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(54) **MEDIUM-CARBON ROUND STEEL FOR COLD EXTRUSION AND MANUFACTURING METHOD THEREFOR**

(57) The present invention discloses a medium carbon round steel, in addition to Fe and inevitable impurities, the medium carbon round steel further comprising the following chemical elements in percentage by mass: C: 0.36~0.43%, Si: 0.1~0.4%, Mn: 0.6~1.0%, Cr: 0.6-1.0%, Mo: 0.2~0.4%, Ni: 1.4~1.7%, Al: 0.02~0.04%, N: 0.008-0.015%; the round steel is obtained by annealing, and has a microstructure of lamellar pearlite + spheroidal pearlite. Furthermore, the present invention also discloses a method for manufacturing the above medium carbon round steel, comprising the following steps performed in sequence: (1) smelting and casting; (2) heating; (3) forging or rolling; (4) step annealing; (5) surface treatment.



Figure 1

**Description****TECHNICAL FIELD**

- 5 **[0001]** The present invention relates to a steel material and a manufacturing method therefor, and in particular to a round steel and a manufacturing method therefor.

**BACKGROUND**

- 10 **[0002]** The working capacity of shaft components of a vehicle speed reducer generally depends on the strength and stiffness of the shaft, and also depends on the vibration stability at high rotational speeds. Moreover, since the shaft bears both bending moment and torque during operation, Requirements are also imposed on the certain toughness of the round steel.

- [0003]** In order to meet the service requirements of the shaft components of the speed reducer, currently there are mainly two process routes for manufacturing shaft products in the speed reducer. One is to use low-carbon steels such as 20CrMnTi, 20CrMo, 20MnCr5 plus surface carburizing for manufacturing; the other is to use medium carbon steels (such as 45, 50 steel) or medium carbon low alloy steels (such as 40Cr, 42CrMo) plus surface induction heat treatment for manufacturing. Under these two process routes, the typical forming method of the round steel is direct turning or hot forging forming, and cold forming is seldom adopted. Even if cold forming is adopted, it is usually applied to low-carbon steels. Medium carbon steel, would have relatively large stress in the round steel after cold forming due to its relatively poor plasticity and toughness and thus is prone to cracking during subsequent quenching, so cold forming is usually not used for medium carbon steel.

- [0004]** In speed reducers of automobile, the failure circumstances of shaft components are mostly fatigue fracture, and the fatigue resistance of the shaft components is not only related to their strength and toughness, but also closely related to the microstructure and surface quality of the round steel before cold extrusion. Therefore, in addition to ensuring the strength and toughness of the round steel through composition design, a microstructure suitable for cold extrusion and good surface quality are the keys to ensuring the fatigue resistance of the shaft components. In the prior art, steel for shafts of traditional fuel vehicles is mostly used to manufacture shaft components of speed reducers, and the processes adapted thereto are mostly turning or hot forging.

- 30 **[0005]** For example: the Chinese patent with Publication No. CN104975235A, published on October 14, 2015, and titled "A 120KSI steel grade high-strength and high-toughness medium-carbon quenched and tempered round steel and a manufacturing method therefor" relates to a high-strength and high-toughness medium-carbon quenched and tempered round steel and a manufacturing method therefor, in which the element composition of the steel is as follows: C: 0.35~0.50%, Si: 0.15~0.40%, Mn: 0.60~1.30%, P:  $\leq 0.015\%$ , S:  $\leq 0.040\%$ , Cr: 0.75~1.30%, Mo: 0.15~0.35%, Ni:  $\leq 0.25\%$ , Cu:  $\leq 0.25\%$ , Al: 0.015~0.040%, V:  $\leq 0.10\%$ , Nb:  $\leq 0.10\%$ , Ti:  $\leq 0.05\%$ , N:  $\leq 0.008\%$ , B:  $\leq 0.0010\%$ , and the balance of Fe and inevitable impurities, wherein V and Nb are not simultaneously  $\leq 0.010\%$ . It achieves the requirements of high strength and high toughness mainly through the composition design of the steel material combined with the subsequent quenching and tempering heat treatment process.

- 40 **[0006]** For another example: the Chinese patent with Publication No. CN112981233A, published on June 18, 2021, and titled "A low-silicon medium-carbon gear steel suitable for cold forging and a manufacturing method therefor" relates to a low-silicon medium-carbon gear steel suitable for cold forging and a manufacturing method therefor, in which the element composition of the steel is as follows: C: 0.35~0.45%, Si:  $\leq 0.08\%$ , Mn: 0.30~0.60%, Cr: 0.20~0.50%, P:  $\leq 0.020\%$ , S: 0.010~0.040%, Cu:  $\leq 0.10\%$ , Ni:  $\leq 0.05\%$ , Mo:  $\leq 0.05\%$ , Al:  $\leq 0.050\%$ , N:  $\geq 0.005\%$ , B: 0.0005~0.0035%, Ti:  $\leq 0.010\%$ , [O]:  $\leq 0.0020\%$ , (Cu+Ni+Mo):  $\leq 0.15\%$ , and the balance of Fe and inevitable impurities. Through the composition design of the steel material and the control of dimensional accuracy, decarburization layer depth, spheroidizing hardness and microstructure spheroidization rate, a medium-carbon gear steel with excellent cold forging performance is obtained, but no specific surface treatment is performed on the surface hardened layer that causes cold forging cracking.

50 **SUMMARY**

- [0007]** One of the objects of the present invention is to provide a medium carbon round steel for cold extrusion, wherein by precisely identifying the influence of each alloying element on the actual hardenability, a hardenability curve conforming to the service conditions of the speed reducer input shaft is obtained to ensure good strength and toughness of the output shaft.

- 55 **[0008]** In order to achieve the above object, the present invention provides a medium carbon round steel, in addition to Fe and inevitable impurities, the medium carbon round steel further comprising the following chemical elements in percentage by mass:

C: 0.36~0.43%, Si: 0.1~0.4%, Mn: 0.6~1.0%, Cr: 0.6~1.0%, Mo: 0.2~0.4%, Ni: 1.4~1.7%, Al: 0.02~0.04%, N: 0.008~0.015%;

wherein a DI value of the medium carbon round steel is 4.72~10.21in, wherein  $DI = (0.171 + 0.001C + 0.265C^2)(1 + 3.333Mn)(1 + 0.7Si)(1 + 0.365Cu)(1 + 2.16Cr)(1 + 3Mo)(1 + 0.363Ni)(1 + 1.73V)$ , wherein during calculation, each element symbol in the formula is substituted with the numerical value before the percent symbol of the mass percentage of the corresponding element. For example, when the C content in the steel is 0.41%, 0.41 is substituted for calculation.

**[0009]** DI is a key parameter for quantitatively characterizing the hardenability of steel material, which is calculated by a mathematical formula combining the contents of the main alloying elements (such as C, Mn, Si, Cr, Ni, etc.) in the steel. and the DI value directly reflects the hardenability of the material under standard test conditions. The unit is in (inch), and the DI value refers to the critical diameter of the steel material during quenching.

**[0010]** The medium carbon round steel is obtained by annealing, and the medium carbon round steel has a micro-structure of lamellar pearlite + spheroidal pearlite.

**[0011]** Preferably, the medium carbon round steel according to the present invention consists of the following chemical elements in percentage by mass:

C: 0.36~0.43%, Si: 0.1~0.4%, Mn: 0.6~1.0%, Cr: 0.6~1.0%, Mo: 0.2~0.4%, Ni: 1.4~1.7%, Al: 0.02~0.04%, N: 0.008~0.015%, and the balance of Fe and inevitable impurities.

**[0012]** In the medium carbon round steel according to the present invention, the design principles of each chemical element are specifically described as follows:

C: In the medium carbon round steel according to the present invention, as the C content in austenite increases, the critical cooling rate of the steel is greatly reduced, which increases the critical diameter of the steel, thereby improving the hardenability of the steel and ensuring the strength and stiffness of the shaft. However, an excessively high C content will increase the tendency of cracking in quenching. On this basis, in the medium carbon round steel according to the present invention, the C content is configured to 0.36~0.43%.

**[0013]** Si: In the medium carbon round steel according to the present invention, Si is an element that strengthens ferrite and can improve hardenability to a certain extent. Si replaces Fe atoms in a substitutional manner in the steel, hindering dislocation movement, and is beneficial to the improvement of the strength of the steel material. However, excessive Si will reduce the plasticity and toughness of the steel material. On this basis, in the medium carbon round steel according to the present invention, the Si content is configured to 0.1~0.4%.

**[0014]** Mn: In the medium carbon round steel according to the present invention, Mn dissolves into ferrite, forming a substitutional solid solution and resulting a solid solution strengthening effect. Mn and its carbides dissolve in austenite, shifting the isothermal transformation curve of austenite to the right, increasing the stability of supercooled austenite, inhibiting pearlite transformation, and the hardenability is improved. However, an excessively high Mn content will lead to severe segregation of the round steel, which is prone to cause quenching cracking. On this basis, in the medium carbon round steel according to the present invention, the Mn content is configured to 0.6~1.0%.

**[0015]** Cr: In the medium carbon round steel according to the present invention, adding an appropriate amount of Cr element can inhibit the diffusional phase transformation of the steel, form a hardened martensite structure, and obtain a steel material with relatively high strength. Meanwhile, during the heating process, if the carbides of Cr are not completely dissolved, they can also provide the effect in inhibiting austenite grain growth. It should be noted that the content of Cr element in the steel should not be too high. When the content of Cr element in the steel is too high, coarse carbides will form, deteriorating the impact properties of the steel material. On this basis, in the medium carbon round steel according to the present invention, the Cr content is configured to 0.6~1.0%.

**[0016]** Mo: In the medium carbon round steel according to the present invention, Mo is a ferrite-forming element. Adding an appropriate amount of Mo element is beneficial to improving the hardenability of the steel, enabling the steel to easily form bainite and martensite strengthening phases during quenching. During tempering in a relatively high temperature range, fine carbides will form to improve the strength of the steel. It should be noted that Mo is a precious alloying element, and adding a relatively high content of Mo will lead to an increase in cost. On this basis, in the medium carbon round steel according to the present invention, the Mo content is configured to 0.2~0.4%.

**[0017]** Ni: In the medium carbon round steel according to the present invention, Ni element presents in the steel in the form of a solid solution. Specifically, Ni is present as an Fe-Ni-Mn FCC phase, which can reduce the stacking fault energy and improve the low-temperature impact properties of the steel. Furthermore, it should be noted that Ni is an austenite-forming element. An excessively high content of Ni should not be added to the steel. Adding excessive Ni will lead to an excessively high residual austenite content in the steel material and reduce the strength of the steel material. In addition, Ni element is also a precious metal, and adding a relatively high content of Ni will lead to an increase in cost. On this basis, in the medium carbon round steel according to the present invention, the Ni content is configured to 1.4~1.7%.

**[0018]** Al: In the medium carbon round steel according to the present invention, Al forms fine AlN precipitates during

steelmaking, which inhibits austenite grain growth and refines austenite grains during the subsequent cooling process. An excessively high Al content will lead to the formation of relatively large Al oxides. Coarse and hard alumina inclusions will deteriorate the fatigue properties of the steel. On this basis, in the medium carbon round steel according to the present invention, the Al content is configured to 0.02~0.04%.

**[0019]** N: In the medium carbon round steel according to the present invention, N is an interstitial atom, and is also an element that forms MX-type precipitates. It can improve the strength and toughness of the round steel through the fine grain strengthening effect of AlN. However, an excessively high N content will lead to its increased accumulation at defects, and also form coarse nitride precipitate particles, especially the formation of angular TiN particles, affecting the impact toughness of the round steel. On this basis, in the medium carbon round steel according to the present invention, the N content is configured to 0.008~0.015%.

**[0020]** Preferably, the medium carbon round steel according to the present invention further comprises at least one of the following chemical elements:  $0 < \text{Cu} \leq 0.20\%$ ,  $0 < \text{V} \leq 0.05\%$ ,  $0 < \text{Nb} \leq 0.05\%$ .

**[0021]** In the medium carbon round steel according to the present invention, the design principles of the above chemical elements are specifically described as follows:

**Cu:** In the medium carbon round steel according to the present invention, Cu can improve the hardenability and corrosion resistance of the steel material. However, an excessively high Cu content will accumulate at grain boundaries, leading to grain boundary weakening and thus cracking. On this basis, in some preferred embodiments of the medium carbon round steel according to the present invention, the Cu content is configured to  $0 < \text{Cu} \leq 0.20\%$ .

**[0022]** V: In the medium carbon round steel according to the present invention, V can combine with C or N in the steel to form precipitates, improving the strength of the steel. However, if the content is too high, coarse VC particles will form, deteriorating the plasticity and toughness of the steel material. On this basis, in some preferred embodiments of the medium carbon round steel according to the present invention, the V content is configured to  $0 < \text{V} \leq 0.05\%$ .

**[0023]** Nb: In the medium carbon round steel according to the present invention, after Nb is added into the steel, it will form fine precipitated phase, which can provide the effect in fine grain strengthening and reducing hydrogen embrittlement sensitivity. However, excessive Nb will form coarse NbC particles during the smelting process, which in turn reduces the impact toughness. On this basis, in some preferred embodiments of the medium carbon round steel according to the present invention, the Nb content is configured to  $0 < \text{Nb} \leq 0.05\%$ .

**[0024]** Preferably, in the medium carbon round steel according to the present invention, the inevitable impurities at least satisfy one of the following:  $\text{P} \leq 0.015\%$ ,  $\text{S} \leq 0.025\%$ ,  $\text{H} \leq 0.0002\%$ ,  $\text{B} \leq 0.001\%$ ,  $\text{O} \leq 0.0020\%$ ,  $0 < \text{Ti} \leq 0.08\%$ , preferably  $0 < \text{Ti} \leq 0.01\%$ .

**[0025]** In the above technical solution, P, S, H, B, O and Ti are all impurity elements in the steel. If the technical conditions permit, the contents of impurity elements in the steel should be reduced as much as possible so as to obtain steel material with better properties and higher quality, wherein:

**P:** In the medium carbon round steel according to the present invention, P segregates at grain boundaries, which would reduce the binding energy of grain boundaries and deteriorate the low-temperature impact properties of the steel. Moreover, the coexistence of P and Mn can aggravate the temper embrittlement of the steel. Furthermore, P segregated at grain boundaries can cause intergranular fracture when the steel faces impact load, forming relatively large cleavage planes, and reducing the energy absorbed by the steel upon impact. On this basis, in some preferred embodiments of the medium carbon round steel according to the present invention, in order to ensure the low-temperature impact toughness of the input shaft, the P content is controlled at:  $\text{P} \leq 0.015\%$ .

**[0026]** S: In the medium carbon round steel according to the present invention, S has very little solubility in  $\delta$ -ferrite and austenite. During the solidification of molten steel, S will segregate. If the S content is relatively high, more coarse sulfide inclusions will form, harming the fatigue resistance of the round steel. However, adding an appropriate amount of S to the steel can form CaS, which can improve the machinability. On this basis, in some preferred embodiments of the medium carbon round steel according to the present invention, in order to ensure the fatigue resistance of the round steel and to allow for the user's demand for easy-cutting, the S content is controlled at:  $\text{S} \leq 0.025\%$ .

**[0027]** H: In the medium carbon round steel according to the present invention, H will accumulate at defects due to the influence from the hydrostatic stress field of edge dislocations in the steel, causing hydrogen embrittlement. In steels with high tensile strength grades, the densities of dislocations, sub-grain boundaries, etc. are high. If the H content in the steel is too high, after quenching and tempering heat treatment of the steel, a relatively large amount of H atoms will accumulate at the defects. The accumulation of H atoms will form H molecules, causing delayed fracture to occur in the steel. On this basis, in the medium carbon round steel according to the present invention, in some preferred embodiments, the H content is controlled at:  $\text{H} \leq 0.0002\%$ .

**[0028]** B: In the medium carbon round steel according to the present invention, B has a strong affinity with N and O, and is very prone to react with metals such as Ti to form extremely hard boride  $\text{TiB}_2$ . Meanwhile, a very small amount of B can also significantly improve the hardenability of the round steel. On this basis, in some preferred embodiments of the medium carbon round steel according to the present invention, the B content is controlled at:  $\text{B} \leq 0.001\%$ .

**[0029]** O: In the medium carbon round steel according to the present invention, O forms inclusions such as  $\text{Al}_2\text{O}_3$ ,

TiO with Al and Ti in the steel. On this basis, in the medium carbon round steel according to the present invention, in some preferred embodiments, in order to ensure the continuity and the fatigue resistance of the steel matrix, the O content is controlled at:  $O \leq 0.0020\%$ .

**[0030]** Ti: In the medium carbon round steel according to the present invention, Ti combines with N and C in the steel to form TiC, Ti(CN), TiN. Angular TiN disrupts the collective continuity and can adversely affect the fatigue properties of the steel. On this basis, in some preferred embodiments of the medium carbon round steel according to the present invention, the Ti content is controlled at:  $0 < Ti \leq 0.08\%$ , preferably  $0 < Ti \leq 0.01\%$ .

**[0031]** Preferably, in the medium carbon round steel according to the present invention, the contents of Al and N elements satisfy:  $[Al]/[N] \geq 2$ ,  $[Al][N] \geq 2 \times 10^{-4}$ .

**[0032]** In the present invention, during calculation, [Al] and [N] in the above formula should be respectively substituted with the numerical values before the percent symbol of the mass percentages of the Al and N elements in the steel. For example, when the Al content in the steel is 0.02%, the numerical value 0.02 is substituted for calculation.

**[0033]** The present invention can further ensure the AlN content in the steel by controlling  $[Al][N] \geq 2 \times 10^{-4}$ .

**[0034]** Furthermore, as described above, an excessively high Al content will lead to the formation of relatively large Al oxides. Coarse and hard alumina inclusions will deteriorate the fatigue properties of the steel. The inventors have found that by controlling the contents of Al and N in the steel to satisfy  $[Al]/[N] \geq 2$  and  $[Al][N] \geq 2 \times 10^{-4}$ , the content and size of nitrides in the steel can be ensured to be within a suitable range, thereby further improving the properties of the medium carbon round steel.

**[0035]** Preferably, in the medium carbon round steel according to the present invention, the lamellar pearlite has a volume fraction of 35~45%.

**[0036]** Preferably, the medium carbon round steel according to the present invention satisfies at least one of the following: a hardness of 185-210HBW, yield strength  $\geq 400\text{MPa}$ , tensile strength  $\geq 600\text{MPa}$ , elongation  $\geq 30\%$ , reduction of area  $\geq 60\%$ , impact energy Akv2 at  $-40^\circ\text{C} \geq 20\text{J}$ .

**[0037]** Unless otherwise specified, the "medium carbon round steel" referred to in the present invention means the medium carbon round steel without quenching and tempering.

**[0038]** Preferably, after quenching and tempering, the medium carbon round steel according to the present invention has a yield strength of  $\geq 1100\text{MPa}$ , a tensile strength of  $\geq 1250\text{MPa}$ , an elongation of  $\geq 15\%$ , a reduction of area of  $\geq 50\%$ , and an impact energy Akv2 at  $-40^\circ\text{C}$  of  $\geq 40\text{J}$ .

**[0039]** Preferably, after quenching and tempering, the medium carbon round steel according to the present invention has a microstructure of tempered sorbite.

**[0040]** Another aspect of the present invention provides a method for manufacturing the above medium carbon round steel. By adopting this method in combination with the composition design described above, it can not only avoid excessively high hardness leading to excessive deformation resistance in subsequent cold extrusion, but also avoid excessively low hardness leading to bending of the shaft rod during cold extrusion, so that the energy consumption is reduced, the heat treatment time is saved, and the production efficiency is improved. At the same time, it also ensures that the surface of the round steel after the surface treatment process has no cryptocrystalline martensite layer (hardened layer) produced by turning and calendaring, thereby avoiding surface cracking of the round steel during the cold extrusion process.

**[0041]** To achieve the above objective, the present invention provides a method for manufacturing the above medium carbon round steel, comprising the following steps performed in sequence:

(1) smelting and casting;

(2) heating;

(3) forging or rolling to obtain a round steel;

(4) step annealing: first, holding at a temperature of  $770\sim 790^\circ\text{C}$  for 1~3h, then holding at a temperature of  $590\sim 610^\circ\text{C}$  for 2~4h, then holding at a temperature of  $730\sim 750^\circ\text{C}$  for 1~3h, then holding at a temperature of  $690\sim 710^\circ\text{C}$  for 2~4h, then furnace cooling to below  $350^\circ\text{C}$  and discharging from the furnace for air cooling;

(5) surface treatment to remove a martensitic hardened layer on the surface of the round steel, so as to obtain a medium carbon round steel having no martensitic hardened layer on the surface.

**[0042]** The hardness of the round steel of the present invention after forging or rolling is about 260HBW, which means excessive deformation resistance for the subsequent cold extrusion process, which may not only damage the die but also cause excessive stress in the round steel after cold extrusion, leading to high possibility of cracking during subsequent quenching.

**[0043]** In some known references, spheroidizing annealing was adopted to treat the microstructure before cold extrusion. However, although spheroidizing annealing can soften the microstructure and reduce hardness, the heat treatment time is too long (usually  $\geq 24$  hours). Furthermore, when processing shaft rod parts, the fully spheroidized microstructure has excessively low hardness, leading to high possibility of bending during cold extrusion.

**[0044]** On this basis, the present invention provides a novel step annealing heat treatment process: first, holding at a temperature of 770~790°C for 1~3h, during which the round steel is fully austenitized; then holding at a temperature of 590~610°C for 2~4h, during which the austenite transforms into lamellar pearlite; then holding at a temperature of 730~750°C for 1~3h, so that part of the lamellar pearlite is austenitized; then holding at a temperature of 690~710°C for 2~4h, during which the partially austenitized portion gradually transforms into spheroidal pearlite; and finally furnace cooling to below 350°C and discharging from the furnace for air cooling. The present invention adopts the above step annealing process to replace conventional spheroidizing annealing.

**[0045]** By adopting the step annealing process of the present invention, the microstructure of the medium carbon round steel can satisfy a volume fraction of lamellar pearlite of 35~45%, and a hardness of the obtained round steel is 185~210HBW, which not only avoids excessively high hardness leading to excessive deformation resistance in subsequent cold extrusion, but also avoids excessively low hardness leading to bending of the shaft rod during cold extrusion, so that the energy consumption is reduced, the heat treatment time is saved, and the production efficiency is improved.

**[0046]** Preferably, in step (2) of the method according to the present invention, a heating temperature is 1050~1250°C.

**[0047]** In the method according to the present invention, the heating temperature is controlled at 1050~1250°C because the steel is heated at 1050°C~1250°C for austenization. During the heating process, the carbides of Mn are partially or completely dissolved in austenite. During the subsequent rolling/forging and cooling process, Al forms fine carbonitrides, pinning the austenite grain boundaries and refining the as-rolled microstructure of the steel. Mn dissolved in solid solution in austenite can also increase the hardening capacity of martensite during quenching while improving the hardenability of the steel.

**[0048]** Preferably, in step (3) of the method according to the present invention, a finishing rolling or finishing forging temperature is  $\geq 800^\circ\text{C}$ .

**[0049]** In the method according to the present invention, the finishing rolling or finishing forging temperature is controlled at  $\geq 800^\circ\text{C}$  because under this condition, recrystallization and strain-induced precipitation, etc. occur in the steel material, forming a matrix microstructure of ferrite and pearlite, and fine carbonitrides precipitate.

**[0050]** Preferably, in step (5) of the method according to the present invention, the surface treatment comprises turning, wherein a turning feed rate is 0.06~0.10 mm/r, and a coolant flow rate is 20~28 L/min.

**[0051]** Regarding the turning feed rate in the turning process, in some known references, the turning feed rate for shafts is  $\geq 0.2$  mm/r. However, in the preferred embodiment of the present invention, the turning feed rate is 0.06~0.1 mm/r, which can ensure a certain efficiency while ensuring that the heat generated by turning is not excessively high.

**[0052]** Regarding the coolant flow rate in the turning process, in some known references, the coolant flow rate for shaft turning is  $\leq 15$  L/min. However, in the present invention, the coolant flow rate is 20~28 L/min, which increases the coolant flow rate, thereby ensuring that the temperature of the round steel during turning is not excessively high.

**[0053]** Preferably, in step (5) of the method according to the present invention, the surface treatment comprises calendaring, wherein a calendaring pressure is 16~20 KN.

**[0054]** Regarding the calendaring process, in some known references, the calendaring pressure for shafts is  $\geq 25$  KN. The calendaring process of the present invention controls the pressure at 16~20 KN, ensuring that the stress in the round steel is not excessively high.

**[0055]** Preferably, in step (5) of the method according to the present invention, the surface treatment comprises sand belt polishing, by which the cryptocrystalline martensite layer produced by turning and calendaring is removed, i.e., the depth of sand belt polishing exceeds the depth of the cryptocrystalline martensite layer produced by turning and calendaring, thereby ensuring that no martensitic hardened layer is present on the surface of the round steel before cold extrusion, and avoiding surface cracking of the round steel during the cold extrusion process.

**[0056]** Preferably, after the above step (5), a step (6) of quenching and tempering is further performed, wherein a quenching temperature is 850°C~930°C, a holding time is 60~180 min, and water quenching or oil quenching is adopted; a tempering temperature is 460~530°C, a holding time is 60~180 min, and air cooling or water cooling is performed after tempering.

**[0057]** The medium carbon round steel according to the present invention has the following advantages and beneficial effects compared with the prior art:

The medium carbon round steel of the present invention adopts economical alloy compositions after fully identifying the influence of each alloy composition on hardenability, so as to meet the hardenability requirements of the steel for cold extrusion of speed reducer input shafts. By controlling the DI value within a reasonable range (e.g., 4.72~10.21 in), the complex performance requirements are quantified into indexes that are easy to measure and evaluate, thereby achieving precise control and optimization in the production process, improving the consistency and economy of material properties.

**[0058]** The method of the present invention adopts step annealing to replace spheroidizing annealing, so that the microstructure and hardness of the round steel are adapted to the cold extrusion process, reducing energy consump-

tion, improving production efficiency, solving the problem of incompatibility between medium carbon steel and cold forming processes, and can meet the user's demand for steel for cold extrusion of speed reducer input shafts.

**[0059]** Furthermore, in a preferred embodiment of the method of the present invention, an improved surface treatment process for the round steel is adopted, ensuring that no martensitic hardened layer is present on the surface of the round steel before cold extrusion, thereby avoiding surface cracking of the round steel during cold extrusion.

**[0060]** In a preferred embodiment of the present invention, the medium carbon round steel according to the present invention is obtained by annealing, the microstructure of the medium carbon round steel satisfies a volume fraction of lamellar pearlite of 35~45%, and the hardness of the round steel obtained after annealing is 185~210HBW, which not only avoids excessively high hardness leading to excessive deformation resistance in subsequent cold extrusion but also avoids excessively low hardness leading to bending of the shaft rod during cold extrusion, so that the energy is saved, consumption is reduced, and production efficiency is improved. Moreover, after overall quenching and tempering heat treatment of the round steel with a diameter of  $\leq 90$ mm, the steel achieves a yield strength of  $\geq 1100$ MPa, a tensile strength of  $\geq 1250$ MPa, an elongation of  $\geq 15\%$ , a reduction of area of  $\geq 50\%$ , and an impact energy  $A_{kv2}$  at  $-40^{\circ}\text{C}$  of  $\geq 40$ J, satisfying the strength and toughness requirements of the round steel.

**[0061]** In addition, it should be noted that the chemical composition and process design of the medium carbon round steel according to the present invention are reasonable, and the process window is wide. Mass commercial production on bar production lines can be achieved, having good promotion prospects and application value.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0062]**

Figure 1 shows the as-rolled microstructure morphology of the medium carbon round steel of Example 1.

Figure 2 shows the microstructure morphology of the medium carbon round steel of Example 1 after step annealing.

Figure 3 shows the surface morphology of the medium carbon round steel of Example 1 after surface treatment.

Figure 4 shows the microstructure morphology of the medium carbon round steel of Example 1 after quenching and tempering.

## DETAILED DESCRIPTION

**[0063]** The medium carbon round steel according to the present invention and the manufacturing method therefor will be further explained and illustrated below in conjunction with the drawings and specific examples. However, the explanation and illustration shall not unduly limit the technical solutions of the present invention.

### Examples 1-6 and Comparative Examples 1-4

**[0064]** The medium carbon round steels of Examples 1-6 and the comparative round steels of Comparative Examples 1-4 were all manufactured by the following steps:

(1) smelting using an electric furnace or a converter, and casting into continuous casting billets or steel ingots with chemical compositions as shown in Table 1-1 and Table 1-2; during the casting process, mold casting or continuous casting may be used.

(2) heating: the heating temperature was controlled at  $1050\sim 1250^{\circ}\text{C}$ .

(3) forging or rolling: a finishing rolling or finishing forging temperature was controlled at  $\geq 800^{\circ}\text{C}$ . If forging is adopted, final required round steel size can be directly forged during the forging process. If rolling is adopted, during the rolling process, the steel billet can be directly rolled to the final specification, or the steel billet can be rolled to a specified intermediate billet size, and then heated and rolled to the final finished round steel size.

(4) Step annealing: the step annealing heat treatment process was holding at a temperature of  $770\sim 790^{\circ}\text{C}$  for 1~3h first, then holding at a temperature of  $590\sim 610^{\circ}\text{C}$  for 2~4h, then holding at a temperature of  $730\sim 750^{\circ}\text{C}$  for 1~3h, then holding at a temperature of  $690\sim 710^{\circ}\text{C}$  for 2~4h, then furnace cooling to below  $350^{\circ}\text{C}$  and discharging from the furnace for air cooling.

(5) Surface treatment: including turning, calendaring and sand belt polishing processes; wherein a turning feed rate was  $0.06\sim 0.10$  mm/r, a coolant flow rate was  $20\sim 28$  L/min, and a calendaring pressure was  $16\sim 20$  KN; the depth of sand belt polishing must exceed the depth of the cryptocrystalline martensite layer (white and shiny layer) produced by turning and calendaring.

**[0065]** Furthermore, to further improve the properties of the medium carbon round steel, a step (6) of quenching and

tempering heat treatment may be further performed after the above step (5): wherein a quenching temperature was 850°C~930°C, a holding time was 60~180 min, and water quenching or oil quenching was adopted; a tempering temperature was 460~530°C, a holding time was 60~180 min, and air cooling or water cooling was performed after tempering.

**[0066]** The medium carbon round steels of Examples 1-6 of the present invention were all manufactured by the above steps, and their chemical compositions and related process parameters all meet the design specification control requirements of the present invention.

**[0067]** The comparative round steels of Comparative Examples 1-4 were also manufactured by the above steps, but they have chemical composition design and related specific process parameters that do not meet the design specification requirements of the present invention.

**[0068]** Table 1-1 and Table 1-2 list each chemical element in percentage by mass in the medium carbon round steels of Examples 1-6 and the comparative round steels of Comparative Examples 1-4 (the balance of the chemical composition is Fe and inevitable impurities other than P, S, H, B, O, and Ti), the DI values, the values of  $[Al]/[N]$ , and the values of  $[Al]/[N] \times 10^4$ . The unit of chemical composition is wt%, and the unit of DI is in.  $[Al]/[N]$  and  $[Al]/[N] \times 10^4$  are obtained by substituting numbers for calculation and are dimensionless.

Table 1-1

| No.                   | Chemical elements |      |       |      |      |      |       |              |      |       |       |
|-----------------------|-------------------|------|-------|------|------|------|-------|--------------|------|-------|-------|
|                       | C                 | Si   | Mn    | Cr   | Mo   | Ni   | Al    | N            | Cu   | V     | Nb    |
| Example 1             | 0.385             | 0.20 | 0.6   | 0.75 | 0.20 | 1.5  | 0.02  | 0.01         | 0.02 | 0.003 | 0.005 |
| Example2              | 0.41              | 0.37 | 0.8   | 0.90 | 0.40 | 1.6  | 0.04  | 0.008        | 0    | 0     | 0     |
| Example3              | 0.43              | 0.10 | 0.7   | 0.85 | 0.25 | 1.6  | 0.03  | 0.015        | 0.10 | 0.01  | 0.05  |
| Example4              | 0.36              | 0.40 | 0.7   | 0.80 | 0.30 | 1.6  | 0.025 | 0.012        | 0.10 | 0.02  | 0     |
| Example5              | 0.37              | 0.20 | 1.0   | 0.60 | 0.22 | 1.4  | 0.028 | 0.013        | 0.20 | 0.05  | 0.02  |
| Example6              | 0.40              | 0.23 | 0.7   | 1.0  | 0.30 | 1.7  | 0.025 | 0.01         | 0.03 | 0     | 0.01  |
| Comparative Example 1 | 0.43              | 0.40 | 1.0   | 1.0  | 0.40 | 1.7  | 0.024 | 0.011        | 0.20 | 0.05  | 0.005 |
| Comparative Example 2 | 0.39              | 0.30 | 0.8   | 0.90 | 0.25 | 1.5  | 0.025 | <u>0.006</u> | 0.03 | 0.003 | 0.004 |
| Comparative Example 3 | 0.40              | 0.20 | 0.8 5 | 0.80 | 0.22 | 1.6  | 0.035 | <u>0.006</u> | 0.10 | 0.02  | 0.03  |
| Comparative Example 4 | 0.41              | 0.35 | 0.9   | 0.90 | 0.26 | 1.55 | 0.033 | <u>0.007</u> | 0.08 | 0.04  | 0.002 |

Table 1-2

| No.                   | Chemical elements |       |         |        |        |       | DI           | $[Al]/[N]$ | $[Al]/[N] \times 10^4$ |
|-----------------------|-------------------|-------|---------|--------|--------|-------|--------------|------------|------------------------|
|                       | P                 | S     | H       | B      | O      | Ti    |              |            |                        |
| Example 1             | 0.007             | 0.001 | 0.00015 | 0.0002 | 0.0019 | 0.002 | 4.72         | 2          | 2                      |
| Example 2             | 0.01              | 0.02  | 0.0002  | 0.001  | 0.002  | 0.01  | 10.21        | 5          | 3.2                    |
| Example 3             | 0.007             | 0.001 | 0.00018 | 0.0002 | 0.0013 | 0.003 | 6.5          | 2          | 4.5                    |
| Example 4             | 0.015             | 0.025 | 0.0002  | 0.0008 | 0.0008 | 0.08  | 7.71         | 2.1        | 3                      |
| Example 5             | 0.006             | 0.005 | 0.0001  | 0.0004 | 0.0012 | 0.002 | 6.87         | 2.2        | 3.6                    |
| Example 6             | 0.003             | 0.002 | 0.00012 | 0.0003 | 0.0011 | 0.06  | 8.12         | 2.5        | 2.5                    |
| Comparative Example 1 | 0.005             | 0.003 | 0.00018 | 0.0005 | 0.0012 | 0.002 | <u>16.02</u> | 2.2        | 2.6                    |
| Comparative Example 2 | 0.012             | 0.008 | 0.00018 | 0.0008 | 0.0015 | 0.04  | 7.59         | 4.2        | <u>1.5</u>             |
| Comparative Example 3 | 0.014             | 0.024 | 0.00019 | 0.0005 | 0.0016 | 0.03  | 7.17         | 5.8        | 2.1                    |
| Comparative Example 4 | 0.015             | 0.01  | 0.0002  | 0.0004 | 0.0019 | 0.005 | 9.69         | 4.7        | 2.3                    |

**[0069]** Table 2-1 and Table 2-2 list the specific process parameters of the medium carbon round steels of Examples 1-6 and the comparative round steels of Comparative Examples 1-4 in the above process steps.

Table 2-1

| No.                   | Step (2)                 | Step (3)                                       |                                                           |                                  |                                             |                                    | Step (4)                            |                                        |
|-----------------------|--------------------------|------------------------------------------------|-----------------------------------------------------------|----------------------------------|---------------------------------------------|------------------------------------|-------------------------------------|----------------------------------------|
|                       | Heating temperature (°C) | Whether an intermediate billet is manufactured | Finishing rolling temperature of intermediate billet (°C) | Intermediate billet heating (°C) | Intermediate billet size (mm <sup>2</sup> ) | Finishing rolling temperature (°C) | Step annealing temperature and time | Furnace cooling final temperature (°C) |
| Example 1             | 1050                     | Yes                                            | 800                                                       | 1070                             | 215×215                                     | 820                                | 780°C×2h+600°C×3h+740°C×2h+700°C×3h | 305                                    |
| Example 2             | 1150                     | Yes                                            | 880                                                       | 1100                             | 215×215                                     | 830                                | 770°C×3h+600°C×3h+740°C×2h+700°C×3h | 210                                    |
| Example 3             | 1180                     | No                                             | -                                                         | -                                | -                                           | 940                                | 790°C×2h+610°C×2h+740°C×2h+700°C×2h | 348                                    |
| Example 4             | 1220                     | No                                             | -                                                         | -                                | -                                           | 800                                | 780°C×3h+600°C×4h+750°C×3h+690°C×4h | 105                                    |
| Example 5             | 1250                     | Yes                                            | 860                                                       | 1250                             | 215×215                                     | 880                                | 780°C×1h+600°C×2h+730°C×1h+700°C×2h | 51                                     |
| Example 6             | 1200                     | Yes                                            | 830                                                       | 1150                             | 215×215                                     | 860                                | 780°C×2h+590°C×2h+740°C×2h+710°C×2h | 302                                    |
| Comparative Example 1 | 1170                     | No                                             | -                                                         | -                                | -                                           | 880                                | 780°C×3h+600°C×2h+740°C×2h+700°C×3h | 56                                     |
| Comparative Example 2 | 1200                     | No                                             | -                                                         | -                                | -                                           | 900                                | 780°C×2h+600°C×2h+740°C×2h+700°C×2h | 108                                    |
| Comparative Example 3 | 1180                     | Yes                                            | 850                                                       | 1050                             | 215×215                                     | 850                                | <u>740°C×8h+700°C×6h</u>            | 210                                    |
| Comparative Example 4 | 1210                     | Yes                                            | 900                                                       | 1200                             | 215×215                                     | 820                                | 780°C×2h+600°C×2h+740°C×2h+700°C×2h | 188                                    |

Table 2-2

| No.                   | Step (5)                 |                           |                           | Step (6)                   |                            |                            |                            | Finished bar diameter (mm) |
|-----------------------|--------------------------|---------------------------|---------------------------|----------------------------|----------------------------|----------------------------|----------------------------|----------------------------|
|                       | Turning feed rate (mm/r) | Coolant flow rate (L/min) | Calendaring pressure (KN) | Quenching temperature (°C) | Quenching holding time (h) | Tempering temperature (°C) | Tempering holding time (h) |                            |
| Example 1             | 0.10                     | 20                        | 20                        | 860                        | 3                          | 520                        | 3                          | 90                         |
| Example 2             | 0.08                     | 22                        | 18                        | 860                        | 2                          | 520                        | 2                          | 60                         |
| Example 3             | 0.09                     | 23                        | 16                        | 930                        | 3                          | 460                        | 3                          | 90                         |
| Example 4             | 0.07                     | 21                        | 17                        | 860                        | 1                          | 520                        | 1                          | 30                         |
| Example 5             | 0.10                     | 20                        | 20                        | 850                        | 3                          | 530                        | 3                          | 90                         |
| Example 6             | 0.06                     | 28                        | 18                        | 900                        | 3                          | 500                        | 3                          | 90                         |
| Comparative Example 1 | 0.09                     | 23                        | 16                        | 860                        | 3                          | 520                        | 3                          | 90                         |
| Comparative Example 2 | 0.07                     | 21                        | 17                        | 860                        | 3                          | 520                        | 3                          | 90                         |
| Comparative Example 3 | 0.10                     | 20                        | 20                        | 860                        | 3                          | 520                        | 3                          | 90                         |
| Comparative Example 4 | <u>0.20</u>              | <u>15</u>                 | <u>30</u>                 | 860                        | 3                          | 520                        | 3                          | 90                         |

**[0070]** After step (5) and before step (6), the obtained medium carbon round steels of Examples 1-6 and the comparative round steels of Comparative Examples 1-4 were sampled and subjected to various related performance tests:

(1) The bar specimens of the examples and comparative examples were tested according to GB/T 231.1 "Metallic materials-Brinell hardness test-Part 1: Test method" to detect the Brinell hardness of the bars of the examples and comparative examples, and the measured Brinell hardness results are listed in Table 3-1.

(2) The bar specimens of the examples and comparative examples were subjected to microstructure inspection according to GB/T 13298 "Inspection methods of microstructure for metals" to obtain the thickness of the white and shiny layer and the volume fraction of lamellar pearlite of the bars of the examples and comparative examples, and the inspection results are listed in Table 3-2.

**[0071]** The medium carbon round steels of Examples 1-6 and the comparative round steels of Comparative Examples 1-4 obtained before and after step (6) were sampled and tested according to GB/T 228.1 "Metallic materials-Tensile testing-Part 1: Method of test at room temperature" and GB/T 229 "Metallic materials-Charpy notch impact test method" to obtain the mechanical properties of the bars of the examples and comparative examples. The relevant examination results are listed in Table 3-3 (without quenching and tempering) and Table 3-4 (after quenching and tempering).

Table 3-1

| No.                   | Brinell hardness (HBW) |
|-----------------------|------------------------|
| Example 1             | 197                    |
| Example 2             | 193                    |
| Example 3             | 205                    |
| Example 4             | 202                    |
| Example 5             | 188                    |
| Example 6             | 195                    |
| Comparative Example 1 | 210                    |
| Comparative Example 2 | 185                    |
| Comparative Example 3 | <b><u>165</u></b>      |
| Comparative Example 4 | 190                    |

Table 3-2

| No.                   | White and shiny layer thickness ( $\mu\text{m}$ ) | Volume fraction of lamellar pearlite (%) |
|-----------------------|---------------------------------------------------|------------------------------------------|
| Example 1             | 0                                                 | 40                                       |
| Example 2             | 0                                                 | 38                                       |
| Example 3             | 0                                                 | 42                                       |
| Example 4             | 0                                                 | 41                                       |
| Example 5             | 0                                                 | 37                                       |
| Example 6             | 0                                                 | 39                                       |
| Comparative Example 1 | 0                                                 | 45                                       |
| Comparative Example 2 | 0                                                 | 35                                       |
| Comparative Example 3 | 0                                                 | <b><u>19</u></b>                         |
| Comparative Example 4 | <b><u>9.2</u></b>                                 | 37                                       |

Table 3-3

| No.                   | Yield strength (MPa) | Tensile strength (MPa) | Elongation (%) | Reduction of area (%) | Longitudinal impact energy KV2 at -40°C (J) |
|-----------------------|----------------------|------------------------|----------------|-----------------------|---------------------------------------------|
| Example 1             | 421                  | 623                    | 36             | 64                    | 28                                          |
| Example 2             | 412                  | 615                    | 37             | 66                    | 30                                          |
| Example 3             | 452                  | 650                    | 34             | 62                    | 25                                          |
| Example 4             | 442                  | 641                    | 35             | 63                    | 27                                          |
| Example 5             | 409                  | 605                    | 38             | 66                    | 29                                          |
| Example 6             | 422                  | 620                    | 36             | 64                    | 29                                          |
| Comparative Example 1 | 460                  | 662                    | 32             | 61                    | 23                                          |
| Comparative Example 2 | 402                  | 601                    | 39             | 68                    | 24                                          |
| Comparative Example 3 | <b>389</b>           | <b>585</b>             | 40             | 70                    | 28                                          |
| Comparative Example 4 | 423                  | 621                    | 36             | 65                    | 39                                          |

Table 3-4

| No.                   | Yield strength (MPa) | Tensile strength (MPa) | Elongation (%) | Reduction of area (%) | Longitudinal impact energy KV2 at -40°C (J) |
|-----------------------|----------------------|------------------------|----------------|-----------------------|---------------------------------------------|
| Example 1             | 1118                 | 1250                   | 16             | 53                    | 41                                          |
| Example 2             | 1180                 | 1290                   | 15             | 51                    | 42                                          |
| Example 3             | 1130                 | 1259                   | 16             | 53                    | 45                                          |
| Example 4             | 1124                 | 1260                   | 16             | 52                    | 45                                          |
| Example 5             | 1140                 | 1265                   | 15             | 51                    | 43                                          |
| Example 6             | 1175                 | 1286                   | 16             | 52                    | 51                                          |
| Comparative Example 1 | 1220                 | 1315                   | 15             | 50                    | 53                                          |
| Comparative Example 2 | <b>1086</b>          | <b>1190</b>            | 16             | 56                    | 40                                          |
| Comparative Example 3 | 1120                 | 1255                   | 15             | 52                    | 43                                          |
| Comparative Example 4 | 1142                 | 1270                   | 16             | 53                    | 47                                          |

**[0072]** Table 3-5 lists the statistical results of the number of cracked pieces after cold extrusion among 10,000 samples of speed reducer shaft components manufactured from the medium carbon round steels of Examples 1-6 and the comparative round steels of Comparative Examples 1-4, wherein for Comparative Example 3, the number of bent pieces was counted. Cold extrusion was carried out in a closed die, with a maximum deformation of  $20\% \pm 1\%$ . After cold extrusion, magnetic particle inspection was adopted to determine whether the sample was cracked, and visual inspection was adopted to determine whether the sample was bent.

Table 3-5

| No.       | Number of cracked or bent pieces (piece) |
|-----------|------------------------------------------|
| Example 1 | 0                                        |
| Example 2 | 1                                        |
| Example 3 | 2                                        |
| Example 4 | 0                                        |
| Example 5 | 0                                        |
| Example 6 | 1                                        |

(continued)

| No.                   | Number of cracked or bent pieces (piece) |
|-----------------------|------------------------------------------|
| Comparative Example 1 | <u>715</u>                               |
| Comparative Example 2 | <u>153</u>                               |
| Comparative Example 3 | <u>536</u>                               |
| Comparative Example 4 | <u>865</u>                               |

**[0073]** It can be seen from Table 3-1 that, compared with Comparative Example 3, the Brinell hardness of the medium carbon round steels of Examples 1-6 manufactured by the technical solution of the present invention all meet the requirement of 185~210HBW, while Comparative Example 3 results in relatively low hardness due to the adoption of a conventional spheroidizing annealing process, which leads to bending of the shaft billet during the subsequent cold extrusion process.

**[0074]** It can be seen from Table 3-2 that, compared with Comparative Example 4, the surfaces of the medium carbon round steels of Examples 1-6 manufactured by the technical solution of the present invention have no hardened layer, and the volume fraction of lamellar pearlite is within the range of 35~45%, whereas Comparative Example 4, for which the surface treatment process was not strictly controlled, has a hardened layer on the surface, which increases the cracking rate in the subsequent cold extrusion process.

**[0075]** It can be seen from Table 3-3 that, compared with Comparative Example 3, the mechanical properties of the medium carbon round steels of Examples 1-6 manufactured by the technical solution of the present invention all meet the yield strength of  $\geq 400\text{MPa}$ , the tensile strength of  $\geq 600\text{MPa}$ , the elongation of  $\geq 30\%$ , the reduction of area of  $\geq 60\%$ , and the impact energy  $A_{kv2}$  at  $-40^\circ\text{C}$  of  $\geq 20\text{J}$ . While Comparative Example 3 results in a relatively low proportion of lamellar pearlite due to the adoption of a conventional annealing process, so the strength is lower than the requirement of the present invention.

**[0076]** It can be seen from Table 3-4 that, compared with Comparative Example 2, the mechanical properties of the medium carbon round steels of Examples 1-6 manufactured by the technical solution of the present invention after quenching and tempering all meet the requirements of yield strength  $\geq 1100\text{MPa}$ , tensile strength  $\geq 1250\text{MPa}$ , elongation  $\geq 15\%$ , reduction of area  $\geq 50\%$ , and impact energy  $A_{kv2}$  at  $-40^\circ\text{C}$   $\geq 40\text{J}$ , while for Comparative Example 2, the N content does not meet the requirements of the present invention, the fine grain strengthening effect of AlN is not fully exhibited, and thus the strength does not meet the requirements.

**[0077]** It can be seen from Table 3-5 that, compared with Comparative Examples 1-4, the medium carbon round steels of Examples 1-6 manufactured by the technical solution of the present invention have a very low cracking rate after cold extrusion, all within five per ten thousand.

**[0078]** Figure 1 shows the as-rolled microstructure morphology of the medium carbon round steel of Example 1. As shown in Figure 1, the as-rolled microstructure of the medium carbon round steel of Example 1 is bainite.

**[0079]** Figure 2 shows the microstructure morphology of the medium carbon round steel of Example 1 after step annealing. As shown in Figure 2, the microstructure of the annealed medium carbon round steel of Example 1 is lamellar pearlite + spheroidal pearlite, and the volume fraction of lamellar pearlite is about 40%.

**[0080]** Figure 3 shows the surface morphology of the medium carbon round steel of Example 1 after surface treatment. As shown in Figure 3, after surface treatment, the surface of the medium carbon round steel of Example 1 has only very slight burrs and no other surface defects.

**[0081]** Figure 4 shows the microstructure morphology of the medium carbon round steel of Example 1 after quenching and tempering. As shown in Figure 4, the microstructure of the quenched and tempered medium carbon round steel of Example 1 is tempered sorbite.

**[0082]** In summary, it can be seen that the present invention solves the problem of incompatibility between medium carbon steel and the cold forming process through reasonable chemical composition design combined with an optimized process, and can obtain a medium carbon round steel for cold extrusion that meets the requirements.

**[0083]** It should be noted that the chemical composition and process design of the medium carbon round steel according to the present invention are reasonable, and the process window is wide. Mass commercial production on bar production lines can be achieved, having good promotion prospects and application value.

**[0084]** In addition, the combination manner of the technical features in the present invention are not limited to the combination manner recorded in the claims or in the specific embodiments of the present invention, and all the technical features recorded in the present invention can be freely combined or joined in any manner, unless they contradict each other.

**[0085]** It should also be noted that the above-listed are only specific embodiments of the present invention, and it is obvious that the present invention is not limited to the above embodiments, and many similar variations follow. All

variations that those skilled in the art can directly derive or associate from the disclosure of the present invention shall fall within the protection scope of the present invention.

## Claims

1. A medium carbon round steel, **characterized in that**, in addition to Fe and inevitable impurities, the medium carbon round steel further comprises the following chemical elements in percentage by mass:

C: 0.36~0.43%, Si: 0.1~0.4%, Mn: 0.6~1.0%, Cr: 0.6~1.0%, Mo: 0.2~0.4%, Ni: 1.4~1.7%, Al: 0.02~0.04%, N: 0.008~0.015%;

wherein a DI value of the medium carbon round steel is 4.72~10.21in, wherein  $DI = (0.171 + 0.001C + 0.265C^2)(1 + 3.333Mn)(1 + 0.7Si)(1 + 0.365Cu)(1 + 2.16Cr)(1 + 3Mo)(1 + 0.363Ni)(1 + 1.73V)$ ; wherein during calculation, each element symbol in the formula is substituted with the numerical value before the percent symbol of the mass percentage of the corresponding element in the medium carbon round steel;

wherein the medium carbon round steel is obtained by annealing, and the medium carbon round steel has a microstructure of lamellar pearlite + spheroidal pearlite.

2. The medium carbon round steel according to claim 1, **characterized in that**, the medium carbon round steel consists of the following chemical elements in percentage by mass:

C: 0.36~0.43%, Si: 0.1~0.4%, Mn: 0.6~1.0%, Cr: 0.6~1.0%, Mo: 0.2~0.4%, Ni: 1.4~1.7%, Al: 0.02~0.04%, N: 0.008~0.015%, and the balance of Fe and inevitable impurities.

3. The medium carbon round steel according to claim 1 or 2, **characterized in that**, the medium carbon round steel further comprises at least one of the following chemical elements:  $0 < Cu \leq 0.20\%$ ,  $0 < V \leq 0.05\%$ ,  $0 < Nb \leq 0.05\%$ .

4. The medium carbon round steel according to claim 1 or 2, **characterized in that**, the inevitable impurities at least satisfy one of the following:  $P \leq 0.015\%$ ,  $S \leq 0.025\%$ ,  $H \leq 0.0002\%$ ,  $B \leq 0.001\%$ ,  $O \leq 0.0020\%$ ,  $0 < Ti \leq 0.08\%$ , preferably  $0 < Ti \leq 0.01\%$ .

5. The medium carbon round steel according to claim 1 or 2, **characterized in that**, Al and N elements in the medium carbon round steel satisfy:  $[Al]/[N] \geq 2$ ,  $[Al][N] \geq 2 \times 10^{-4}$ .

6. The medium carbon round steel according to claim 1 or 2, **characterized in that**, the lamellar pearlite in the medium carbon round steel has a volume fraction of 35~45%.

7. The medium carbon round steel according to claim 1 or 2, **characterized in that**, the medium carbon round steel has a hardness of 185~210HBW.

8. The medium carbon round steel according to claim 1 or 2, **characterized in that**, the medium carbon round steel satisfies at least one of the following: yield strength  $\geq 400\text{MPa}$ , tensile strength  $\geq 600\text{MPa}$ , elongation  $\geq 30\%$ , reduction of area  $\geq 60\%$ , impact energy Akv2 at  $-40^\circ\text{C} \geq 20\text{J}$ .

9. The medium carbon round steel according to claim 1 or 2, **characterized in that**, after quenching and tempering, the medium carbon round steel has a yield strength of  $\geq 1100\text{MPa}$ , a tensile strength of  $\geq 1250\text{MPa}$ , an elongation of  $\geq 15\%$ , a reduction of area of  $\geq 50\%$ , and an impact energy Akv2 at  $-40^\circ\text{C} \geq 40\text{J}$ .

10. A method for manufacturing the medium carbon round steel according to any one of claims 1-9, **characterized in that**, the method comprises the following steps performed in sequence:

(1) smelting and casting;

(2) heating;

(3) forging or rolling to obtain a round steel;

(4) step annealing: first, holding at a temperature of  $770\sim 790^\circ\text{C}$  for 1~3h, then holding at a temperature of  $590\sim 610^\circ\text{C}$  for 2~4h, then holding at a temperature of  $730\sim 750^\circ\text{C}$  for 1~3h, then holding at a temperature of  $690\sim 710^\circ\text{C}$  for 2~4h, then furnace cooling to below  $350^\circ\text{C}$  and discharging from the furnace for air cooling;

(5) surface treatment to remove a martensitic hardened layer on the surface of the round steel, so as to obtain a medium carbon round steel having no martensitic hardened layer on the surface.

11. The method according to claim 10, **characterized in that**, in step (2), a heating temperature is 1050~1250°C.
12. The method according to claim 10, **characterized in that**, in step (3), a finishing rolling or finishing forging temperature is  $\geq 800^{\circ}\text{C}$ .
- 5 13. The method according to claim 10, **characterized in that**, in step (5), the surface treatment comprises turning, wherein a turning feed rate is 0.06~0.10 mm/r, and a coolant flow rate is 20~28 L/min.
- 10 14. The method according to claim 10, **characterized in that**, in step (5), the surface treatment comprises calendaring, wherein a calendaring pressure is 16~20 KN.
- 15 15. The method according to claim 10, **characterized in that**, in step (5), the surface treatment comprises sand belt polishing, by which a cryptocrystalline martensite layer produced by turning and calendaring is removed.
- 20 16. The method according to any one of claims 10-15, **characterized in that**, the method further comprises a step (6) of quenching and tempering after step (5), wherein a quenching temperature is 850°C~930°C, a holding time is 60~180 min, and water quenching or oil quenching is adopted; a tempering temperature is 460~530°C, a holding time is 60~180 min, and air cooling or water cooling is performed after tempering.

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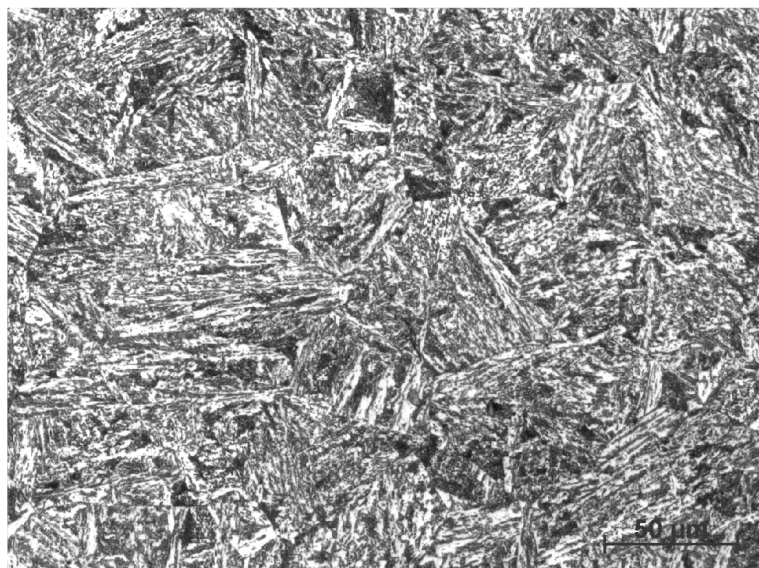


Figure 1

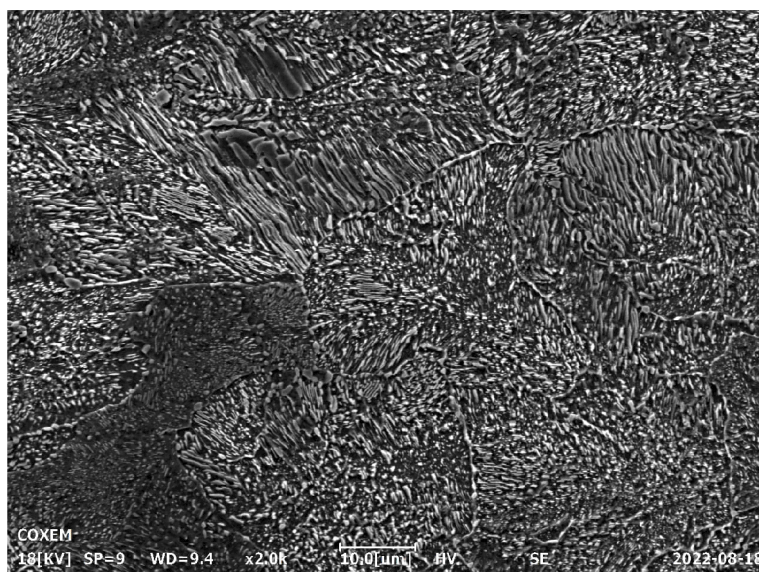


Figure 2

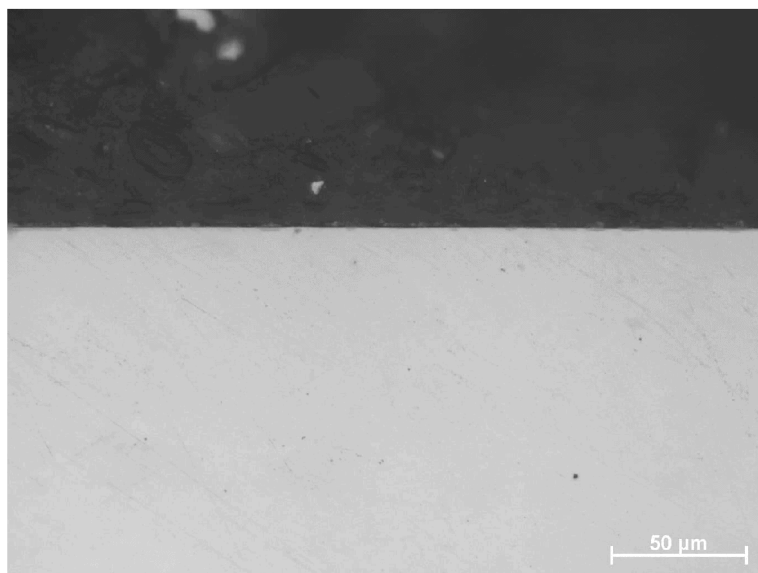


Figure 3

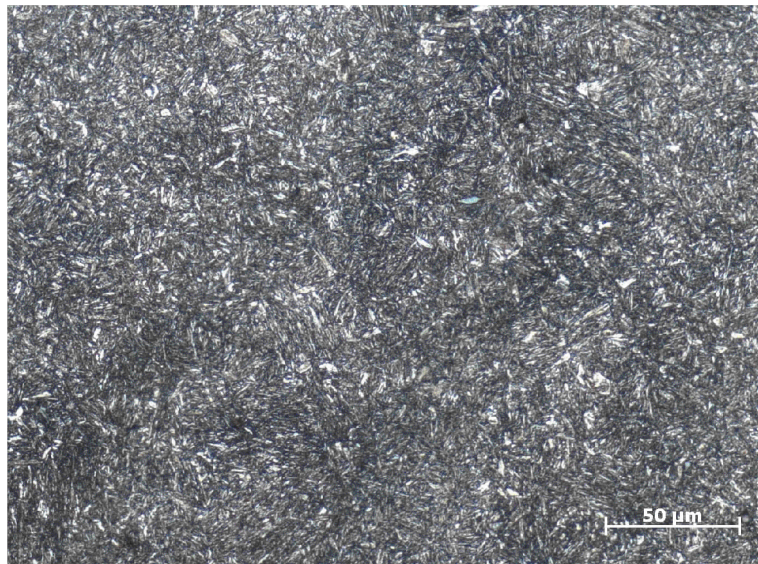


Figure 4

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2025/074311

## A. CLASSIFICATION OF SUBJECT MATTER

C22C38/02(2006.01)i; C22C38/04(2006.01)i; C22C38/06(2006.01)i; C22C38/44(2006.01)i; C21D8/06(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)

IPC:C22C, C21D

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)

CNTXT, ENTXTC, VEN, WPABS, WPABSC, Web of Science, CNKI: 圆钢, 退火, 片状珠光体, 球状珠光体, 碳, 锰, 镍, 铬, 钼, C, Mn, Ni, Cr, Mo, round steel, annealed, lamellar pearlite, spheroidal pearlite, carbon, manganese, nickel, chromium, molybdenum

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                                                                        | Relevant to claim No. |
|-----------|-----------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
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| A         | CN 112981233 A (JIANGYIN XINGCHENG SPECIAL STEEL WORKS CO., LTD.) 18 June 2021 (2021-06-18)<br>entire document                                            | 1-16                  |
| A         | CN 111378824 A (NORTHEASTERN UNIVERSITY) 07 July 2020 (2020-07-07)<br>entire document                                                                     | 1-16                  |
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| A         | HU P9701641 A3 (HANÁK, J.) 28 December 1999 (1999-12-28)<br>entire document                                                                               | 1-16                  |

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

|                                                                                                                                                                         |                                                                                                                                                                                                                                                  |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| * Special categories of cited documents:                                                                                                                                | "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                                              |
| "A" document defining the general state of the art which is not considered to be of particular relevance                                                                | "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                                                                     |
| "D" document cited by the applicant in the international application                                                                                                    | "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 |
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| "P" document published prior to the international filing date but later than the priority date claimed                                                                  |                                                                                                                                                                                                                                                  |

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|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------|
| Date of the actual completion of the international search<br><b>10 April 2025</b>                                                                                                              | Date of mailing of the international search report<br><b>18 April 2025</b> |
| Name and mailing address of the ISA/CN<br><b>China National Intellectual Property Administration (ISA/CN)<br/>China No. 6, Xitucheng Road, Jimenqiao, Haidian District,<br/>Beijing 100088</b> | Authorized officer<br><br><br>Telephone No.                                |

Form PCT/ISA/210 (second sheet) (July 2022)

**INTERNATIONAL SEARCH REPORT**  
**Information on patent family members**

International application No.

**PCT/CN2025/074311**

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| Patent document cited in search report |              |    |  | Publication date (day/month/year) |  | Patent family member(s) |            | Publication date (day/month/year) |  |
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Form PCT/ISA/210 (patent family annex) (July 2022)

**REFERENCES CITED IN THE DESCRIPTION**

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