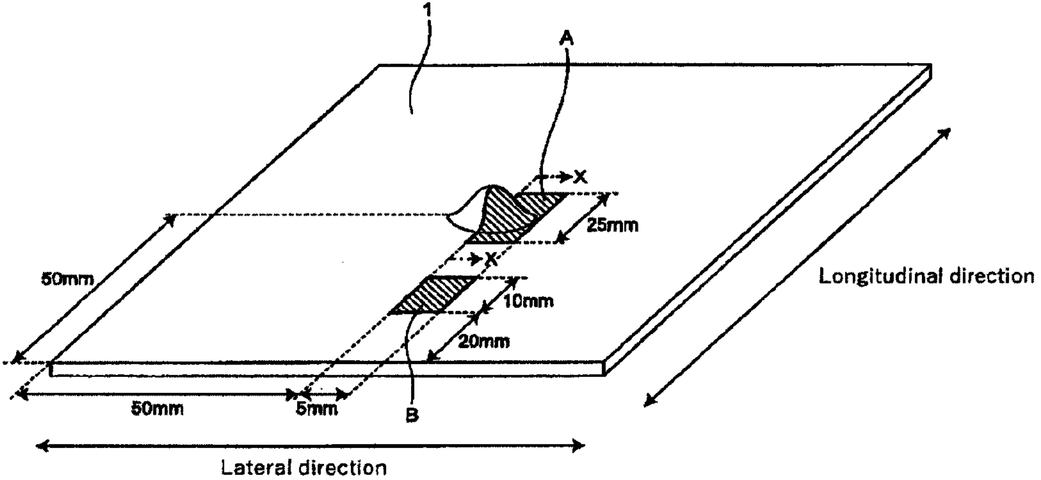
25mm
X
10mm
20mm
50mm
50mm
5mm
B
Longitudinal direction
Lateral direction

[FIG. 4]


2
3
4
5
6
7
8
9
10
1
3.75mm
7.5mm


1
A
X
25mm
X
50mm
10mm
20mm
Longitudinal direction
50mm
5mm
B
Lateral direction