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(54) ENERGY-SAVING COLD FORGING STEEL AND MANUFACTURING METHOD THEREFOR

(57) A cold forging steel and a manufacturing method therefor. The cold forging steel comprises the following chemical elements in percentage by mass: C: 0.170-0.220%, Si: 0.10-0.30%, Mn: 1.00-1.20%, S: 0.010-0.020%, Cr: 1.10-1.30%, Al: 0.015-0.045%, N: 0.0100-0.0180%, and Ti: 0.040-0.100%, with the balance being Fe and inevitable impurities. The cold forging steel has excellent plasticity and cold working properties. Compared with a conventional cold forging steel, when the present cold forging steel is used to produce and manufacture a forged part (in particular a high-precision forged part, such as a gear), energy can be effectively saved, and environmental pollution is reduced.

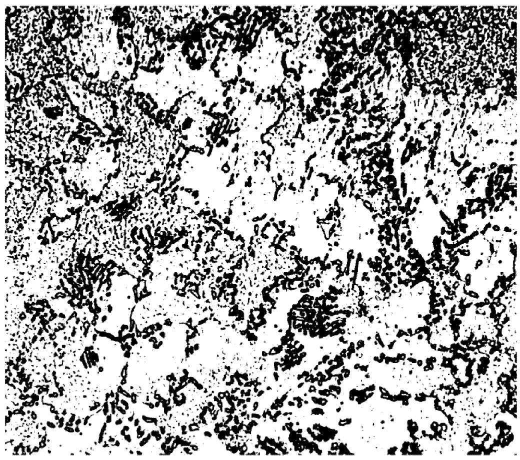

Figure 1

EP 4 553 184 A1

Description

TECHNICAL FIELD

[0001] The present invention relates to a steel and a manufacturing method thereof, in particular to a cold forging steel and a manufacturing method thereof.

BACKGROUND ART

[0002] With the rapid development of the automobile industry, the demand for transmissions has remained high in the face of the vast automobile market. Due to the special shape of gears and high requirements for dimensional accuracy, many companies use hot forging processing followed by precision machining to produce gears. However, when using such conventional gear manufacturing process for production, on one hand, the material utilization rate is low. On the other hand, hot forging requires high energy consumption, which increases processing costs and causes environmental pollution.

[0003] Therefore, some part processing companies use cold forging technology to produce gears. Cold forging for parts has many advantages, including high-precision sizes of forged parts, resistance to oxidation skin formation with good surface finish, high material utilization that reduces cutting waste and heating loss, the ability to direct the metal fiber flow in specific directions, no need for heat treatment, minimizing pollution issues, and lowering production costs by eliminating heating expenses. It can be seen that cold forging technology is more in line with the future trend of clean manufacturing and environmental protection, which can create favorable conditions for sustainable development.

[0004] However, cold forging technology has very high requirements on plasticity of materials. Since the shape of gears is relatively complex and materials are required to have excellent plasticity by cold forging, it is often the case that steel cracks or develops microcracks during extrusion due to insufficient plasticity of the steel, resulting in high scrap rate of parts after processing and increased testing cost. Conventional cold forging steel typically undergo the following treatment: the material is hot rolled, cooled to room temperature, and finally subjected to spheroidizing annealing. Since spheroidizing annealing takes more than ten hours or even dozens of hours, it consumes a lot of time and energy.

[0005] Therefore, there is a need in the field for an energy-saving cold forging steel with excellent plasticity and cold working properties.

SUMMARY OF THE INVENTION

[0006] In view of the above-mentioned defects and deficiencies of the prior arts, the inventors obtained a cold forging steel with excellent plasticity and cold working properties via rational chemical composition. Compared to conventional cold forging steel, using the cold forging steel of the present invention for the production of forged parts (in particular high-precision forged parts, such as gears) can effectively save energy and reduce environmental pollution.

[0007] In a first aspect, the present disclosure provides a cold forging steel, the cold forging steel comprises 90% or more of Fe and inevitable impurities and further comprises the following chemical elements in percentage by mass:

C: 0.170-0.220%, Si: 0.10-0.30%, Mn: 1.00-1.20%, S: 0.010-0.020%, Cr: 1.10-1.30%, Al: 0.015-0.045%, N: 0.0100-0.0180%, and Ti: 0.040-0.100%.

[0008] In a second aspect, the present disclosure provides a cold forging steel having the following chemical elements in percentage by mass:

C: 0.170-0.220%, Si: 0.10-0.30%, Mn: 1.00-1.20%, S: 0.010-0.020%, Cr: 1.10-1.30%, Al: 0.015-0.045%, N: 0.0100-0.0180%, and Ti: 0.040-0.100%, the balance being Fe and inevitable impurities.

[0009] In a preferred embodiment, the cold forging steel of the present disclosure further comprises Ca, with a Ca content satisfying: $0<Ca\leq 0.005\%$, preferably $0.001\%<Ca\leq 0.003\%$.

[0010] In a preferred embodiment, a Mn content in the cold forging steel of the present disclosure is 1.10-1.20%.

[0011] In a preferred embodiment, a Cr content in the cold forging steel of the present disclosure is 1.16-1.30%.

[0012] In a preferred embodiment, a Ti content in the cold forging steel of the present disclosure is 0.050-0.080%.

[0013] In an embodiment, the inevitable impurities in the cold forging steel of the present disclosure comprise P and O. In a preferred embodiment, $P\leq 0.015\%$, and/or $O\leq 0.0030\%$.

[0014] In a preferred embodiment, a microstructure of the cold forging steel of the present disclosure is ferrite + spheroidal carbide.

[0015] In a preferred embodiment, a structural spheroidization rate of the cold forging steel of the present disclosure is 90% or more.

[0016] Mechanical performances of the cold forging steel of the present disclosure satisfy at least one of the following: yield strength of 220-270MPa, tensile strength of 430-480MPa, elongation ≥35%, and reduction of area ≥66%. Preferably, the mechanical performances of the cold forging steel of the present disclosure satisfy the following: yield strength of

220-270MPa, tensile strength of 430-480MPa, elongation ≥35%, and reduction of area ≥66%.

[0017] In a third aspect, the present invention provides a manufacturing method for the above-mentioned cold forging steel, comprising the following steps: (1) smelting and casting molten steel to obtain a cast billet; (2) heating and rolling the cast billet to obtain an intermediate billet; (3) heating and rolling the intermediate billet to obtain a rolled round steel; (4) cooling the rolled round steel; (5) annealing.

[0018] In one embodiment, in step (1), smelting can be performed by electric furnace smelting or converter smelting; and/or, casting can be performed by die casting or continuous casting.

[0019] In one embodiment, in step (2), the cast billet is heated to 1000-1120°C, preferably 1000-1100°C.

[0020] In one embodiment, in step (3), the intermediate billet is heated to 1050-1200°C, preferably 1050-1120°C, and held for 5-6 hours.

[0021] In one embodiment, in step (3), the amount of rolling single pass deformation (ξ) is 20-40%, the final rolling temperature (T) is 870-930°C, and the amount of rolling single pass deformation (ξ) and the final rolling temperature (T) satisfy the relationship: $4.00 \leq \ln(T-850)-\ln\xi \leq 6.00$. Preferably, $4.05 \leq \ln(T-850)-\ln\xi \leq 5.95$.

[0022] In one embodiment, in step (4), the rolled round steel is cooled to 370-410°C at a cooling rate of 20°C/s or more (e.g., 20-30°C/s). By using a cooling rate of 20°C/s or more, a martensitic structure can be formed in the matrix, ensuring that there is a large amount of distortion energy in the matrix, thereby providing phase transformation energy for subsequent structural transformation, which is beneficial to the precipitation and spheroidization of carbides. In addition, by using a cooling rate of 20°C/s or more to cool the rolled round steel to 370-410°C, it not only ensures that the matrix completes the martensitic transformation, but also saves energy consumption in subsequent annealing process.

[0023] In one embodiment, in step (5), the annealing temperature is 740±10°C, and the holding time is 8 hours or more.

[0024] In one embodiment, after the annealing step, the annealed round steel is taken out of furnace for air-cooling.

[0025] In the manufacturing method of the present disclosure, the manufacturing process parameters of the cold forging steel are optimized, and the plasticity of the cold forging steel is further improved. The manufacturing method of the present disclosure does not comprise the step of spheroidizing annealing, which can effectively reduce energy consumption. When parts are processed by using the cold forging steel obtained via this way, the steps of heating and normalizing prior to hot forging of the parts can be omitted, which is time-saving and energy-efficient.

[0026] The cold forging steel obtained by the present disclosure via rational design of chemical compositions and optimized manufacturing method not only achieves excellent plasticity and cold working properties, but also makes it possible to omit the step of spheroidizing annealing in its production process, which effectively reduces energy consumption. In addition, when using the cold forging steel of the present disclosure to produce and manufacture parts, the steps of heating and normalizing prior to hot forging of the parts can be omitted. It has broad applicability, good promotion prospect and application value.

BRIEF DESCRIPTION OF THE DRAWINGS

[0027]

Figure 1 schematically shows the microstructure of the cold forging steel of Example 4 under an optical microscope.

Figure 2 schematically shows the microstructure of the cold forging steel of Comparative Example 1 under an optical microscope.

DETAILED DESCRIPTION OF THE EMBODIMENTS

[0028] Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly understood by those skilled in the art to which the present disclosure belongs.

[0029] As used herein, the term "and/or" refers to and encompasses any and all possible combinations of one or more listed item.

[0030] Herein, "yield strength" is the yield limit of a metal material when yielding occurs, that is, the stress that resists a slight amount of plastic deformation.

[0031] Herein, "tensile strength" is the critical value of the transition of a metal from uniform plastic deformation to localized plastic deformation. It is also the maximum load-bearing capacity of a metal under static tensile conditions. Tensile strength indicates the resistance to maximum uniform plastic deformation of a material.

[0032] Herein, "elongation" is the percentage of the total deformation (ΔL) of the gauge section after tensile fracture to the original gauge length (L) of the material, expressed as: $\delta=\Delta L/L\times 100\%$, which is an indicator describing the plastic performance of a material.

[0033] Herein, "reduction of area" is the percentage of the maximum reduction in cross-sectional area at the necking region after the specimen fractures relative to the original cross-sectional area of the specimen.

[0034] Herein, the yield strength, tensile strength, elongation, and reduction of area are measured according to

GB/T228-2010.

[0035] Herein, the "structural spheroidization rate" is measured according to ASTM F2282.

[0036] In the cold forging steel of the present disclosure, the design principles of each chemical element are specifically described as follows:

C (carbon): In the cold forging steel of the present disclosure, the C element is one of the key elements that affect hardenability of the steel. Adding an appropriate amount of the C element can ensure that the steel has good hardenability and appropriate strength, which is beneficial to improving the wear resistance of the final parts. When the content of the C element in the steel is too low, it cannot be guaranteed that the steel obtains a high tensile strength, resulting in low structural strength of the gear core, reducing deformation resistance of the gear and shortening fatigue life of the gear. However, it is not desirable to add excessive C to the steel. An increase in the content of the C element in the steel will increase hardness of a material, causing the strength of the material to be too high for subsequent processing, increasing wear on the die during cold forging process, and causing an increase in downstream processing costs. Therefore, to achieve narrow hardenability of the steel, the percentage by mass of the C element in the cold forging steel of the present disclosure is controlled between 0.170-0.220%.

[0037] Si (silicon): In the cold forging steel of the present disclosure, the Si element is a ferrite-forming element, which has a strong effect of solid solution strengthening and can effectively improve the strength of the steel. In addition, Si as a deoxidizer can also effectively reduce oxygen content in molten steel. However, it should be noted that the content of the Si element in the steel should not be too high. When the content of the Si element in the steel is too high, the plasticity of the steel will be reduced. Therefore, the percentage by mass of the Si element in the cold forging steel of the present disclosure is controlled between 0.10-0.30%.

[0038] Mn (manganese): In the cold forging steel of the present disclosure, when there is a certain amount of S element in the steel, the Mn element can easily form plastic MnS with S. In subsequent gear finishing processes, MnS can effectively promote the effect of chip breaking and improve the cutting performance. However, it should be noted that the content of the Mn element in the steel should not be too high. When the Mn element content in the steel is too high, it will lead to increased segregation of the steel, which is harmful to the uniformity of the structure of the material. Mn is a core element that affects the hardenability of gear steel. Therefore, to improve cutting performance of the material while avoiding severe segregation of the steel and reducing fluctuations of hardenability, the percentage by mass of the Mn element in the cold forging steel of the present disclosure is controlled between 1.00-1.20%.

[0039] S (sulfur): In the cold forging steel of the present disclosure, the S element can form MnS with the Mn element to improve cutting performance. Adding an appropriate amount of the S element to the steel can avoid the phenomenon of tool adhesion during subsequent finishing processes. However, if the content of the S element is too high, it will cause hot brittleness in the steel matrix and cause cracks on the steel material surface. Therefore, the percentage by mass of the S element in the cold forging steel of the present disclosure is controlled between 0.010-0.020%.

[0040] Cr (chromium): In the cold forging steel of the present disclosure, an appropriate amount of Cr element can be added. The diffusion rate of the Cr element in austenite is relatively low and can prevent the diffusion of C, which can inhibit the diffusion-based phase transformation of steel, is beneficial to the stability of the austenite, shifts the C curve of the steel to the right, and reduces the critical cooling rate. However, it should be noted that the Cr content in the steel should not be too high. When the Cr content in the steel is too high, coarse carbides will be formed, which will deteriorate the cold deformation performance. In addition, the Cr element can also affect the hardenability of gear steel to a relatively large extent. Therefore, to ensure performances of the steel, the percentage by mass of the Cr element in the cold forging steel of the present disclosure is controlled between 1.10-1.30%.

[0041] Al (aluminum): In the cold forging steel of the present disclosure, the Al element can effectively reduce the oxygen content in the steel during the steelmaking process. The Al element can combine with N to form fine AlN precipitates that are dispersed at the grain boundaries, which inhibits the growth of austenite grains in subsequent cooling process, thereby refining the austenite grains and improving the plasticity of the material. At the same time, the dispersed AlN can serve as nucleation sites for precipitation of carbide, shortening incubation period for the nucleation and precipitation of carbide, reducing annealing time, and saving energy consumption. However, it should be noted that the Al content in the steel should not be too high. When the Al content in the steel is too high, large Al oxides will be formed, and thus coarse B-type inclusions will be formed. Hard inclusions of coarse aluminum oxide will worsen fatigue performance of the steel and cause tool failure during machining. Therefore, to enable the Al element to effectively exert its beneficial effects, the percentage by mass of the Al element in the cold forging steel of the present disclosure is controlled between 0.015-0.045%.

[0042] N (nitrogen): In the cold forging steel of the present disclosure, the N element can form AlN or TiN in the steel, which plays a role in refining the austenite grains. However, too high a content of N in the steel will lead to an increase in its enrichment at the defects, and at the same time, coarse nitride precipitates will be formed, adversely affecting the fatigue life of the steel. Therefore, in the cold forging steel of the present disclosure, the percentage by mass of the N element is controlled between 0.0100-0.0180%, preferably 0.0100-0.0175%.

[0043] Ti (titanium): In the cold forging steel of the present disclosure, the Ti element can form corresponding compounds with C and N in the steel. The formation temperature of TiN is 1400°C or higher, and TiN is usually precipitated from liquid phase or δ ferrite, thereby having an effect in refining austenite grains. However, it should be noted that the Ti content in the steel should not be too high. When the Ti content in the steel is too high, coarse TiN precipitates will be formed, thereby resulting in reduced fatigue performance of the steel. Therefore, the percentage by mass of the Ti element in the cold forging steel of the present disclosure is controlled between 0.040-0.100%, preferably 0.050-0.100%.

[0044] In the cold forging steel of the present disclosure, P and O are inevitable impurity elements. Under the premise that technical conditions permit, the content of impurity elements in the steel should be controlled as low as possible.

[0045] P (phosphorus): The P element in the steel tends to accumulate at the grain boundaries, reducing binding energy of the grain boundary and worsening the plasticity of the steel. P and Fe will combine to form hard and brittle Fe_3P phase, causing the steel to become cold brittle during cold working, resulting in poor plasticity of the steel. When the steel is subjected to impact loads, intergranular fracture occurs, forming a large cleavage plane. Therefore, to avoid increased brittleness of the steel, the percentage by mass of the P element in the cold forging steel of the present disclosure is controlled as P≤0.015%.

[0046] O (oxygen): Impurity element O can form Al_2O_3, TiO, etc. with Al and Ti elements in steel. Therefore, to ensure structural uniformity of the steel, the percentage by mass of O in the cold forging steel of the present disclosure is controlled as O≤0.0030%.

[0047] In a preferred embodiment, the cold forging steel of the present disclosure also comprises Ca. The Ca element can further improve performances of the cold forging steel, and the design principles of the chemical element thereof are as follows:

Ca (calcium): Adding an appropriate amount of Ca element to the cold forging steel of the present disclosure can improve castability of molten steel. However, the Ca content in the steel should not be too high. When the Ca content in the steel is too high, DS inclusions with a large size will be produced. Therefore, the percentage by mass of the Ca element in the cold forging steel of the present disclosure is controlled as 0<Ca≤0.005%, preferably 0.001%<Ca≤0.003%.

[0048] In the manufacturing method of the present disclosure, the manufacturing process parameters of the cold forging steel are optimized. By controlling the process parameters, in particular the process parameters of heat treatment, the forged or rolled round steel bars are controlled, and then the annealing process is used so that the matrix of the cold forging steel obtained by the manufacturing method of the present disclosure comprises a large amount of ferrite, which effectively ensures good plasticity of the cold forging steel, eliminates internal stress of the steel, and ensures good structural uniformity.

[0049] In one embodiment, in step (4) of the manufacturing method of the present disclosure, the rolled round steel is rapidly cooled (at a cooling rate of 20°C/s or more). The cooling rate exceeds the critical cooling rate for martensite, allowing the matrix to basically complete the martensitic transformation, and providing phase transformation energy for structural transformation of subsequent annealing process, which facilitates precipitation and spheroidization of carbide.

[0050] In one embodiment, the Mf point (the temperature at which the steel is completely transformed to martensite) of the steel of the present invention is about 425°C. By controlling the cooling rate of step (4) as 20°C/s or more and cooling the round steel to 370-410°C, it can ensure that the matrix completes the martensitic transformation and save heating energy consumption in subsequent annealing process.

[0051] The cold forging steel and its manufacturing method of the present disclosure have the following advantages and beneficial effects:

(1) The cold forging steel of the present disclosure appropriately controls the contents of P, N, and O, ensuring that the cold forging steel has suitable strength and excellent plasticity and elongation, while effectively saving energy consumption.

(2) The cold forging steel of the present disclosure has good plasticity and reduction of area at low temperatures with excellent cold forging performance. The yield strength of the cold forging steel is 220-270MPa, the tensile strength is 430-480MPa, the elongation is ≥35%, and the reduction of area is ≥66%. The cold forging steel has excellent plasticity and cold working properties.

(3) The cold forging steel of the present disclosure, through rational chemical composition design, makes full use of the effects of various alloy elements on phase transformation and microstructure, while incorporating specific controlled rolling and controlled cooling processes, to form a uniform ferrite + spheroidal carbide matrix structure with a structural spheroidization rate of 90% or more.

(4) The chemical composition and process design of the cold forging steel of the present disclosure are reasonable, and the process window thereof is broad, which can realize batch commercial production on bar or plate production line, having good promotion prospect and application value.

[0052] The present disclosure is further described in detail below with drawings and examples. The following examples are only used to illustrate the present disclosure and are not used to limit the scope of the present disclosure.

Examples

[0053] The cold forging steels of Examples 1-6 and Comparative Examples 1-3 were prepared according to the chemical compositions shown in Table 1, using the following steps:

(1) Smelting and casting the molten steel to obtain a cast billet: using an electric furnace or converter for smelting and casting into a cast billet of 320mm*425mm.
(2) Heating and rolling the cast billet to obtain an intermediate billet: hot-charging the cast billet and placing it in a heating furnace, controlling the heating temperature of the cast billet between 1000-1100°C, and holding for 4 hours; rolling the cast billet into an intermediate billet of 215mm*215mm.
(3) Heating and rolling the intermediate billet to obtain a round steel: heating the intermediate billet to 1050-1120°C and holding for 5 hours, and then rolling with a large amount of deformation, the amount of rolling single pass deformation is 20-40%, the final rolling temperature is 870-930°C, and the final size of the round steel is 20-40mm (diameter).
(4) Cooling the round steel: cooling the rolled round steel through water, controlling the amount of water according to the final rolling temperature, and cooling the round steel to 370-410°C at a cooling rate of 20°C/s or higher.
(5) Annealing: placing the round steel in an annealing furnace for annealing, the annealing temperature is 740±10°C, the holding time is 8 hours, and then taking the annealed round steel out of the furnace for air-cooling.

[0054] The cold forging steels of Comparative Examples 4-5 were prepared using the same method as described above, with the following differences: the rolling parameters in step 3) and the cooling rate in step 4).
[0055] The cold forging steel of Comparative Example 6 was prepared by the following steps:
After smelting and casting the molten steel, the conventional continuous furnace spheroidizing annealing process as described below was used: the furnace was heated to 600°C, the material was charged into the furnace, the temperature was raised to 760°C in about 1 hour, held at 760°C for 1 hour, then rapidly raised to 780°C and held for 5 hours. The temperature was lowered to 740°C within 1 hour, held at 740°C for 2 hours, then reduced to 720°C within 1 hour and held for 6 hours. The temperature was lowered to 630°C within about 2 hours and held for 2 hours before removal from furnace.
[0056] Comparative Example 6 is a 20CrMnTiH cold forging steel that used conventional spheroidizing annealing (taking 21 hours or more).
[0057] The specific composition and process of the cold forging steel of Examples 1-6 and Comparative Examples 1-6 are shown in Tables 1 and 2.

Table 1: Percentage by mass (wt%) of each chemical element in cold forging steel of Examples 1-6 and Comparative Examples 1-6

(The balance is Fe and other inevitable impurities except P and O)											
Number	C	Si	Mn	S	Cr	Al	N	Ti	Ca	P	O
Example 1	0.172	0.25	1.12	0.016	1.16	0.015	0.0118	0.050	0.005	0.015	0.0030
Example 2	0.183	0.24	1.04	0.018	1.29	0.019	0.0154	0.080	0.003	0.011	0.0013
Example 3	0.194	0.11	1.20	0.016	1.21	0.033	0.0105	0.100	0.002	0.009	0.0022
Example 4	0.219	0.30	1.09	0.013	1.10	0.036	0.0170	0.072	0.003	0.007	0.0025
Example 5	0.198	0.25	1.17	0.020	1.23	0.045	0.0175	0.060	0.002	0.006	0.0012
Example 6	0.206	0.17	1.01	0.010	1.18	0.024	0.0160	0.092	0.001	0.005	0.0016
Comparative Example 1	0.212	0.23	***1.45***	0.017	1.24	0.026	0.0124	0.054	0.003	0.008	0.0014
Comparative Example 2	0.203	0.24	1.15	0.014	***1.38***	0.024	0.0116	0.080	0.002	0.009	0.0013
Comparative Example 3	0.204	0.22	1.14	0.016	1.19	0.021	0.0132	***0.300***	0.003	0.007	0.0015
Comparative Example 4	0.193	0.19	1.12	0.017	1.18	0.029	0.0128	0.050	0.003	0.008	0.0016
Comparative Example 5	0.197	0.20	1.07	0.013	1.23	0.034	0.0143	0.070	0.002	0.013	0.0018
Comparative Example 6	0.187	0.27	1.08	0.014	1.17	0.026	0.0111	0.040	0.004	0.013	0.0009

Table 2: Specific process parameters for cold forging steel in Examples 1-6 and Comparative Examples 1-6

Number	Step (2)	Step (3)					Step (4)		Step (5)
	Heating Temperature (°C)	Heating Temperature (°C)	Amount of Rolling Deformation (ξ) (%)	Final Rolling Temperature T (°C)	Final Size of the Round Steel (mm)	ln(T-850)-ln&	Cooling Rate (°C/s)	Cooling Temperature (°C)	Annealing Temperature (°C)
Example 1	1003	1063	40	879	28	4.28	27	393	735
Example 2	1031	1087	35	905	32	5.06	25	410	740
Example 3	1045	1093	25	916	40	5.58	21	372	750
Example 4	1064	1118	20	927	20	5.95	30	389	730
Example 5	1010	1052	40	873	25	4.05	28	382	745
Example 6	1098	1078	30	912	35	5.33	23	400	730
Comparative Example 1	1033	1086	28	908	30	5.33	22	383	740
Comparative Example 2	1056	1097	30	921	35	5.47	23	387	745
Comparative Example 3	1047	1069	36	899	36	4.91	25	397	735
Comparative Example 4	1049	1160	***10***	***980***	38	***7.17***	28	405	750
Comparative Example 5	1089	1112	30	928	25	5.56	***10***	391	740
Comparative Example 6	Furnace heating to 600°C, material charged, raised to 760°C in about 1 hour, held at 760°C for 1 hour, rapidly heated to 780°C and held for 5 hours, lowered to 740°C in 1 hour, held at 740°C for 2 hours, lowered to 720°C in 1 hour, held for 6 hours, lowered to 630°C in about 2 hours, and held for 2 hours before removal from furnace.								

[0058] Samples of the cold forging steels of Examples 1-6 and Comparative Examples 1-6 were taken for various performance testing. The results of the performance tests are listed in Table 3. The structural spheroidization rate was measured according to the standard ASTM F2282. The relevant test methods of mechanical properties are as follows: under the normal temperature conditions, the samples of cold forging steel were processed into M16*128 threaded specimens, and tensile tests were performed according to the GB/T228-2002 standard to obtain data such as yield strength, tensile strength, elongation, and reduction of area.

Table 3: Mechanical properties of cold forging steel of Examples 1-6 and Comparative Examples 1-6

Number	Yield Strength (MPa)	Tensile Strength (MPa)	Elongation (%)	Reduction of Area (%)	Structural Spheroidization Rate (%)
Example 1	225	433	40	70	95
Example 2	242	461	39	68	90
Example 3	234	452	41	71	95
Example 4	266	479	35	66	95
Example 5	251	453	37	67	90
Example 6	247	458	38.5	68	95
Comparative Example 1	***328***	***546***	36	66	90
Comparative Example 2	***319***	***536***	36	67	90
Comparative Example 3	243	443	***32***	***63***	***85***
Comparative Example 4	268	478	***33***	***64***	***80***
Comparative Example 5	***296***	***503***	***31***	***62***	***75***
Comparative Example 6*	234	441	39	71	95
*20CrMnTiH steel using conventional spheroidizing annealing process.					

[0059] As can be seen from Table 3, the cold forging steel of Examples 1-6 have excellent overall mechanical properties. The yield strength of each example is between 225-266MPa, the tensile strength is between 433-479MPa, the elongation is ≥35%, the reduction of area is ≥66%, and the structural spheroidization rate is 90% or more. The cold forging steel of Examples 1-6 have excellent mechanical properties, good plasticity and reduction of area at low temperatures, as well as excellent cold working properties.

[0060] The inventors surprisingly found that when using the manufacturing method of the present disclosure, it is possible to fully utilize the residual heat from the steel after rolling. Only about 8 hours of time of annealing and softening is required to enable the material properties to achieve the material performance that would normally require conventional spheroidizing annealing (taking 20 hours or more). The manufacturing method of the present disclosure not only effectively reduces the energy consumption in material production, but also effectively improves production efficiency.

[0061] Figure 1 shows the microstructure of the cold forging steel of Example 4 under an optical microscope.

[0062] Figure 2 shows the microstructure of the cold forging steel of Comparative Example 1 under an optical microscope.

[0063] It can be seen by comparing Figure 1 and Figure 2 that the microstructure of the cold forging steel of Example 4 is ferrite + spheroidal carbide, which satisfies the structural requirements of conventional spheroidizing annealing.

[0064] All publications, patent applications, patents, and other references mentioned in the present disclosure are incorporated herein by reference in their entirety.

[0065] Although the disclosure has been illustrated and described by reference to certain preferred embodiments of the disclosure, it should be understood by those skilled in the art that the above content is a further detailed description of the disclosure with specific embodiments and should not be construed as limiting the disclosure to these descriptions. Those skilled in the art may perform various changes in formality and details, including performing several simple deductions or substitutions, without departing from the essence and scope of the present disclosure.

Claims

1. A cold forging steel, wherein in addition to comprising 90% or more of Fe and inevitable impurities, the cold forging steel further comprises the following chemical elements in percentage by mass: C: 0.170-0.220%, Si: 0.10-0.30%, Mn: 1.00-1.20%, S: 0.010-0.020%, Cr: 1.10-1.30%, Al: 0.015-0.045%, N: 0.0100-0.0180%, and Ti: 0.040-0.100%.

2. A cold forging steel, wherein the cold forging steel comprises the following chemical elements in percentage by mass: C: 0.170-0.220%, Si: 0.10-0.30%, Mn: 1.00-1.20%, S: 0.010-0.020%, Cr: 1.10-1.30%, Al: 0.015-0.045%, N: 0.0100-0.0180%, Ti: 0.040-0.100%, with the balance being Fe and inevitable impurities.

3. The cold forging steel according to claim 1 or 2, wherein the cold forging steel further comprises Ca, and a Ca content in percentage by mass satisfies: $0<Ca\leq 0.005\%$, preferably $0.001\%<Ca\leq 0.003\%$.

4. The cold forging steel according to claim 1 or 2, wherein a Mn content is 1.10-1.20%, a Cr content is 1.16-1.30%, and/or a Ti content is 0.050-0.080%.

5. The cold forging steel according to claim 1 or 2, wherein the inevitable impurities include: $P\leq 0.015\%$ and/or $O\leq 0.0030\%$.

6. The cold forging steel according to claim 1 or 2, wherein a microstructure of the cold forging steel is ferrite + spheroidal carbide; preferably, a structural spheroidization rate of the cold forging steel is 90% or more.

7. The cold forging steel according to claim 1 or 2, wherein mechanical properties of the cold forging steel satisfy at least one of the following: yield strength of 220-270MPa, tensile strength of 430-480MPa, elongation ≥35%, and reduction of area ≥66%; preferably, the mechanical properties of the cold forging steel satisfy the following: yield strength of 220-270MPa, tensile strength of 430-480MPa, elongation ≥35%, and reduction of area ≥66%.

8. A manufacturing method for the cold forging steel according to any one of claims 1 to 7, wherein the manufacturing method comprises the following steps: (1) smelting and casting molten steel to obtain a cast billet; (2) heating and rolling the cast billet to obtain an intermediate billet; (3) heating and rolling the intermediate billet to obtain a rolled round steel; (4) cooling the rolled round steel; (5) annealing; and optionally (6) taking the annealed round steel out of furnace for air cooling.

9. The manufacturing method according to claim 8, wherein in step (2), the cast billet is heated to a temperature of 1000-1120°C, preferably 1000-1100°C.

10. The manufacturing method according to claim 8, wherein in step (3), the intermediate billet is heated to 1050-1200°C, preferably 1050-1120°C, and held for 5-6 hours.

11. The manufacturing method according to claim 8, wherein in step (3), an amount of rolling single pass deformation ξ is 20-40%, a final rolling temperature T is 870-930°C, and a relationship between the amount of rolling single pass deformation ξ and the final rolling temperature T satisfies: $4.00\leq \ln(T-850)-\ln\xi\leq 6.00$.

12. The manufacturing method according to claim 8, wherein in step (4), the rolled round steel is cooled to 370-410°C at a cooling rate of 20°C/s or more.

13. The manufacturing method according to any one of claims 8 to 12, wherein in step (5), an annealing temperature is 740 ±10°C and a holding time is 8 hours or more.

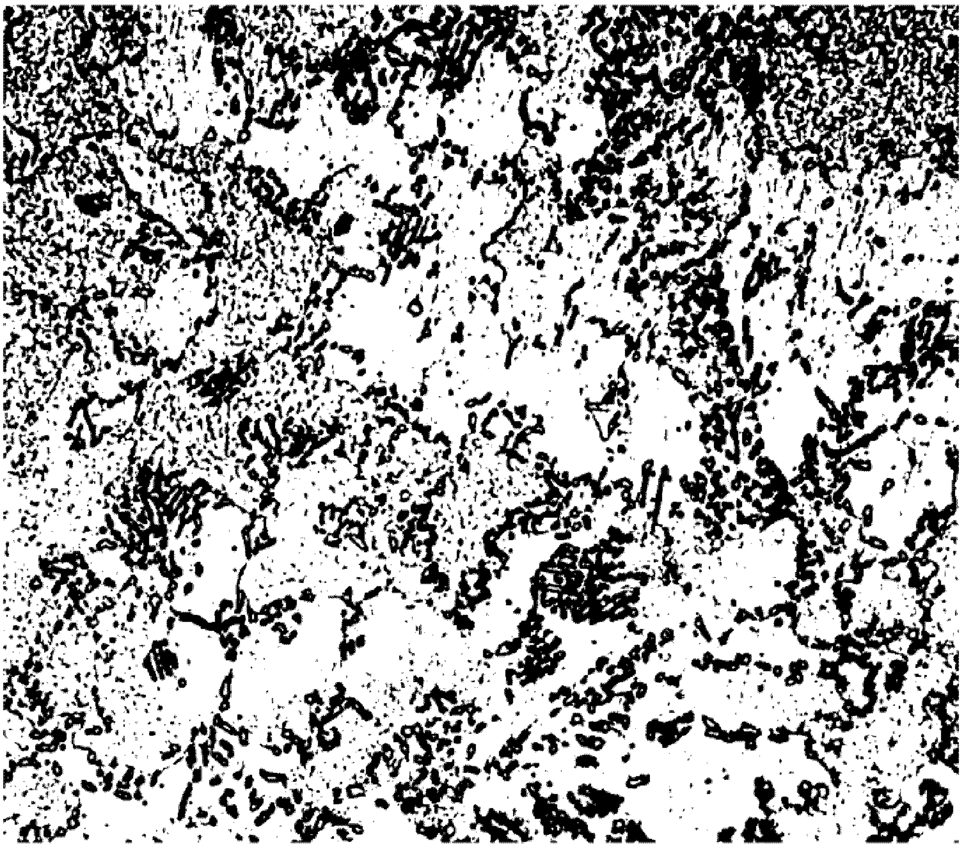

Figure 1

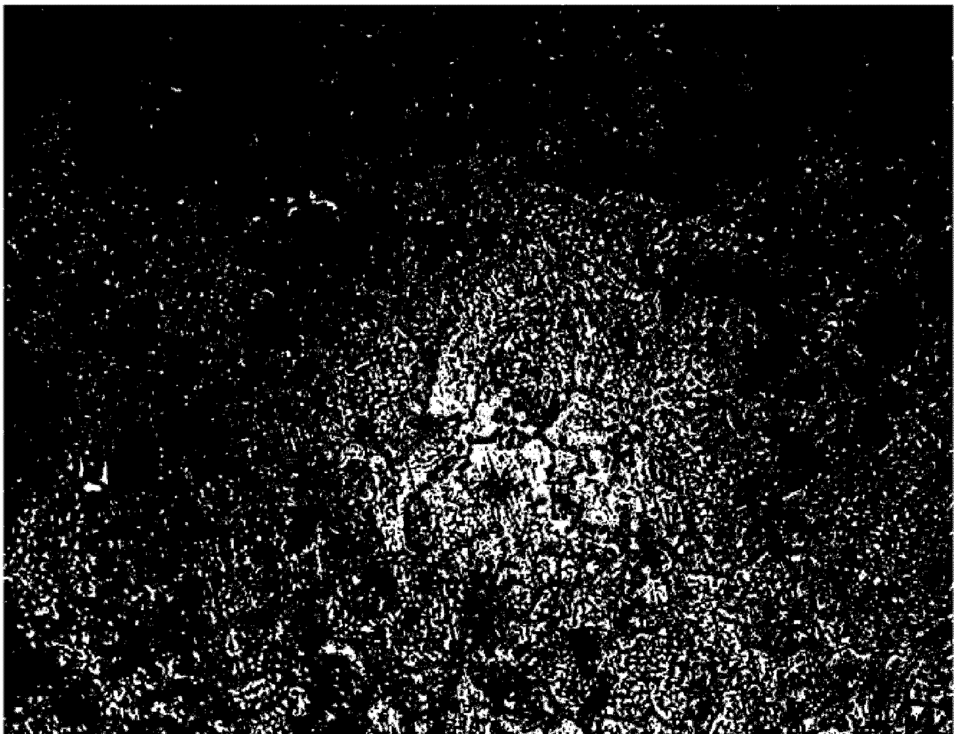

Figure 2

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2023/112178

A. CLASSIFICATION OF SUBJECT MATTER

C22C38/02(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C22C38/-

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

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

USTXT; CNABS; EPTXT; 中国期刊网全文数据库, CJFD; DWPI; ENTXTC; CNTXT: 宝山钢铁股份有限公司, 章军, 赵四新, 黄宗泽, 冷锻, 铁素体, 碳化物, 渗碳体, 球化, 球状, 可浇性, 流动性, 铸造性, 可动性, 钢水, 钢液, 铁水, 铁液, 中间坯, 轧, 退火, 圆钢, 球化退火, 软化退火, 粘度, 流变性, 流平性, 粘性, cold forging, cold hammering, ferrite, carbide, cementite, balling, globuling, spheroidizing, nodular, flowability, fluidness, liquidity, mobility, castability, liquid steel, molten steel, intermediate cog, roll bar steel, round bar iron, spheroidal annealing, softening anneal, viscosity, rheological property, stickiness

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 2005133153 A (KOBE STEEL LTD.) 26 May 2005 (2005-05-26) description, paragraphs 12-17 and 45-47	1-2, 4-7
Y	JP 2005133153 A (KOBE STEEL LTD.) 26 May 2005 (2005-05-26) description, paragraphs 12-17 and 45-47	3, 8-13
Y	JP 2002322535 A (SUMITOMO METALS KOKURA LTD.) 08 November 2002 (2002-11-08) description, paragraphs 7 and 14	3
Y	JP 2014031525 A (NIPPON STEEL CORP.) 20 February 2014 (2014-02-20) description, paragraphs 69-81	8-13
A	CN 111424219 A (JIANGYIN XINGCHENG SPECIAL STEEL WORKS CO., LTD.) 17 July 2020 (2020-07-17) entire document	1-13

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"D" document cited by the applicant in the international application
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
04 September 2023	**12 September 2023**

Name and mailing address of the ISA/CN	Authorized officer
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INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2023/112178

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2011225897 A (SUMITOMO METAL INDUSTRIES, LTD.) 10 November 2011 (2011-11-10) entire document	1-13
A	JP 2010168628 A (JFE STEEL CORP.) 05 August 2010 (2010-08-05) entire document	1-13
A	JP 2017193767 A (NIPPON STEEL CORP.) 26 October 2017 (2017-10-26) entire document	1-13
A	JP 2012229475 A (SUMITOMO METAL INDUSTRIES, LTD.) 22 November 2012 (2012-11-22) entire document	1-13

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2023/112178

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JP	2010168628	A	05 August 2010	JP	5332646	B2	06 November 2013
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JP	2012229475	A	22 November 2012	JP	5736936	B2	17 June 2015

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