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(54) AGE-HARDENING STEEL AND METHOD OF MANUFACTURING PARTS USING AGE-HARDENING STEEL

(57) Age hardening steel excellent in machinability before aging treatment and excellent in fatigue characteristics, toughness, and low cycle fatigue characteristics after aging treatment, that is, age hardening steel containing predetermined amounts of C, Si, Mn, S, Cr, Al, V, Nb, Ca, and REM, limiting contents of P, Ti, and N to predetermined amounts or less, having a balance of Fe and impurities, having an area ratio of bainite structures of 70% or more, and, furthermore, having a chemical composition where F1 expressed by C+0.3×Mn+0.25×Cr is 0.68 or more, F2 expressed by C+0.1×Si+0.2×Mn+0.15×Cr+0.35×V is 0.85 or less, F3 expressed by -4.5×C+Mn+Cr-3.5×V is 0.00 or more, and F4 expressed by 10×Ca+REM is 0.012 to 0.08, is provided. Note that, the symbols of elements in the formulas showing F1 to F4 mean the contents by mass% of those elements.

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Description

Technical Field

[0001] The present invention relates to age hardening steel, more particularly relates to age hardening steel which is cut etc. to work it to a predetermined shape, then is treated for age hardening (below, referred to simply as "aging treatment"). Further, the present invention relates to a method of production of a part using such age hardening steel.

Background Art

[0002] From the viewpoints of lightening weight aiming at higher output of an engine and improvement of fuel efficiency etc., machine parts of automobiles, industrial machinery, construction machinery, etc. are required to exhibit high fatigue strength. Steel can be easily provided with a high fatigue strength by adding alloy elements, heat treatment, etc. so as to raise the hardness of the steel. However, if producing a machine part by the method of first hot forging to shape a material, then cutting to finish it to a predetermined product shape, a sufficient machinability is also demanded. That is, at the stage of shaping the machine part, the steel is required to exhibit machinability, while at the stage of the final product, the steel is required to exhibit fatigue strength.

[0003] To deal with such demands, age hardening steel which can be kept low in hardness at the shaping stage and, after that, can be treated to age it to raise the hardness in the final product stage has been proposed (for example, see WO2010/090238A (PLT 1), Japanese Patent Publication No. 2012-246527A (PLT 2), Japanese Patent Publication No. 2011-241441A (PLT 3), Japanese Patent Publication No. 2012-193416A (PLT 4), and Japanese Patent No. 5343923B2 (PLT 5)).

[0004] PLTs 1 and 2 disclose a method of production controlling the cooling rate after shaping by hot forging, suppressing the formation of structures other than bainite, keeping down the amount of precipitation of VC during cooling, and securing the amount of solute V so as to be able to obtain a sufficient age hardenability. However, in the method of production described in PLTs 1 and 2, at the time of the cooling step after hot forging, it is necessary to control the cooling rate at each specific temperature region, there are restrictions in facilities, apparatuses, etc., and also sometimes quenching is not possible on an actual production line, so it was difficult to stably produce age hardening steel.

[0005] Therefore, PLTs 3 to 5 propose age hardening steel for use as a material of a machine part not requiring strict conditions to be set at the cooling step after hot forging and enabling cooling by air cooling and fans in production.

Summary of Invention

Technical Problem

[0006] As explained above, the steel used as a material for a machine part is required to be excellent in machinability at the stage of production of the machine part and to be excellent in fatigue strength after the machine part is completed. When using a method of production including aging treatment to produce a machine part, the above demands can be met by steel provided with the characteristics of being low in hardness before the aging treatment and being raised in hardness after aging treatment. A large difference between the hardness before the aging treatment and the hardness after aging treatment (that is, a high age hardenability) is preferable for obtaining a machine part which is excellent in both productivity and fatigue strength.

[0007] However, the methods of production for obtaining age hardening steel according to the prior art require inclusion of a step of quenching the steel. This quenching step causes an increase in the cost of manufacturing age hardening steel.

[0008] Further, steel treated to age it so as to cause fine precipitates to disperse in the steel and cause the strength to rise is known to be greatly degraded in toughness. If steel is degraded in toughness, the steel rises in notch sensitivity, so if some reason or another causes a surface flaw to occur at the steel, the steel falls in low cycle fatigue strength. The "low cycle fatigue strength" is a characteristic demanded from steel in which application of stress exceeding the elasticity region is envisioned. The method of production of age hardening steel disclosed in PLTs 3 to 5 does not require increase of the cooling rate after hot forging and has the effect of suppressing the increase in the manufacturing cost, but it was difficult to obtain steel sufficient in toughness after aging treatment.

[0009] The present invention was made in consideration of such an actual situation and has as its object the provision of age hardening steel in which the production conditions are not particularly limited, the machinability before aging treatment is excellent, hardening by aging treatment can be used to stably improve the fatigue strength, and a drop in toughness due to aging treatment can be suppressed.

Solution to Problem

[0010] To secure sufficient hardness, fatigue strength, and low cycle fatigue strength after aging treatment, it is necessary to suitably control the amount of formation of carbides, carbonitrides, and other compounds precipitating due to the aging treatment in accordance with the types of the precipitates.

[0011] Here, the inventors focused on the matters explained below. V is present forming a solid solution in steel during the hot forging performed at a general temperature. The reason is that the starting temperature for formation of V carbides or V carbonitrides (precipitation temperature) is low. On the other hand, V is strong in ability to form precipitates (V carbides or V carbonitrides) at the aging treatment, so is an element effective for hardening by aging treatment. However, if the content of N is large, V nitrides are formed at the time of cooling after hot forging and before aging treatment, the hardness rises before aging treatment, and the machinability becomes impaired. Based on these discoveries, the inventors experimented with the promotion of formation of V carbides or V carbonitrides after aging treatment and suppression of formation of V nitrides before aging treatment.

[0012] Further, Ti bonds with N and C to form coarse Ti carbonitrides and, even in a trace amount of a content of 0.005% or so, causes a great degradation of the toughness. Therefore, based on these discoveries, the inventors experimented with decreasing the Ti content of steel.

[0013] Further, Nb precipitates in steel as carbides or carbonitrides in the process of heating and being worked at the time of hot forging and has the effect of refining the austenite crystal grain size due to the pinning effect, and, after that, refining the bainite structure in the bainite transformation. Furthermore, part of the Nb in steel does not precipitate as carbides or carbonitrides at the time of hot forging but is present as solute Nb. This solute Nb precipitates as Nb carbides or Nb carbonitrides at the time of aging treatment after hot forging and has the effect of raising the hardness without inviting a drop in toughness and thereby achieving an improvement in the low cycle fatigue strength and fatigue strength. Based on these discoveries, the inventors experimented with utilizing Nb to suppress the drop in toughness due to aging treatment.

[0014] Furthermore, to stably raise the fatigue strength and stably prevent a drop in toughness after aging treatment as well, it is necessary to control not only the types and amounts of formation of carbides, carbonitrides, and other precipitates due to the aging treatment, but also the form of the inclusions present in the steel.

[0015] Therefore, the inventors focused on the matters explained below. REMs are elements which form sulfide-based inclusions or oxide-based inclusions and have the effect of causing the inclusions to finely disperse and making the inclusions spherical in shape. However, if the content of REMs is too great, a drop in the hot ductility of the steel material at the time of hot rolling or hot forging will end up being caused. Based on this discovery, the inventors tried to find the suitable REM content and searched for and determined conditions enabling stable improvement of the fatigue strength by hardening by aging treatment and stably preventing a drop in toughness after aging treatment.

[0016] The present invention was made based on such a discovery and has as its gist the following:

[1] An age hardening steel containing, by mass%, C: 0.05 to 0.20%, Si: 0.01 to 0.50%, Mn: 1.50 to 2.50%, S: 0.005 to 0.080%, Cr: 0.03 to 1.60%, Al: 0.005 to 0.050%, V: 0.25 to 0.50%, Nb: 0.010 to 0.100%, Ca: 0.0005 to 0.0050%, and REM: 0.001 to 0.05%, limiting P to 0.030% or less, Ti to less than 0.005%, and N to less than 0.0080%, having a balance of Fe and impurities, having an area ratio of a bainite structure of 70% or more and, furthermore, having a chemical composition where the following F1 expressed by formula (1) is 0.68 or more, F2 expressed by formula (2) is 0.85 or less, F3 expressed by formula (3) is 0.00 or more, and F4 expressed by formula (4) is 0.012 to 0.08:.

$$F1=C+0.3\times Mn+0.25\times Cr \cdots (1)$$

$$F2=C+0.1\times Si+0.2\times Mn+0.15\times Cr+0.35\times V \cdots (2)$$

$$F3=-4.5\times C+Mn+Cr-3.5\times V \cdots (3)$$

$$F4=10\times Ca+REM \cdots (4)$$

where the symbols of elements in the above formula (1) to formula (4) mean the contents by mass% of those elements

[2] An age hardening steel containing, by mass%, C: 0.05 to 0.20%, Si: 0.01 to 0.50%, Mn: 1.50 to 2.50%, S: 0.005 to 0.080%, Cr: 0.03 to 1.60%, Al: 0.005 to 0.050%, V: 0.25 to 0.50%, Nb: 0.010 to 0.100%, Ca: 0.0005 to 0.0050%, and REM: 0.001 to 0.05%, having an area ratio of bainite structures of 70% or more, furthermore, satisfying any

one or more of the conditions of the composition shown by the following <a> to <c>, limiting P to 0.030% or less, Ti to less than 0.005%, and N to less than 0.0080%, having a balance of Fe and impurities, and, furthermore, having a chemical composition where the following F1' expressed by formula (1') is 0.68 or more, F2' expressed by formula (2') is 0.85 or less, and F3' expressed by formula (3') is 0.00 or more, and F4 expressed by formula (4) is 0.012 to 0.08:

<a> Mo: 0.01 to 1.0%
<b> One or both of Cu: 0.01 to 0.30% and Ni: 0.01% to 0.30%
<c> Bi: 0.01 to 0.400%

$$F1' = C + 0.3 \times Mn + 0.25 \times Cr + 0.6 \times Mo \quad \cdots (1')$$

$$F2' = C + 0.1 \times Si + 0.2 \times Mn + 0.15 \times Cr + 0.35 \times V + 0.2 \times Mo \quad \cdots (2')$$

$$F3' = -4.5 \times C + Mn + Cr - 3.5 \times V - 0.8 \times Mo \quad \cdots (3')$$

$$F4 = 10 \times Ca + REM \quad \cdots (4)$$

where the symbols of elements in the above formula (1') to formula (3') and formula (4) mean the contents by mass% of those elements

[3] A method of production of a part using age hardening steel comprising a forging step of heating age hardening steel according to [1] or [2] at 1200 to 1250°C for 5 to 60 minutes, then forging it so that a surface temperature after final forging becomes 1100°C or more, then, after that, cooling it by an average cooling rate in a 800 to 400°C temperature region of 15 to 60°C/min down to room temperature, a cutting step of cutting the forged steel, and an aging treatment step of holding the cut steel in a 540 to 700°C temperature region for 30 to 1000 minutes.

Advantageous Effects of Invention

[0017] According to the present invention, it is possible to provide age hardening steel which is not particularly limited in production conditions, is excellent in machinability before aging treatment, can use the hardening by the aging treatment to stably improve the fatigue strength, and can keep down a drop in toughness due to aging treatment. Further, by using the age hardening steel of the present invention as a material, it is possible to provide a machine part which is excellent in productivity, excellent in fatigue strength, and is sufficient in toughness.

[0018] Note that, the age hardening steel of the present invention has, as an indicator of the cutting resistance, a Vicker's hardness before aging treatment of 290 Hv or less. The amount of rise of the Vicker's hardness (age hardenability, ΔHv) due to the aging treatment when making the age hardening steel of the present invention a substantially columnar shape with a diameter of 35 mm and holding this steel at a temperature of 620°C for 120 minutes is 30 Hv or more. The age hardening steel of the present invention after the aging treatment has a fatigue strength of 425 MPa or more.

[0019] Further, the age hardening steel of the present invention after aging treatment has an absorption energy at 20°C of 50J or more in a Charpy impact test performed using a standard test piece with a U-notch with a notch depth of 2 mm and a notch bottom radius of 1 mm and has a low cycle fatigue strength of 520 MPa or more.

[0020] In this way, the age hardening steel of the present invention can be extremely suitably used as a material for a machine part of automobiles, industrial machinery, construction machinery, etc. Its contribution to industry is extremely remarkable.

Brief Description of Drawings

[0021] FIG. 1 is a view showing the shape of a monoaxial tension and compression type of fatigue test piece used in the examples. The numerical values in the figure show the dimensions (units: mm).

Description of Embodiments

Discovery Leading to Derivation of Present Invention

[0022] Below, the chemical composition of the age hardening steel according to the present embodiment will be explained focusing on the elements important from the viewpoint of age hardening. Note that, the main application for the age hardening steel according to the present embodiment (below, sometimes abbreviated as the "steel according to the present embodiment") is as the material of a machine part produced by a method of production including hot forging, machining, aging treatment, etc. Therefore, to explain the features of the steel according to the present embodiment, sometimes reference will be made to characteristics of steel after hot forging, machining, and aging treatment. However, the steel according to the present embodiment does not necessarily require such treatment. That is, the applications of the steel according to the present embodiment are not limited to hot forging, machining, etc.

[0023] First, in the steel according to the present embodiment, the fact that the V content has to be made 0.25 mass% or more was discovered by the present inventors. By making the V content 0.25 mass% or more, it is possible to make the amount of carbides of V or carbonitrides of V formed due to the aging treatment increase, raise the hardness after aging treatment, and secure fatigue strength.

V, once forming a solid solution in steel, will not precipitate until the steel is cooled down to near 850°C and is strong in ability to form carbides or carbonitrides at the age hardening treatment temperature. Furthermore, in the steel according to the present embodiment, in the same way as V, it is also possible to add Mo which is relatively low in temperature of precipitation of carbides and can be easily used for age hardening. If making steel containing V in 0.25 mass% or more further contain Mo, the aging treatment causes composite carbides of V and Mo or composite carbonitrides of V and Mo to be formed, so the hardness after aging treatment rises more.

[0024] As explained above, V has the property of not precipitating once forming a solid solution in the steel until cooling the steel down to near 850°C, so is an element which can remain stably present in the steel in the solute state. However, V carbides easily precipitate at the phase boundaries when austenite transformed to ferrite. If the amount of precipitation of V carbides increases, the amount of solute V decreases. That is, if a large amount of proeutectoid ferrite is formed during the cooling after hot forging, V carbides will precipitate at the phase boundaries, so it becomes no longer possible to secure the amount of solute V necessary for precipitation hardening due to aging treatment after that. Therefore, to secure a sufficient amount of solute V in the age hardening steel before aging treatment, it is necessary that in the structure after hot forging and before aging treatment, the phase accounting for an area ratio of a 70% or more (below, sometimes referred to as "main phase") becomes bainite. Further, to prevent skyrocketing costs of manufacturing a machine part, such control of the structure has to be performed not by controlling the hot forging conditions, but by controlling the chemical composition of the steel.

[0025] The structure after hot forging is closely correlated with the C, Mn, and Cr improving the hardenability and, furthermore, the content of Mo. The present inventors discovered that if making the values of the indicators F1 and F1' of hardenability expressed by the following formula (1) and formula (1') specific numerical values or more by controlling the contents of these elements in these formulas, precipitation of a large amount of proeutectoid ferrite harmful to securing the solute V is suppressed in the usual cooling process after hot forging (cooling rate 15°C/min to 60°C/min). That is, the present inventors discovered that by controlling F1 and F1', the steel structure easily becomes a structure having bainite as its main phase, that is, becomes a structure including bainite by an area ratio of 70% or more, so a sufficient amount of solute V can be secured:

$$F1 = C + 0.3 \times Mn + 0.25 \times Cr \quad \cdots (1)$$

$$F1' = C + 0.3 \times Mn + 0.25 \times Cr + 0.6 \times Mo \quad \cdots (1')$$

[0026] However, even if making the steel structure a structure having bainite as its main phase (area ratio of 70% or more) so as to secure a sufficient amount of solute V, sometimes the hardness before aging treatment (hardness of structure containing bainite as main phase) becomes high. In this case, sometimes a rise in the cutting resistance of the steel after hot forging is invited and the machinability falls. The present inventors studied the method of solving this problem. As a result, the present inventors discovered that if controlling the chemical composition of the steel according to the present embodiment so that the values of indicators F2 and F2' of hardness before aging treatment expressing the contents of C, Si, Mn, Cr, V, and Mo by the following formula (2) and formula (2') become specific numerical values or less, it is possible to keep the hardness before aging treatment low and possible to suppress a rise in the cutting resistance:

$$F2=C+0.1\times Si+0.2\times Mn+0.15\times Cr+0.35\times V \quad \cdots (2)$$

$$F2'=C+0.1\times Si+0.2\times Mn+0.15\times Cr+0.35\times V+0.2\times Mo \quad \cdots (2')$$

[0027] Further, the present inventors produced steel containing 0.25 mass% or more of V and adjusted in ingredients so that F1 and F2 or F1' and F2' in which the contents of C, Si, Mn, Cr, Mo, and V are found by the above formula (1) and formula (2) or formula (1') and formula (2') satisfy specific ranges of numerical values, hot forged, then treated this steel to age to prepare samples, and investigated the toughness of the samples. Specifically, they hot forged and treated the above steel to age, prepared standard test samples with U-notches with a notch depth of 2 mm and notch bottom radius of 1 mm, ran the test pieces through a Charpy impact test, and investigated the effects of the ingredients on the toughness after aging treatment.

[0028] As a result of the above investigations, the inventors learned that to obtain steel able to suppress a drop in toughness due to aging treatment, it is necessary to control the contents of C, Mn, Cr, V, and Mo of steel so that the values of indicators F3 and F3' expressed by the following formula (3) and formula (3') and showing the toughness after aging treatment become specific values or more:

$$F3=-4.5\times C+Mn+Cr-3.5\times V \quad \cdots (3)$$

$$F3'=-4.5\times C+Mn+Cr-3.5\times V-0.8\times Mo \quad \cdots (3')$$

[0029] If F3 and F3' are large, the toughness of the steel after aging treatment will be sufficient. Further, increasing the contents of C, V, and Mo decreases F3 and F3'. Therefore, formula (3) or formula (3') mean that the contents of C, V, and Mo, which are required for improving the hardness and the fatigue strength after aging treatment, have to be reduced to suppress a drop in toughness due to aging treatment.

[0030] Furthermore, to achieve both strength and toughness, it is necessary to utilize elements other than C, V, and Mo to raise the hardness after aging treatment and improve the strength.

[0031] To suppress a drop in toughness after aging treatment, refining the structure is effective. To refine the main phase bainite structure, refining the austenite grain size before bainite transformation is effective. To refine the austenite grain size, in general inclusion of Ti is effective, but in the steel according to the present embodiment, this means cannot be used. The present inventors discovered that Ti forms coarse Ti carbonitrides causing the steel according to the present embodiment to degrade in toughness, so even if the Ti content is a 0.005% or so trace amount, the Ti causes the steel after aging treatment to greatly degrade in toughness. Therefore, the steel according to the present embodiment has to be restricted in content of Ti as much as possible to zero or a specific value or less.

[0032] Further, if inclusions having a detrimental effect on toughness are present in the steel, a sufficient toughness cannot be obtained. To keep down the presence of inclusions in steel detrimental to toughness, the content of S has to be made a specific value or less. Further, S is also an element which bonds with Mn to form coarse MnS and degrade the toughness, so excessive addition of S has to be avoided. On the other hand, MnS is an inclusion essential for securing sufficient machinability. Therefore, it is not preferable to make the content of S completely zero. To raise the machinability of the steel before aging treatment and keep down a drop in toughness of the steel due to the aging treatment, it is necessary to suitably control the content of S so that the amount of MnS does not become too great.

[0033] The present inventors discovered that inclusion of Nb is effective as a means for sufficiently raising the machinability before aging treatment and low cycle fatigue strength after aging treatment and suppressing a drop in toughness due to the aging treatment. Nb has the effect of refining the austenite grain size before bainite transformation in the same way as Ti.

[0034] Nb is an element having the effect of refining the austenite grain size and has the ability to form a compound at the aging treatment temperature (secondary phase). This is because Nb has a higher precipitation temperature than V and Mo. That is, since Nb has a relatively high precipitation temperature, part of the contained Nb precipitates as carbides or carbonitrides at the time of hot forging. The carbides and other Nb precipitates contribute to the refining of the austenite grain size.

[0035] Steel satisfying the condition of the formula (1) or formula (1') becoming a specific range has solute Nb present in it. As explained above, this is because the main phase of the steel satisfying formula (1) or formula (1') is the bainite structure and Nb easily forms a solid solution in a bainite structure. For this reason, steel where the formula (1) or formula (1') becomes a specific range may be treated for aging to make Nb carbides or Nb carbonitrides precipitate. Further, it was discovered by the present inventors that even if these Nb-based precipitates precipitate, it is possible to raise the hardness of the steel after aging treatment without inviting a drop in toughness. Furthermore, it was discovered by the present inventors that by including Nb, it is possible to realize steel where excellent low cycle fatigue strength is obtained by refining the bainite structure and by precipitation strengthening.

[0036] As explained above, the present inventors obtained the discovery relating to age hardening steel which is not particularly limited in the production conditions of the steel material, is excellent in the machinability before aging treatment, is improved in the fatigue strength by hardening by aging treatment, and can suppress a drop in toughness after aging treatment. However, with just the above-mentioned discovery, sometimes the fatigue strength and toughness after aging treatment become somewhat low levels though still within the ranges of the desired values.

[0037] Therefore, the present inventors carefully investigated the mechanism by which the fatigue strength or toughness becomes lower in level after aging treatment and as a result discovered that the coarse inclusions contained inside the steel are the cause. That is, they clarified that by suppressing the formation of such coarse inclusions, it is possible to stably improve the fatigue strength after aging treatment and suppress a drop in toughness after aging treatment.

[0038] To keep down coarse inclusions, the present inventors focused on a REM. A REM has the effect of forming sulfide-based inclusions or oxide-based inclusions and making both the sulfide-based inclusions and oxide-based inclusions finely disperse. However, if the REM content is too large, the hot ductility of the steel material at the time of hot rolling or hot forging ends up being made to fall.

[0039] However, if just adjusting the REM content, both the sulfide-based inclusions and the oxide-based inclusions cannot stably finely disperse. The present inventors learned that it is necessary to control the contents of Ca and a REM so that the value of the control indicator F4 of the forms of inclusions with a REM and Ca expressed by the following formula (4) becomes a specific range. The inventors discovered that by doing this, the sulfide-based inclusions disperse finely in spherical shapes and the oxide-based inclusions finely disperse:

$$F4 = 10 \times Ca + REM \quad \cdots (4)$$

[0040] If F4 is 0.012 or more, both the sulfide-based inclusions and the oxide-based inclusions stably finely disperse. Further, if F4 is over 0.08, the effect becomes saturated and the hot ductility of the steel is liable to be lowered, so it is necessary to make the contents of Ca and REM suitable.

[0041] The present invention relates to age hardening steel obtained based on the results of the studies of the present inventors and the findings they obtained explained above. Below, the requirements of age hardening steel according to an embodiment of the present invention will be explained in detail.

Chemical Composition

[0042] First, the composition of the age hardening steel according to the present embodiment will be explained. Note that, the "%" of the content of the elements mean "mass%".

Essential Elements

C: 0.05 to 0.20%

[0043] C is an important element in the present embodiment. C bonds with V due to the aging treatment to form carbides and strengthen the steel. However, if the content of C is less than 0.05%, the force driving the precipitation of V carbides becomes smaller and it becomes difficult for V carbides to precipitate, so the desired strengthening effect cannot be obtained. On the other hand, if the content of C is over 0.20%, the C not bonded with V bonds with Fe to form carbides (cementite) and cause a remarkable degradation of toughness of the steel. Further, if the content of C exceeds 0.20%, the concentration of C concentrating in the austenite also becomes higher in the middle of the transformation from austenite to bainite and the structure after bainite transformation becomes partially contaminated by martensite. If cementite and/or martensite is contained in steel in this way, the cutting resistance ends up rising and the machinability falls. Therefore, the content of C is made 0.05 to 0.20%. The content of C is preferably made 0.08% or more, more preferably 0.10% or more. Further, the content of C is preferably made 0.18% or less, more preferably 0.16% or less.

Si: 0.01 to 0.50%

[0044] Si is used as a deoxidizing element at the time of steelmaking and simultaneously has the action of forming a solid solution in the matrix and improving the strength of the steel. To sufficiently obtain these effects, Si has to be made 0.01% or more in content. However, if the content of Si becomes excessive, a rise occurs in the hot workability and cutting resistance of the steel and a drop in machinability is invited. In particular, if the content of Si is over 0.50%, a drop in the hot workability and a rise in the cutting resistance of the steel become remarkable. Furthermore, Si is liable to promote the formation of proeutectoid ferrite and decrease the amount of bainite, so to stably obtain bainite, excessive inclusion of Si is not preferable. Note that, if proeutectoid ferrite is formed at the stage of production of the steel, as explained above, V carbides will precipitate at the phase boundaries of the proeutectoid ferrite and austenite and it will become difficult to secure the amount of solute V required for precipitation hardening by aging treatment and as a result the age hardenability of the steel is liable to be caused to decrease. Therefore, the content of Si is made 0.01 to 0.50%. The content of Si is preferably made 0.06% or more. Further, the content of Si is preferably made 0.45% or less, more preferably is made less than 0.35%.

Mn: 1.50 to 2.50%

[0045] Mn has the effect of improving the hardenability and making the main phase of the structure bainite. Furthermore, Mn has the action of causing a reduction in the bainite transformation temperature and by doing so has the effect of refining the structure to raise the toughness of the matrix. Note that, the structure which accounts for the majority of the volume of the steel will be called the "matrix". The matrix of the steel according to the present embodiment is bainite. Further, Mn has the action forming MnS in the steel to cause a drop in the cutting resistance and thereby improve the machinability. Further, if the amount of Mn is less than 1.50%, formation of proeutectoid ferrite is promoted and, as explained above, a reduction in the amount of bainite and drop in the age hardenability are liable to be caused. To sufficiently obtain these effects, Mn has to be made at least 1.50% in content. However, Mn is an element which easily segregates at the time of solidification of the steel, so the content increases. In particular, if over 2.50%, the hardness inside the part after hot forging will unavoidably greatly vary. Therefore, the content of Mn is made 1.50 to 2.50%. The content of Mn is preferably made 1.60% or more, more preferably is made 1.70% or more. Further, the content of Mn is preferably made 2.30% or less, more preferably is made 2.10% or less.

S: 0.005 to 0.080%

[0046] S bonds with the Mn in the steel to form MnS which causes a drop in the cutting resistance and improvement of the machinability. To obtain sufficient machinability, 0.005% or more of S has to be included. However, if the content of S becomes excessively high, the coarse MnS will increase and the toughness and fatigue strength are liable to be degraded. In particular, if the content of S exceeds 0.080%, the drop in the toughness and the fatigue strength becomes remarkable. Therefore, the content of S is made 0.005 to 0.080%. The content of S is preferably made 0.010% or more. Further, the content of S is preferably made 0.050% or less, more preferably is made 0.030% or less.

Cr: 0.03 to 1.60%

[0047] Cr has the effect of raising the hardenability and making the main phase of the structure bainite. Furthermore, Cr has the action of causing a drop in the bainite transformation temperature and has the effect of refining the structure by doing so and thereby raising the toughness of the matrix. However, if the content of Cr is over 1.60%, the hardenability becomes too large and, depending on the size or location of the part, the hardness before the aging treatment is liable to become a Vicker's hardness of over 290 Hv, so sometimes the cutting resistance will rise and the machinability will fall. Therefore, the content of Cr is made 0.03 to 1.60%. The lower limit of the content of Cr is preferably made 0.05% or more, more preferably is made 0.10% or more. The upper limit of the content of Cr is preferably 1.00% or less, more preferably is made 0.50% or less.

Al: 0.005 to 0.050%

[0048] Al is an element having a deoxidizing action. To obtain such an action, the content has to be made 0.005% or more. However, if the content of Al is over 0.050%, coarse oxides are formed and the steel falls in toughness and fatigue strength. Therefore, the content of Al is made 0.005 to 0.050%. The content of Al is preferably 0.040% or less.

V: 0.25 to 0.50%

[0049] V is the most important element in the steel according to the present embodiment. V has the action at the time of aging treatment of bonding with C to form fine V carbides or of bonding with C and N to form fine V carbonitrides and thereby raise the strength of the steel after the aging treatment. Further, V also has the effect of precipitating compositely with Mo due to the aging treatment and further raising the age hardenability of the steel. To sufficiently obtain these effects, V has to be made 0.25% or more in content. However, if the content of V becomes excessive, even in heating at the time of hot forging, undissolved carbonitrides will easily remain and a drop in toughness will be invited. In particular, if the content exceeds 0.50%, the drop in toughness will become remarkable. Further, if the content of V exceeds 0.50%, undissolved carbides will remain and along with this sometimes the cutting resistance will end up rising and the machinability of the steel will also remarkably fall. Therefore, the content of V is made 0.25 to 0.50%. The content of V is preferably made less than 0.45%, more preferably is made 0.40% or less. Further, the content of V is preferably made 0.27% or more.

Nb: 0.010 to 0.100%

[0050] Nb is one of the important elements in the steel according to the present embodiment. Part of the Nb contained in the steel precipitates in steel as Nb carbides or Nb carbonitrides in the process of heating and being worked at the time of hot forging and causes refinement of the austenite crystal grains due to the pinning effect. The refinement of the austenite crystal grains at the time of hot working has the effect of refining the bainite structure in the bainite transformation after the end of hot working. Furthermore, part of the Nb in the steel at the time of hot forging remains present as solute Nb. This solute Nb precipitates as Nb carbides or Nb carbonitrides at the time of aging treatment after hot forging so has the effect of raising the hardness and achieving improvement of the low cycle fatigue strength and improvement of the fatigue strength without inviting a drop in toughness. To sufficiently obtain these effects, Nb has to be made 0.010% or more in content. However, if the content of Nb becomes excessive, undissolved carbonitrides easily remain even at the time of heating at the time of hot forging and the effect of improvement of the hardness after aging treatment and/or the effect of improvement of the fatigue strength after aging treatment becomes saturated. Further, if the content of Nb exceeds 0.100%, along with the remaining presence of undissolved carbides or carbonitrides, sometimes the cutting resistance ends up rising and the machinability of the steel remarkably falls. Therefore, the content of Nb is made 0.010 to 0.100%. The content of Nb is preferably made less than 0.080%, more preferably is made 0.050% or less. Further, the content of Nb is preferably made 0.020% or more.

Ca: 0.0005 to 0.0050%

[0051] Ca is one of the important elements in the steel according to the present embodiment. The Ca contained in the steel finely disperses and precipitates in steel as sulfide-based inclusions or oxide-based inclusions and therefore has the effect of suppressing increase of the fatigue strength after aging treatment and drop of the toughness after aging treatment. To sufficiently obtain this effect, Ca has to be made 0.0005% or more in content. However, if the content of Ca exceeds 0.0050%, conversely coarse oxide-based inclusions end up being formed, a drop in the hot ductility and fatigue strength after aging treatment are caused, and the effect of suppression of the drop in toughness after aging treatment cannot be obtained. Therefore, the content of Ca is made 0.0005 to 0.0050%. Note that the content of Ca is preferably made 0.0010% or more, more preferably is made 0.0015% or more.

REM: 0.001 to 0.05%

[0052] A REM is one of the important elements in the steel according to the present embodiment. A REM contained in the steel finely disperses and precipitates in the steel as sulfide-based inclusions or oxide-based inclusions and thereby has the effect of improving the fatigue strength after aging treatment and, further, suppressing a drop in toughness after aging treatment. To sufficiently obtain this effect, the REM content has to be made 0.001% or more. However, if the content of a REM exceeds 0.05%, a drop in the hot ductility is invited. Therefore, the content of a REM is made 0.001 to 0.05%. The content of a REM is preferably made 0.003% or more, more preferably is made 0.005% or more.

[0053] The age hardening steel of the present embodiment is steel comprised of the above-mentioned C, Si, Mn, S, Cr, Al, V, Nb, Ca, and REM and a balance of Fe and impurities, restricting P, Ti, and N in the later mentioned impurities to P: 0.030% or less, Ti: less than 0.005%, and N: less than 0.0080%, and, furthermore, having a chemical composition where the F1 expressed by the above formula (1) is 0.68 or more, the F2 expressed by the formula (2) is 0.85 or less, the F3 expressed by the formula (3) is 0.00 or more, and the F4 expressed by the formula (4) is 0.012 to 0.08. Note that, "impurities" indicates elements entering from the starting material ore, scraps, the manufacturing environment, etc. when producing a ferrous material industrially.

P: 0.030% or less

[0054] P is an element contained as an impurity and not preferable in the steel according to the present embodiment. That is, P segregates at the grain boundaries and causes a drop in the toughness. In particular, if its content is over 0.030%, the drop in toughness becomes extremely remarkable. Therefore, the content of P is limited to 0.030% or less. The content of P is preferably limited to 0.025% or less. Note that, the effect of the steel according to the present embodiment is exhibited without particularly determining the lower limit of the content of P. The lower limit value of the P content may also be made 0%. However, if excessively decreasing the P, an extreme rise in the cost of dephosphorization is invited and the result becomes disadvantageous economically, so the lower limit of the amount of P is preferably made 0.005%.

Ti: less than 0.005%

[0055] Ti is an element contained as an impurity and not preferable in the steel according to the present embodiment. That is, Ti bonds with the N and C to form coarse Ti carbonitrides which invite a drop in toughness. In particular, if the content becomes 0.005% or more, the toughness is made to greatly degrade. Therefore, the content of Ti is limited to less than 0.005%. To suppress a drop in toughness due to the aging treatment, the content of Ti is preferably limited to 0.0035% or less, more preferably is limited to 0.0015% or less. The lower limit value of the Ti content may also be made 0%.

N: less than 0.0080%

[0056] N is an element contained as an impurity and ends up fixing V as VN so is not preferable in the steel according to the present embodiment. That is, the V precipitating as VN no longer contributes to age hardening, so to suppress precipitation of VN, the content of N must be lowered. To suppress the precipitation of VN and secure a sufficient amount of solute V at the stage before the aging treatment, it is necessary to limit the content of N to less than 0.0080%. The upper limit value of the N content is preferably 0.0070%, 0.0060%, or 0.0050%. The lower limit value of the N content is 0%.

[0057] Another embodiment of the age hardening steel according to the present embodiment is steel comprising elements from the above C to REMs, a composition satisfying one or more of any of the above <a> to <c>, and a balance of Fe and impurities, having P, Ti, and N in the impurities limited to P: 0.03% or less, Ti: less than 0.005%, and N: 0.020% or less, and, furthermore, having a chemical composition where the F1' expressed by formula (1') is 0.68 or more, F2' expressed by formula (2') is 0.85 or less, F3' expressed by formula (3') is 0.00 or more, and F4 expressed by formula (4) is 0.012 to 0.08.

Optional Elements

[0058] Below, the action and effects of any elements shown in <a> to <c> selectively added in another embodiment of the age hardening steel according to the present embodiment and the reasons for limitation of their contents will be explained.

<a> Mo: 0.01 to 1.0%

[0059] Inclusion of Mo is not essential, so the lower limit value of the Mo content is 0%. On the other hand, Mo has the action of raising the hardenability, making the main phase of the structure of the steel after hot forging bainite, and increasing the area ratio of the bainite. Mo also has the action of forming carbides together with V to increase the age hardenability in steel containing 0.25% or more of V. For this reason, if necessary, Mo may also be included. However, Mo is an extremely expensive element, so if the content increases, the cost of manufacturing the steel increases and furthermore the toughness also falls. Therefore, the amount of Mo when included is made 1.0% or less. The amount of Mo when included is preferably made 0.50% or less, more preferably is made 0.40% or less, still more preferably is made less than 0.30%. On the other hand, to stably obtain the above effect of Mo, the amount of Mo when included is preferably made 0.01% or more, more preferably is made 0.05% or more, still more preferably is made 0.10% or more.

<b> One or Both of Cu: 0.01 to 0.30% and Ni: 0.01 to 0.30%

[0060] Cu and Ni both have the action of increasing the fatigue strength of steel after aging treatment. For this reason, when desiring to obtain a greater fatigue strength, it is also possible to include these elements in the ranges explained below.

Cu: 0.01 to 0.30%

[0061] Inclusion of Cu is not essential, so the lower limit value of the Cu content is 0%. On the other hand, Cu has the action of increasing the fatigue strength of the steel after aging treatment. For this reason, Cu may also be included in accordance with need. However, if the content of Cu exceeds 0.30%, the hot workability falls. Therefore, the amount of Cu when included is made 0.30% or less. The amount of Cu when included is preferably made 0.25% or less. On the other hand, to stably obtain the above-mentioned effect of increasing the fatigue strength of Cu, the amount of Cu when included is preferably made 0.01% or more, more preferably is made 0.05% or more, still more preferably is made 0.10% or more.

Ni: 0.01 to 0.3%

[0062] Inclusion of Ni is not essential, so the lower limit value of the Ni content is 0%. On the other hand, Ni has the action of improving the fatigue strength of steel after aging treatment. Furthermore, Ni has the action of suppressing a drop in the hot workability due to Cu. For this reason, Ni may also be included in accordance with need. However, if the content of Ni exceeds 0.30%, the cost swells and in addition the above effect becomes saturated. Therefore, the amount of Ni when included is made 0.30% or less. The amount of Ni when included is preferably made 0.25% or less. On the other hand, to stably obtain the above effect of Ni, the amount of Ni when included is preferably made 0.01% or more, more preferably is made 0.05% or more, still more preferably is made 0.10% or more.
[0063] Note that, the above Cu and Ni may be included as single types among these or as combination of the two types. The total content of the elements when included may be 0.6% when the contents of Cu and Ni are respectively the upper limit values.

<c> Bi: 0.01 to 0.400%

[0064] Bi has the action of lowering the cutting resistance and increasing the machinability of the steel before the aging treatment. For this reason, when desiring to obtain a better machinability, Bi may be included in the range explained below.
[0065] Inclusion of Bi is not essential, so the lower limit value of the Bi content is 0%. On the other hand, Bi has the action of lowering the cutting resistance of the steel before the age hardening and the action of improving the scrap disposability. For this reason, if necessary, Bi may also be included. However, if the content of Bi is over 0.400%, a drop in the hot workability is caused. Therefore, the amount of Bi when included is made 0.400% or less. The amount of Bi when included is preferably made 0.300% or less. On the other hand, to stably obtain the above-mentioned effect of reducing the cutting resistance of Bi and the effect of improving the scrap disposability, the amount of Bi when included is preferably made 0.010% or more, more preferably is made 0.030% or more.
[0066] In the above explained embodiment and other embodiments, the balance besides the above elements is substantially Fe and unavoidable impurities, but other elements may be added in trace amounts to an extent not impairing the action and effect of the present invention.

Formula (1) to Formula (4) and Formula (1') to Formula (3')

[0067] Next, the F1 to F4 expressed by the above-mentioned formula (1) to formula (4) and the F1' to F3' expressed by formula (1') to formula (3') will be explained:

F1 or F1': 0.68 or more

[0068] When the age hardening steel according to the present embodiment does not contain Mo, F1 expressed by

$$F1=C+0.3\times Mn+0.25\times Cr \quad \cdots (1)$$

has to be 0.68 or more. On the other hand, when the age hardening steel according to the present embodiment contains Mo, F1' expressed by

$$F1'=C+0.3\times Mn+0.25\times Cr+0.6\times Mo \quad \cdots (1')$$

has to be 0.68 or more.
[0069] As already explained, the symbols of elements in formula (1) and formula (1') mean the contents of those elements by mass%.
[0070] F1 and F1' are indicators of the hardenability. If the amounts of the alloy elements contained in the steel satisfy the above ranges and F1 and F1' satisfy the above conditions, even if water cooling or other accelerated cooling was not performed after hot forging, the structure after hot forging becomes one having bainite as its main phase.
[0071] When F1 or F1' is less than 0.68, proeutectoid ferrite is mixed in the structure after hot forging and V carbides precipitate at the phase boundaries, so the hardness before aging treatment rises or the age hardenability becomes smaller.
[0072] F1 and F1' are preferably 0.70 or more, more preferably are 0.72 or more. On the other hand, an excessive increase in the hardenability is liable to invite a drop in toughness of the steel, so F1 and F1' are preferably 1.00 or less,

more preferably are 0.98 or less.

F2 or F2': 0.85 or less

[0073] If the age hardening steel according to the present embodiment does not contain Mo, F2 expressed by

$$F2=C+0.1\times Si+0.2\times Mn+0.15\times Cr+0.35\times V \quad \cdots(2)$$

must be 0.85 or less. On the other hand, if the age hardening steel according to the present embodiment contains Mo, F2' expressed by

$$F2'=C+0.1\times Si+0.2\times Mn+0.15\times Cr+0.35\times V+0.2\times Mo \quad \cdots(2')$$

must be 0.85 or less.

[0074] As already explained, the symbols of elements in formula (2) and formula (2') mean the contents of those elements by mass%.

[0075] F2 and F2' are indicators showing the hardness before aging treatment. Even if steel satisfies the condition of the above F1 or F1', if F2 or F2' becomes within a suitable range, sometimes the hardness before aging treatment becomes too high, the cutting resistance rises, and a good machinability can no longer be secured. That is, if F2 or F2' exceeds 0.85, the hardness of the bainite structure becomes too high. For this reason, sometimes a rise in the cutting resistance becomes unavoidable and a good machinability can no longer be secured.

[0076] F2 and F2' are preferably 0.82 or less, more preferably are 0.80 or less. On the other hand, if F2 and F2' are too low, the hardness after age hardening is liable to become insufficient, so F2 and F2' are preferably 0.55 or more, more preferably are 0.60 or more.

F3 or F3': 0.00 or more

[0077] If the age hardening steel according to the present embodiment does not contain Mo, F3 expressed by

$$F3=-4.5\times C+Mn+Cr-3.5\times V \quad \cdots(3)$$

must be 0.00 or more. On the other hand, if the age hardening steel according to the present embodiment contains Mo, F3' expressed by

$$F3'=-4.5\times C+Mn+Cr-3.5\times V-0.8\times Mo \quad \cdots(3')$$

must be 0.00 or more.

[0078] As already explained, the symbols of elements in formula (3) and formula (3') mean the contents of those elements by mass%.

[0079] F3 and F3' are indicators of the toughness after aging treatment. That is, even if the conditions of F1 or F1' and F2 or F2' were satisfied, if F3 or F3' is in a suitable range, sometimes the toughness of the steel after aging treatment falls and the targeted toughness can no longer be secured. That is, when F3 or F3' is less than 0.00 (negative number), the toughness after aging treatment falls. F3 and F3' are preferably 0.01 or more.

[0080] Note that, if F1 is 0.68 or more and F2 is 0.85 or less, it is not particularly necessary to provide a limit for the upper limit of F3.
Similarly, if F1' is 0.68 or more and F2' is 0.85 or less, it is not particularly necessary to provide a limit for the upper limit of F3'.

F4: 0.012 to 0.08

[0081] In the age hardening steel according to the present embodiment, F4 expressed by

$$F4=10\times Ca+REM \quad \cdots(4)$$

must be 0.012 to 0.08.

[0082] As already explained, the symbols of elements in formula (4) mean the contents of those elements by mass%.

[0083] F4 is an indicator showing a control indicator of the form of inclusions. That is, even if the steel satisfies the conditions of F1 or F1' and F2 or F2' and F3 or F3', if F4 is in a suitable range, sometimes the fatigue strength of the steel after aging treatment will not stably rise or the drop in toughness after aging treatment cannot be stably suppressed. That is, when F4 is less than 0.012, sometimes sulfide-based inclusions and oxide-based inclusions cannot be finely dispersed, the fatigue strength of the steel after aging treatment will not stably rise, and the drop in toughness after aging treatment cannot be stably suppressed. Therefore, F4 was made 0.012 or more. To sufficiently obtain the effect of refining the inclusions, F4 is preferably 0.014 or more. Further, 0.016 or more is more preferable. Further, the more F4 increases, the more the effect of refining the inclusions can be exhibited, but if F4 is over 0.08, conversely sometimes coarsening of the oxide-based inclusions is invited or a drop in the hot ductility is invited, so the upper limit of F4 was made 0.08 or less. F4 is preferably 0.07 or less, more preferably is 0.06 or less.

Steel Structure (Microstructure)

[0084] Next, the steel structure (microstructure) of the age hardening steel according to the present embodiment will be explained.

[0085] As explained above, before the aging treatment, formation of a large amount of proeutectoid ferrite is not preferable. Furthermore, from the viewpoint of the machinability, formation of a large amount of martensite is also not preferable. For this reason, it is important that the main phase before the aging treatment of the age hardening steel according to the present embodiment be made bainite. That is, to secure a sufficient machinability and solute V, the structure before the aging treatment must have an area ratio of bainite of 70% or more. Note that, the area ratio of bainite is preferably 80% or more, while the bainite single phase, that is, the area ratio of bainite of 100%, is most preferable. If the area ratio of bainite is less than 100%, the phases other than the main phase of bainite includes a ferrite phase, pearlite structure, martensite structure, etc., but the smaller these phase and structures, the better.

Relationship of Age Hardening Ability, Machinability, and Fatigue Strength of Steel

[0086] If making the steel a diameter 35 mm substantially columnar shape and defining the amount of rise of the Vicker's hardness of the steel when holding this steel at a temperature of 620°C for 120 minutes as the age hardenability of the steel, the lower limit value of the age hardenability of the steel according to the present embodiment is preferably 30 Hv, more preferably is 33 Hv, 35 Hv, or 40 Hv. Note that, "treatment holding the steel at a temperature of 620°C for 120 minutes" means general aging treatment conditions when treating the steel according to the present embodiment for age hardening to produce a machine part. If the age hardenability is 30 Hv or more, the steel according to the present embodiment has an excellent machinability before the aging treatment and has an excellent fatigue strength after the aging treatment.

Method of Production of Age Hardening Steel and Method of Production of (Machine) Part Using Age Hardening Steel

[0087] The method of production of age hardening steel of the present embodiment is not particularly limited. A general method may be used to smelt the steel and adjust the chemical composition. Below, one example of the method of production of a machine part in automobiles, industrial machinery, construction machinery, etc. using as a material the age hardening steel according to the present embodiment produced in the above way will be shown.

[0088] First, from steel adjusted in chemical composition to the above-mentioned range, age hardening steel used for forming a part (below, referred to as "intermediate material") is prepared. As the above intermediate material, a billet obtained by blooming an ingot, a billet obtained by blooming a continuously cast material, a steel rod obtained by hot rolling or hot forging these billets, or other such material may be used. However, at the time of fabrication of the intermediate material, if holding the material for a certain time in a temperature region where V carbides easily precipitate, the age hardenability is liable to be lost. For example, when maintaining the temperature of the intermediate materials within the range of 540 to 700°C for 30 minutes or more after blooming or after hot rolling or hot forging, the age hardenability is liable to be lost. However, if in accordance with the general method, the intermediate material is allowed to stand in a room temperature environment after blooming or after hot rolling or hot forging, such a situation will not arise.

[0089] Next, the above intermediate material was hot forged and furthermore was cut to finish it into a predetermined part shape. The above hot forging, for example, heats the intermediate material at 1200 to 1250°C for 5 to 60 minutes, then forges it so that the surface temperature after the final forging becomes 1100°C or more, then, after that, makes the average cooling rate in the 800 to 400°C temperature region 15 to 60°C/min to cool the material down to room temperature. Such an average cooling rate is easily obtained by allowing the forged steel to stand in a room temperature environment. However, if the cooling rate is less than 15°C/min, the V carbides precipitate during cooling and the age hardenability is liable to become 30Hv or less. After the material is cooled in this way, it is further cut to finish it to the desired part shape.

[0090] Finally, the roughly shaped material formed to a predetermined part shape is treated to age it to obtain a machine part of automobiles, industrial machinery, construction machinery, etc. provided with the desired characteristics. The above aging treatment is, for example, performed in a 540 to 700°C temperature region, preferably a 560 to 680°C temperature region, more preferably a 580 to 660°C temperature region. The holding time of this aging treatment is suitably adjusted to, for example, 30 to 1000 minutes etc. by the size (mass) of the machine part. If the aging treatment temperature is less than 540°C, V carbides or V carbonitrides cannot be sufficiently formed and the desired age hardenability of 30Hv cannot be obtained. On the other hand, if the aging treatment temperature exceeds 700°C, the formed V carbides or V carbonitrides become coarser, so no longer contribute to hardening and the desired age hardenability of 30 Hv cannot be obtained. Similarly, if the holding time is less than 30 minutes, V carbides or V carbonitrides cannot be sufficiently formed, so the desired age hardenability of 30Hv cannot be obtained. On the other hand, if the holding time exceeds 1000 minutes, the formed V carbides or V carbonitrides become coarser, so no longer contribute to hardening and the desired age hardenability of 30Hv cannot be obtained.

[0091] In the above way, it is possible to produce age hardening steel according to the present embodiment and a machine part using the same as a material.

Examples

[0092] Below, Examples 1 and 2 will be used to explain the present invention in further detail. The conditions in Examples 1 and 2 shown below are examples of conditions adopted for confirming the workability and advantageous effects of the present invention. The present invention is not limited to these examples of conditions. Further, the present invention can adopt various conditions so long as not departing from the gist of the present invention and achieving the object of the present invention.

Example 1

[0093] Each of the Steels 1 to 26 of the chemical compositions shown in Table 1 was smelted by a 50 kg vacuum melting furnace. The Steels 1 to 13 in Table 1 are steels with chemical compositions within the ranges prescribed by the present invention. On the other hand, the Steels 14 to 26 in Table 1 are steels with chemical compositions outside the conditions prescribed by the present invention. Note that, in the section on Ti, "<0.001" indicates the content of Ti as an impurity is below the lower limit value of detection in emission spectroscopy of 0.001%.

Table 1

Steel	Chemical composition (mass%), Balance: Fe and impurities																			
	C	Si	Mn	P	S	Cr	Al	Ti	Nb	V	N	Mo	Cu	Ni	Ca	Bi	REM	F1 or F1'	F2 or F2'	F3 or F3'	F4
1	0.11	0.21	1.74	0.007	0.010	0.30	0.021	<0.001	0.022	0.29	0.0045	-	-	-	0.0010	-	0.005	0.71	0.63	0.53	0.015
2	0.12	0.19	1.82	0.010	0.018	0.29	0.019	<0.001	0.013	0.34	0.0043	-	-	-	0.0007	-	0.01	0.74	0.67	0.38	0.017
3	0.12	0.05	1.98	0.012	0.015	0.41	0.020	<0.001	0.015	0.45	0.0041	-	-	-	0.0012	-	0.01	0.82	0.74	0.28	0.022
4	0.13	0.18	1.84	0.008	0.035	0.24	0.006	<0.001	0.012	0.30	0.0039	-	-	-	0.0011	-	0.015	0.74	0.66	0.45	0.026
5	0.16	0.19	1.82	0.014	0.022	0.59	0.023	<0.001	0.015	0.35	0.0062	0.25	-	-	0.0012	-	0.022	1.00	0.80	0.27	0.034
6	0.12	0.20	1.83	0.009	0.012	0.41	0.026	<0.001	0.012	0.39	0.0040	0.19	-	-	0.0014	-	0.011	0.89	0.74	0.18	0.025
7	0.13	0.44	1.82	0.015	0.020	0.20	0.022	<0.001	0.021	0.33	0.0042	0.28	-	-	0.0010	-	0.008	0.89	0.74	0.06	0.018
8	0.13	0.20	1.95	0.008	0.011	0.25	0.022	<0.001	0.015	0.33	0.0048	0.15	0.21	0.24	0.0011	-	0.008	0.87	0.72	0.34	0.019
9	0.14	0.24	1.65	0.018	0.013	0.63	0.032	<0.001	0.018	0.29	0.0036	0.21	0.08	-	0.0009	-	0.012	0.92	0.73	0.47	0.021
10	0.11	0.14	2.05	0.020	0.020	0.81	0.011	0.002	0.020	0.28	0.0055	0.12	0.04	0.12	0.0010	-	0.006	1.00	0.78	1.29	0.016
11	0.13	0.21	1.82	0.012	0.015	0.71	0.026	<0.001	0.018	0.29	0.0059	-	-	0.11	0.0007	-	0.009	0.85	0.72	0.93	0.016
12	0.14	0.05	1.90	0.008	0.020	0.49	0.018	<0.001	0.015	0.40	0.0078	-	-	-	0.0010	0.025	0.008	0.83	0.74	0.36	0.018
13	0.15	0.20	1.82	0.010	0.018	0.08	0.026	<0.001	0.011	0.32	0.0055	-	-	-	0.0042	-	0.016	0.72	0.66	0.11	0.058
14	0.12	0.14	1.96	0.018	0.020	0.72	0.012	<0.001	0.012	0.28	0.0068	-	-	-	0.0010	-	-	0.89	0.73	1.16	0.010
15	0.13	0.03	1.89	0.008	0.018	0.48	0.021	<0.001	0.015	0.39	0.0063	-	-	-	-	-	0.003	0.82	0.72	0.42	**0.003**
16	0.14	0.18	1.85	0.008	0.015	0.76	0.021	<0.001	0.020	0.30	0.0055	-	-	-	0.0006	-	0.002	0.89	0.75	0.93	**0.008**
17	0.12	0.20	1.80	0.012	0.018	0.29	0.022	<0.001	0.012	0.34	0.0052	-	-	-	-	-	-	0.73	0.66	0.36	-
18	0.15	0.18	1.81	0.012	0.021	0.08	0.026	<0.001	0.011	0.29	0.0068	-	-	-	-	-	-	0.71	0.64	0.20	-
19	0.16	0.20	1.80	0.013	0.020	0.62	0.025	<0.001	0.014	0.36	0.0055	0.24	-	-	-	-	-	1.00	0.81	0.25	-
20	0.13	0.18	1.96	0.008	0.012	0.25	0.022	<0.001	0.015	0.34	0.0048	0.14	0.20	0.24	-	-	-	0.86	0.72	0.32	-
21	0.14	0.04	1.92	0.008	0.020	0.48	0.015	<0.001	0.014	0.42	0.0080	-	-	-	-	0.024	-	0.84	0.75	0.30	-
22	0.12	0.19	1.50	0.010	0.016	0.06	0.021	<0.001	0.014	0.29	0.0042	-	-	-	-	-	-	**0.59**	0.55	0.01	-
23	0.18	0.40	2.18	0.010	0.015	0.36	0.022	<0.001	0.015	0.34	0.0041	0.49	0.10	0.10	-	-	-	1.22	**0.93**	0.15	-
24	0.11	0.20	1.49	0.012	0.018	0.20	0.018	<0.001	0.015	0.28	0.0042	-	-	-	0.0013	-	0.010	**0.61**	0.56	0.22	0.023
25	0.18	0.45	2.20	0.010	0.014	0.38	0.019	<0.001	0.020	0.35	0.0067	0.28	0.10	0.10	0.0010	-	0.008	1.10	**0.90**	0.32	0.018
26	0.19	0.34	1.76	0.015	0.021	0.20	0.021	<0.001	0.016	0.31	0.0078	0.10	0.10	0.10	0.0008	-	0.005	0.83	0.73	**-0.06**	0.013

[0094] An ingot of each steel was heated at 1250°C, then hot forged to a diameter 60 mm steel rod. Each hot forged steel rod was allowed to cool once in the atmosphere to cool it down to room temperature. After that, furthermore, the steel rod cooled down to room temperature was heated as an intermediate material to 1250°C and was again hot forged to a diameter 35 mm steel rod while making the finishing temperature 950°C or more. This second hot forging was performed for simulating forging to a part shape. The second hot forged steel rod was allowed to cool in the atmosphere to cool it down to room temperature. The cooling rate at the time of the second hot forging was measured using a radiant thermometer. The average cooling rate after hot forging in the 800 to 400°C temperature region (in Table 2, indicated as "cooling rate") was 50°C/min in each case.

[0095] In the obtained Steels 1 to 26, some of the hot forged diameter 35 mm steel rods were trimmed in the state with no aging treatment (that is, in the state as cooled) to cut off 100 mm from each of the two ends of the steel rods, then test pieces were cut out from the remaining center parts and were investigated for the Vicker's hardness before aging treatment and the area ratio of bainite of the structures. On the other hand, the remaining hot forged diameter 35 mm steel rods were treated to age them by holding them at 620°C for 120 minutes, then were trimmed at the two end parts of the steel rods to cut off 100 mm each, test pieces were cut out from the remaining center parts and were investigated for the Vicker's hardness after aging treatment. Further, in the obtained Steels 1 to 26, test pieces were cut out from the aging treated steel rods and were investigated for the absorption energy in Charpy impact tests after aging treatment and the low cycle fatigue strength and fatigue strength.

[0096] The Vicker's hardness was measured in the following way.

First, a steel rod cut laterally to give a cut cross-section as the examined surface was buried in a resin. The examined surface was polished to a mirror finish to prepare a test piece. Next, based on the "Vicker's Hardness Test - Test Method" in JIS Z 2244 (2009), 10 points near the R/2 part of the examined surface ("R" indicates the radius) were measured for hardness under a load of 9.8N. The measured values of hardness at the 10 points were arithmetically averaged. The obtained value was made the Vicker's hardness of the steel rod. Note that, if the Vicker's hardness before aging treatment was 290 Hv or less, it was judged sufficiently low and was used as the target. Further, if the difference between the Vicker's hardness after aging treatment and the Vicker's hardness before aging treatment (below, referred to as the "amount of hardening ΔHV") was 30 Hv or more, the age hardenability was judged sufficiently high and was used as the target.

[0097] The area ratio of the bainite in the structure was measured in the following way. First, a test piece used for measurement of hardness and obtained by burial in a resin and polishing to a mirror finish was etched by Nital. The etched test piece was photographed for structure at a power of 200X using an optical microscope. From the obtained photograph, image analysis was used to measure the area ratio of bainite. If the area ratio of the bainite was 70% or more, the structure was judged to be sufficiently converted to bainite and was used as the target.

[0098] The toughness was measured using a standard test piece with a U-notch with a notch depth of 2 mm and a notch bottom radius of 1 mm. If the absorption energy at 20°C after aging treatment evaluated in this Charpy impact test was 50J or more, it was judged sufficiently high and was used as the target.

[0099] The fatigue strength was investigated by taking a monoaxial tension and compression type fatigue test piece. That is, a smooth fatigue test piece shaped with a diameter of the parallel part shown in FIG. 1 of 3.4 mm and a length of the parallel part of 12.7 mm was taken in parallel to the forging direction from the R/2 part of the steel rod (longitudinal direction of steel rod) and was tested for fatigue room temperature, in the atmosphere, under conditions of a stress ratio of 0.05 and a test rate of 10 Hz. The maximum stress where the test piece does not break at 10^7 repeated application of stress under the above conditions was made the fatigue strength. If the fatigue strength was 425 MPa or more, the fatigue strength was judged sufficiently high and was used as the target.

[0100] The low cycle fatigue strength was found by the following method: First, a parallelopiped member of vertical and horizontal spans in the longitudinal direction cross-section of respectively 13 mm and a length of 100 mm was taken from a steel rod in parallel with the forging direction (longitudinal direction of steel rod) so that the sampled portion become the R/2 part of the steel rod. After that, furthermore, a four-point bending test piece provided with a radius 2 mm semicircular notch at a part at the center in the longitudinal direction of one face of that parallelopiped member (that is, the face having the part for evaluation of fatigue) was obtained. The low cycle fatigue test was conducted at room temperature in the atmosphere. It was performed by performing a four-point bending fatigue test under conditions of a stress ratio of 0.1, a distance between support points of 45 mm, and a test frequency of 5Hz. Under the above conditions, stress was repeatedly applied. The 5×10^3th strength was defined as the "low cycle fatigue strength" for evaluation of the strength. If the low cycle fatigue strength was 520 MPa or more, it was judged that the low cycle fatigue strength was sufficiently high and this was used as the target.

[0101] Table 2 shows the results of the above investigations. Note that, in the column on "Bainitization", test pieces with a bainite area ratio of 70% or more or meeting the target were indicated as "GOOD", while test pieces of less than 70% or not reaching the target were indicated as "BAD". Further, in Table 2, an "absorption energy in a Charpy impact test" was indicated as the "Charpy absorption energy".

Table 2

Test no.	Test	Cooling rate (°C)	Before aging treatment		After aging treatment				Amount of hardening (ΔHV)	Remarks
			Hardness (HV)	Bainitization	Hardness (HV)	Fatigue strength (MPa)	Charpy absorption energy (J)	Low cycle fatigue strength (MPa)		
A1	1		254	GOOD	309	428	72	625	55	Inv. ex.
A2	2		274	GOOD	315	426	60	605	41	
A3	3		284	GOOD	346	432	51	610	62	
A4	4		265	GOOD	320	427	59	600	55	
A5	5		285	GOOD	334	430	53	615	49	
A6	6		287	GOOD	343	427	52	615	56	
A7	7		285	GOOD	336	425	51	610	51	
A8	8		282	GOOD	325	429	55	610	43	
A9	9		284	GOOD	338	426	55	608	54	
A10	10		287	GOOD	340	430	55	615	53	
A11	11		286	GOOD	338	426	52	620	52	
A12	12		288	GOOD	342	430	51	605	54	
A13	13		275	GOOD	316	426	52	602	41	

(continued)

Test no.	Test	Cooling rate (°C)	Before aging treatment		After aging treatment				Amount of hardening (ΔHV)	Remarks
			Hardness (HV)	Bainitization	Hardness (HV)	Fatigue strength (MPa)	Charpy absorption energy (J)	Low cycle fatigue strength (MPa)		
B1	14	50	287	GOOD	329	**402**	**45**	600	42	Comp. ex.
B2	15		288	GOOD	330	**410**	**47**	600	42	
B3	16		289	GOOD	342	**421**	56	615	53	
B4	17		287	GOOD	347	429	**36**	610	60	
B5	18		261	GOOD	296	**368**	51	595	35	
B6	19		285	GOOD	335	**412**	**43**	615	50	
B7	20		282	GOOD	321	**414**	55	605	39	
B8	21		290	GOOD	342	428	**47**	600	52	
B9	22		265	**BAD**	287	**346**	48	585	**22**	
B10	23		**316**	GOOD	365	**444**	**15**	595	49	
B11	24		261	**BAD**	285	**370**	**46**	585	**24**	
B12	25		**313**	GOOD	358	**440**	50	598	45	
B13	26		285	GOOD	330	428	**35**	601	45	

[0102] As clear from Table 2, in the case of each of the "invention examples" of Test Nos. A1 to A13 having chemical compositions prescribed in the present invention, it will be understood that the Vicker's hardness HV before aging treatment was 290 or less, the aging treatment caused hardening to a Vicker's hardness of 30Hv or more, furthermore, in the Charpy impact test, the absorption energy was also 50J or more, the fatigue strength was 425 MPa or more, and the low cycle fatigue strength was 520 MPa or more, that is, the targets were achieved, and both the fatigue strength and toughness after aging treatment and the machinability before aging treatment could be achieved.

[0103] As opposed to this, in the case of the "comparative examples" of Test Nos. B1 to B13 off from the provisions of the present invention, at least one of the targeted performances could not be obtained.

Example 2

[0104] Each of the Steels 26 to 39 comprised of the Steel 1 of the chemical composition shown in Table 1 changed in at least one of the Ca content, REM content, and value of F4 was smelted by a 50 kg vacuum melting furnace. The Steel 1 and Steels 27, 30, 33, and 36 to 39 in Table 3 are steels with chemical compositions within the scope prescribed by the present invention. On the other hand, Steels 28, 29, 31, 32, 34, and 45 in Table 3 are steels with chemical compositions off from the conditions prescribed in the present invention. Note that, in the section on Ti, "<0.001" indicates the content of Ti as an impurity is below the lower limit value of detection in emission spectroscopy of 0.001%.

Table 3

Steel	Chemical composition (mass%), Balance: Fe and impurities																			
	C	Si	Mn	P	S	Cr	Al	Ti	Nb	V	N	Mo	Cu	Ni	Ca	Bi	REM	F1 or F1'	F2 or F2'	F3 or F3'	F4
1	0.11	0.21	1.74	0.007	0.01	0.3	0.021	<0.001	0.022	0.29	0.0045	-	-	-	0.0010	-	0.005	0.71	0.63	0.53	0.015
27	0.11	0.21	1.74	0.007	0.01	0.3	0.021	<0.001	0.022	0.29	0.0045	-	-	-	0.0022	-	0.005	0.71	0.63	0.53	0.027
28	0.11	0.21	1.74	0.007	0.01	0.3	0.021	<0.001	0.022	0.29	0.0045	-	-	-	0.0002	-	0.011	0.71	0.63	0.53	0.013
29	0.11	0.21	1.74	0.007	0.01	0.3	0.021	<0.001	0.022	0.29	0.0045	-	-	-	0.0054	-	0.005	0.71	0.63	0.53	0.059
30	0.11	0.21	1.74	0.007	0.01	0.3	0.021	<0.001	0.022	0.29	0.0045	-	-	-	0.0010	-	0.018	0.71	0.63	0.53	0.028
31	0.11	0.21	1.74	0.007	0.01	0.3	0.021	<0.001	0.022	0.29	0.0045	-	-	-	0.0010	-	0.0005	0.71	0.63	0.53	0.011
32	0.11	0.21	1.74	0.007	0.01	0.3	0.021	<0.001	0.022	0.29	0.0045	-	-	-	0.0010	-	0.057	0.71	0.63	0.53	0.067
33	0.11	0.21	1.74	0.007	0.01	0.3	0.021	<0.001	0.022	0.29	0.0045	-	-	-	0.0025	-	0.015	0.71	0.63	0.53	0.040
34	0.11	0.21	1.74	0.007	0.01	0.3	0.021	<0.001	0.022	0.29	0.0045	-	-	-	0.0007	-	0.002	0.71	0.63	0.53	0.009
35	0.11	0.21	1.74	0.007	0.01	0.3	0.021	<0.001	0.022	0.29	0.0045	-	-	-	0.0046	-	0.041	0.71	0.63	0.53	0.087
36	0.11	0.21	1.74	0.007	0.01	0.3	0.021	<0.001	0.022	0.29	0.0045	-	-	-	0.0024	-	0.019	0.71	0.63	0.53	0.043
37	0.11	0.21	1.74	0.007	0.01	0.3	0.021	<0.001	0.022	0.29	0.0045	-	-	-	0.0010	-	0.021	0.71	0.63	0.53	0.031
38	0.11	0.21	1.74	0.007	0.01	0.3	0.021	<0.001	0.022	0.29	0.0045	-	-	-	0.0023	-	0.005	0.71	0.63	0.53	0.028
39	0.11	0.21	1.74	0.007	0.01	0.3	0.021	<0.001	0.022	0.29	0.0045	-	-	-	0.0034	-	0.022	0.71	0.63	0.53	0.056

[0105] An ingot of each steel was heated at 1250°C, then hot forged to a diameter 60 mm steel rod. Each hot forged steel rod was allowed to cool once in the atmosphere to cool it down to room temperature. After that, furthermore, the steel rod cooled down to room temperature was heated as an intermediate material to 1250°C and was again hot forged to a diameter 35 mm steel rod while making the finishing temperature 950°C or more. This second hot forging was performed for simulating forging to a part shape. The second hot forged steel rod was allowed to cool in the atmosphere to cool it down to room temperature. The cooling rate at the time of the second hot forging was measured using a radiant thermometer. The average cooling rate after hot forging in the 800 to 400°C temperature region (in Table 4, indicated as "cooling rate") was 50°C/min in each case.

[0106] The obtained Steel 1 and Steels 27 to 39 were examined in the same way as with the methods performed in Example 1 so as to investigate the Vicker's hardness before aging treatment, the area ratio of bainite in the structure, the absorption energy in the Charpy impact test, the low cycle fatigue strength, and the fatigue strength. Table 4 shows the results of the above investigations. Note that the notations of Table 4 are similar to the notations of Table 2.

Table 4

Test no.	Steel	Cooling rate (°C/min)	Before aging treatment		After aging treatment				Amount of hardening (ΔHV)	Remarks
			Hardness (HV)	Bainitization	Hardness (HV)	Fatigue strength (MPa)	Charpy absorption energy (J)	Low cycle fatigue strength (MPa)		
A1	1	50	254	GOOD	309	428	72	625	55	Inv. ex.
A27	27		253	GOOD	308	431	73	625	55	Inv. ex.
B28	28		254	GOOD	309	**403**	55	618	55	Comp. ex.
B29	29		255	GOOD	310	**395**	51	610	55	Comp. ex.
A30	30		255	GOOD	308	430	71	624	53	Inv. ex.
B31	31		254	GOOD	308	**420**	68	618	54	Comp. ex.
B32	32		253	GOOD	309	431	**4**8	608	56	Comp. ex.
A33	33		253	GOOD	308	437	71	627	55	Inv. ex.
B34	34		254	GOOD	310	**401**	**49**	601	56	Comp. ex.
B35	35		253	GOOD	310	**398**	52	599	57	Comp. ex.
A36	36		255	GOOD	309	432	73	628	54	Inv. ex.
A37	37		255	GOOD	308	431	71	626	53	Inv. ex.
A38	38		254	GOOD	310	430	72	624	56	Inv. ex.
A39	39		254	GOOD	309	439	74	629	55	Inv. ex.

[0107] As clear from Table 4, in the case of Test Nos. A27, 30, 33, and 36 to 39 where at least one of the Ca content, REM content, and value of F4 were made values more preferable than Test No. A1, the result was a higher fatigue strength compared with Test No. A1. This is due to the fact that compared with Test No. A1, the sulfide-based inclusions or oxide-based inclusions are more finely dispersed.

[0108] As opposed to this, in the case of the "comparative examples" of Test Nos. B28, B29, B31, B32, B34, and B35 where one or more of the Ca content, REM content, and the value of F4 were outside the scope of the present invention, the result was a lower fatigue strength or toughness compared with Test No. A1. This is due to the fact that compared with Test No. A1, the sulfide-based inclusions or oxide-based inclusions became coarser, so a drop in the fatigue strength or a drop in the toughness was invited.

Industrial Applicability

[0109] According to the age hardening steel of the present invention, the hardness before aging treatment is 290 Hv or less so a good machinability can be expected. Further, if using the age hardening steel of the present invention, aging treatment performed after cutting causes the steel to harden to a Vicker's hardness of 30 Hv or more, so a 425 MPa or more fatigue strength is obtained. Furthermore, if using the age hardening steel of the present invention, the absorption energy at 20°C after aging treatment is 50J or more and a drop in toughness due to the aging treatment can be sufficiently suppressed. In addition, if using the age hardening steel of the present invention, it is possible to make the low cycle fatigue strength 520 MPa or more. For this reason, the age hardening steel of the present invention can be extremely suitably used as the material for machine parts of automobiles, industrial machinery, construction machinery, etc.

Claims

1. An age hardening steel containing, by mass%, C: 0.05 to 0.20%, Si: 0.01 to 0.50%, Mn: 1.50 to 2.50%, S: 0.005 to 0.080%, Cr: 0.03 to 1.60%, Al: 0.005 to 0.050%, V: 0.25 to 0.50%, Nb: 0.010 to 0.100%, Ca: 0.0005 to 0.0050%, and REM: 0.001 to 0.05%, limiting P to 0.030% or less, Ti to less than 0.005%, and N to less than 0.0080%, having a balance of Fe and impurities, having an area ratio of bainite structures of 70% or more and, furthermore, having a chemical composition where the following F1 expressed by formula (1) is 0.68 or more, F2 expressed by formula (2) is 0.85 or less, F3 expressed by formula (3) is 0.00 or more, and F4 expressed by formula (4) is 0.012 to 0.08:

$$F1=C+0.3\times Mn+0.25\times Cr \quad \cdots (1)$$

$$F2=C+0.1\times Si+0.2\times Mn+0.15\times Cr+0.35\times V \quad \cdots (2)$$

$$F3=-4.5\times C+Mn+Cr-3.5\times V \quad \cdots (3)$$

$$F4=10\times Ca+REM \quad \cdots (4)$$

where the symbols of elements in the above formula (1) to formula (4) mean the contents by mass% of those elements.

2. An age hardening steel containing, by mass%, C: 0.05 to 0.20%, Si: 0.01 to 0.50%, Mn: 1.50 to 2.50%, S: 0.005 to 0.080%, Cr: 0.03 to 1.60%, Al: 0.005 to 0.050%, V: 0.25 to 0.50%, Nb: 0.010 to 0.100%, Ca: 0.0005 to 0.0050%, and REM: 0.001 to 0.05%, having an area ratio of bainite structures of 70% or more, furthermore, satisfying any one or more of the conditions of composition shown by the following <a> to <c>, limiting P to 0.030% or less, Ti to less than 0.005%, and N to less than 0.0080%, having a balance of Fe and impurities, and, furthermore, having a chemical composition where the following F1' expressed by formula (1') is 0.68 or more, F2' expressed by formula (2') is 0.85 or less, and F3' expressed by formula (3') is 0.00 or more, and F4 expressed by formula (4) is 0.012 to 0.08:

<a> Mo: 0.01 to 1.0%
<b> One or both of Cu: 0.01 to 0.30% and Ni: 0.01% to 0.30%
<c> Bi: 0.01 to 0.400%

$$F1'=C+0.3\times Mn+0.25\times Cr+0.6\times Mo \quad \cdots(1')$$

$$F2'=C+0.1\times Si+0.2\times Mn+0.15\times Cr+0.35\times V+0.2\times Mo \quad \cdots(2')$$

$$F3'=-4.5\times C+Mn+Cr-3.5\times V-0.8\times Mo \quad \cdots(3')$$

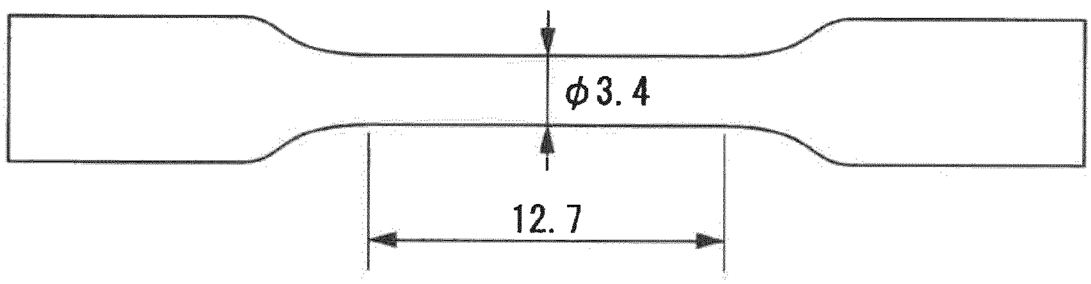
$$F4=10\times Ca+REM \quad \cdots(4)$$

where the symbols of elements in the above formula (1) to formula (3') and formula (4) mean the contents by mass% of those elements.

3. A method of production of a part using age hardening steel comprising:

a forging step of heating age hardening steel according to claim 1 or 2 at 1200 to 1250°C for 5 to 60 minutes, then forging it so that a surface temperature after final forging becomes 1100°C or more, then, after that, cooling it by an average cooling rate in a 800 to 400°C temperature region of 15 to 60°C/min down to room temperature,
a cutting step of cutting the forged steel, and
an aging treatment step of holding the cut steel in a 540 to 700°C temperature region for 30 to 1000 minutes.

FIG. 1



INTERNATIONAL SEARCH REPORT

International application No.
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A. CLASSIFICATION OF SUBJECT MATTER
C22C38/00(2006.01)i, *C21D8/06*(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)
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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	1996-2016
Kokai Jitsuyo Shinan Koho	1971-2016	Toroku Jitsuyo Shinan Koho	1994-2016

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	WO 2012/161321 A1 (Nippon Steel & Sumitomo Metal Corp.), 29 November 2012 (29.11.2012), & JP 2012-246527 A & US 2013/0186529 A1 & CN 103210108 A & KR 10-2013-0083924 A	1-3
A	WO 2014/017074 A1 (JFE Steel Corp.), 30 January 2014 (30.01.2014), & JP 5567747 B2 & US 2015/0159261 A1 & EP 2878695 A1 & CN 104508164 A & KR 10-2015-0028354 A	1-3
A	JP 2011-153364 A (Honda Motor Co., Ltd.), 11 August 2011 (11.08.2011), & EP 2357262 A1	1-3

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

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2016/058585

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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