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(54) **STEEL PLATE**

(57) In a steel sheet, a cleanliness of a metal structure is 0.08% or less, α which is an Mn segregation degree is 1.6 or less, and a difference ΔHv between a low strain formed portion that undergoes a plastic strain of 5% or less and a high strain formed portion that undergoes a plastic strain of 20% or higher in a hot forming in average hardness after the hot forming is 40 or less.

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Description

[Technical Field of the Invention]

[0001] The present invention relates to a steel sheet (steel sheet for hot forming) which is appropriate for applications, in which quenching is performed simultaneously with hot forming or immediately after hot forming, such as hot press. More specifically, the present invention relates to a steel sheet for hot forming in which, for example, even in a case where hot forming accompanied with high strain forming, which is a forming process by which a formed portion receives a plastic strain of 20% or higher, is performed, strain-induced ferritic transformation in the formed portion is suppressed, and thus the hardness after the hot forming is uniform, resulting in excellent toughness and low anisotropy in toughness after the hot forming.

[0002] Priority is claimed on Japanese Patent Application No. 2012-187959, filed on August 28, 2012, the content of which is incorporated herein by reference.

[Related Art]

[0003] Recently, in the field of steel sheets used for vehicles, in order to enhance the fuel efficiency or impact resistance of a vehicle, applications of a high strength steel sheet having a high tensile strength have increased. In general, as the strength of the steel sheet increases, press formability decreases. Therefore, depending on the application of the high strength steel sheet, it is difficult to manufacture a product having a complex shape. Specifically, since ductility decreases as the strength of the steel sheet increases, breaking may occur from a region which is heavily worked, or a degree of spring back or wall camber is increased as the strength of the steel sheet increases. As a result, there is a problem of deterioration in the dimensional accuracy of a worked member and the like. Accordingly, it is not easy to manufacture a product having a complex shape by press forming using a steel sheet having a high strength, particularly, having a tensile strength of 780 MPa or higher.

[0004] When roll forming is performed as the forming instead of the press forming, a high strength steel sheet can be worked to a certain degree. However, roll forming has limitations in that it can be applied only to a member having a uniform cross-section in the longitudinal direction, and thus the degree of freedom of a member configuration is significantly limited.

[0005] Here, as a technique of press-forming a hardly press formable material such as a high strength steel sheet, for example, in Patent Document 1, a hot forming technique of performing forming after heating a material to be formed (for example, hot pressing) is disclosed. This technique is a technique of performing quenching simultaneously with or immediately after forming on a steel sheet which is soft before the forming such that a formed member having a high strength is obtained through the quenching performed after the forming while good formability is secured during the forming. According to this technique, a structure mainly including martensite can be obtained after the quenching, and thus a formed member having excellent local deformability and toughness can be obtained compared to a case of using a high strength steel sheet having a dual-phase structure.

[0006] Currently, hot pressing as described above is being applied to a member having a relatively simple shape, and in the future, application thereof to a member on which more difficult forming such as burring is performed is expected. However, when the hot pressing is applied to a member on which more difficult forming is performed, there is concern that strain-induced ferritic transformation may occur in a high strain formed portion and thus the hardness of the member after the hot forming may be locally reduced.

[0007] In order to suppress the strain-induced ferritic transformation, the hot forming may be performed in a higher temperature range. However, an increase in the hot forming temperature causes a reduction in productivity, an increase in manufacturing cost, the deterioration of surface property, and the like and thus is not easily applied to mass production technology. For example, in Patent Document 1, a technique of performing press work at 850°C or higher is described. However, in actual hot pressing, there may be a case where temperature of the steel sheet decreases to 850°C or less while the steel sheet which is heated to about 900°C in a heating furnace is extracted from the heating furnace and is then transported to and inserted into a press machine. In this case, it is difficult to suppress the strain-induced ferritic transformation during the forming.

[0008] From the viewpoint of increasing the productivity of hot pressing and increasing the material stability in a member after the forming, in Patent Document 2, a method of manufacturing a hot-pressed high strength steel member having excellent productivity, in which a process of cooling a material by heat dissipation from a press die can be omitted, is disclosed. The method disclosed in Patent Document 2 is an excellent; however, it is necessary that a large amount of elements having an action of enhancing hardenability such as Mn, Cr, Cu, and Ni is contained in steel. Therefore, the technique disclosed in Patent Document 2 has a problem of an increase in cost. In addition, in the member manufactured by using the technique disclosed in Patent Document 2, there is concern that deterioration in toughness due to various inclusions being present and the anisotropy in toughness caused by inclusions (mainly, MnS) that are stretched in the rolling direction will occur. The actual performance of the member is constrained by the properties on the low toughness side, and thus original base metal properties cannot be sufficiently exhibited when there is anisotropy in toughness. The anisotropy in toughness can be reduced by performing morphology control on the stretched inclusions with a Ca treatment described, for example, in Patent Document 3. However, in this case, the toughness value is enhanced in a direction in which the toughness is lowest. However, the amount of inclusions in the member is increased and thus there is a problem in that toughness values in the other directions are reduced.

[Prior Art Document]

[Patent Document]

[0009]

[Patent Document 1] Japanese Unexamined Patent Application, First Publication No. 2002-102980
[Patent Document 2] Japanese Unexamined Patent Application, First Publication No. 2006-213959
[Patent Document 3] Japanese Unexamined Patent Application, First Publication No. 2009-242910

[Disclosure of the Invention]

[Problems to be Solved by the Invention]

[0010] As described above, in the related art, the applications of the hot pressing remain in members having a relatively simple shape. Therefore, technical problems of a local reduction in the hardness, the anisotropy in the toughness, and a reduction in the toughness value of the member after the hot forming (a steel sheet subjected to the hot forming process) caused by the strain-induced ferritic transformation in a high strain formed portion, which occur in a case where a member on which more difficult forming such as burring is performed, have not been examined.
[0011] An object of the present invention is to provide a steel sheet for hot forming in which, even in the case of the above-described problems, that is, even in the case where hot forming accompanied with high strain forming is performed, strain-induced ferritic transformation in a formed portion is suppressed, and thus the hardness after the hot forming is uniform (a difference in hardness is small), resulting in excellent toughness and low anisotropy in toughness after the hot forming.

[Means for Solving the Problem]

[0012] The inventors conducted diligent research in order to solve the above-described problems.
[0013] As a result, it was found that, by controlling the chemical composition of a steel sheet, the amount of inclusions, and center segregation, a steel sheet for hot forming in which, even in a case where hot forming accompanied with high strain forming is performed, strain-induced ferritic transformation is suppressed, and thus the hardness after the hot forming is uniform, resulting in excellent toughness and low anisotropy in toughness after the hot forming can be obtained. In addition, in the following description, there may be a case where uniform hardness is referred to as stable hardness distribution.
[0014] The summary of the present invention based on the new findings is as follows.

(1) A steel sheet according to an aspect of the present invention includes as a chemical composition, by mass%: C : 0.18% to 0.275%; Si : 0.02% to 0.15%; Mn: 1.85% to 2.75%; sol.Al: 0.0002% to 0.5%; Cr : 0.05% to 1.00%; B : 0.0005% to 0.01%; P: 0.1 % or less; S : 0.0035% or less; N: 0.01% or less; Ni : 0% to 0.15%; Cu: 0% to 0.05%; Ti : 0% to 0.1%; Nb : 0% to 0.2%; and a remainder including Fe and impurities, in which a cleanliness of a metal structure is 0.08% or less, α which is an Mn segregation degree expressed by the following expression a is 1.6 or less, and in a hot forming, a difference ΔHv in an average hardness after the hot forming between a low strain formed portion that undergoes a plastic strain of 5% or less and a high strain formed portion that undergoes a plastic strain of 20% or higher is 40 or less.

α = (a maximum Mn concentration by mass% in a thickness center portion of the steel sheet) / (an average Mn concentration by mass% at a position at a depth of 1/4 of a sheet thickness from a surface of the steel sheet): expression a

(2) In the steel sheet described in (1), the chemical composition may further include, instead of a portion of Fe, by mass%, one or two selected from the group consisting ofNi : 0.02% to 0.15%, and Cu : 0.003% to 0.05%.
(3) In the steel sheet described in (1) or (2), the chemical composition may further include, instead of a portion of Fe, by mass%, one or two selected from the group consisting of Ti : 0.005% to 0.1 %, and Nb : 0.005% to 0.2%.
(4) In the steel sheet described in any one of (1) to (3), the surface of the steel sheet may further include a coated layer.

[Effects of the Invention]

[0015] According to the aspect of the present invention, even in a case where the hot forming accompanied with high strain forming such as burring is performed, strain-induced ferritic transformation in the formed portion is suppressed, and thus a steel sheet having a stable hardness distribution after the hot forming, and excellent toughness and low anisotropy in toughness after the hot forming, can be obtained. The steel sheet is appropriate for, for example, a material of a mechanical structure member including a body structure member, an underbody member, and the like of a vehicle, and thus the present invention is very useful in industrial fields.

[0016] In addition, the hot forming may be performed according to a routine method. For example, a steel sheet material may be heated to a temperature of an Ac_3 point or higher (about 800°C) and the Ac_3 point + 200°C or less, may be held for 0 second or longer and 600 seconds or less, may be transported to a press machine and is then press-formed, and may be held for 5 seconds or longer at the bottom dead center of the press machine. At this time, a heating method may be appropriately selected, and in a case of rapid heating, electric heating or high-frequency heating may be performed. In addition, as typical heating, furnace heating which is set to a heating temperature, or the like may be used. Air cooling is performed during the transportation to the press machine, and thus there is a possibility that, when the transportation time is lengthened, ferritic transformation may occur until pressing is started and softening may occur. Therefore, the transportation time is preferably 15 seconds or less. In order to prevent an increase in die temperature, cooling of a die may be performed. In this case, as a cooling method, appropriate cooling, such as a cooling method of installing cooling piping in a die and supplying a refrigerant to flow therethough, may be performed.

[Embodiment of the Invention]

[0017] Hereinafter, a steel sheet according to an embodiment of the present invention (in some cases, referred to as a steel sheet according to this embodiment) will be described in more detail. In the following description, % related to the chemical composition of the steel sheet is mass%.

1. Chemical Composition

(1)C: 0.18% to 0.275%

[0018] C is an important element for increasing the hardenability of steel, determining strength after quenching, and further controlling local ductility and toughness after hot forming. In addition, C is an austenite former, and thus has an action of suppressing strain-induced ferritic transformation during high strain forming, thereby facilitating obtaining a stable hardness distribution of a member after the hot forming. However, when the C content is less than 0.18%, it is difficult to secure a tensile strength of 1100 MPa or higher, which is a preferable strength after the quenching, and an effect of obtaining a stable hardness distribution by the above action cannot be obtained. On the other hand, when the C content is higher than 0.275%, local ductility and toughness are reduced. Therefore, the C content is 0.18% to 0.275%. The preferable upper limit of the C content is 0.26%, and the more preferable upper limit thereof is 0.24%.

(2) Si: 0.02% to 0.15%

[0019] Si is an element which increases hardenability and enhances scale adhesion after hot forming. However, when the Si content is less than 0.02%, there may be a case where the above-described effect cannot be sufficiently obtained. Therefore, the lower limit of the Si content is 0.02%. The preferable lower limit thereof is 0.03%. On the other hand, when the Si content is higher than 0.15%, a heating temperature necessary for austenitic transformation during the hot forming is significantly high. Therefore, there may be a case where the cost necessary for a heat treatment is increased or quenching is insufficiently performed due to insufficient heating. In addition, Si is a ferrite forming element. Accordingly, when the Si content is too high, strain-induced ferritic transformation is likely to occur during high strain forming. Therefore, there may be a case where the hardness of a member after the hot forming is locally reduced, and thus a stable hardness distribution is not obtained. Furthermore, there may be a case where a large amount of Si being contained causes a reduction in wettability in a case of performing a hot dip coating treatment, resulting in non-coated parts. Therefore, the upper limit of the Si content is 0.15%.

(3) Mn: 1.85% to 2.75%

[0020] Mn is an element effective in increasing the hardenability of steel and stably securing the strength of the steel after the quenching. In addition, Mn is an austenite former, and thus suppresses strain-induced ferritic transformation during high strain forming, thereby facilitating obtaining a stable hardness distribution of a member after hot forming. However, when the Mn content is less than 1.85%, there may be a case where the above-described effect cannot be sufficiently obtained. Therefore, the lower limit of the Mn content is 1.85%. On the other hand, when the Mn content is higher than 2.75%, the above-described effect is saturated, and deterioration in toughness after the quenching is caused. Accordingly, the upper limit of the Mn content is 2.75%. The preferable upper limit of the Mn content is 2.5%.

(4) sol.Al: 0.0002% to 0.5%

[0021] Al is an element which deoxidizes molten steel and thus improves the soundness of the steel. When the sol.Al content is less than 0.0002%, deoxidation is insufficiently performed. Accordingly, the lower limit of the sol.Al content is 0.0002%. Furthermore, Al is also an effective element in increasing the hardenability of a steel sheet and stably securing strength after quenching, and thus may be actively contained. However, even when the Al content is higher than 0.5%, the effect is saturated, and an increase in cost is caused. Therefore, the upper limit of the Al content is 0.5%.
[0022] Sol.Al indicates acid-soluble Al, and the sol.Al content does not include the amount of Al contained in Al_2O_3 and the like which is not dissolved in an acid.

(5) Cr: 0.05% to 1.00%

[0023] Cr is an element which increases the hardenability of steel. In addition, Cr is an austenite former, and thus suppresses strain-induced ferritic transformation during high strain forming, thereby facilitating obtaining a stable hardness distribution of a member after hot forming. However, when the Cr content is less than 0.05%, there may be a case where the above-described effect cannot be sufficiently obtained. Therefore, the lower limit of the Cr content is 0.05%. The preferable lower limit thereof is 0.1%, and the more preferable lower limit thereof is 0.2%. On the other hand, when the Cr content is higher than 1.00%, Cr is concentrated in carbides in the steel. As a result, when the steel is provided in the hot forming, solutionizing of carbides during a heating process is delayed, and hardenability is reduced. Accordingly, the upper limit of the Cr content is 1.00%. The preferable upper limit of the Cr content is 0.8%.

(6) B: 0.0005% to 0.01%

[0024] B is an element effective in increasing the hardenability of steel and stably securing strength after quenching. When the B content is less than 0.0005%, there may be a case where the above-described effect cannot be sufficiently obtained. Accordingly, the lower limit of the B content is 0.0005%. On the other hand, when the B content is higher than 0.01%, the effect is saturated, and the deterioration in the toughness of a quenched portion is caused. Therefore, the upper limit of the B content is 0.01%. The preferable upper limit of the B content is 0.005%.

(7) P: 0.1% or less

[0025] P is an element which is generally contained as an impurity. However, P has an action of increasing the hardenability of steel and stably securing the strength of the steel after the quenching, and thus may be actively contained. However, when the P content is higher than 0.1 %, toughness is significantly deteriorated. Accordingly, the P content is limited to 0.1 %. The preferable upper limit of the P content is 0.05%. The lower limit of the P content does not need to be particularly limited, but an excessive reduction in the P content causes a significant increase in cost. Therefore, the lower limit of the P content may be 0.0002%.

(8) S: 0.0035% or less

[0026] S is an element which is contained as an impurity. In addition, particularly, S forms MnS, and thus is a main factor in the reduction in toughness and the anisotropy in toughness. When the S content is higher than 0.0035%, the deterioration in toughness becomes significant, and thus the S content is limited to 0.0035%. The lower limit of the S content does not need to be particularly limited, but an excessive reduction in the S content causes a significant increase in cost. Therefore, the lower limit of the S content may be 0.0002%.

(9) N: 0.01% or less

[0027] N is an element which is contained as an impurity. When the N content is higher than 0.01%, coarse nitrides are formed in steel and local deformability and toughness are significantly deteriorated. Accordingly, the N content is limited to 0.01%. The lower limit of the N content does not need to be particularly limited, but an excessive reduction in the N content causes a significant increase in cost. Therefore, the lower limit of the N content may be 0.0002%. The preferable lower limit of the N content is 0.0008% or higher.

[0028] In addition to the above-mentioned elements, the steel sheet according to this embodiment may contain arbitrary elements described below. Such elements are not necessarily contained therein. Therefore, the lower limits of the amounts thereof are not particularly limited, and the lower limits thereof are 0%.

(10) Ni: 0.15% or less, Cu: 0.05% or less

[0029] Ni and Cu are elements effective in increasing the hardenability of steel and stably securing strength after quenching. Therefore, one or two of the elements may be contained. However, even when an amount of any of the elements higher than the upper limit is contained, the above-described effect is saturated, which is disadvantageous in terms of cost. Accordingly, the amount of each of the elements is set as described above. Preferably, the Ni content is 0.10% or less, and the Cu content is 0.03% or less. In order to more reliably obtain the above-described effect, it is preferable that one or two selected from the group consisting of Ni: 0.02% or higher and Cu: 0.003% or higher are contained.

(11) Ti: 0.1% or less, Nb: 0.2 or less

[0030] Ti and Nb are elements which suppress recrystallization and further suppress grain growth by forming fine carbides, thereby forming fine austenite grains when a steel sheet is heated to an Ac_3 point or higher and is provided for hot forming. When fine austenite grains are formed, the toughness of a hot-formed member is significantly improved. In addition, Ti is primarily bonded to N in steel to generate TiN, and thereby the consumption of B due to precipitation of BN is suppressed. As a result, by including Ti, hardenability through B can be increased. In order to obtain the above-described effect, one or two of the elements may be contained. When a higher amount of any of the elements than the upper limit is contained, the precipitation amount of TiC or NbC is increased and thus C is consumed, therefore, there may be a case where strength after quenching is reduced. Accordingly, the amount of each of the elements is set as described above. Preferably, the upper limit of the Ti content is 0.08%, and the upper limit of the Nb content is 0.15%. In addition, in order to more reliably obtain the above-described effect, it is preferable that one or two selected from the group consisting of Ti: 0.005% or higher and Nb: 0.005% or higher are contained.

[0031] The remainder excluding the above-described components includes Fe and an impurity. The impurity indicates a raw material such as ore or scrap, or a material incorporated from a manufacturing environment.

[0032] The steel sheet according to the present invention may be any of a hot-rolled steel sheet and a cold-rolled steel sheet, and may be an annealed hot-rolled steel sheet or an annealed cold-rolled steel sheet which is obtained by performing annealing on the hot-rolled steel sheet or the cold-rolled steel sheet.

2. Metal Structure

(1) Cleanliness: 0.08% or less

[0033] Cleanliness in this embodiment is defined as the sum of the amounts of A series, B series, and C series inclusions contained in a steel sheet, which are obtained by an arithmetic calculation specified in JIS G 0555. When the amounts of inclusions are increased, crack propagation easily occurs, resulting in the deterioration in toughness and an increase in the degree of anisotropy in toughness. Therefore, the upper limit of the cleanliness is 0.08%. The preferable upper limit thereof is 0.04%. In the steel sheet according to this embodiment, MnS which is the A series inclusion is a main factor of deterioration of the degree of anisotropy in toughness. Therefore, particularly, the amount of A series inclusion is preferably 0.06% or less. More preferably, the amount of A series inclusion is 0.03% or less.

[0034] In addition, the cleanliness is preferably as low as possible. However, from the viewpoint of cost, the lower limit thereof may be 0.003% or 0.005%.

(2) Mn Segregation Degree α: 1.6 or less

[0035] Mn is likely to segregate to the vicinity of a thickness center portion of a steel sheet during casting. In a case where center segregation significantly occurs, inclusions such as MnS are concentrated on a segregated portion, resulting in a reduction in toughness and an increase in the degree of anisotropy in toughness. Furthermore, martensite generated in the segregated portion during quenching is hard, and thus the toughness is deteriorated. In addition, due to the interaction between Mn and P, P segregation is also increased in degree in the Mn segregated portion, which also causes the deterioration in toughness. Therefore, an Mn segregation degree α expressed by the following expression 1 is 1.6 or less. The Mn segregation degree α is preferably approximately 1.0 (that is, segregation does not occur). However, from the viewpoint of cost, the lower limit thereof may be 1.03 or 1.05.

α = (the maximum Mn concentration (mass%) in a thickness center portion) / (the average Mn concentration (mass%) at a position at a depth of 1/4 of the sheet thickness from the surface) ... (expression 1)

3. Coated Layer

[0036] A coated layer may be formed on the surface of the steel sheet for hot forming according to the present invention for the purpose of enhancing corrosion resistance and the like, and obtaining a surface-treated steel sheet. Even when the coated layer is provided, the effect of this embodiment is not reduced. The coated layer may be an electro coated layer, or may be a hot dip coated layer. As the electro coated layer, an electrolytic zinc-coated layer, an electrolytic Zn-Ni alloy coated layer, and the like may be exemplified. As the hot dip coated layer, a hot-dip galvanized layer, a galvannealed layer, a hot-dip aluminium-coated layer, a hot-dip Zn-Al alloy coated layer, a hot-dip Zn-Al-Mg alloy coated layer, a hot-dip Zn-Al-Mg-Si alloy coated layer, and the like may be exemplified. A coated amount is not particularly limited, and may be in a general range.

4. Manufacturing Method

[0037] Next, a representative method of manufacturing the steel sheet for hot forming according to the present invention will be described. By using the manufacturing method including the following processes, the steel sheet according to this embodiment can be easily obtained.

(1) Continuous Casting Process (S1)

[0038] Molten steel having the above-described chemical composition is casted into a slab by a continuous casting method. In this continuous casting process, it is preferable that the molten steel temperature is higher than a liquidus temperature by 5°C or greater, the amount of molten steel being poured per unit time is 6 ton/min or less, and a center segregation reduction treatment is performed before a cast piece completely solidifies.
[0039] When the amount of the molten steel being poured per unit time (pouring rate) of the molten steel during the continuous casting is greater than 6 ton/min, the molten steel in a mold flows fast, and thus inclusions are easily trapped and the amount of the inclusions in the slab is increased. When the molten steel temperature is higher than the liquidus temperature by less than 5°C, the viscosity increases, and thus the inclusions are less likely to float. Therefore, the amount of inclusions in the steel increases, and the cleanliness is deteriorated (the value thereof is increased). When the molten steel is continuously casted, it is more preferable that the temperature of the molten steel is higher than the liquidus temperature by 8°C or greater, and the poured amount is 5 ton/min or less.
[0040] As the center segregation reduction treatment, for example, by performing electromagnetic stirring or unsolidified layer reduction on an unsolidified layer before the cast piece completely solidifies, relieving or extraction of a concentrated portion can be performed.

(2) Slab Homogenization Treatment Process (S2)

[0041] As a segregation reduction treatment after the slab is completely solidified, a slab homogenization treatment of heating the slab to 1150°C to 1350°C and holding the resultant for 10 hours to 50 hours may further be performed. By performing the slab homogenization treatment under the above conditions, the segregation degree can be further reduced. In addition, the preferable upper limit of the heating temperature is 1300°C, and the preferable upper limit of the holding time is 30 hours.

(3) Hot Rolling Process (S3), Cooling Process (S4), and Coiling Process (S5)

[0042] The slab obtained by performing the above-described continuous casting process and the slab homogenization treatment process as necessary, is heated to 1050°C to 1350°C and is then hot-rolled into a steel sheet. The hot-rolled steel sheet is held in the above temperature range for 5 seconds to 20 seconds. After being held, the steel sheet is cooled to a temperature range of 400°C to 700°C by water cooling. Thereafter, the cooled steel sheet is coiled.
[0043] There may be a case where the slab contains nonmetallic inclusions which are a cause of the deterioration in the toughness and the local deformability of a member after quenching is performed on the steel sheet. Therefore, when the slab is provided for the hot rolling, it is preferable that such nonmetallic inclusions are sufficiently solutionized. Regarding the slab having the above-described chemical composition, by heating the slab to 1050°C or higher to be provided for the hot rolling, solutionizing of the nonmetallic inclusions is accelerated. Accordingly, it is preferable that the temperature of the slab provided for the hot rolling is 1050°C or higher. In addition, the temperature of the slab provided for the hot rolling may be 1050°C or higher, and the slab having a temperature of less than 1050°C may be heated to 1050°C or higher.
[0044] In a case where transformation from worked austenite is allowed after finish rolling, a rolled texture remains, which causes anisotropy in a final product. Therefore, in order to allow transformation from recrystallized austenite to occur, it is preferable that the steel sheet after being rolled is held for 5 seconds or longer in the above temperature range. In order to hold the steel sheet for 5 seconds or longer in a manufacturing line, for example, the steel sheet may be transported without being water-cooled in a cooling zone after the finish rolling.
[0045] By setting a coiling temperature to be 400°C or higher, a ferrite area ratio in the metal structure can be increased. When the ferrite area ratio is high, the strength of the hot-rolled steel sheet is suppressed, and thus load control, steel sheet flattening control, and sheet thickness control are facilitated during cold rolling in a subsequent process, resulting in an increase in manufacturing efficiency. Therefore, the coiling temperature is preferably 400°C or higher.
[0046] On the other hand, by setting the coiling temperature to be 700°C or less, scale growth after the coiling is suppressed, and thus the generation of scale defects are suppressed. In addition, the deformation of a coil due to the weight thereof after the coiling is suppressed, and the generation of scratches on the coil surface due to the deformation can be suppressed. Therefore, the coiling temperature is preferably 700°C or less. The deformation is caused by volume expansion due to the ferritic transformation and subsequent thermal contraction, and disappearing the coiling tension in the coil in a case where untransformed austenite remains after the coiling and the untransformed austenite transforms into ferrite after the coiling.

(4) Pickling Process (S6)

[0047] Pickling may be performed on the steel sheet after the coiling process. The pickling may be performed according to a routine method. Before the pickling or after the pickling, in order to accelerate flatness correction or scale exfoliation, skin pass rolling may be performed, and this does not influence the effect of this embodiment. An elongation rate in a case of performing the skin pass rolling does not need to be particularly limited, and for example, may be 0.3% or higher and less than 3.0%.

(5) Cold Rolling Process (S7)

[0048] Cold rolling may be performed on the pickled steel sheet obtained through the pickling process, as necessary. A cold rolling method may be performed according to a routine method. The rolling reduction of the cold rolling may be in a typical range, and is generally 30% to 80%.

(6) Annealing Process (S8)

[0049] Annealing at 700°C to 950°C can be performed on the hot-rolled steel sheet obtained by the coiling process (S5) or the cold-rolled steel sheet obtained by the cold rolling process (S7), as necessary.
[0050] By performing the annealing of holding the hot-rolled steel sheet and the cold-rolled steel sheet within a temperature range of 700°C or higher, the effect of the hot rolling conditions can be reduced, and thus further stabilization of properties after the quenching can be achieved. In addition, regarding the cold-rolled steel sheet, the steel sheet can be softened through recrystallization, and thus workability before the hot forming can be improved. Therefore, in the case of performing the annealing on the hot-rolled steel sheet or the cold-rolled steel sheet, it is preferable that the steel sheet is held within a temperature range of 700°C or higher.
[0051] On the other hand, by setting the annealing temperature to be 950°C or less, the cost necessary for the annealing can be suppressed, and high productivity can be secured. In addition, since the coarsening of the structure can be suppressed, better toughness can be secured after the quenching. Therefore, in the case of performing the annealing

on the hot-rolled steel sheet or the cold-rolled steel sheet, it is preferable that the steel sheet is held within a temperature range of 950°C or less.

[0052] Cooling to 550°C after the annealing in the case of performing the annealing is preferably performed at an average cooling rate of 3 °C/s to 20 °C/s. By setting the average cooling rate to be 3 °C/s or higher, the generation of coarse pearlite or coarse cementite can be suppressed, and thus properties after the quenching can be improved. In addition, by setting the average cooling rate to be 20 °C/s or less, the stabilization of the material is easily achieved.

(7) Coating Process (S9)

[0053] In a case where a coated layer is formed on the surface of the steel sheet to obtain a coated steel sheet, electro coating or hot dip coating may be performed according to a routine method. In the case of the hot dip galvanizing, a continuous hot dip galvanizing facility may be used and the annealing process and a subsequent coating treatment may be performed in the facility. Otherwise, the coating treatment may be performed independently from the annealing process. An alloying treatment may further be performed in addition to the hot dip galvanizing for galvannealing. In the case of performing the alloying treatment, an alloying treatment temperature is preferably 480°C to 600°C. By setting the alloying treatment temperature to be 480°C or higher, unevenness in the alloying treatment can be suppressed. By setting the alloying treatment temperature to be 600°C or less, manufacturing cost can be suppressed, and high productivity can be secured. After the hot dip galvanizing, skin pass rolling may be performed for flatness correction as necessary. The elongation rate of the skin pass rolling may follow a routine method.

[0054] The amount of inclusions and the segregation degree in the steel sheet are mostly determined by the processes to the hot rolling and are not substantially changed before and after the hot forming. Therefore, when the chemical composition, the amount of inclusions (cleanliness), and the segregation degree of the steel sheet before the hot forming satisfy the ranges of this embodiment, a hot-pressed member manufactured by hot pressing performed thereafter also satisfies the ranges of this embodiment.

Examples

[0055] Steels having the chemical compositions shown in Table 1 were melted in a converter for a test, and continuous casting was performed thereon in a continuous casting machine for a test. As shown in Table 2, in the continuous casting process, the pouring rate and the molten steel heating temperature difference (molten steel temperature - liquidus temperature) were variously changed during the casting. In addition, in a slab solidification procedure, electromagnetic stirring was performed. Furthermore, in a final solidified slab portion, extraction of a center segregated portion was performed by unsolidified layer reduction (extrusion) in which the interval between a pair of upper and lower rolls in the continuous casting machine was narrowed. For comparison, slabs on which electromagnetic stirring and/or extrusion (center segregation reduction treatment) were not performed were partially produced. Thereafter, a slab homogenization treatment was performed at 1300°C for 20 hours. The slab homogenization treatment was omitted for some of the slabs. By using the slabs produced as described above, hot rolling was performed, and then the resultants were cooled and coiled to obtain hot-rolled steel sheets having a sheet thickness of 5.0 mm or 2.9 mm. As for the hot rolling conditions at this time, the heating temperature of the slabs was 1250°C, the rolling start temperature was 1150°C, the rolling finish temperature was 900°C, and the coiling temperature was 650°C. The hot rolling was performed through multi-pass rolling, and the holding for 10 seconds was performed after finishing the rolling. Cooling after the hot rolling was performed by water cooling. For comparison, parts thereof were not subjected to the holding.

[0056] In addition, regarding the pouring rates, a size of an actual production facility is different from that of the continuous casting machine for a test used in this example. Therefore, in Table 2, in consideration of size factors, a value which is converted into the pouring rate in the actual production facility is described. In addition, the molten steel heating temperature difference in Table 2 is a value obtained by subtracting a liquidus temperature from a molten steel temperature.

[0057] The obtained hot-rolled steel sheets were subjected to a pickling treatment according to a routine method to obtain pickled steel sheets. The pickled steel sheets having a sheet thickness of 5.0 mm were subjected to cold rolling to obtain cold-rolled steel sheets having a sheet thickness of 2.9 mm. Parts of the hot-rolled steel sheets were subjected to electro coating. Parts of the cold-rolled steel sheets were subjected to recrystallization annealing (at an annealing temperature of 800°C for an annealing time of 60 seconds) in a continuous annealing facility, and parts of the parts were thereafter subjected to electrolytic zinc coating. Furthermore, parts of the hot-rolled steel sheets and the cold-rolled steel sheets were subjected to annealing (at an annealing temperature of 800°C for an annealing time of 60 seconds) and hot dip galvanizing in a continuous hot dip galvanizing facility. The temperature of a hot dip galvanizing bath was 460°C, and parts thereof were subjected to an alloying treatment at 540°C for 20 seconds, thereby obtaining hot-dip galvanized steel sheets and galvannealed steel sheets.

[Table 1]

(mass%)

Steel type	C	Si	Mn	P	S	sol.Al	N	B	Cr	Ni	Cu	Ti	Nb	Liquidus temperature (°C)
A	0.190	0.10	2.45	0.007	0.0015	0.040	0.0050	0.0030	0.47	-	-	0.06	-	1508
B	0.220	0.12	2.20	0.010	0.0025	0.040	0.0030	0.0008	0.21	-	-	0.09	0.02	1508
C	0.260	0.09	2.14	0.015	0.0020	0.008	0.0040	0.0050	0.40	0.05	-	-	-	1505
D	0.210	0.09	2.20	0.011	0.0018	0.026	0.0062	0.0022	0.20	-	-	0.03	-	1509
E	0.250	0.10	1.88	0.010	0.0020	0.020	0.0030	0.0011	0.30	0.01	-	0.01	0.02	1507
F	0.255	0.12	2.00	0.010	0.0080	0.030	0.0040	0.0022	0.25	-	-	-	-	1506
G	0.190	0.03	2.00	0.010	0.0020	0.010	0.0030	0.0030	0.80	-	0.04	-	-	1511
H	0.230	0.05	2.68	0.020	0.0020	0.020	0.0035	0.0025	0.85	-	-	-	-	1504
I	0.220	0.05	2.20	0.010	0.0023	0.100	0.0030	0.0010	0.50	-	-	0.02	-	1508
J	0.210	0.20	1.30	0.011	0.0026	0.026	0.0062	0.0022	0.20	-	-	0.03	-	1514
K	0.200	0.90	2.00	0.012	0.0020	0.042	0.0039	0.0010	0.28	-	-	-	-	1500
L	0.160	0.13	1.93	0.010	0.0050	0.038	0.0048	0.0015	0.02	-	-	-	-	1515
M	0.210	0.10	1.60	0.010	0.0020	0.038	0.0038	0.0010	0.22	-	-	0.03	-	1512
N	0.320	0.10	2.00	0.010	0.0028	0.025	0.0039	0.0015	0.22	-	-	0.02	-	1502
O	0.120	0.13	2.10	0.012	0.0026	0.040	0.0045	0.0020	0.25	-	-	0.04	-	1516
P	0.190	0.10	1.90	0.009	0.0023	0.035	0.0038	0.0018	0.02	-	-	0.03	-	1513
Q	0.210	0.14	5.00	0.020	0.0030	0.025	0.0030	0.0025	0.20	-	-	0.02	-	1492
R	0.220	0.12	2.10	0.015	0.0028	0.038	0.0042	0.0150	0.30	-	-	0.05	-	1508

[Table 2]

(1/2)

Test No.	Steel type	Molten steel heating temperature difference (°C)	Pouring rate (ton/min)	Electromagnetic stirring	Extrusion	Slab homogenization treatment	Holding after finishing	Cleanliness (%)	Mn segregation degree α	Note
1	A	32	4.2	Presence	Presence	Presence	Presence	0.02	1.2	Invention Example
2	A	32	4.2	Presence	Presence	Presence	Absence	0.02	1.2	Invention Example
3	B	32	5.5	Presence	Presence	Presence	Presence	0.03	1.2	Invention Example
4	B	32	7.0	Presence	Presence	Presence	Presence	0.16	1.3	Comparative Example
5	C	35	2.3	Presence	Presence	Absence	Presence	0.01	1.3	Invention Example
6	C	35	2.3	Presence	Presence	Presence	Presence	0.01	1.1	Invention Example
7	D	31	3.3	Presence	Presence	Presence	Presence	0.02	1.3	Invention Example
8	D	31	3.3	Absence	Presence	Presence	Presence	0.02	1.8	Comparative Example
9	E	33	2.5	Presence	Presence	Presence	Presence	0.01	1.2	Invention Example
10	F	34	6.0	Presence	Presence	Presence	Presence	0.12	1.3	Comparative Example
11	G	30	3.0	Presence	Presence	Presence	Presence	0.02	1.3	Invention Example
12	H	36	2.8	Absence	Absence	Absence	Presence	0.02	2.0	Comparative Example

(continued)

(2/2)

Test No.	Steel type	Molten steel heating temperature difference (°C)	Pouring rate (ton/min)	Electromagnetic stirring	Extrusion	Slab homogenization treatment	Holding after finishing	Cleanliness (%)	Mn segregation degree α	Note
13	H	36	2.8	Presence	Presence	Presence	Presence	0.02	1.2	Invention Example
14	I	32	5.7	Presence	Presence	Presence	Presence	0.04	1.1	Invention Example
15	I	2	5.7	Presence	Presence	Presence	Presence	0.17	1.3	Comparative Example
16	J	26	3.4	Presence	Presence	Presence	Presence	0.02	1.2	Comparative Example
17	K	40	4.8	Presence	Presence	Presence	Presence	0.03	1.3	Comparative Example
18	L	25	5.5	Presence	Presence	Presence	Presence	0.09	1.3	Comparative Example
19	M	28	2.5	Presence	Presence	Presence	Presence	0.01	1.1	Comparative Example
20	N	38	3.0	Presence	Presence	Presence	Presence	0.02	1.2	Comparative Example
21	O	24	5.5	Presence	Presence	Presence	Presence	0.03	1.1	Comparative Example
22	P	27	3.0	Presence	Presence	Presence	Presence	0.02	1.2	Comparative Example
23	Q	48	2.2	Presence	Presence	Presence	Presence	0.01	1.5	Comparative Example
24	R	32	5.2	Presence	Presence	Presence	Presence	0.03	1.2	Comparative Example

[0058] Hot press forming was performed on the manufactured steel sheets as samples, by using a hot pressing test apparatus. The steel sheets on which punching was performed with a blank size of 150 mm square and a punching hole diameter of 36 mm (clearance 10%) were heated in a heating furnace until the steel sheet surface temperature had reached 900°C, were held at the temperature for 4 minutes, and were extracted from the heating furnace. Thereafter, the steel sheets were cooled to 750°C by air cooling, were subjected to hot burring at the time when the temperature had reached 750°C, and were held for 1 minute at the bottom dead center of the press machine. Hot burring conditions are as follows.
Punch shape: conical,
Punch diameter: 60 mm,
Press speed: 40 mm/s,
The cooling after the forming was performed by cooling the die, so that the steel sheet was held for 1 minute at the bottom dead center.

[0059] In the cross-section of the hot-pressed steel sheet which is parallel to the rolling direction, the hardnesses of a burring portion (a high strain formed portion which had undergone a plastic strain of 20% or higher) and a flange portion (a low strain formed portion which had undergone a plastic strain amount of 5% or less) at the positions at a depth of 1/4 of the sheet thickness in the cross-section were measured by a Vickers hardness meter. The measuring load was 98 kN. A measuring method was based on JIS Z 2244. The hardness measurement was performed a total of five times while moving by a pitch of 200 μm in the same thickness position. The average value of the five Vickers hardness values obtained from each of the members was obtained as an average hardness (Hv). The difference between the average hardness of the burring portion and the average hardness of the flange portion (ΔHv = (flange portion Hv) - (burring portion Hv)) was obtained, and a case where ΔHv was 40 or less was determined as being acceptable. The examination results of the hardness are shown in Table 3.

[0060] In addition, the amount of strain was obtained by measuring the sheet thickness at each of the positions of the worked steel sheet and calculating the amount of a reduction in the sheet thickness after the work from the sheet thickness before the work.

[0061] In addition, on the manufactured steel sheets as samples, an examination of a toughness value (absolute value of toughness) and the anisotropy in toughness was conducted.

[0062] The examination was conducted in the following manner. First, the steel sheet having a sheet thickness of 2.9 mm was heated until the steel sheet surface temperature had reached 900°C in the heating furnace, was held for 4 minutes at the temperature, and was then extracted from the heating furnace. Next, the steel sheet was cooled to 750°C by air cooling, was interposed between flat plate dies at the time when the temperature had reached 750°C and was held for 1 minute. Thereafter, the front and rear surfaces of the samples were ground to a thickness of 2.5 mm. Charpy impact test samples were collected so that the longitudinal directions of the samples were the rolling direction and a direction perpendicular to the rolling. At this time, a notch was a V-notch at a depth of 2 mm. The impact test was performed on the basis of JIS Z 2242 at room temperature as the test temperature. The ratio between an impact value in the rolling direction (absorbed energy / cross-sectional area) and an impact value in the direction perpendicular to the rolling was used as an index of the anisotropy.

[0063] The results are shown in Table 3. As a result of the test, when the impact value in the longitudinal rolling direction was 70 J/cm^2 or more and the impact value ratio was 0.65 or higher, good properties were determined.

[0064] The cleanliness of the steel sheet was examined on the basis of JIS G 0555. Samples were cut from the steel sheet of each of the Test Nos. at five points, and the cleanliness of each of positions at 1/8, 1/4, 1/2, 3/4, and 7/8 of the sheet thickness was examined by a point counting method. Among the results at each of the sheet thickness positions, a value having the highest cleanliness was determined as the cleanliness of the sample. The cleanliness was the sum of the A series, B series, and C series inclusions.

[0065] The Mn segregation degree was obtained by performing component surface analysis of Mn using an EPMA. Samples were cut from the steel sheet of each of the Test Nos. at five points, 10 visual fields were measured at each of the positions at 1/4 and 1/2 of the sheet thickness with a magnification of 500 times, and the average value of the Mn segregation degrees of each of the visual fields was employed.

[Table 3]

(1/2)

Test No.	Steel type	Process	Coating type	Hardness			Impact value in rolling direction (J/cm²)	Impact value ratio	Note
				Flange portion	Burring portion	ΔHv			
1	A	Hot rolling	-	436	440	-4	110.9	0.785	Invention Example
2	A	Hot rolling	-	440	438	2	101.5	0.727	Invention Example
3	B	Cold rolling and annealing	Hot dip galvanizing	468	455	13	88.9	0.681	Invention Example
4	B	Cold rolling and annealing	Hot dip galvanizing	467	450	17	52.9	0.466	Comparative Example
5	C	Hot rolling	Electro coating	509	489	20	73.2	0.729	Invention Example
6	C	Hot rolling	Electro coating	507	483	24	78.2	0.769	Invention Example
7	D	Hot rolling	Hot dip galvanizing	459	438	21	89.5	0.725	Invention Example
8	D	Hot rolling	Hot dip galvanizing	456	440	16	79.0	0.625	Comparative Example
9	E	Cold rolling	-	496	480	16	79.3	0.749	Invention Example
10	F	Cold rolling	-	503	470	33	58.5	0.407	Comparative Example
11	G	Cold rolling and annealing	Electro coating	438	428	10	106.6	0.714	Invention Example
12	H	Cold rolling and annealing	Hot dip galvanizing	476	473	3	66.9	0.574	Comparative Example

(2/2)

Test No.	Steel type	Process	Coating type	Hardness			Impact value in rolling direction (J/cm²)	Impact value ratio	Note
13	H	Cold rolling and annealing	Hot dip galvanizing	481	480	1	88.9	0.734	Invention Example
14	I	Cold rolling and annealing	-	470	471	-1	85.9	0.701	Invention Example

(continued)

(2/2)									
Test No.	Steel type	Process	Coating type	Hardness			Impact value in rolling direction (J/cm^2)	Impact value ratio	Note
15	I	Cold rolling and annealing	-	467	462	5	55.4	0.466	Comparative Example
16	J	Hot rolling	-	456	395	61	99.0	0.688	Comparative Example
17	K	Hot rolling	Hot dip galvanizing	447	392	55	99.6	0.699	Comparative Example
18	L	Cold rolling		409	310	99	111.3	0.511	Comparative Example
19	M	Cold rolling and annealing	Hot dip galvanizing	458	417	41	101.0	0.769	Comparative Example
20	N	Cold rolling and annealing	Hot dip galvanizing	567	557	10	37.9	0.674	Comparative Example
21	O	Cold rolling and annealing	-	366	322	44	136.0	0.693	Comparative Example
22	P	Cold rolling and annealing	-	435	372	63	109.1	0.711	Comparative Example
23	Q	Cold rolling and annealing	-	519	517	2	62.0	0.615	Comparative Example
24	R	Cold rolling and annealing	-	463	432	31	61.9	0.659	Comparative Example

[0066] In all of the Test Nos. 16 to 19, 21, and 22, the average hardness of the burring portion which was the high strain deformed portion was significantly reduced compared to the average hardness of the flange portion which was the low strain deformed portion, and the ΔHv values were increased to 41 to 99. This is because the burring portion was softened by the strain-induced ferritic transformation caused by the burring work. In this case, in the manufactured hot-formed product, the hardness was locally different, and thus the strength of the formed product was not uniform but was partially reduced. Therefore, reliability as a product was reduced.

[0067] In addition, in the Test Nos. 4, 8,10, 12, 15, 18, 20, 23, and 24, the chemical compositions, the cleanliness or the segregation degree were out of the ranges of the present invention, and thus the impact value in the rolling direction and/or the impact value ratio were insufficient.

[0068] Contrary to this, in all of the steel sheets having the chemical composition of the present invention, regardless of the presence or absence of the cold rolling process, presence or absence of the annealing process, or the coating type, the ΔHv was -4 to 24, the difference between the average hardness of the flange portion and the average hardness of the burring portion was small, and the stability of hardness and strength during the high strain forming was excellent.

[0069] In addition, the toughness after the hot rolling and the anisotropy in toughness exhibited sufficient values.

[Industrial Applicability]

[0070] In the steel sheet of the present invention, even in a case where hot forming accompanied with high strain forming such as burring is performed, strain-induced ferritic transformation in the formed portion is suppressed. Therefore, a steel sheet having a stable hardness distribution after the hot forming, excellent toughness and low anisotropy in toughness after the hot forming can be obtained. The steel sheet is appropriate for, for example, a material of a mechanical structure member including a body structure member, an underbody member, and the like of a vehicle, and thus the present invention is very useful in industrial fields.

Claims

1. A steel sheet comprising as a chemical composition, by mass%,
C : 0.18% to 0.275%;
Si: 0.02% to 0.15%;
Mn : 1.85% to 2.75%;
sol.Al : 0.0002% to 0.5%;
Cr: 0.05% to 1.00%;
B: 0.0005% to 0.01%;
P: 0.1% or less;
S : 0.0035% or less;
N : 0.01% or less;
Ni : 0% to 0.15%;
Cu : 0% to 0.05%;
Ti : 0% to 0.1 %;
Nb: 0% to 0.2%; and
a remainder including Fe and impurities,
wherein a cleanliness of a metal structure is 0.08% or less,
α which is an Mn segregation degree expressed by the following expression 1 is 1.6 or less, and
in a hot forming, a difference ΔHv in an average hardness after the hot forming between a low strain formed portion that undergoes a plastic strain of 5% or less and a high strain formed portion that undergoes a plastic strain of 20% or higher is 40 or less.

α = (a maximum Mn concentration, by mass%, in a thickness center portion of the steel sheet) / (an average Mn concentration, by mass%, at a position at a depth of 1/4 of a sheet thickness from a surface of the steel sheet) ... expression 1

2. The steel sheet according to claim 1, wherein the chemical composition further includes, instead of a portion of Fe, by mass%, one or two selected from the group consisting of Ni : 0.02% to 0.15%, and Cu : 0.003% to 0.05%.

3. The steel sheet according to claim 1 or 2, wherein the chemical composition further includes, instead of a portion of Fe, by mass%, one or two selected from the group consisting of Ti : 0.005% to 0.1%, and Nb : 0.005% to 0.2%.

4. The steel sheet according to any of claims 1 to 3, wherein the surface of the steel sheet further includes a coated layer.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2013/072989

A. CLASSIFICATION OF SUBJECT MATTER
C22C38/32(2006.01)i, *C22C38/58*(2006.01)i, *C23C2/06*(2006.01)i, *C23C2/12*(2006.01)i, *C23C2/40*(2006.01)i, *C21D8/02*(2006.01)n, *C21D9/46*(2006.01)n, *C25D5/26*(2006.01)n

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)
C22C38/00-38/60, C23C2/00-2/40, C21D8/02, C21D9/46, C25D5/26

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	1996-2013
Kokai Jitsuyo Shinan Koho	1971-2013	Toroku Jitsuyo Shinan Koho	1994-2013

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2007-314817 A (Sumitomo Metal Industries, Ltd.), 06 December 2007 (06.12.2007), claims; paragraphs [0010], [0025] to [0029], [0081]; tables 1 to 5; fig. 2 (Family: none)	1-4
A	JP 2011-99149 A (Sumitomo Metal Industries, Ltd.), 19 May 2011 (19.05.2011), claims; paragraphs [0017] to [0023], [0085] to [0091]; tables 1 to 3 (Family: none)	1-4

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

* Special categories of cited documents:
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REFERENCES CITED IN THE DESCRIPTION

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