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(54) **Titre : FEUILLE D'ACIER A HAUTE RESISTANCE POUR LE FORMAGE A CHAUD ET SON PROCEDE DE FABRICATION**
(54) **Title: HIGH-STRENGTH STEEL SHEET FOR WARM PRESS FORMING AND METHOD FOR MANUFACTURING THEREOF**

(57) **Abrégé/Abstract:**

The invention provides a high-strength steel sheet having good warm press formability and exhibiting excellent strength and ductility after warm press forming, and a method for manufacturing such steel sheets. The high-strength steel sheet is such that the tensile strength at room temperature is not less than 780 MPa, the yield stress at a heating temperature range of 400°C to 700°C is not more than 80% of the yield stress at room temperature, the total elongation at the heating temperature range is not less than 1.1 times the total elongation at room temperature, the yield stress of the steel sheet after the steel sheet is heated to the heating temperature range, subjected to a strain of not more than 20% and cooled from the heating temperature to room temperature is not less than 70% of the yield stress at room temperature before the heating, and the total elongation of the steel sheet after the steel sheet is heated to the heating temperature range, subjected to a strain of not more than 20% and cooled from the heating temperature to room temperature is not less than 70% of the total elongation at room temperature before the heating.

ABSTRACT

The invention provides a high-strength steel sheet having good warm press formability and exhibiting excellent strength and ductility after warm press forming, and a method for manufacturing such steel sheets. The high-strength steel sheet is such that the tensile strength at room temperature is not less than 780 MPa, the yield stress at a heating temperature range of 400°C to 700°C is not more than 80% of the yield stress at room temperature, the total elongation at the heating temperature range is not less than 1.1 times the total elongation at room temperature, the yield stress of the steel sheet after the steel sheet is heated to the heating temperature range, subjected to a strain of not more than 20% and cooled from the heating temperature to room temperature is not less than 70% of the yield stress at room temperature before the heating, and the total elongation of the steel sheet after the steel sheet is heated to the heating temperature range, subjected to a strain of not more than 20% and cooled from the heating temperature to room temperature is not less than 70% of the total elongation at room temperature before the heating.

DESCRIPTION

Title of Invention: HIGH-STRENGTH STEEL SHEET FOR WARM PRESS FORMING AND METHOD FOR MANUFACTURING THEREOF

Technical Field

[0001]

The present invention concerns with steel sheets useful for warm press forming at a forming temperature range of 400°C to 700°C. The invention relates to a high-strength steel sheet for warm press forming which has a tensile strength (TS) at room temperature of not less than 780 MPa, which exhibits such a good ductility that the steel sheet can be worked even under severe forming conditions at the above forming temperature range, and which shows small changes in mechanical characteristics between before and after warm press forming, and to a method for manufacturing such steel sheets.

Background Art

[0002]

From the viewpoint of global environmental conservation, the automobile industry as a whole recently aims at improving the fuel efficiency of automobiles in order to reduce CO_2 emissions. Improvements in fuel efficiency can be attained most effectively by making automobiles lighter through reducing the thickness of parts to be used. However, the thinning of parts lowers the crashworthiness of automobiles and thus results in a decrease in safety. Accordingly, the weight reduction of automobile bodies entails that parts are reduced in thickness and are increased in strength. Because a lot of automobile parts are manufactured by forming steel sheets into desired shapes, however, higher strength of steel sheets being formed increases the probability of the occurrence of problems such as deterioration in shape fixability, overloads to molds, and the occurrence of cracks, necking and wrinkles.

[0003]

As an approach to solving the above problems, Patent Literature 1 proposes a technique in which a steel sheet is heated to an austenitic range, starts to be formed with a mold at a temperature of not less than the Ac_3 transformation point, and is quenched simultaneously with the forming by removing heat through the mold and is hardened by martensite transformation. This technique thus provides steel sheets exhibiting hardenability after hot press forming and excellent impact characteristics. Further, Patent Literature 2 proposes a steel sheet for warm press forming which has a microstructure containing not less than 10% by volume of a bainite phase with a high solute carbon content and a high dislocation density, not more than 10% by volume of a total of a pearlite phase and a martensite phase, and the balance being a ferrite phase. It is described that when a steel sheet having this microstructure is subjected to warm press forming at temperatures of not less than 250°C, a large amount of strain aging hardening can be obtained during the forming as well as the subsequent cooling with the result that the warm press formed steel sheet exhibits markedly improved strength.

Citation List

Patent Literature

[0004]

PTL 1: Japanese Unexamined Patent Application Publication No. 2004-211197

PTL 2: Japanese Unexamined Patent Application Publication No. 2002-256388

Summary of Invention

Technical Problem

[0005]

Steel sheets having a tensile strength at room temperature of not less than 780 MPa are very difficult to form into a desired shape by cold press forming because the steel sheets being formed still have high strength and low shape fixability to cause the occurrence of spring back. Further, such forming of steel sheets keeping high strength incurs a heavy load to the mold and shortens the life of the mold.

[0006]

According to the hot press forming technique proposed in Patent Literature 1, the formed steel sheets exhibit poor ductility because the martensite phase which is hard and poor in ductility is utilized. Thus, forming of such steel sheets into a desired shape cannot produce automobile parts having high strength and excellent ductility. Since automobile parts are required to exhibit desired impact absorption performance in case of crash, automobile parts with insufficient ductility are problematic in that the impact absorption performance during crash is low. In addition, because the technique proposed in Patent Literature 1 entails heating of steel sheets to an austenitic range during forming, mass production of automobile parts utilizing the technique has a concern that high energy costs are incurred in the forming step.

[0007]

On the other hand, in warm press forming, a steel sheet as a workpiece is heated before forming to lower the strength of the steel sheet and to increase the ductility so that the steel sheet is formed while deformation resistance is lowered and shape fixability is improved. Thus, warm press forming can suppress the occurrence of spring back and reduces the gall of the mold. Further, the enhancement in ductility by heating allows steel sheets to be formed into complicated shapes. If tensile strength and ductility are not decreased after warm press forming, the impact absorption performance of formed parts is not deteriorated. In addition, warm press forming is advantageous also in terms of energy costs because the above effects are obtained by heating at a lower temperature than in the technique of Patent Literature 1.

[0008]

In the technique related to warm press forming proposed in Patent Literature 2, however, the microstructure of the steel sheet includes a bainite phase which is hard and poor in ductility. In addition, the strength of the steel sheet is increased by strain aging, and this further reduces the ductility and causes the problematic occurrence of cracks or mold damages during warm press forming.

[0009]

Further, because automobile parts and the like are used in a severely corrosive environment, coating treatments such as hot-dip galvanization and galvannealing are frequently carried out in the production of those parts from steel sheets in order to achieve corrosion resistance. It is therefore necessary that steel sheets to be used for such parts as automobile parts do not suffer significant deteriorations in characteristics after coating treatments. However, the techniques proposed in Patent Literatures 1 and 2 involve steel sheets including a martensite or bainite phase which is largely deteriorated in quality by heat. That is, when these steel sheets are subjected to coating treatments with heating such as hot-dip galvanization and galvannealing, the heat history due to such coating treatments causes a change in characteristics, for example, a decrease in the strength of the steel sheets.

[0010]

The present invention advantageously solves the above problems encountered in the art. It is an object of the invention to provide a high-strength steel sheet suited for warm press forming which is excellent in workability (formability) during warm press forming and is applicable to warm press forming even under severe conditions and which has a small change in quality by heat and thus ensures minor deteriorations in strength and ductility after warm press forming, as well as to provide a method for manufacturing such high-strength steel sheets and a method of use of such high-strength steel sheets.

Solution to Problem

[0011]

In order to solve the aforementioned problems, the present inventors carried out extensive studies on various factors that would affect the warm press formability (such as ductility and strength before, during and after heating) of high-strength steel sheets. As a result, the present inventors have found that as long as the yield stress at a prescribed heating temperature range (warm press forming temperature range) is not more than 80% of the yield stress at room temperature and the total elongation at the heating temperature range is not less than 1.1 times the total elongation at room temperature, even a high-strength steel sheet having a tensile strength at room temperature of not less than 780 MPa shows excellent warm press formability by exhibiting a lowered deformation resistance as well as an increased ductility at the warm press forming temperature range and can be formed into a complicated shape. Further, the inventors have found that such steel sheets also exhibit excellent shape fixability. Furthermore, the inventors have found that strength and ductility required for automobile parts can be ensured even after warm press forming as long as steel sheets are such that the yield stress and the total elongation after the steel sheets are heated to the heating temperature range, subjected to a strain of not more than 20% and cooled to room temperature are respectively not less than 70% of the yield stress and the total elongation at room temperature before the heating.

[0012]

The present inventors then studied microstructures and chemical compositions that would allow steel sheets to exhibit the above characteristics.

First, the present inventors focused on a ferrite phase having excellent ductility and a small change in quality by heat, and came up with a configuration in which the microstructure of a steel sheet is controlled to be substantially a ferrite single phase before, during and after warm press forming. Further, the present inventors have found that a steel sheet substantially composed of a ferrite single phase in which a dislocation movement in the ferrite phase is easily activated by heating achieves improvements in warm press formability and in shape fixability because such a steel sheet exhibits a lowered deformation resistance as well as an enhanced ductility when heated to a warm press forming temperature of not less than 400°C, and have further found that such a steel sheet exhibits excellent ductility even after warm press forming.

[0013]

In view of the fact that sufficient strength of steel sheets cannot be obtained with a ferrite single phase, the present inventors studied approaches to increasing the strength of steel sheets substantially composed of a ferrite single phase. Although strain aging hardening due to solute carbon and nitrogen generated during warm press forming can increase the strength of steel sheets after warm press forming, the ductility of steel sheets exhibited during and after warm press forming is insufficient. Further, an approach to increasing strength by grain refining strengthening is not suited for materials to be subjected to warm press forming because grains are grown during heating.

[0014]

The present inventors then arrived at the use of precipitation strengthening by the dispersion of fine carbides. Further, the present inventors have found that in order to improve warm press formability as well as strength and ductility after warm press forming, it is appropriate to increase the strength of steel sheets by precipitating fine titanium carbide or further vanadium carbide, molybdenum carbide and tungsten carbide in a matrix substantially composed of a ferrite single phase. According to the studies carried out by the present inventors, these carbides do not become coarse at a warm press forming temperature range (a heating temperature range) of not more than 700°C and remain finely precipitated even after warm press forming. That is, the present inventors have found that steel sheets exhibiting excellent strength even after warm press forming can be obtained by precipitating these carbides in a matrix substantially composed of a ferrite single phase.

[0015]

Furthermore, the present inventors have found that in order to obtain the above desired microstructure of steel sheets, it is important to control the contents of the elements forming the carbides, namely, the content of titanium or the contents of titanium, vanadium, molybdenum and tungsten in appropriate ranges as well as to control the content of titanium or the contents of titanium, vanadium, molybdenum and tungsten relative to the content of carbon in an appropriate range. Furthermore, the present inventors have found that controlling the conditions in cooling and coiling after hot rolling in appropriate ranges is important in the production of steel sheets having the above desired microstructure, in particular, in order to suppress the coarsening of the carbides.

[0016]

The present invention has been completed based on the above findings. A summary of the invention is as follows.

[1] A steel sheet for warm press forming the steel sheet having a chemical composition containing, in mass%:

C: not less than 0.03% and not more than 0.14%, Si: not more than 0.3%,

Mn: above 0.60% and not more than 1.8%, P: not more than 0.03%,

S: not more than 0.005%, Al: not more than 0.1% and not less than 0.02%,

N: not more than 0.005%, and Ti: not more than 0.25%,

one, or two or more of V: not more than 0.5%, Mo: not more than 0.5% and W: not more than 1.0%, the balance comprising Fe and inevitable impurities, and satisfying Expressions (1) and (2) below, and wherein the steel sheet includes a microstructure which has a matrix having a ferrite grain diameter of not less than 1 μm and a ferrite phase area fraction of not less than 95% and in which a carbide having an average particle diameter of not more than 10 nm is precipitated in the matrix:

Expressions

$$([Ti]/48 + [V]/51 + [Mo]/96 + [W]/184) > 0.0031 \cdots (1)$$

$$0.8 \le ([C]/12)/([Ti]/48 + [V]/51 + [Mo]/96 + [W]/184) \le 1.20 \cdots (2)$$

([C], [Ti], [V], [Mo] and [W]: contents (mass%) of respective elements).

[0017]

[2] The steel sheet for warm press forming according to [1], wherein the tensile strength of the steel sheet at room temperature of not less than 780 MPa, the yield stress of said steel sheet at a heating temperature range of 400°C to 700°C is not more than 80% of the yield stress at room temperature, the total elongation of said steel sheet at the heating temperature range is not less than 1.1 times the total elongation at room temperature, the yield stress of the steel sheet after the steel sheet is heated to the heating temperature range, subjected to a strain of not more than 20% and cooled from the heating temperature to room temperature is not less than 70% of the yield stress at room temperature before the heating, and the total elongation of the steel sheet after the steel sheet is heated to the

heating temperature range, subjected to a strain of not more than 20% and cooled from the heating temperature to room temperature is not less than 70% of the total elongation at room temperature before the heating.

[0018]

[3] The steel sheet for warm press forming according to any one of [1] or [2], wherein the steel sheet has a coating layer on the surface.

[0019]

[4] The steel sheet for warm press forming according to [3], wherein the coating layer is a hot-dip galvanized layer or a galvannealed layer.

[0020]

[5] A method of working steel sheets for warm press forming, comprising heating the high-strength steel sheet for warm press forming described in any one of [1] to [4] to a heating temperature range of 400°C to 700°C and subjecting the steel sheet to a strain of not more than 20%.

[0021]

[6] A method for manufacturing steel sheets for warm press forming, comprising heating a steel slab to a temperature of not less than 1100°C and not more than 1350°C, hot rolling the steel slab to a steel sheet at a finishing temperature of not less than 820°C, starting cooling within 2 seconds after the hot rolling, cooling the steel sheet at an average cooling rate of not less than 30°C/s in the temperature range from a temperature of not less than 820°C to a coiling temperature, and coiling the

steel sheet into a coil at a coiling temperature of not less than 550°C and not more than 680°C, the steel slab having a chemical composition containing, in mass%:

C: not less than 0.03% and not more than 0.14%, Si: not more than 0.3%,

Mn: above 0.60% and not more than 1.8%, P: not more than 0.03%,

S: not more than 0.005%, Al: not more than 0.1% and not less than 0.02%,

N: not more than 0.005%, and Ti: not more than 0.25%,

one, or two or more of V: not more than 0.5%, Mo: not more than 0.5% and W: not more than 1.0%

the balance comprising Fe and inevitable impurities, the chemical composition satisfying Expressions (1) and (2) below:

Expressions

$$([Ti]/48 + [V]/51 + [Mo]/96 + [W]/184) > 0.0031 \cdots (1)$$

$$0.8 \leq ([C]/12)/([Ti]/48 + [V]/51 + [Mo]/96 + [W]/184) \leq 1.20 \cdots (2)$$

([C], [Ti], [V], [Mo] and [W]: contents (mass%) of respective elements).

Advantageous Effects of Invention

[0024]

According to the present invention, high-strength steel sheets having excellent warm press formability can be obtained which have a tensile strength of not less than 780

MPa and can be warm press formed with a low press load into parts with complicated shapes. In addition to excellent warm press formability, the high-strength steel sheets of the invention have minor decreases in strength and ductility after warm press forming, and are therefore suitable for applications such as automobile parts requiring impact absorption performance in case of crash. Further, the high-strength steel sheets of the invention include a microstructure having a small change in quality by heat, and consequently the characteristics of the steel sheets are not substantially altered even when the steel sheets have a heat history due to treatments such as coating treatments.

Accordingly, the inventive steel sheets may be also applicable to the manufacturing of parts required coating treatment from the viewpoint of corrosion resistance. Thus, the invention achieves marked industrial effects.

Description of Embodiments

[0025]

Hereinbelow, the present invention will be described in detail.

High-strength steel sheets for warm press forming according to the invention are steel sheets having a tensile strength at room temperature of not less than 780 MPa. In the invention, the term "room temperature" indicates 22 ± 5°C.

A high-strength steel sheet for warm press forming according to the invention is characterized in that the tensile strength at room temperature is not less than 780 MPa, the yield stress at a heating temperature range of 400°C to 700°C is not more than 80% of the yield stress at room temperature, the total elongation at the heating temperature range is not less than 1.1 times the total elongation at room temperature, the yield stress of the steel sheet after the steel sheet is heated to the heating temperature range, subjected to a strain of not more than 20% and then cooled from the heating temperature to room temperature is not less than 70% of the yield stress at room temperature before the heating, and the total elongation of the steel sheet after the steel sheet is heated to the heating temperature range, subjected to a strain of not more than 20% and then cooled from the heating temperature to room temperature is not less than 70% of the total elongation at room temperature before the heating.

[0026]

In the invention, warm press forming at temperatures of 400°C to 700°C is assumed. Thus, the invention specifies characteristics of steel sheets at a heating temperature range of 400°C to 700°C.

In the case of a steel sheet having a tensile strength at room temperature of not less than 780 MPa, the deformation resistance of the steel sheet exhibited during warm press forming cannot be reduced sufficiently if the yield stress at the heating temperature range of 400°C to 700°C exceeds 80% of the yield stress at room temperature. Consequently, the press load during warm press forming has to be increased to cause a problematic decrease in mold life. The application of a high press load naturally involves a large press machine. However, a large press machine makes it difficult to perform warm press forming at a desired temperature because the temperature of a steel sheet heated to a warm press forming temperature is decreased during the travel to the press machine. Further, such a steel sheet is not sufficiently improved in terms of shape fixability and fails to achieve the aforementioned merits of warm press forming.

[0027]

In the case of a steel sheet having a tensile strength at room temperature of not less than 780 MPa, the formability of the steel sheet exhibited during warm press forming is not sufficiently improved if the total elongation at the heating temperature range of 400°C to 700°C is less than 1.1 times the total elongation at room temperature. As a result, problematic defects such as cracks occur during forming.

[0028]

Warm press forming of a steel sheet often results in a decrease in the strength of the warm press formed steel sheet primarily due to heating of the steel sheet. Further, when a steel sheet is subjected to warm press forming, the ductility of the steel sheet after the warm press forming is sometimes lowered problematically due to the strain aging or work hardening.

In the warm press forming of a steel sheet into a (automobile) part, the steel sheet is usually strained about 1 to 10% in terms of equivalent plastic strain. Thus, the present invention assumes warm press forming at the temperature range of 400°C to 700°C with a strain of 20% at a maximum. That is, the present invention specifies the yield stress and the total elongation of a steel sheet after the steel sheet is heated to the heating temperature range of 400°C to 700°C, subjected to a strain of not more than 20% and then cooled from the heating temperature to room temperature. From the view point of maintaining ductility between before and after warm press forming, the strain applied is desirably not more than 15%.

[0029]

In the invention, the "strain" applied to a steel sheet heated to the heating temperature range of 400°C to 700°C indicates an equivalent plastic strain (ε) and is usually represented by the following equation as described in, for example, Non Patent Literature 1.

[0030]

[Math. 1]

$$\varepsilon = \sqrt{\frac{2}{3}\left\{\left(\varepsilon^p_{xx}\right)^2 + \left(\varepsilon^p_{yy}\right)^2 + \left(\varepsilon^p_{zz}\right)^2\right\} + \frac{1}{3}\left\{\left(\gamma^p_{xy}\right)^2 + \left(\gamma^p_{yz}\right)^2 + \left(\gamma^p_{zx}\right)^2\right\}}$$

[0031]

NPL 1: Husahito YOSHIDA, "Dansosei Rikigaku no Kiso (Basics of elastic plastic dynamics)", first edition, third printing, published by KYORITSU SHUPPAN CO., LTD., October 5, 1999, p. 155.

[0032]

In the case of a steel sheet having a tensile strength at room temperature of not less than 780 MPa, the strength and the total elongation of the steel sheet after warm press forming are insufficient if the yield stress and the total elongation after the warm press forming are each less than 70% of the yield stress and the total elongation at room temperature before heating (before the warm press forming). If such a steel sheet is warm press formed into an automobile part with a desired shape, the impact absorption performance during crash is insufficient and the reliability as an automobile part is deteriorated.

Thus, the present invention provides that the yield stress and the total elongation of a steel sheet after the steel sheet is heated to the heating temperature range of 400°C to 700°C, subjected to a strain of not more than 20% and then cooled from the heating temperature to room temperature are not less than 70% of the yield stress and the total elongation at room temperature before the thermal forming.

[0033]

In order for a steel sheet to exhibit the above characteristics, it is preferable that the steel sheet have a chemical composition containing, in mass%, C: not less than 0.03% and not more than 0.14%, Si: not more than 0.3%, Mn: above 0.60% and not more than 1.8%, P: not more than

0.03%, S: not more than 0.005%, Al: not more than 0.1%, N: not more than 0.005%, and Ti: not more than 0.25%, the balance being Fe and inevitable impurities, and satisfying Expressions (1) and (2) below, as well as that the steel sheet include a microstructure which has a matrix having a ferrite grain diameter of not less than 1 μm and a ferrite phase area fraction of not less than 95% and in which a carbide having an average particle diameter of not more than 10 nm is precipitated in the matrix:

Expressions

$$([Ti]/48 + [V]/51 + [Mo]/96 + [W]/184) > 0.0031 \cdots (1)$$

$$0.8 \leq ([C]/12)/([Ti]/48 + [V]/51 + [Mo]/96 + [W]/184) \leq 1.20 \cdots (2)$$

([C], [Ti], [V], [Mo] and [W]: contents (mass%) of respective elements).

[0034]

First, there will be described the reasons why the microstructure and the carbides are limited.

If a steel sheet includes hard phases such as martensite phase and bainite phase during and after warm press forming, it becomes difficult to obtain desired ductility (total elongation). Thus, it is preferable in the invention that the matrix of a steel sheet be substantially a ferrite single phase. When a steel sheet has the above chemical composition and when the matrix of the steel sheet before the steel sheet is heated to a warm press forming temperature is substantially a ferrite single phase, the matrix of the steel sheet substantially remains a ferrite single phase even when the steel sheet is heated to the heating temperature range (warm press forming temperature range) of 400°C to 700°C. The ductility is increased as the steel sheet is heated so that the total elongation at the heating temperature range of 400°C to 700°C can be brought to not less than 1.1 times the total elongation at room temperature.

[0035]

Further, when a steel sheet having the above chemical composition is warm press formed at the temperature range of 400°C to 700°C, there is substantially no decrease in ductility during the warm press forming because the recovery of dislocation takes place during the forming of the steel sheet. Further, because the microstructure is not changed by the cooling of the warm press formed steel sheet to room temperature, the matrix of the steel sheet substantially remains a ferrite single phase and the steel sheet exhibits excellent ductility. Accordingly, configuring the matrix of a steel sheet (before warm press forming) to be substantially a ferrite single phase ensures that the total elongation of the steel sheet after the steel sheet is heated to the heating temperature range of 400°C to 700°C, subjected to a strain of not more than 20% and then cooled from the heating temperature to room temperature is not less than 70% of the total elongation at room temperature before the thermal forming (before the warm press forming).

[0036]

Heating the ferrite phase to not less than 400°C lowers the deformation resistance because a dislocation movement is activated with an increase in temperature, resulting in a decrease in the yield stress of the steel sheet. Thus, the yield stress of the steel sheet at the heating temperature range of 400°C to 700°C becomes not more than 80% of the yield stress of the steel sheet at room temperature.

[0037]

The ferrite grain diameter is preferably not less than 1 μm. If the ferrite grain diameter is less than 1 μm, grain growth easily occurs during warm press forming and the stability of the quality of the warm press formed steel sheet is deteriorated. If the ferrite grain diameter is excessively large, however, it may be sometimes difficult to obtain a desired strength of the steel sheet because the amount of grain refining strengthening is small. Thus, it is preferable that the ferrite grain diameter be not more than 15 μm, and more preferably not less than 1 μm and not more than 12 μm.

[0038]

In order to achieve excellent ductility or to suppress a change in quality by heat, it is preferable that the matrix of a steel sheet be a ferrite single phase. If hard phases such as bainite phase and martensite phase are mixed in the ferrite phase, warm press formability may be lowered because these hard phases and ferrite phase have a large difference in hardness. Even if the matrix is not a perfect ferrite single phase, however, the steel sheet can exhibit sufficient ductility during and after warm press forming and can be kept from a change in quality by heat as long as the matrix is substantially a ferrite single phase, that is, the area fraction of the ferrite phase is not less than 95% relative to the area of the entirety of the matrix.

[0039]

In the steel sheet of the invention, exemplary metallic microstructures other than the ferrite phase include cementite, pearlite, bainite phase, martensite phase and retained austenite phase. The presence of these phases is acceptable as long as the total area fraction thereof is not more than 5% relative to the entire microstructure.

[0040]

As discussed above, sufficient ductility (total elongation) of a steel sheet during and after warm press forming can be ensured by configuring the matrix of the steel sheet before the warm press forming to be substantially a ferrite single phase. However, it is difficult to obtain the desired strength of the steel sheet (tensile strength: not less than 780 MPa) with the ferrite single phase.

[0041]

Thus, the present invention aims at increasing the strength of the steel sheet by precipitating fine carbides, namely, titanium carbide or further vanadium carbide, molybdenum carbide and tungsten carbide in the matrix substantially composed of a ferrite single phase. Here, the desired strength of the steel sheet (tensile strength: not less than 780 MPa) cannot be obtained if the average particle diameter of the carbides exceeds 10 nm. Thus, the average particle diameter of the carbides is specified to be not more than 10 nm, and preferably not more than 7 nm.

[0042]

Carbides present in a steel sheet are usually coarsened during heating and lower their precipitation strengthening performance. However, the above carbides (titanium carbide or further vanadium carbide, molybdenum carbide and tungsten carbide) having an average particle diameter of not more than 10 nm are not coarsened and maintain an average particle diameter of not more than 10 nm as long as the heating temperature is not more than 700°C. That is, the steel sheet having a matrix which is substantially a ferrite single phase and which includes the carbides (titanium carbide or further vanadium carbide, molybdenum carbide and tungsten carbide) with an average particle diameter of not more than 10 nm is heated to the heating temperature range of 400°C to 700°C and warm press formed while a decrease in the strength of the steel sheet after the warm press forming is significantly suppressed because the coarsening of the carbides is suppressed. Accordingly, the configuration in which the steel sheet has a microstructure having a matrix which is substantially a ferrite single phase and which includes the carbides with an average particle diameter of not more than 10 nm ensures that the yield stress of the steel sheet after the steel sheet is heated to the heating temperature range of 400°C to 700°C, subjected to a strain of up to 20% and then cooled from the heating temperature to room temperature is not less than 70% of the yield stress at room temperature before the thermal forming (before the warm press forming).

[0043]

Next, there will be described the reasons why the chemical composition is limited. The term "%" in the following chemical composition of components indicates mass% unless otherwise mentioned.

C: not less than 0.03% and not more than 0.14%

Carbon forms carbides with titanium or further vanadium, molybdenum and tungsten, and is finely dispersed in steel. Thus, this element is essential in order to increase the strength of steel sheets. In order to obtain a steel sheet having a tensile strength of not less than 780 MPa, the steel preferably contains carbon in at least 0.03% or more. On the other hand, if the C content exceeds 0.14%, toughness is markedly deteriorated and the steel sheet fails to exhibit good impact absorption performance (represented by, for example, TS × El wherein TS: tensile strength and El: total elongation). Thus, the C content is preferably not less than 0.03% and not more than 0.14%, and more preferably not less than 0.04% and not more than 0.13%.

[0044]

Si: not more than 0.3%

Silicon is a solid solution strengthening element and lowers warm press formability by inhibiting the decrease in strength at the heating temperature range. It is therefore preferable that silicon be reduced as much as possible. However, a Si content of up to 0.3% is acceptable. Thus, the Si content is preferably not more than 0.3%, and more preferably not more than 0.1%.

[0045]

Mn: above 0.60% and not more than 1.8%

Manganese is an element which contributes to strengthening by lowering the transformation point of steel and facilitating the occurrence of fine precipitates. Thus, it is preferable that the Mn content be in excess of 0.60%, and more preferably not less than 0.8%. If the Mn content exceeds 1.8%, however, the workability of steel sheets is markedly deteriorated. Thus, the Mn content is preferably not more than 1.8%, and more preferably not more than 1.5%.

[0046]

P: not more than 0.030%

Phosphorus is an element which has very high solid solution strengthening performance and inhibits the decrease in the strength of steel sheets during warm press forming. Further, phosphorus is an element which segregates at grain boundaries to lower ductility during and after warm press forming. Thus, phosphorus is preferably reduced as much as possible, and the P content is preferably not more than 0.030%.

[0047]

S: not more than 0.005%

Sulfur is a harmful element which is present as an inclusion in steel. In particular, this element bonds to manganese to form a sulfide and lowers ductility at warm temperatures. Thus, sulfur is preferably reduced as much as possible, and the S content is preferably not more than 0.005%.

[0048]

Al: not more than 0.1%

Aluminum is an element which acts as a deoxidizer. In order to obtain this effect, the Al content is preferably not less than 0.02%. At the same time, however, aluminum lowers ductility by forming oxides. If the Al content exceeds 0.1%, the inclusions come to exert considerable adverse effects on ductility at warm temperatures. Thus, the Al content is preferably not more than 0.1%, and more preferably not more than 0.07%.

[0049]

N: not more than 0.005%

Nitrogen bonds to titanium and vanadium in the steel making process to form coarse nitrides, thereby significantly lowering the strength of steel sheets. Thus, nitrogen is preferably reduced as much as possible, and the N content is preferably not more than 0.005%.

[0050]

Ti: not more than 0.25%

Titanium is an element which contributes to strengthening of steel sheets by forming a carbide with carbon. Titanium is an element which contributes to strengthening of steel sheets by forming a carbide with carbon. In order to obtain this effect, the Ti content is preferably not less than 0.01%. In the case where vanadium, molybdenum and tungsten described later are not added, the

Ti content is preferably not less than 0.13%, and more preferably not less than 0.15% in order to obtain a steel sheet strength of not less than 780 MPa. If the Ti content exceeds 0.25%, however, coarse TiC remains during the heating of a slab before hot rolling to cause the formation of microvoids. Thus, the Ti content is preferably not more than 0.25%, and more preferably not more than 0.20%.

[0051]

While a preferred basic chemical composition in the invention is described above, the steel may further contain one, or two or more of V: not more than 0.5%, Mo: not more than 0.5% and W: not more than 1.0% in addition to the basic chemical composition.

V: not more than 0.5%, Mo: not more than 0.5% and W: not more than 1.0%

Similarly to titanium, vanadium, molybdenum and tungsten are elements which contribute to strengthening of steel sheets by forming carbides. Thus, these elements may be optionally added in the case where a further increase in the strength of steel sheets is required. In order to obtain this effect, it is preferable that the V content be not less than 0.01%, the Mo content 0.01%, and the W content not less than 0.01%.

[0052]

However, any V content exceeding 0.5% causes the facilitated coarsening of the carbide. Thus, the carbide is coarsened at the heating temperature range of 400°C to 700°C and will hardly have an average particle diameter of not more than 10 nm after cooled to room temperature.

Thus, the V content is preferably not more than 0.5%, and more preferably not more than 0.35%.

If the Mo content and the W content exceed 0.5% and 1.0%, respectively, ferrite transformation is extremely delayed. As a result, a bainite phase and a martensite phase come to be mixed in the microstructure of the steel sheet and make it difficult for the microstructure to be substantially a ferrite single phase. Thus, the Mo content and the W content are preferably not more than 0.5% and not more than 1.0%, respectively, and more preferably not more than 0.4% and not more than 0.9%, respectively.

[0053]

In order for a steel sheet with the above chemical composition to have a tensile strength at room temperature of not less than 780 MPa, exhibit excellent ductility during warm press forming and achieve excellent strength and ductility after warm press forming, Expressions (1) and (2) described below need to be satisfied.

$$([Ti]/48 + [V]/51 + [Mo]/96 + [W]/184) > 0.0031 \quad \cdots \ (1)$$

$$0.8 \le ([C]/12)/([Ti]/48 + [V]/51 + [Mo]/96 + [W]/184) \le 1.20 \quad \cdots \ (2)$$

In Expressions (1) and (2), [C], [Ti], [V], [Mo] and [W] are the contents (mass%) of the respective elements. In the case where [V], [Mo] and [W] are each less than 0.01% or the elements are absent, these contents are regarded as zero in the calculation using the above Expressions.

[0054]

$([Ti]/48 + [V]/51 + [Mo]/96 + [W]/184) > 0.0031 \cdots (1)$

In an embodiment of the invention in which the steel sheet has a matrix that is substantially a ferrite single phase, as already described above, the strength of the steel sheet is increased by precipitation strengthening in which carbides, specifically, titanium carbide or further vanadium carbide, molybdenum carbide and tungsten carbide, having an average particle diameter of not more than 10 nm are finely dispersed in the matrix. Thus, it is necessary that the steel contain titanium or further vanadium, molybdenum and tungsten as carbide-forming elements in required amounts in order to increase the tensile strength of the steel sheet. Regarding the contents of titanium or further vanadium, molybdenum and tungsten as the carbide-forming elements, the amounts of carbides precipitated in the matrix become insufficient and it is difficult for the steel sheet to have a tensile strength of not less than 780 MPa if ([Ti]/48 + [V]/51 + [Mo]/96 + [W]/184) is 0.0031 or less. Thus, when the aforementioned chemical composition of steel is adopted,

$([Ti]/48 + [V]/51 + [Mo]/96 + [W]/184)$ is specified to be more than 0.0031, and preferably more than 0.0033.

[0055]

$$0.8 \leq ([C]/12)/([Ti]/48 + [V]/51 + [Mo]/96 + [W]/184) \leq 1.20 \cdots (2)$$

If the steel sheet contains a large amount of solute carbon, strain aging occurs during warm press forming and the ductility of the steel sheet during and after the warm press forming is deteriorated. Further, the presence of hard and micrometer-order cementite in the steel sheet causes a decrease in the ductility of the steel sheet during and after warm press forming because microvoids are formed at the interface between the ferrite phase and the cementite during the warm press forming.

That is, in order for a steel sheet with the above chemical composition to have a tensile strength at room temperature of not less than 780 MPa, exhibit excellent ductility during warm press forming and achieve excellent strength and ductility after warm press forming, it is preferable that the fine carbides be actively precipitated in the steel sheet as well as that the amount of carbon which is not involved in the formation of carbides be controlled so as to reduce the amounts of solute carbon and cementite in the steel sheet to a minimum.

[0056]

Thus, in the case where the aforementioned chemical composition of steel is adopted, the content of titanium or further the contents of vanadium, molybdenum and tungsten relative to the content of carbon are controlled.

If ([C]/12)/([Ti]/48 + [V]/51 + [Mo]/96 + [W]/184) becomes less than 0.8, the carbide-forming elements are not sufficiently precipitated as carbides and the steel sheet fails to achieve a tensile strength at room temperature of not less than 780 MPa.

On the other hand, if ([C]/12)/([Ti]/48 + [V]/51 + [Mo]/96 + [W]/184) exceeds 1.2, excess carbon will be present as solute carbon or cementite without forming bonds with carbides with the result that good ductility cannot be obtained during heating at the heating temperature range of 400°C to 700°C (during warm press forming) or after the warm press forming.

Thus, in the case where the aforementioned chemical composition of steel is adopted, ([C]/12)/([Ti]/48 + [V]/51 + [Mo]/96 + [W]/184) is controlled to satisfy Expression (2), namely, to be not less than 0.8 and not more than 1.20.

[0057]

In the invention, the balance after the deduction of the aforementioned elements is iron and inevitable impurities. Examples of the inevitable impurities include elements which are not specified in the present invention such as O (oxygen), Cu, Cr, Ni and Co. The presence of such elements is acceptable as long as the total content thereof is not more than 0.5%.

[0058]

As mentioned above, the steel sheet having a matrix which is substantially a ferrite single phase and in which fine carbides are precipitated can be heat treated without suffering adverse effects on its quality by the heat treatment as long as the heating temperature is up to 700°C. Thus, the steel sheet can be subjected to a coating treatment to form, on its surface, a coating layer such as an electroplating layer, an electroless plating layer or a hot-dip plating layer. The alloy components forming the coating layers are not particularly limited, and zinc coatings and zinc alloy coatings may be used.

[0059]

As mentioned above, the steel sheet of the invention can exhibit excellent warm press formability and can also exhibit excellent strength and ductility after the warm press forming when the steel sheet has been subjected to an equivalent tensile strain of not more than 20% at the heating temperature range of 400°C to 700°C. Thus, the high-strength steel sheet for warm press forming according to the invention is preferably made into a part such as an automobile part by being heated to the heating temperature range of 400°C to 700°C and being warm press formed through working which applies a strain of not more than 20%.

[0060]

Next, a method for manufacturing the high-strength steel sheets for warm press forming according to the invention will be described.

For example, the inventive high-strength steel sheet for warm press forming may be obtained by producing a molten steel having the aforementioned composition to made into a steel slab, heating the steel slab to a temperature of not less than 1100°C and not more than 1350°C, then hot rolling the steel slab to a steel sheet at a finishing temperature (the temperature of the steel sheet at the completion of the hot rolling) of not less than 820°C, starting cooling within 2 seconds after the hot rolling, cooling the steel sheet at an average cooling rate of not less than 30°C/s in the temperature range from a temperature of not less than 820°C to a coiling temperature, and coiling the steel sheet into a coil at a coiling temperature of not less than 550°C and not more than 680°C.

[0061]

In the invention, the steel may be produced by melting by any method without limitation. For example, a steel having the desired chemical composition may be produced by melting in a furnace such as a converter or an electric furnace, and by subsequent secondary refining in a vacuum degassing furnace. The molten steel is made into a steel slab by a known casting method, and preferably by a continuous casting method in view of productivity and quality. After being cast, the steel slab is heated and hot rolled in accordance with the inventive method.

[0062]

Temperature for heating steel slab: not less than 1100°C and not more than 1350°C

In the heating before hot rolling, it is necessary that a substantially homogeneous austenite phase is formed in the steel slab and coarse carbides in the steel slab be dissolved. Heating the steel slab at a temperature of less than 1100°C cannot dissolve coarse carbides, and consequently the amount of carbides finely dispersed in the final steel sheet obtained is reduced, resulting in a marked decrease in the strength of the steel sheet. On the other hand, heating at a temperature exceeding 1350°C results in the occurrence of scale inclusion, and consequently surface quality is deteriorated. Thus, the temperature for heating the steel slab is specified to be not less than 1100°C and not more than 1350°C, and preferably not less than 1150°C and not more than 1300°C.

When the steel slab, that is after casting, has the above heating temperature (not less than 1100°C and not more than 1350°C), the steel slab may be directly rolled without being heated. In the practice of hot rolling of the steel slab by rough rolling and finish rolling, the rough rolling may be performed under any conditions without limitation.

[0063]

Finishing temperature: not less than 820°C

If the finishing temperature is less than 820°C, elongation of ferrite grains occurs in the microstructure and further a mixed grain microstructure having ferrite grain diameters significantly different each other is generated, causing a marked decrease in the strength of steel sheets. In order to obtain a microstructure having a ferrite grain diameter of not less than 1 μm, it is necessary that the number of nucleation sites during ferrite transformation be not excessively large. The number of nucleation sites is closely related to the strain energy accumulated in the steel sheet during rolling. If the finishing temperature is less than 820°C, excessive accumulation of strain energy cannot be prevented and it becomes difficult to obtain a microstructure having a ferrite grain diameter of not less than 1 μm. Thus, the finishing temperature is specified to be not less than 820°C, and preferably not less than 860°C.

[0064]

Time from completion of hot rolling to initiation of cooling: not more than 2 seconds

Immediately after finish rolling, a large amount of strain energy is accumulated in the austenite phase in the steel. As a result, strain-induced precipitation occurs in the steel immediately after finish rolling. The carbides resulting from this strain-induced precipitation tend to become coarse because the precipitation occurs at a high temperature. Thus, the generation of large amounts of carbides by the strain-induced precipitation makes it difficult to realize fine precipitation of carbides in the final steel sheet obtained. In the present invention, therefore, it is necessary that cooling be initiated as quickly as possible after the completion of hot rolling so as to suppress the occurrence of strain-induced precipitation. Thus, the present invention specifies that cooling is initiated within 2 seconds after the hot rolling.

[0065]

Average cooling rate in temperature range from temperature of not less than 820°C to coiling temperature: not less than 30°C/s

Similarly as described above, the coarsening of carbides generated by strain-induced precipitation proceeds easily as the steel is held at a high temperature for a longer time. It is therefore necessary that the steel be quenched after the finish rolling. In order to suppress the coarsening of carbides, the steel sheet needs to be cooled at an average cooling rate of not less than 30°C/s, and desirably not less than 50°C/s in the temperature range from a temperature of not less than 820°C to a coiling temperature.

[0066]

Coiling temperature: not less than 550°C and not more than 680°C

If the coiling temperature is less than 550°C, the amount of carbides precipitated in the steel sheet becomes insufficient to cause a decrease in the strength of the steel sheet. On the other hand, coiling at a temperature of above 680°C causes the precipitated carbides to become coarse, resulting in a decrease in the strength of the steel sheet. Thus, the coiling temperature is specified to be not less than 550°C and not more than 680°C, and preferably not less than 575°C and not more than 660°C.

[0067]

After the hot rolling, the characteristics of the steel sheet are not changed irrespective of whether the steel sheet has scales attached on its surface or the steel sheet has been descaled by pickling.

The steel sheet obtained above may be subjected to a coating treatment to form, on the surface of the steel sheet, a coating layer such as a hot-dip galvanized layer or a galvannealed layer. The coating layer may be formed by a known coating method, for example, by dipping the steel sheet into a plating bath. The coating amount (the thickness of the coating layer) is variable depending on the temperature of the plating bath and the duration of soaking in the bath as well as the speed of lifting from the bath. It is preferable that the thickness of the coating layer be not less than 4 μm, and more preferably not less than 6 μm. An alloying treatment for forming a galvannealed layer may be carried out in a furnace capable of heating the surface of the steel sheet, such as a gas furnace, after the coating treatment.

EXAMPLES

[0068]

Steels Nos. A to L which had chemical compositions described in Table 1 were produced in a converter and then cast into steel slabs. The steel slabs were heated and soaked at temperatures set out in Table 2, and were hot rolled under conditions described in Table 2 to produce coils of hot-rolled steel sheets (sheet thickness 1.6 mm) Nos. 1 to 18. Of the steel sheets (the hot-rolled steel sheets) described in Table 2, the steel sheets Nos. 9, 11 and 13 (test pieces Nos. o, q and s set out in Table 3 described later) were passed through a continuous hot-dip galvanization line in which they were heated to 700°C, soaked in a hot-dip galvanization bath at 460°C and subjected to an alloying treatment at 500°C, thereby forming a galvannealed layer with a thickness of 7 μm on the surface of each of the steel sheets. Some of the steel sheet No. 2 was treated in the same manner as above to form a galvannealed layer (test pieces Nos. b to e set out in Table 3 described later), and the other was not passed through the continuous hot-dip galvanization lines, namely, any coating layer was not formed (test pieces Nos. f to h set out in Table 3 described later).

[0069]

[Table 1]

Steel No.	Chemical composition (mass%)											Expression (1) *1	Expression (2) *2
	C	Si	Mn	P	S	Al	N	Ti	Mo	V	W		
A	0.042	0.252	1.75	0.012	0.0025	0.045	0.0048	0.152	-	-	-	0.0032	1.11
B	0.041	0.010	1.24	0.015	0.0023	0.041	0.0032	0.114	-	0.05	-	0.0034	1.02
C	0.084	0.025	1.08	0.012	0.0024	0.042	0.0035	0.145	0.20	0.15	-	0.0080	0.87
D	0.071	0.011	0.86	0.013	0.0022	0.041	0.0033	0.092	0.28	0.11	-	0.0070	0.85
E	0.124	0.022	1.35	0.012	0.0023	0.052	0.0041	0.151	0.08	0.30	-	0.0099	1.05
F	0.096	0.015	1.52	0.015	0.0021	0.045	0.0038	0.141	0.05	-	0.80	0.00781	1.02
G	0.086	0.012	1.25	0.015	0.0026	0.038	0.0029	0.028	0.12	0.32	-	0.0081	0.88
H	0.032	0.010	1.18	0.016	0.0022	0.039	0.0033	0.012	0.11	0.13	-	0.0039	0.68
I	0.043	0.029	0.57	0.016	0.0021	0.043	0.0041	0.153	-	-	-	0.0032	1.12
J	0.041	0.016	1.35	0.017	0.0018	0.041	0.0027	0.080	0.05	0.04	-	0.0030	1.15
K	0.065	0.016	1.35	0.017	0.0018	0.041	0.0027	0.145	0.05	0.03	-	0.0041	1.31
L	0.091	0.023	1.55	0.018	0.0025	0.029	0.0028	0.012	0.12	0.02	1.17	0.0083	0.92

*1: Value of ([Ti]/48+[V]/51+[Mo]/96+[W]/184)

*2: Value of ([C]/12)/([Ti]/48+[V]/51+[Mo]/96+[W]/184)

[0070]

[Table 2]

Steel sheet No.	Steel No.	Slab heating temp. (°C)	Finishing temp. (°C)	Time from completion of finish rolling to initiation of cooling (s)	Average cooling rate (°C/s)	Coiling temp. (°C)	Remarks
1	A	1250	890	1.1	74	590	Inv. Ex.
2	B	1250	890	0.9	85	610	Inv. Ex.
3		1070	860	1.2	81	600	Comp. Ex.
4		1240	810	1.0	79	610	Comp. Ex.
5		1250	860	2.6	94	570	Comp. Ex.
6		1260	900	1.3	27	600	Comp. Ex.
7		1250	910	0.9	84	710	Comp. Ex.
8		1250	910	0.9	83	540	Comp. Ex.
9	C	1250	890	0.8	85	610	Inv. Ex.
10	D	1250	870	0.7	81	580	Inv. Ex.
11	E	1260	880	0.9	86	600	Inv. Ex.
12	F	1250	900	1.1	82	610	Inv. Ex.
13	G	1250	900	0.9	85	600	Inv. Ex.
14	H	1250	890	1.0	86	630	Comp. Ex.
15	I	1250	900	1.2	84	580	Comp. Ex.
16	J	1250	900	0.8	85	580	Comp. Ex.
17	K	1260	900	1.3	75	590	Comp. Ex.
18	L	1250	900	1.1	76	600	Comp. Ex.

[0071]

Test pieces were sampled from the obtained hot-rolled steel sheets and were subjected to a tensile test, microstructure observation, precipitate observation, and an enlarge test at a warm press forming temperature range to determine the tensile strength at room temperature, the yield stress and the total elongation at the warm press forming temperature range, and the yield stress and the total elongation after the test pieces had been subjected to a strain (up to 15% strain) described in Table 3 at the warm press forming temperature range and cooled to room temperature. Further, test pieces were sampled from the obtained hot-rolled steel sheets and were analyzed to determine the ferrite grain diameter, the ferrite phase area fraction and the average particle diameter of carbides before the steels were heated to the warm press forming temperature range, as well as to determine the hole expanding ratio at the warm press forming temperature range. Testing methods were as described below.

[0072]

(i) Tensile test

13-B tensile test pieces specified in JIS Z 2201 (1998) were sampled from the obtained hot-rolled steel sheets in a direction perpendicular to the rolling direction, and a tensile test was performed in accordance with JIS G 0567

(1998) to determine the average yield stress (YS-1), tensile strength (TS-1) and total elongation (El-1) at room temperature (22 ± 5°C) as well as to determine the average yield stress (YS-2), tensile strength (TS-2) and total elongation (El-2) at temperatures in the temperature range of 400 to 800°C. Further, test pieces were sampled in the same manner as above and were subjected to a tensile test under the same conditions as those in the above elevated temperature tensile test to introduce a strain described in Table 3 at each of the temperatures; thereafter, the test pieces were cooled to room temperature (22 ± 5°C) at a cooling rate described in Table 3. The resultant test pieces were tensile tested at room temperature to determine the average yield stress (YS-3), tensile strength (TS-3) and total elongation (El-3).

[0073]

All the above tensile tests were performed at a cross head speed of 10 mm/min. In the elevated temperature tensile test in the heating temperature range, the test pieces were heated in an electric furnace to a temperature set out in Table 3 and were held for 15 minutes after the temperature of the test pieces became stable in the testing temperature ± 3°C.

[0074]

(ii) Microstructure observation

Test pieces were sampled from the hot-rolled steel sheets. A central portion along the sheet thickness in a cross section (L-cross section) parallel to the rolling direction was etched with 5% Nital and the exposed microstructure was observed with a scanning electron microscope (SEM) at x400 magnification. Ten fields of view were photographed.

To determine the ferrite phase fraction (area fraction), the (SEM) images of the microstructure obtained above were analyzed to separate the ferrite phase from other phases, and the area fraction of the ferrite phase relative to the observed fields of view was obtained. While the ferrite phase is characteristic in that corrosion marks are not observed in the grains and the grain boundaries are seen as smooth curves, grain boundaries observed as linear shape were counted as part of the ferrite phase.

The ferrite grain diameter was measured by a linear intercept method in accordance with ASTM E112-10 with respect to the images of the microstructure obtained above.

[0075]

To determine the average particle diameter of carbides, a sample was prepared by a thin-film method from a central portion along the sheet thickness of the hot-rolled steel sheet, and was observed with a transmission electron microscope (magnification: x120000), and the diameters of at least 100 particles (100 to 300 particles) of carbides were measured, the results being averaged. In the calculation of the particle diameters of carbides, particles larger than the micrometer order, namely, coarse cementite larger than 1 μm and nitrides were excluded.

[0076]

(iii) Enlarge test at warm press forming temperature range (warm press formability)

Testing temperature: An enlarge test was performed at 550°C, and warm press formability was evaluated based on the obtained hole expanding ratio.

The enlarge test was carried out in accordance with standards by The Japan Iron and Steel Federation (T1001-1996). In detail, a 100 W × 100 L mm test piece was sampled from the hot-rolled steel sheet, and a 10 mm diameter hole was formed by punching in the center of the test piece with a clearance of 12%. Next, the test piece was heated and soaked at 600°C in a heating furnace, and a cylindrical base as a punch was inserted into the hole of the test piece at 550 ± 25°C. The hole in the test piece was enlarged until the hole expanding ratio calculated by Expression (3) below became 80%.

(Hole expanding ratio) = (diameter of hole after test - diameter of hole before test (= 10 mm))/(diameter of hole before test) × 100··· (3)

[0077]

After the enlarge test, each test piece was inspected for the presence or absence of a crack running through the edge face of the hole. Further, part of the test piece was cut after the test, and a central portion along the sheet thickness of the exposed cross section was subjected to a Vickers test. The testing load in the Vickers test was 1 kgf, and the hardness was measured with respect to 5 points.

Warm press formability was evaluated to be good (○) when there was no crack running through the edge face of the hole and the Vickers hardness of the test piece was not less than 260 HV. Warm press formability was evaluated to be poor (×) when there was a crack running through the edge face of the hole or when the Vickers hardness of the test piece was less than 260 HV.

The obtained results are set out in Tables 3 and 4.

[0078]

[Table 3]

Test piece No.	Steel sheet No.	Microstructure of steel sheet			Mechanical characteristics at room temp.			Tensile conditions at elevated temp.			Mechanical characteristics during heating			Mechanical characteristics after heating			Remarks
		Ferrite grain diameter (μm)	Ferrite phase area fraction (%)	Precipitate particle diameter (nm)	YS-1 (MPa)	TS-1 (MPa)	El-1 (%)	Heating temp. (°C)	Strain (%)	Rate of cooling after tension (°C/s)	YS-2 (MPa)	TS-2 (MPa)	El-2 (%)	YS-3 (MPa)	TS-3 (MPa)	El-3 (%)	
a	1	3.5	99	3	708	795	18.2	500	10	12	502	518	38.2	711	782	20.3	Inv. Ex.
b	2	3.6	100	4	757	836	18.0	400	5	35	552	571	25.2	768	839	19.8	Inv. Ex.
c								500	8	95	522	538	39.6	748	822	20.3	Inv. Ex.
d								600	10	82	462	475	50.4	745	828	20.7	Inv. Ex.
e								700	10	45	409	415	63.0	567	630	21.3	Inv. Ex.
f								800	10	22	351	368	79.2	507	603	10.5	Comp. Ex.
g								500	8	150	523	534	39.7	742	825	20.4	Inv. Ex.
h								500	26	20	524	541	39.1	763	838	10.1	Comp. Ex.
i	3	6.9	94	3	604	746	20.6	500	10	15	508	526	30.9	578	598	16.7	Comp. Ex.
j	4	5.8	98	8	653	768	18.4	500	12	13	457	471	42.3	540	626	18.3	Comp. Ex.
k	5	4.3	100	12	642	774	19.4	500	15	14	469	484	40.7	628	748	19.6	Comp. Ex.
l	6	8.6	100	11	623	742	20.1	500	15	14	449	462	44.2	602	743	19.7	Comp. Ex.
m	7	5.9	100	14	603	726	21.1	500	10	13	440	457	44.3	574	699	20.4	Comp. Ex.
n	8	3.1	94	3	623	769	19.7	500	5	15	529	538	27.6	678	779	13.1	Comp. Ex.
o	9	3.8	100	4	987	1085	14.8	570	2	15	622	638	42.9	938	1020	18.4	Inv. Ex.
p	10	3.6	100	4	804	887	16.7	690	15	14	571	585	61.8	611	670	17.5	Inv. Ex.
q	11	3.5	100	3	1104	1187	12.6	540	10	15	740	763	30.2	938	1031	13.4	Inv. Ex.
r	12	3.2	100	5	996	1071	14.7	500	5	15	727	741	30.9	1006	1105	14.6	Inv. Ex.
s	13	3.6	100	4	1006	1093	14.3	550	10	16	654	672	36.6	945	1039	15.8	Inv. Ex.
t	14	3.8	100	5	713	767	19.5	500	15	14	521	530	41.0	606	666	20.7	Comp. Ex.
u	15	3.2	99	13	639	743	21.3	500	12	10	454	573	46.9	703	764	23.0	Comp. Ex.
v	16	3.3	98	4	702	771	19.4	500	15	15	498	517	44.6	631	686	20.3	Comp. Ex.
w	17	3.5	92	3	707	803	17.3	400	10	11	643	681	17.5	777	845	18.1	Comp. Ex.
x	18	3.6	74	6	885	1092	9.8	500	10	25	797	948	8.5	593	689	10.2	Comp. Ex.

[0079]

[Table 4]

Test piece No.	Steel sheet No.	TS-1 (MPa)	Changes in quality relative to quality at room temp.				Warm press formability			Remarks
			(YS-2)/(YS-1)	(El-2)/(El-1)	(YS-3)/(YS-1)	(El-3)/(El-1)	Cracks	Hardness (HV)	Evaluation	
a	1	795	0.71	2.1	1.00	1.12	○	○	○	Inv. Ex.
b	2	836	0.73	1.4	1.01	1.10	○	○	○	Inv. Ex.
c			0.69	2.2	0.99	1.13	○	○	○	Inv. Ex.
d			0.61	2.8	0.98	1.15	○	○	○	Inv. Ex.
e			0.54	3.5	0.75	1.18	○	○	○	Inv. Ex.
f			0.46	4.4	0.67	0.68	○	×	×	Comp. Ex.
g			0.69	2.2	0.98	1.13	○	○	○	Inv. Ex.
h			0.69	2.2	1.01	0.56	×	○	×	Comp. Ex.
i	3	746	0.84	1.7	0.76	0.81	×	×	×	Comp. Ex.
j	4	768	0.70	2.4	0.71	0.99	○	×	×	Comp. Ex.
k	5	774	0.73	2.3	0.83	1.01	○	×	×	Comp. Ex.
l	6	742	0.72	2.5	0.80	0.98	○	×	×	Comp. Ex.
m	7	726	0.73	2.5	0.76	0.97	○	×	×	Comp. Ex.
n	8	769	0.85	1.5	0.90	0.66	×	×	×	Comp. Ex.
o	9	1085	0.63	2.9	0.95	1.24	○	○	○	Inv. Ex.
p	10	887	0.71	3.7	0.76	1.05	○	○	○	Inv. Ex.
q	11	1187	0.67	2.4	0.85	1.06	○	○	○	Inv. Ex.
r	12	1071	0.73	2.1	1.01	0.99	○	○	○	Inv. Ex.
s	13	1093	0.65	2.6	0.94	1.10	○	○	○	Inv. Ex.
t	14	767	0.73	2.1	0.85	1.06	○	×	×	Comp. Ex.
u	15	743	0.71	2.2	1.10	1.08	○	×	×	Comp. Ex.
v	16	771	0.71	2.3	0.90	1.05	○	×	×	Comp. Ex.
w	17	803	0.91	1.0	1.10	1.05	×	×	×	Comp. Ex.
x	18	1092	0.90	0.9	0.67	1.04	×	×	×	Comp. Ex.

[0080]

For all the steel sheets in Inventive Examples (the test pieces Nos. a, b, c, d, e, g, o, p, q, r and s), the tensile strength at room temperature (TS-1) was not less than 780 MPa, the yield stress of the steel sheet heated to the temperature range of 400°C to 700°C (YS-2) was not more than 80% of the yield stress at room temperature (YS-1), and the total elongation of the steel sheet heated to the temperature range of 400°C to 700°C (El-2) was not less than 1.1 times the total elongation at room temperature (El-1). Further, for all the steel sheets in Inventive Examples, the yield stress (YS-3) and the total elongation (El-3) after the steel sheet was subjected to a strain of not more than 20% at the above heating temperature range and cooled to room temperature were each not less than 70% of the yield stress (YS-1) and the total elongation (El-1) at room temperature (before the introduction of the strain). Furthermore, all the steel sheets in Inventive Examples exhibited good warm press formability.

[0081]

On the other hand, the steel sheets in Comparative Examples (the test pieces Nos. f, h, i, j, k, l, m, n, t, u, v, w and x), that is, the steel sheets which fail to satisfy the inventive range in terms of any of the tensile strength at room temperature (TS-1), the yield stress (YS-2) or the total elongation (El-2) of the steel sheet heated to the temperature range of 400°C to 700°C, and the yield stress (YS-3) or the total elongation (El-3) after the steel sheet was subjected to a strain of not more than 20% at the above heating temperature range and cooled to room temperature, exhibited poor warm press formability.

When the steel sheets were worked under conditions outside the warm press forming conditions according to the invention (the test pieces Nos. f and h), the yield stress after the steel sheet was cooled to room temperature (YS-3) failed to be not less than 70% of the yield stress at room temperature before heating (YS-1), or the total elongation after the steel sheet was cooled to room temperature (El-3) failed to be not less than 70% of the total elongation at room temperature before heating (El-1) as a result.

[0082]

Because the testing temperature (the heating temperature) in the elevated temperature tensile test for the test piece No. f in Comparative Example had exceeded 700°C, an austenite phase was formed and carbides became coarse during heating, resulting in a marked deterioration in mechanical characteristics after heating.

Because an excessively large strain was applied to the test piece No. h in Comparative Example, the dislocation was not fully recovered during heating and the steel sheet cooled to room temperature after heating exhibited poor ductility.

For the test pieces Nos. i and j in Comparative Examples, the tensile strength at room temperature (TS-1) did not reach 780 MPa because of the low temperature for heating the slab and because of the low finishing temperature, respectively.

[0083]

In the test pieces Nos. k, l and m in Comparative Examples, the average particle diameter of carbides was above 10 nm because of the excessively long exposure to a high temperature after finish rolling or because the average cooling rate or the coiling temperature had been outside the inventive range. Consequently, the tensile strength at room temperature (TS-1) did not reach 780 MPa.

For the test piece No. n in Comparative Example, a sufficient amount of carbides was not obtained because of the low coiling temperature. Consequently, the tensile strength at room temperature (TS-1) did not reach 780 MPa. Further, because much carbon was present in the form of solute carbon instead of being precipitated as carbides, the strain aging precipitation of solute carbon occurred during heating with the results that the decrease in stress and the increase in ductility at the time of heating were suppressed as well as that the steel sheet cooled to room temperature after heating exhibited poor ductility.

[0084]

For the test piece No. t in Comparative Example, the tensile strength at room temperature (TS-1) did not reach 780 MPa because Expression (2) failed to be satisfied and the balance among the contents of carbide-forming elements, namely, carbon, titanium, vanadium, tungsten and molybdenum, was not appropriate.

In the test piece No. u in Comparative Example, the tensile strength at room temperature (TS-1) did not reach 780 MPa because the Mn content was so low that carbides were precipitated at a high temperature and became coarse.

For the test piece No. v in Comparative Example, the tensile strength at room temperature (TS-1) did not reach 780 MPa because Expression (1) was not satisfied and the amount of precipitated carbides was insufficient.

[0085]

The test piece No. w in Comparative Example failed to satisfy Expression (2) and contained a large amount of carbon which was not involved in the formation of carbides. As a result, strain aging occurred during heating for warm press forming, the yield stress at the heating temperature range (the warm press forming temperature range) (YS-2) was high, and the total elongation at the heating temperature range (the warm press forming temperature range) (El-2) was insufficient. Thus, the steel sheet was shown to be unsuited for warm press forming.

In the test piece No. x in Comparative Example, ferrite transformation was delayed and the ferrite phase area fraction was small because of the high W content. Consequently, deteriorations were observed in mechanical characteristics at room temperature after heating.

[0086]

Next, among the steel sheets described in Table 2, the steel sheets corresponding to Inventive Examples (Nos. 1, 2, 9, 10, 11, 12 and 13) were tensile tested in the same manner as described above (the elevated temperature tensile test and the tensile test after cooling to room temperature) to determine relations between mechanical characteristics (yield stress and total elongation) at the heating temperature range of 400 to 700°C as well as the mechanical characteristics after the steel sheets were subjected to a strain of not more than 20% at the heating temperature range and cooled to room temperature, and the mechanical characteristics at room temperature before heating.

In detail, a tensile test was carried out at a testing temperature of 400°C or 650°C to determine the average yield stress (Y2-2) and total elongation (El-2); separately, test pieces were subjected to a tensile test at 400°C or 650°C in which a strain of not more than 20% described in Table 5 was applied to the test piece, and were thereafter cooled to room temperature at a cooling rate described in Table 5, and the resultant test pieces were tensile tested at room temperature to determine the average yield stress (YS-3) and total elongation (El-3). The results are described in Table 5.

[0087]

[Table 5]

Steel sheet No.	Microstructure of steel sheet			Mechanical characteristics at room temp.			Tensile conditions at elevated temp.			Mechanical characteristics during heating		Mechanical characteristics after heating		Changes in quality relative to quality at room temp.				Remarks
	Ferrite grain diameter (μm)	Ferrite phase area fraction (%)	Precipitate particle diameter (nm)	YS-1 (MPa)	TS-1 (MPa)	El-1 (%)	Heating temp. (℃)	Strain (%)	Rate of cooling after tension (℃/s)	YS-2 (MPa)	El-2 (%)	YS-3 (MPa)	El-3 (%)	(YS-2)/(YS-1)	(El-2)/(El-1)	(YS-3)/(YS-1)	(El-3)/(El-1)	
1	3.5	99	3	708	795	18.2	400	1	12	562	24.8	721	18.5	0.8	1.4	1.0	1.0	Inv. Ex.
								10	15			711	16.5			1.0	0.9	
							650	1	16	415	54.6	715	19.1	0.6	3.0	1.0	1.0	
								10	20			705	20.3			1.0	1.1	
2	3.6	100	4	757	836	18.0	400	1	50	552	25.2	762	18.6	0.7	1.4	1.0	1.0	Inv. Ex.
								10	60			748	16.8			1.0	0.9	
							650	1	60	433	55.8	761	18.8	0.6	3.1	1.0	1.0	
								15	60			703	26.7			0.9	1.5	
9	3.8	100	4	987	1085	14.8	400	1	15	658	20.8	997	15.3	0.7	1.4	1.0	1.0	Inv. Ex.
								10	16			964	12.6			1.0	0.9	
							650	1	14	521	49.9	991	15.7	0.5	3.4	1.0	1.1	
								18	15			829	22.5			0.8	1.5	
10	3.6	100	4	804	887	16.7	400	1	52	586	22.1	807	16.4	0.7	1.3	1.0	1.0	Inv. Ex.
								10	55			784	14.9			1.0	0.9	
							650	1	59	502	50.2	806	17.2	0.6	3.0	1.0	1.0	
								18	58			706	24.4			0.9	1.5	
11	3.5	100	3	1104	1187	12.6	400	1	16	763	16.7	1115	12.3	0.7	1.3	1.0	1.0	Inv. Ex.
								10	15			1085	11.8			1.0	0.9	
							650	1	16	541	39.1	1098	13.4	0.5	3.1	1.0	1.1	
								18	15			982	20.2			0.9	1.6	
12	3.2	100	5	996	1071	14.7	400	1	65	624	20.5	1002	14.5	0.6	1.4	1.0	1.0	Inv. Ex.
								10	68			976	12.8			1.0	0.9	
							650	1	65	535	49.0	994	14.5	0.5	3.3	1.0	1.0	
								18	66			847	22.6			0.9	1.5	
13	3.6	100	4	1006	1093	14.3	400	1	16	654	18.4	1015	14.1	0.7	1.3	1.0	1.0	Inv. Ex.
								10	16			990	12.9			1.0	0.9	
							650	1	15	539	47.2	994	15.0	0.5	3.3	1.0	1.0	
								18	16			845	22.0			0.8	1.5	

[0088]

In all the steel sheets according to the present invention, as shown in Table 5, the tensile strength at room temperature (TS-1) was not less than 780 MPa, the yield stress of the steel sheet heated to the heating temperature range of 400°C to 700°C (YS-2) was not more than 80% of the yield stress at room temperature (YS-1), the total elongation of the steel sheet heated to the heating temperature range of 400°C to 700°C (El-2) was not less than 1.1 times the total elongation at room temperature (El-1), the yield stress (YS-3) and the total elongation (El-3) after the steel sheet was subjected to a strain of not more than 20% at the heating temperature range stated above and cooled to room temperature were each not less than 70% of the yield stress (YS-1) and the total elongation (El-1) at room temperature (before the introduction of the strain).

[0089]

In Inventive Examples where the microstructures and the chemical compositions of the steel sheets were controlled to be the preferred microstructures and chemical compositions, the microstructures remain substantially a ferrite single phase at the heating temperature range of 400°C to 700°C, and the state of carbides in the steel sheets does not change at the heating temperature range to such an extent that the quality of the steel sheets is adversely affected.

Thus, the steel sheets which have been heated to the heating temperature range (warm press forming temperature range) and subjected to warm press forming may be cooled to room temperature at any cooling rate without suffering any adverse effects on the quality of the steel sheets after warm press forming. Accordingly, the inventive high-strength steel sheets for warm press forming can be applied to warm press forming in a facility fitted with a quenching apparatus which rapidly cools the steel sheets after warm press forming. It is needless to mention that the inventive high-strength steel sheets for warm press forming can also be applied to warm press forming in a facility which is not fitted with such a quenching apparatus.

CLAIMS

[Claim 1]

A steel sheet for warm press forming the steel sheet having a chemical composition containing, in mass%:

C: not less than 0.03% and not more than 0.14%, Si: not more than 0.3%,

Mn: above 0.60% and not more than 1.8%, P: not more than 0.03%,

S: not more than 0.005%, Al: not more than 0.1% and not less than 0.02%,

N: not more than 0.005%, and Ti: not more than 0.25%,

one, or two or more of V: not more than 0.5%, Mo: not more than 0.5% and W: not more than 1.0%,

the balance comprising Fe and inevitable impurities, and satisfying Expressions (1) and (2) below, and wherein the steel sheet includes a microstructure which has a matrix having a ferrite grain diameter of not less than 1 μm and a ferrite phase area fraction of not less than 95% and in which a carbide having an average particle diameter of not more than 10 nm is precipitated in the matrix:

Expressions

$$([Ti]/48 + [V]/51 + [Mo]/96 + [W]/184) > 0.0031 \cdots (1)$$

$$0.8 \leq ([C]/12)/([Ti]/48 + [V]/51 + [Mo]/96 + [W]/184) \leq 1.20 \cdots (2)$$

([C], [Ti], [V], [Mo] and [W]: contents (mass%) of respective elements).

[Claim 2]

The steel sheet for warm press forming according to claim 1, wherein the tensile strength of the steel sheet at room temperature of not less than 780 MPa, the yield stress of said steel sheet at a heating temperature range of 400°C to 700°C is not more than 80% of the yield stress at room temperature, the total elongation of said steel sheet at the heating temperature range is not less than 1.1 times the total elongation at room temperature, the yield stress of the steel sheet after the steel sheet is heated to the heating temperature range, subjected to a strain of not more than 20% and cooled from the heating temperature to room temperature is not less than 70% of the yield stress at room temperature before the heating, and the total elongation of the steel sheet after the steel sheet is heated to the heating temperature range, subjected to a strain of not more than 20% and cooled from the heating temperature to room temperature is not less than 70% of the total elongation at room temperature before the heating.

[Claim 3]

The steel sheet for warm press forming according to any one of claims 1 or 2, wherein the steel sheet has a coating layer on the surface.

[Claim 4]

The steel sheet for warm press forming according to claim 3, wherein the coating layer is a hot-dip galvanized layer or a galvannealed layer.

[Claim 5]

A method of working steel sheets for warm press forming, comprising heating the high-strength steel sheet for warm press forming described in any one of claims 1 to 4 to a heating temperature range of 400°C to 700°C and subjecting the steel sheet to a strain of not more than 20%.

[Claim 6]

A method for manufacturing steel sheets for warm press forming, comprising heating a steel slab to a temperature of not less than 1100°C and not more than 1350°C, hot rolling the steel slab to a steel sheet at a finishing temperature of not less than 820°C, starting cooling within 2 seconds after the hot rolling, cooling the steel sheet at an average cooling rate of not less than 30°C/s in the temperature range from a temperature of not less than 820°C to a coiling temperature, and coiling the steel sheet into a coil at a coiling temperature of not less than 550°C and not more than 680°C, the steel slab having a chemical composition containing, in mass%:

C: not less than 0.03% and not more than 0.14%, Si: not more than 0.3%,

Mn: above 0.60% and not more than 1.8%, P: not more than 0.03%,

S: not more than 0.005%, Al: not more than 0.1% and not less than 0.02%,

N: not more than 0.005%, and Ti: not more than 0.25%,

one, or two or more of V: not more than 0.5%, Mo: not more than 0.5% and W: not more than 1.0%

the balance comprising Fe and inevitable impurities, the chemical composition satisfying Expressions (1) and (2) below:

Expressions

$$([Ti]/48 + [V]/51 + [Mo]/96 + [W]/184) > 0.0031 \cdots (1)$$

$$0.8 \leq ([C]/12)/([Ti]/48 + [V]/51 + [Mo]/96 + [W]/184) \leq 1.20 \cdots (2)$$

([C], [Ti], [V], [Mo] and [W]: contents (mass%) of respective elements).