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(54) HOT PRESS MOLDED ARTICLE, METHOD FOR PRODUCING SAME, AND THIN STEEL SHEET FOR HOT PRESS MOLDING

(57) There is provided a hot press-formed product, including a thin steel sheet formed by a hot press-forming method, and having a metallic structure that contains martensite at 80% to 97% by area and retained austenite at 3% to 20% by area, the remainder structure of which is at 5% by area or lower, whereby balance between strength and elongation can be controlled in a proper range and high ductility can be achieved.

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Description

TECHNICAL FIELD

[0001] The present invention relates to a hot press-formed product required to have high strength, such as used for structural members of automobile parts, a process for producing the same, and a thin steel sheet for hot press forming. In particular, the present invention relates to a hot press-formed product that can be provided with a prescribed shape and at the same time heat treated to have prescribed strength when a preheated steel sheet (blank) is formed into the prescribed shape, a process for producing such a hot press-formed product, and a thin steel sheet for hot press forming.

BACKGROUND ART

[0002] As one of the measures for fuel economy improvement of automobiles beginning from global environmental problems, automobile body lightening has proceeded, and steel sheets to be used for automobiles need to be strengthened as highly as possible. However, highly strengthening of steel sheets for automobile lightening lowers elongation EL or r value (Lankford value), resulting in the deterioration of press formability or shape fixability.

[0003] To solve such a problem, a hot press-forming method has been adopted for production of parts, in which method a steel sheet is heated to a prescribed temperature (e.g., a temperature for change in austenite phase) to lower its strength (i.e., make it easily formable) and then formed with a press tool at a temperature (e.g., room temperature) lower than that of the thin steel sheet, whereby the steel sheet is provided with a shape and at the same time heat treated by rapid cooling (quenching), which makes use of a temperature difference between both, to secure its strength after forming.

[0004] According to such a hot pressing method, a steel sheet is formed in a state of low strength, and therefore, the steel sheet has decreased springback (favorable shape fixability). In addition, the use of a material having excellent hardenability, to which alloy elements such as Mn and B have been added, thereby obtaining a strength of 1500 MPa class in terms of tensile strength by rapid cooling. Such a hot press-forming method has been called with various names, in addition to a hot press method, such as a hot forming method, a hot stamping method, a hot stamp method, and a die quench method.

[0005] Fig. 1 is a schematic explanatory view showing the structure of a press tool for carrying out hot press forming as described above (hereinafter represented sometimes by "hot stamp"). In this figure, reference numerals 1, 2, 3, and 4 represent a punch, a die, a blank holder, and a steel sheet (blank), respectively, and abbreviations BHF, rp, rd, and CL represent a blank holding force, a punch shoulder radius, a die shoulder radius, and a clearance between the punch and the die, respectively. In these parts, punch 1 and die 2 have passage 1a and passage 2a, respectively, formed in the inside thereof, through which passages a cooling medium (e.g., water) can be allowed to pass, and the press tool is made to have a structure so that these members can be cooled by allowing the cooling medium to pass through these passages.

[0006] When a steel sheet is subjected to hot stamp (e.g., hot deep drawing) with such a press tool, the forming is started in a state where steel sheet (blank) 4 is softened by heating to a temperature within single-phase region, which is not lower than Ac_3 transformation point. More specifically, steel sheet 4 is pushed into a cavity of die 2 (between the parts indicated by reference numerals 2 and 2 in Fig. 1) by punch 1 with steel sheet 4 in high-temperature state being sandwiched between die 2 and blank holder 3, thereby forming steel sheet 4 into a shape corresponding to the outer shape of punch 1 while reducing the outer diameter of steel sheet 4. In addition, heat is removed from steel sheet 4 to the press tool (punch 1 and die 2) by cooling punch 1 and die 2 in parallel with the forming, and the hardening of the material is carried out by further retaining and cooling steel sheet 4 at the lower dead point in the forming (the point of time when the punch head is positioned at the deepest level: the state shown in Fig. 1). Formed products with high dimension accuracy and strength of 1500 MPa class can be obtained by carrying out such a forming method. Furthermore, such a forming method results in that the volume of a pressing machine can be made smaller because a forming load can be reduced as compared with the case where parts of the same strength class are formed by cold pressing.

[0007] As steel sheets for hot stamp, which have widely been used at present, there are known steel sheets based on 22MnB5 steel. These steel sheets have tensile strengths of 1500 MPa and elongations of about 6% to 8%, and have been applied to impact-resistant members (members neither deformed nor fractured as much as possible at the time of impact). In addition, some developments have also proceeded for C content increase and further highly strengthening (in 1500 to 1800 MPa class) based on 22MnB5 steel.

[0008] However, there is almost no application of steel grades other than 22MnB5 steel. One can find a present situation where little consideration is made on steel grades or methods for controlling the strength and elongation of parts (e.g., strength lowering to 980MPa class and elongation enhancement to 20%) to extend their application range to other than impact-resistant members.

[0009] In middle or higher class automobiles, taking into consideration compatibility (function of, when a small class automobile comes to collide, making safe of the other side) at the time of side or back impact, both functions as an impact-resistant portion and an energy-absorbing portion may sometimes be provided in parts such as B pillars or rear side members. To produce such members, there has mainly been used so far, for example, a method in which ultra-high tensile strength steel sheets having high strength of 980 MPa class and high tensile strength steel sheets having elongation of 440 MPa class are laser welded (to prepare a tailor welded blank, abbreviated as TWB) and then cold press formed. However, in recent years, the development of a technique has proceeded, in which parts are each provided with different strengths by hot stamp.

[0010] For example, Non-patent Document 1 has proposed a method of laser welding 22MnB5 steel for hot stamp and a material that does not have high strength even if quenched with a press tool (to prepare a tailor welded blank, abbreviated as TWB), followed by hot stamp, in which method different strengths are provided so that tensile strength at a high strength side (i.e., impact-resistant portion side) becomes 1500 MPa (and elongation becomes 6% to 8%) and tensile strength at a low strength side (i.e., energy-absorbing portion side) becomes 440 MPa (and elongation becomes 12%). In addition, as the technique of providing parts each with different strengths, some techniques have also been proposed, such as disclosed in Non-patent Documents 2 to 4.

[0011] The techniques disclosed in Non-patent Documents 1 and 2 provide a tensile strength of not higher than 600 MPa and an elongation of about 12% to 18% at an energy-absorbing portion side, in which techniques, however, laser welding (to prepare a tailor welded blank, abbreviated as TWB) is needed previously, thereby increasing the number of steps and resulting in high cost. In addition, it results in the heating of energy-absorbing portions, which need not to be hardened originally. Therefore, these techniques are not preferred from the viewpoint of energy consumption.

[0012] The technique disclosed in Non-patent Document 3 is based on 22MnB5 steel, in which boron addition, however, adversely affects the robustness of strength after quenching against heating to a temperature within two-phase region, making difficult the control of strength at an energy-absorbing portion side, and further making it possible to obtain only an elongation as low as 15%.

[0013] The technique disclosed in Non-patent Document 4 is based on 22MnB5 steel, and therefore, this technique is not economic in that control is made in such a manner that 22MnB5, which originally has excellent hardenability, is not hardened (control of press tool cooling).

PRIOR ART DOCUMENTS

NON-PATENT DOCUMENTS

[0014]

Non-patent Document 1: Klaus Lamprecht, Gunter Deinzer, Anton Stich, Jurgen Lechler, Thomas Stohr, Marion Merklein, "Thermo-Mechanical Properties of Tailor Welded Blanks in Hot Sheet Metal Forming Processes", Proc. IDDRG2010, 2010.

Non-patent Document 2: Usibor1500P(22MnB5) / 1500MPa-8%-Ductibor500/550-700MPa-17% [searched on April 27, 2013] Internet <http://www.arcelormittal.com/tailoredblanks/pre/seifware.pl>

Non-patent Document 3: 22MnB5/above AC3/1500MPa-8%-below AC3/Hv190-Ferrite/Cementite Rudiger Erhardt and Johannes Boke, "Industrial application of hot forming process simulation", Proc, of 1 st Int. Conf. on Hot Sheet Metal Forming of High-Performance steel, ed. By Steinhoff, K., Oldenburg, M, Steinhoff, and Prakash, B., pp83-88, 2008.

Non-patent Document 4: Begona Casas, David Latre, Noemi Rodriguez, and Isaac Valls, "Tailor made tool materials for the present and upcoming tooling solutions in hot sheet metal forming", Proc, of 1st Int. Conf. on Hot Sheet Metal Forming of High-Performance steel, ed. By Steinhoff, K., Oldenburg, M, Steinhoff, and Prakash, B., pp23-35, 2008.

SUMMARY OF THE INVENTION

PROBLEMS TO BE SOLVED BY THE INVENTION

[0015] The present invention has been made in view of the above-described circumstances, and its object is to provide a hot press-formed product in which balance between strength and elongation can be controlled in a proper range and high ductility can be achieved, a process useful for producing such a hot press-formed product, and a thin steel sheet for hot press forming.

MEANS FOR SOLVING THE PROBLEMS

[0016] The hot press-formed product of the present invention, which can achieve the above object, is a hot press-formed product, characterized by comprising a thin steel sheet formed by a hot press-forming method, and having a metallic structure that contains martensite at 80% to 97% by area and retained austenite at 3% to 20% by area, the remainder structure of which is at 5% by area or lower.

[0017] In the hot press-formed product of the present invention, the chemical element composition thereof is not particularly limited, typical examples of which may include the following chemical element composition: C at 0.15% to 0.35% (where "%" means "% by mass", and the same applies to the below with respect to the chemical element composition); Si at 0.5% to 3%; Mn at 0.5% to 2%; P at 0.05% or lower (not including 0%); S at 0.05% or lower (not including 0%); Al at 0.01 % to 0.1%; Cr at 0.01 % to 1%; B at 0.0002% to 0.01%; Ti at (N content) x 4% to 0.1 %; and N at 0.001 % to 0.01 %, and the remainder consisting of iron and unavoidable impurities.

[0018] In the hot press-formed product of the present invention, it is also useful to allow additional elements to be contained, when needed; for example, (a) one or more selected from the group consisting of Cu, Ni, and Mo at 1% or lower (not including 0%) in total; and (b) V and/or Nb at 0.1 % or lower (not including 0%) in total. Depending on the kind of element to be contained, the hot press-formed product may have further improved characteristics.

[0019] When the hot press-formed product of the present invention is produced, the following steps may be used, i.e., heating a thin steel sheet to a temperature not lower than Ac_3 transformation point and not higher than 1000°C; and then starting the forming of the thin steel sheet with a press tool to produce the hot press-formed product, during which forming an average cooling rate of 20°C/sec or higher is kept in the press tool, and which forming is finished at a temperature not higher than (martensite transformation starting temperature Ms point - 50°C).

[0020] The present invention further includes a thin steel sheet for hot press forming, which is intended for producing a hot press-formed product as described above, and this thin steel sheet is characterized by having a chemical element composition as described above.

EFFECTS OF THE INVENTION

[0021] The present invention makes it possible that: retained austenite can be allowed to exist at a proper fraction to adjust the metallic structure of a hot press-formed product by properly controlling the conditions of a hot press-forming method; a hot press-formed product having more enhanced ductility (retained ductility) inherent to the formed product as compared with the case where conventional 22MnB5 steel is used; and strength and elongation can be controlled by a combination of heat treatment conditions and pre-forming steel sheet structure (initial structure).

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] Fig. 1 is a schematic explanatory view showing the structure of a press tool for carrying out hot press forming.

MODE FOR CARRYING OUT THE INVENTION

[0023] The present inventors have studied from various angles to realize a hot press-formed product having high strength and further exhibiting excellent ductility (elongation) after forming when a thin steel sheet is heated to a prescribed temperature and then hot press formed to produce the formed product.

[0024] As a result, the present inventors have found that a hot press-formed product having excellent balance between strength and ductility can be achieved when heating temperature and forming conditions are properly controlled so that its structure is adjusted to contain retained austenite at 3% to 20% by area in the press forming of a thin steel sheet with a press tool to produce the hot press-formed product, thereby completing the present invention.

[0025] The reasons for setting the ranges of the respective structures (basic structure) in the hot press-formed product of the present invention are as follows:

[Martensite at 80% to 97% by area]

[0026] Strength of a hot press-formed product can be secured by making its structure composed mainly of high-strength martensite. From this viewpoint, the area fraction of martensite should be controlled to 80% by area or higher. However, when this fraction is higher than 97% by area, the faction of retained austenite becomes insufficient, resulting in the lowering of ductility (retained ductility). The fraction of martensite may preferably be not lower than 83% by area as the preferred lower limit (more preferably not lower than 85% by area) and not higher than 95% by area as the preferred upper limit (more preferably not higher than 93% by area).

[Retained austenite at 3% to 20% by area]

[0027] Retained austenite is transformed into martensite during plastic deformation, thereby having the effect of increasing work hardening rate (transformation-inducing plasticity) to improve the ductility of a formed product. To make such an effect exhibited, the fraction of retained austenite should be controlled to 3% by area or higher. When the fraction of retained austenite is higher, ductility becomes more excellent. In a composition to be used for automobile steel sheets, retained austenite that can be secured is limited, of which upper limit becomes about 20% by area. The fraction of retained austenite may preferably be not lower than 5% by area as the preferred lower limit (more preferably not lower than 7% by area) and not higher than 17% by area as the preferred upper limit (more preferably not higher than 15% by area or not higher than 10% by area).

[The remainder structure at 5% by area or lower]

[0028] Besides the above structures, the metallic structure of a hot press-formed product may contain ferrite, pearlite, and/or bainite as the remainder structure, but may preferably contain the remainder structure as low as possible, because these structures are softer than martensite and have lower contributions to strength as compared with the other structures. However, the fraction of the remainder structure up to 5% by area may be acceptable. The fraction of the remainder structure may more preferably be not higher than 3% by area, still more preferably 0% by area.

[0029] When the hot press-formed product of the present invention is produced, a thin steel sheet may be used (which has the same chemical element composition as that of the hot press-formed product), and when the thin steel sheet is press formed with a press tool, the thin steel sheet may be heated to a temperature not lower than Ac_3 transformation point and not higher than 1000°C, and then the forming of the thin steel sheet may be started, during which forming an average cooling rate of 20°C/sec or higher may be kept in the press tool, and which forming may be finished at a temperature not higher than (martensite transformation starting temperature Ms point - 50°C). The reasons for defining the respective requirements in this process are as follows:

[Heating a thin steel sheet to a temperature not lower than Ac_3 transformation point and not higher than 1000°C, and then starting the forming]

[0030] To properly adjust the structure of a hot press-formed product, the heating temperature should be controlled in a prescribed range. The proper control of the heating temperature makes it possible to cause transformation into a structure composed mainly of martensite while securing a prescribed fraction of retained austenite in the subsequent cooling step to provide the final hot press-formed product with a desired structure. When the heating temperature of the thin steel sheet is lower than Ac_3 transformation point, a sufficient fraction of austenite cannot be obtained during heating, and therefore, a prescribed fraction of retained austenite cannot be secured in the final structure (the structure of a formed product). When the heating temperature of the thin steel sheet is higher than 1000°C, the grain size of austenite becomes increased during heating, thereby causing a rise of martensite transformation starting temperature (Ms point) and martensite transformation finishing temperature (Mf point), and retained austenite cannot be secured during quenching, thereby making it impossible to achieve excellent formability.

[0031] [During forming, an average cooling rate of 20°C/sec or higher is kept in the press tool, and the forming is finished at a temperature not higher than (martensite transformation stating temperature Ms point - 50°C).

[0032] To change the austenite, which was formed in the above heating step, into a desired structure, while preventing the formation of structures such as ferrite, pearlite, and bainite, the average cooling rate during forming and the forming finishing temperature should properly be controlled. From this viewpoint, the average cooling rate during forming should be controlled to 20°C/sec or higher, and the forming finishing temperature should be controlled to a temperature not higher than (martensite transformation starting temperature Ms point - 50°C, sometimes abbreviated as "Ms point - 50°C"). In particular, when a steel sheet having high Si content is used, cooling carried out under such conditions makes it possible to achieve the mixed structure of martensite and retained austenite. The average cooling rate during forming may preferably be 30°C/sec or higher (more preferably 40°C/sec or higher).

[0033] With respect to the forming finishing temperature, the forming may be finished while cooling to room temperature at an average cooling rate as described above. Alternatively, cooling may be carried out to (Ms point - 50°C) or lower (preferably to a temperature of Ms point - 50°C), and then cooling may further be carried out to 200°C or lower at an average cooling rate of lower than 20°C/sec (two-step cooling). The addition of such cooling steps makes it possible that carbon in martensite is concentrated in untransformed austenite, thereby increasing the fraction of retained austenite. The average cooling rate during cooling as the second step when such two-step cooling is carried out may preferably be 10°C/sec or lower (more preferably 5°C/sec or lower). The control of the average cooling temperature during forming can be achieved by a means of, for example, (a) controlling the temperature of a press tool (using a cooling medium shown in Fig. 1 above) or (b) controlling the thermal conductivity of a press tool.

[0034] The hot press-forming method of the present invention can be applied, not only to the case where a hot press-formed product having a simple shape as shown in Fig. 1 above is produced (i.e., direct method), but also to the case where a formed product having a relatively complicated shape is produced. However, in the case of a complicated product shape, it may be difficult to provide a product with the final shape by a single press forming step. In such a case, there can be used a method of cold press forming in a step prior to hot press forming (this method has been referred to as "indirect method"). This method includes previously forming a difficult-to-form portion into an approximate shape by cold processing and then hot press forming the other portions. When such a method is used to produce, for example, a formed product having three projections (profile peaks) by forming, two projections are formed by cold press forming and the third projection is then formed by hot press forming.

[0035] The present invention is intended for a hot press-formed product made of a high-strength steel sheet, the steel grade of which is acceptable, if it has an ordinary chemical element composition as a high-strength steel sheet, in which, however, C, Si, Mn, P, S, Al, Cr, B, Ti, and N contents may preferably be controlled in their respective proper ranges. From this viewpoint, the preferred ranges of these chemical elements and the grounds for limiting their ranges are as follows:

[C at 0.15% to 0.35%]

[0036] C is an important element for controlling the strength of martensite structure. When C content is decreased, the strength becomes insufficient even if the structure is full of martensite. When C content is less than 0.15%, the strength of martensite becomes insufficient, and therefore, high strength of a hot press-formed product cannot be secured. When C content becomes higher than 0.35%, it results in that strength becomes too high, thereby making it impossible to obtain excellent ductility. C content may more preferably be not lower than 0.18% as the more preferred lower limit (still more preferably not lower than 0.20%) and not higher than 0.30% as the more preferred upper limit (still more preferably not higher than 0.27%, and further still more preferably not higher than 0.25%).

[Si at 0.5% to 3%]

[0037] Si exhibits the action of forming retained austenite during quenching. It further exhibits the action of enhancing strength by solid solution enhancement without deteriorating ductility too much. When Si content is less than 0.5%, retained austenite cannot be secured at a prescribed fraction, making it impossible to obtain excellent ductility. When Si content becomes more than 3%, the degree of solid solution enhancement becomes too high, resulting in the drastic deterioration of ductility. Si content may more preferably be not lower than 1.15% as the more preferred lower limit (still more preferably not lower than 1.20%) and not higher than 2.7% as the more preferred upper limit (still more preferably not higher than 2.5%).

[Mn at 0.5% to 2%]

[0038] Mn is an element to stabilize austenite, and it contributes to an increase of retained austenite. It enhances hardenability, and therefore, it is an element to prevent the formation of ferrite, pearlite, and bainite, during cooling after heating, thereby contributing to the securement of retained austenite. To make such an effect exhibited, Mn may preferably be contained at 0.5% or higher. Mn content may be preferred when it is higher, in the case where only characteristics are taken into consideration, but Mn content may preferably be controlled to 2% or lower, because of a cost increase by alloy element addition. In addition, a considerable improvement of austenite strength increases a hot rolling load, thereby making it difficult to produce steel sheets, and therefore, even from the viewpoint of productivity, it is not preferable that Mn is contained at higher than 2%. Mn content may more preferably be not lower than 0.7% as the more preferred lower limit (still more preferably not lower than 0.9%) and not higher than 1.8% as the more preferred higher limit (still more preferably not higher than 1.6%).

[P at 0.05% or lower (not including 0%)]

[0039] P is an element unavoidably contained in steel and deteriorates ductility. Therefore, P content may preferably be reduced as low as possible. However, extreme reduction causes an increase of steel production cost, and reduction to 0% is difficult in the actual production. Therefore, P content may more preferably be controlled to 0.05% or lower (not including 0%). P content may more preferably be not higher than 0.045% as the more preferred upper limit (still more preferably not higher than 0.040%).

[S at 0.05% or lower (not including 0%)]

[0040] S is also an element unavoidably contained in steel and deteriorates ductility, similarly to P. Therefore, S content may preferably be reduced as low as possible. However, extreme reduction causes an increase of steel production cost, and reduction to 0% is difficult in the actual production. Therefore, S content may preferably be controlled to 0.05% or lower (not including 0%). S content may more preferably be not higher than 0.045% as the more preferred upper limit (still more preferably not higher than 0.040%).

[Al at 0.01 % to 0.1%]

[0041] Al is useful as a deoxidizing element and further useful for fixation of dissolved N in steel as AlN to improve ductility. To make such an effect effectively exhibited, Al content may preferably be controlled to 0.01% or higher. However, when Al content becomes higher than 0.1%, it results in the excessive formation of Al_2O_3 to deteriorate ductility. Al content may more preferably be not lower than 0.013% as the more preferred lower limit (still more preferably not lower than 0.015%) and not higher than 0.08% as the more preferred upper limit (still more preferably not higher than 0.06%).

[Cr at 0.01 % to 1%]

[0042] Cr has the action of suppressing ferrite transformation, pearlite transformation, and bainite transformation, and therefore, it is an element to prevent the formation of ferrite, pearlite, and bainite, during cooling after heating, thereby contributing to the securement of retained austenite. To make such an effect exhibited, Cr may preferably be contained at 0.01 % or higher. Even if Cr is contained at higher than 1%, it results in a cost increase. Cr content may more preferably be not lower than 0.02% as the more preferred lower limit (still more preferably not lower than 0.05%) and not higher than 0.8% as the more preferred higher limit (still more preferably not higher than 0.5%).

[B at 0.0002% to 0.01%)]

[0043] B has the action of enhancing hardenability and suppressing ferrite transformation, pearlite transformation, and bainite transformation, and therefore, it is an element to prevent the formation of ferrite, pearlite, and bainite, during cooling after heating, thereby contributing to the securement of retained austenite. To make such an effect exhibited, B may preferably be contained at 0.0002% or higher, but even if B is contained beyond 0.01%, the effect is saturated. B content may more preferably be not lower than 0.0003% as the more preferred lower limit (still more preferably not lower than 0.0005%) and not higher than 0.008% as the more preferred upper limit (still more preferably not higher than 0.005%).

[Ti at (N content) x 4% to 0.1%]

[0044] Ti fixes N and maintains B in solid solution state, thereby exhibiting the effect of improving hardenability. To make such an effect exhibited, Ti may preferably be contained at least 4 times higher than N content. However, when Ti content becomes excessive beyond 0.1 %, it results in excessive formation of TiC, thereby causing an increase of strength by precipitation enhancement but a deterioration of ductility. Ti content may more preferably be not lower than 0.05% as the more preferred lower limit (still more preferably not lower than 0.06%) and not higher than 0.09% as the more preferred higher limit (still more preferably not higher than 0.08%).

[N at 0.001 % to 0.01%]

[0045] N is an element to fix B as BN, thereby lowering the effect of hardenability improvement, and a reduction of N content as low as possible may be preferred, which has, however, a limitation in actual process. Therefore, the lower limit of N content was set to 0.001%. When N content becomes excessive, it results in the formation of coarse TiN, which becomes the origin of fracture, thereby deteriorating ductility. Therefore, the upper limit of N content was set to 0.01%. N content may more preferably be not higher than 0.008% as the more preferred upper limit (still more preferably not higher than 0.006%).

[0046] The basic chemical components in the press-formed product of the present invention are as described above, and the remainder consists essentially of iron. The wording "consists essentially of iron" means that the press-formed product of the present invention can contain, in addition to iron, minor components (e.g., besides Mg, Ca, Sr, and Ba, REM such as La, and carbide-forming elements such as Zr, Hf, Ta, W, and Mo) in such a level that these minor components do not inhibit the characteristics of the steel sheet of the present invention, and can further contain unavoidable impurities (e.g., O, H) other than P and S.

[0047] It is also useful to allow the press-formed product of the present invention to contain additional elements, when needed; for example, (a) one or more selected from the group consisting of Cu, Ni, and Mo at 1% or lower (not including 0%) in total; and (b) V and/or Nb at 0.1 % or lower (not including 0%) in total. The hot press-formed product may have further improved characteristics depending on the kinds of elements contained. When these elements are contained, their preferred ranges and grounds for limitation of their ranges are as follows:

[One or more selected from the group consisting of Cu, Ni, and Mo at 1% or lower (not including 0%) in total]

[0048] Cu, Ni, and Mo suppress ferrite transformation, pearlite transformation, and bainite transformation, and therefore, prevent the formation of ferrite, pearlite, and bainite, during cooling after heating, and effectively act the securement of retained austenite. To make such an effect exhibited, these elements may preferably be contained at 0.01 % or higher in total. Taking only characteristics into consideration, their content may be preferable when it is higher, but may preferably be controlled to 1% or lower in total because of a cost increase by alloy element addition. In addition, these elements have the action of considerably enhancing the strength of austenite, thereby increasing a hot rolling load so that the production of steel sheets becomes difficult. Therefore, even from the viewpoint of productivity, their content may preferably be controlled to 1% or lower. These elements' content may more preferably be not lower than 0.05% as the more preferred lower limit (still more preferably not lower than 0.06%) in total and not higher than 0.9% as the more preferred upper limit (still more preferably not higher than 0.8%) in total.

[V and/or Nb at 0.1 % or lower (not including 0%) in total]

[0049] V and Nb have the effect of forming fine carbide and make structure fine by pinning effect. To make such an effect exhibited, these elements may preferably be contained at 0.001 % or higher in total. However, when these elements' content becomes excessive, it results in the formation of coarse carbide, which becomes the origin of fracture, thereby deteriorating ductility in contrast. Therefore, these elements' content may preferably be controlled to 0.1 % or lower in total. These elements' content may more preferably be not lower than 0.005% as the more preferred lower limit (still more preferably not lower than 0.008%) in total and not higher than 0.08% as the more preferred upper limit (still more preferably not higher than 0.06%) in total.

[0050] The thin steel sheet for hot press forming of the present invention may be either a non-plated steel sheet or a plated steel sheet. When it is a plated steel sheet, the type of plating may be either ordinary galvanization or aluminium coating. The method of plating may be either hot-dip plating or electroplating. After the plating, alloying heat treatment may be carried out, or additional plating may be carried out as multilayer plating.

[0051] According to the present invention, the characteristics of formed products, such as strength and elongation, can be controlled by properly adjusting press forming conditions (heating temperature and cooling rate), and in addition, hot press-formed products having high ductility (retained ductility) can be obtained, so that they can be applied even to parts (e.g., energy-absorbing members), to which conventional hot press-formed products have hardly been applied; therefore, the present invention is extremely useful for extending the application range of hot press-formed products. The formed products, which can be obtained in the present invention, have further enhanced residual ductility as compared with formed products, of which structure was adjusted by ordinary annealing after cold press forming.

[0052] The following will describe the advantageous effects of the present invention more specifically by way of Examples, but the present invention is not limited to the Examples described below. The present invention can be put into practice after appropriate modifications or variations within a range capable of meeting the gist described above and below, all of which are included in the technical scope of the present invention.

[0053] The present application claims the benefit of priority based on Japanese Patent Application No. 2011-130635 filed on June 10, 2011 and Japanese Patent Application No. 2011-208032 filed September 22, 2011. The entire contents of the specification of Japanese Patent Application No. 2011-130635 filed on June 10, 2011 and Japanese Patent Application No. 2011-208032 filed September 22, 2011 are hereby incorporated by reference into the present application.

EXAMPLES

[0054] Steel materials having respective chemical element compositions shown in Table 1 below were formed into slabs for experimental use by a vacuum fusion method, after which the slabs were hot rolled, followed by cooling, and then wound. These rolled sheets were further cold rolled into thin steel sheets. In Table 1, Ac_3 transformation point and Ms point were determined respectively using formulas (1) and (2) described below (see, e.g., the Japanese translation of "The Physical Metallurgy of Steels" originally written by William C. Leslie, published by Maruzen, 1985).

$$Ac_3 \text{ transformation point } (^\circ C) = 910 - 203 \times [C]^{1/2} + 44.7 \times [Si] - 30 \times [Mn] + 700 \times [P] + 400 \times [Al] + 400 \times [Ti] + 104 \times [V] - 11 \times [Cr] + 31.5 \times [Mo] - 20 \times [Cu] - 15.2 \times [Ni] \text{ --- (1)}$$

$$\text{Ms point (°C)} = 550 - 361 \times [C] - 39 \times [Mn] - 10 \times [Cu] - 17 \times [Ni] - 20 \times [Cr] - 5 \times [Mo] + 30 \times [Al] \text{ --- (2)}$$

where [C], [Si], [Mn], [P], [Al], [Ti], [V], [Cr], [Mo], [Cu], and [Ni] indicate C, Si, Mn, P, Al, Ti, V, Cr, Mo, Cu, and Ni contents (% by mass), respectively. When some element indicated in a certain term of formula (1) or (2) above is not contained, calculation is carried out under the assumption that the term does not exist in the formula.

[Table 1]

Steel grade	Chemical element composition* (% by mass)															Ac_3 transformation point	Ms Point
	C	Si	Mn	P	S	Cu	Ni	Cr	Mo	V	Nb	Ti	B	Al	N		
A	0.232	1.19	1.41	0.014	0.0021			0.21				0.027	0.0033	0.053	0.0047	863	409
B	0.346	1.21	1.28	0.013	0.0017			0.21				0.027	0.0033	0.050	0.0044	844	372
C	0.232	0.18	1.41	0.014	0.0021			0.21				0.027	0.0033	0.053	0.0047	818	409
D	0.232	1.19	1.41	0.014	0.0021			0.21						0.053	0.0047	852	409
E	0.047	1.22	1.25	0.014	0.0021			0.19				0.027	0.0033	0.053	0.0047	923	482
F	0.225	1.31	1.33	0.014	0.0021	0.15		0.12				0.027	0.0033	0.053	0.0047	870	415
G	0.234	1.10	1.52	0.014	0.0021		0.22	0.13				0.027	0.0033	0.053	0.0047	852	401
H	0.231	1.21	1.39	0.014	0.0021							0.027	0.0033	0.053	0.0047	867	414
I	0.231	1.21	1.39	0.014	0.0021			0.05				0.027	0.0033	0.053	0.0047	866	413
J	0.229	1.04	1.41	0.014	0.0021	0.07		0.18				0.027	0.0033	0.053	0.0047	856	410
K	0.219	1.20	1.14	0.014	0.0021			0.15	0.03			0.027	0.0033	0.053	0.0047	876	425
L	0.225	1.23	1.26	0.014	0.0021			0.10	0.17			0.027	0.0033	0.053	0.0047	877	418
M	0.217	1.41	1.44	0.014	0.0021			0.20		0.03		0.027	0.0033	0.053	0.0047	878	413
N	0.230	0.89	1.37	0.014	0.0021			0.19			0.03	0.027	0.0033	0.053	0.0047	851	411
O	0.230	1.2	0.92	0.014	0.0021			0.19				0.027	0.0033	0.053	0.0047	878	429

* The remainder consists of iron and unavoidable impurities other than P and S.

[0055] The steel sheets thus obtained were heated under the respective conditions shown in Table 2 below, and then subjected to cooling treatment using a high speed heat treatment testing system for steel sheets (CAS series, available from ULVAC-RIKO, Inc.), which can control an average cooling rate. The steel sheets to be subjected to forming and cooling treatment had a size of 190 mm x 70 mm (and a sheet thickness of 1.4 mm). Cooling rates 1 and 2 shown in Table 2 indicate an average cooling rate from heating temperature to (Ms point - 50°C) or lower (forming finishing temperature), and an average cooling rate from the forming finishing temperature to 200°C or lower, respectively. When needed, the steel sheet is subjected to hot-dip galvanization to obtain a hot-dip galvanized steel sheet (Test No. 21).

[0056] For the respective steel sheets after the above treatments (heating, forming, and cooling), measurement of tensile strength (TS) and elongation (total elongation EL), and observation of metallic structure (fraction of each structure), were carried out by the methods described below.

[Tensile strength (TS) and elongation (total elongation EL)]

[0057] JIS No. 5 specimens were used for tensile tests to measure tensile strength (TS) and elongation (EL). At that time, strain rate in the tensile tests was set to 10 mm/sec. In the present invention, the specimens were evaluated as "passing" when fulfilling the condition (a): tensile strength (TS) is 1470 MPa and elongation (EL) is 9% or higher.

[Observation of metallic structure (fraction of each structure)]

[0058]

(1) For martensite and the other structures (e.g., ferrite, bainitic ferrite) in the steel sheets, the steel sheets were each subjected to nital etching, and then observed by SEM (with a magnification of 1000x or 2000x), in which martensite and the other structures were measured for their respective fractions (area fractions).

(2) For the fraction of retained austenite in the steel sheets, the steel sheets were each measured by an X-ray diffraction method, after grinding to one-quarter thicknesses of the steel sheets and subsequent chemical polishing (see, e.g., ISJJ Int. Vol. 33 (1933), No. 7, p. 776).

[0059] These results are shown in Table 2 below, together with production conditions (heating temperature, forming finishing temperature, and average cooling rates).

[Table 2]

No.	Steel grade	Production conditions				Plated or non-plated	Structure of formed product (% by area)			Tensile strength TS (MPa)	Elongation EL (%)
		Heating temperature (°C)	Average cooling rate 1 (°C/sec)	Forming finishing temperature (°C)	Average cooling rate 2 (°C/sec)		Martensite	Retained austenite	Other structure*		
1	A	930	40	200	15	Non-plated	95	5	-	1550	10
2	A	930	40	350	2.5	Non-plated	94	6	-	1520	11
3	A	930	15	-	-	Non-plated	45	5	a:15, B:35	1332	12
4	A	825	40	200	15	Non-plated	40	10	a:50	1003	24
5	A	930	40	500	15	Non-plated	20	5	B:75	1240	17
6	B	930	40	200	15	Non-plated	92	8	-	1933	10
7	C	930	40	200	15	Non-plated	100	O	-	1545	7
8	C	930	40	350	2.5	Non-plated	99	1	-	1481	8
9	D	900	40	200	15	Non-plated	75	6	B:19	1420	11
10	E	900	40	200	15	Non-plated	98	2	-	1250	7
11	F	900	40	200	15	Non-plated	95	5	-	1525	11
12	G	900	40	200	15	Non-plated	95	5	-	1549	11
13	H	900	40	200	15	Non-plated	78	6	B:16	1451	10
14	I	900	40	200	15	Non-plated	95	5	-	1549	11
15	J	900	40	200	15	Non-plated	95	5	-	1529	11
16	K	900	40	200	15	Non-plated	95	5	-	1532	11
17	L	900	40	200	15	Non-plated	95	5	-	1507	11
18	M	900	40	200	15	Non-plated	95	5	-	1528	10
19	N	900	40	200	15	Non-plated	95	5	-	1536	11
20	O	900	40	200	15	Non-plated	87	8	B:5	1488	10

(continued)

No.	Steel grade	Production conditions				Plated or non-plated	Structure of formed product (% by area)			Tensile strength TS (MPa)	Elongation EL (%)
		Heating temperature (°C)	Average cooling rate 1 (°C/sec)	Forming finishing temperature (°C)	Average cooling rate 2 (°C/sec)		Martensite	Retained austenite	Other structure*		
21	A	930	40	350	2.5	Plated	94	6	-	1520	11

*a and B indicate ferrite and bainitic ferrite, respectively.

[0060] From these results, discussions can be made as follows: Test Nos. 1, 2, 6, 11, 12, and 14 to 21 are Examples fulfilling the requirements defined in the present invention, thereby indicating that parts having satisfactory balance between strength and ductility were obtained. In particular, Test No. 6 indicates that parts having extremely high strength and further exhibiting excellent ductility were obtained.

[0061] In contrast, Test Nos. 3 to 5, 7 to 10, and 13 are Comparative Examples not fulfilling any of the requirements defined in the present invention, thereby deteriorating any of the characteristics. More specifically, Test No. 3 was the case where cooling rate after heating was low, so that the fraction of martensite was not secured (ferrite and bainitic ferrite were formed), thereby failing to secure strength. Test No. 4 was the case where heating temperature was lower than Ac_3 transformation point, so that the fraction of martensite was not secured, thereby failing to secure strength.

[0062] Test No. 5 was the case in which forming was finished at Ms point or higher, so that the fraction of martensite was not secured (bainitic ferrite was formed), thereby failing to secure strength. Test Nos. 7 and 8 were intended for conventional 22MnB5 equivalent steel (steel grade C shown in Table 1), so that retained austenite was not secured, thereby obtaining only low elongation (EL), although high strength was obtained.

[0063] Test No. 9 was the case where steel free of Ti and B (steel grade shown in Table 1) was used, so that the fraction of martensite was not secured, thereby failing to secure strength. Test No. 10 was the case where steel short of C content (steel grade E shown in Table 1) was used, so that retained austenite was not secured, thereby obtaining low elongation (EL).

[0064] Test No. 13 was the case where steel free of Cr (steel grade H shown in Table 1) was used, so that the fraction of martensite and strength was not secured, thereby failing to secure strength.

INDUSTRIAL APPLICABILITY

[0065] The present invention makes it possible to provide a hot press-formed product, including a thin steel sheet formed by a hot press-forming method, and having a metallic structure that contains martensite at 80% to 97% by area and retained austenite at 3% to 20% by area, the remainder structure of which is at 5% by area or lower, whereby balance between strength and elongation can be controlled in a proper range and high ductility can be achieved.

DESCRIPTION OF REFERENCE NUMERALS

[0066]

1 Punch
2 Die
3 Blank holder
4 Steel sheet (Blank)

Claims

1. A hot press-formed product, comprising a thin steel sheet formed by a hot press-forming method, and having a metallic structure that contains martensite at 80% to 97% by area and retained austenite at 3% to 20% by area, the remainder structure of which is at 5% by area or lower.

2. The hot press-formed product according to claim 1, having the following chemical element composition:

C at 0.15% to 0.35% (where "%" means "% by mass", and the same applies to the below with respect to the chemical element composition);
Si at 0.5% to 3%;
Mn at 0.5% to 2%;
P at 0.05% or lower (not including 0%);
S at 0.05% or lower (not including 0%);
Al at 0.01% to 0.1%;
Cr at 0.01% to 1%;
B at 0.0002% to 0.01%;
Ti at (N content) x 4% to 0.1 %; and
N at 0.001 % to 0.01 %,

and the remainder consisting of iron and unavoidable impurities.

3. The hot press-formed product according to claim 2, further comprising, as additional elements, one or more selected from the group consisting of Cu, Ni, and Mo at 1% or lower (not including 0%) in total.

4. The hot press-formed product according to claim 2 or 3, further comprising, as additional elements, V and/or Nb at 0.1% or lower (not including 0%) in total.

5. A process for producing a hot press-formed product as set forth in claim 1, comprising:

heating a thin steel sheet to a temperature not lower than Ac_3 transformation point and not higher than 1000°C; and then
starting the forming of the thin steel sheet with a press tool to produce the hot press-formed product, during which forming an average cooling rate of 20°C/sec or higher is kept in the press tool, and which forming is finished at a temperature not higher than (martensite transformation starting temperature Ms point - 50°C).

6. A thin steel sheet for hot press forming, which is intended for use in producing a hot press-formed product as set forth in claim 1, and which has the following chemical element composition:

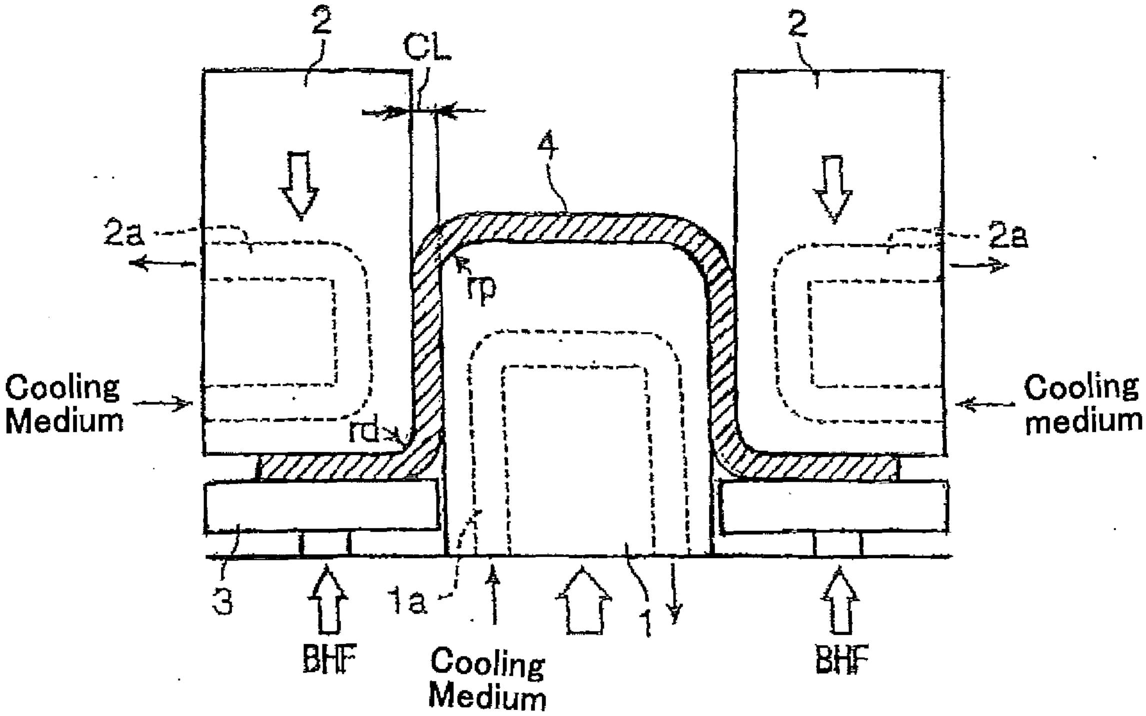
C at 0.15% to 0.35%;
Si at 0.5% to 3%;
Mn at 0.5% to 2%;
P at 0.05% or lower (not including 0%);
S at 0.05% or lower (not including 0%);
Al at 0.01% to 0.1%;
Cr at 0.01% to 1%;
B at 0.0002% to 0.01%;
Ti at (N content) x 4% to 0.1 %; and
N at 0.001 % to 0.01 %,

and the remainder consisting of iron and unavoidable impurities.

7. The thin steel sheet for hot press forming according to claim 6, further comprising, as additional elements, one or more selected from the group consisting of Cu, Ni, and Mo at 1% or lower (not including 0%) in total.

8. The hot press-formed product according to claim 6 or 7, further comprising, as additional elements, V and/or Nb at 0.1% or lower (not including 0%) in total.

[Fig.1]


2
CL
2
4
2a
2a
rp
Cooling
Medium
Cooling
medium
rd
3
1a
1
BHF
Cooling
Medium
BHF

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2012/064851

A. CLASSIFICATION OF SUBJECT MATTER
C22C38/00(2006.01)i, *B21D22/20*(2006.01)i, *C21D1/18*(2006.01)i, *C21D9/00*(2006.01)i, *C22C38/60*(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C22C38/00, B21D22/20, C21D1/18, C21D9/00, C22C38/60

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

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2012
Kokai Jitsuyo Shinan Koho	1971-2012	Toroku Jitsuyo Shinan Koho	1994-2012

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
JSTPlus/JMEDPlus/JST7580(JDreamII), Science Direct

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	Heping Liu, et al., Enhanced mechanical properties of a hot stamped advanced high-strength steel treated by quenching and partitioning process, Scripta Materialia, 2011.04, Vol.64 No.8, pages 749 to 752	1,5 2-4,6-8
X A	JP 2010-527407 A (Corus Staal B.V.), 12 August 2010 (12.08.2010), claims; paragraphs [0023] to [0026] & US 2010/0026048 A1 & WO 2008/102012 A1 & CN 101617059 A & KR 10-2009-0123877 A & RU 2009135392 A & MX 2009008557 A	1-2,6 3-5,7-8
A	JP 2005-205477 A (Nippon Steel Corp.), 04 August 2005 (04.08.2005), entire text (Family: none)	1-8

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
23 August, 2012 (23.08.12)	04 September, 2012 (04.09.12)

Name and mailing address of the ISA/	Authorized officer
Japanese Patent Office	
Facsimile No.	Telephone No.

Form PCT/ISA/210 (second sheet) (July 2009)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2012/064851

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P,X	JP 2012-41613 A (Nippon Steel Corp.), 01 March 2012 (01.03.2012), claims; paragraphs [0008], [0040], [0047]; table 2 (Family: none)	1

Form PCT/ISA/210 (continuation of second sheet) (July 2009)

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

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- **Y WILLIAM C. LESLIE.** The Physical Metallurgy of Steels. Maruzen **[0054]**
- *ISJJ Int.,* 1933, vol. 33 (7), 776 **[0058]**