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(54) STEEL FOR ALLOY STRUCTURE AND MANUFACTURING METHOD THEREFOR

(57) Disclosed is a steel for an alloy structure, the chemical elements of the steel being, in percentage by mass: 0.35-0.45% of C, 0.27-0.35% of Si, 0.6-0.8% of Mn, 0.015-0.05% of Al, 0.06-0.1% of V, 0.2-1.0% of Zr, 0.001-0.005% of Mg, 0.025% or less of P, 0.015% or less of S, 0.005% or less of N, 0.001% or less of O, the balance being Fe and other inevitable impurities. In addition, also disclosed is a manufacturing method for the steel for an alloy structure, the method comprising steps of: (1) smelting, refining, and casting; (2) blooming and cogging; (3) secondary hot rolling to form a product; and (4) heat treatment including quenching and tempering. The steel for an alloy structure is designed by adding trace alloy elements, the steel for an alloy structure is further strengthened and toughened, and the manufacturing cost is low.

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Description

Field

[0001] The present invention relates to a steel type and a manufacturing method thereof, in particular to a steel for an alloy structure and a manufacturing method therefor.

Background

[0002] 40CrV can be used for manufacturing various variable-load and high-load important parts, such as a locomotive connecting rod, a crankshaft, a pushing rod, a propeller, a beam, a shaft sleeve bracket, a double-ended stud, a screw, a non-carburized gear, various gears and pins subjected to carburization, a high-pressure boiler water pump shaft (the diameter is smaller than 30mm), a high-pressure cylinder, a steel pipe, a bolt (its working temperature is lower than 420°C, and the strength is 30MPa), and the like.

[0003] According to the alloy structure steel standard (GB/T 3077-2015), the ingredient range of the existing 40CrV is as follows: 0.37-0.44wt% of C; 0.17-0.37wt% of Si; 0.5-0.8wt% of Mn; 0.015wt% or less of S; 0.025wt% or less of P; 0.8-1.1wt% of Cr; 0.1-0.2wt% of V; and 0.015wt or more of Al. The mechanical properties of the steel type are as follows: the yield strength (Rel) is 735MPa or more; the tensile strength (Rm) is 885MPa or more; the elongation percentage is 10% or more; the hardness is 241HB or more; and the impact toughness is 71J or more.

[0004] With development of technologies, the mechanical properties of the steel type cannot completely meet the requirements of actual application and manufacturing at present, and on this basis, it is expected to obtain a steel for an alloy structure, which is higher in mechanical property, higher in impact toughness and more reasonable in cost, so as to meet the requirement of actual application.

Summary

[0005] One objective of the present invention is to provide a steel for an alloy structure. The steel for the alloy structure is designed by adding trace alloy elements. By adding a proper amount of Zr and Mg, controlling the low content of total oxygen, and utilizing the characteristics of the added trace alloy elements, the steel for the alloy structure is further strengthened and toughened, so that the steel for the alloy structure has high strength and low material cost.

[0006] In order to achieve the objective above, the present invention provides a steel for an alloy structure, including the following chemical elements in percentage by mass:

[0007] 0.35-0.45% of C, 0.27-0.35% of Si, 0.6-0.8% of Mn, 0.015-0.05% of Al, 0.06-0.1% of V, 0.2-1.0% of Zr, 0.001-0.005% of Mg, 0.025% or less of P, 0.015% or less of S, 0.005% or less of N, 0.001% or less of O, the balance being Fe and other inevitable impurities.

[0008] In the steel for the alloy structure according to the present invention, a design principle of each chemical element is as follows:

[0009] C: in the steel for the alloy structure according to the present invention, C mainly influences the precipitation amount and the precipitation temperature range of carbides. Controlling the relatively low mass percentage of C is beneficial for improving the mechanical properties of the steel for the alloy structure according to the present invention. In addition, C has a certain strengthening effect, but the excessively high mass percentage of C may reduce the corrosion resistance of the material. In view of the production capacity of smelting equipment and consideration to the mechanical properties and the impact toughness of the material, in the steel for the alloy structure according to the present invention, the mass percentage of C is controlled within a range of 0.35-0.45%.

[0010] Si: Si can improve the strength of the steel, but is disadvantageous for the formability and the toughness of the steel. In addition, there is often residual Si in the smelting process, so it is very important to properly select the content of Si. On this basis, in the steel for the alloy structure according to the present invention, the mass percentage of Si is controlled within a range of 0.27-0.35%.

[0011] Mn: Mn is a relatively weak austenite element, and can inhibit the adverse effect of sulphur in steel for the alloy structure and improve the thermoplasticity. However, the excessively high mass percentage of Mn is disadvantageous for ensuring the corrosion resistance of the steel. In consideration of a case that there is often residual Mn in the smelting process, in the technical solution of the present invention, the mass percentage of Mn is controlled within a range of 0.6-0.8%

[0012] Al: in the steel for the alloy structure according to the present invention, Al mainly influences the dislocation behavior by controlling the oxygen content in steel so as to strengthen alloy structure. Increase of the total amount of Al can obviously increase the solution temperature and improve the mechanical properties, but may cause loss of plasticity. In addition, adding Al is beneficial to the elongation deformation performance of the steel and beneficial for improving the machining performance of the steel. The excessively high Al content may reduce the impact toughness

of the steel. On this basis, in the steel for the alloy structure according to the present invention, the mass percentage of Al is controlled within a range of 0.015-0.05%.

[0013] V: in the technical solution of the present invention, V has ultra-strong affinity for carbon and oxygen and can form corresponding stable compounds. V exists in steel mainly in a form of carbide, and V has the main effects of refining the structure and crystal grains of the steel and reducing the strength and the toughness of the steel. When V is dissolved into a solid solution at a high temperature, the quenching degree is improved; and on the contrary, if V exists in the form of carbide, the quenching degree is reduced. In addition, V can improve the tempering stability of quenched steel and generate the secondary hardening effect. Vanadium in the steel for the alloy structure may reduce the quenching degree under the general heat treatment conditions, and thus is usually combined with manganese and chromium elements for use in the steel for the alloy structure. Vanadium is mainly used for improving the strength and the yield strength ratio of the steel, refining the crystal grains, and reducing the overheating sensitivity in quenched and tempered steel. On this basis, in the steel for the alloy structure according to the present invention, the mass percentage of V is controlled within a range of 0.06-0.1%.

[0014] Zr: in the steel for the alloy structure according to the present invention, Zr is a strong carbide forming element and has the effects similar to those of niobium, tantalum, and vanadium in steel. Addition of a small amount of Zr can take effects of degasifying, purifying and refining the crystal grains, which is beneficial to the low-temperature performance of the steel and improves the stamping performance. In addition, the small amount of Zr is added, and part of Zr is solutionized in the steel to form a proper amount of ZrC and ZrN so as to facilitate refining the crystal grains and improving the stamping performance. On this basis, in the steel for the alloy structure according to the present invention, the mass percentage of Zr is controlled within a range of 0.2-1.0%.

[0015] Mg: Mg is a very active metal element and has very strong affinity for O, N and S. Therefore, Mg is a good deoxidizing and desulfurizing agent in steel smelting, and meanwhile, is also a good nodulizing agent for cast iron. However, Mg is very difficult to dissolve in a the cast iron, and exists in a state of compounds MgS, MgO, Mg_3N_2, and Mg_2Si. In addition, Mg and C may also form a series of compounds, such as MgC_2 and Mg_2C_3. On this basis, in the steel for the alloy structure according to the present invention, the mass percentage of Mg is controlled within a range of 0.001-0.005%.

[0016] P and S: both P and S may seriously influence the mechanical properties and the machining performance of the steel for the alloy structure in the invention and the mass percentages of P and S must be strictly controlled, and thus, P is 0.025% or less and S is 0.015% or less.

[0017] N: N is an element that stabilizes austenite. Controlling the relatively low mass percentage of N is beneficial for improving the impact toughness of the steel for the alloy structure according to the present invention. In addition, the relatively high mass percentage of nitrogen may cause reduction of the toughness and the malleability of the steel and may also reduce the hot workability. On this basis, in the steel for the alloy structure according to the present invention, the mass percentage of N is controlled within a range of 0.005% or less.

[0018] O: in the steel for the alloy structure according to the present invention, O exists mainly in a form of an oxide inclusion, and the high total oxygen content represents the high inclusion content. Reduction of the total oxygen content is beneficial for improving the comprehensive performance of the material. In order to ensure the excellent mechanical properties and corrosion resistance of the material, in the technical solution of the present invention, the mass percentage of O is controlled within a range of 0.001% or less.

[0019] Further, the steel for the alloy structure according to the present invention further includes at least one selected from the following chemical elements: Ce, Hf, La, Re, Sc, and Y, and the total addition amount of these elements is 1% or less.

[0020] In the technical solution of the present invention, preferably, a small amount of the above rare earth elements can be added to be combined with oxygen and sulphur elements in the steel so as to form rare earth oxide and sulfide, thereby purifying molten steel and reducing the size of the inclusion. In addition, the formed rare earth oxide and sulfide can be used as nucleation particles in a solidification process to refine initially solidified crystal grains, and also has a certain help for improving the performance of the steel.

[0021] Further, in the steel for the alloy structure according to the present invention, the content by mass of elements satisfies at least one of the following:

0.08-0.1% of V;
0.3-0.7% of Zr; and
0.001-0.003% of Mg.

[0022] Further, in the steel for the alloy structure according to the present invention, a ratio of the content by mass of elements further satisfies at least one of the following:

$$Zr/N=40\text{-}200;$$

$$Zr/V=2\text{-}16.7;$$

and

$$Zr/C=0.4\text{-}2.8.$$

[0023] In the solution, the mass percentages of Zr, N, V and C are controlled so as to facilitate controlling the amount of formed ZrC and ZrN, formation of ZrC and ZrN can take effects of refining the crystal grains and improving the mechanical properties and the stamping resistance of the steel, and meanwhile, can also take effects of solidifying part of N in the steel and reducing the mass percentage of solutionized N.

[0024] Further, in the steel for the alloy structure according to the present invention, a ratio of the content by mass of elements further satisfies at least one of the following:

$$Mg/O=0.5\sim3;$$

and

$$Mg/S=0.6\sim5.0.$$

[0025] In the solution, control on the mass percentages of Mg and O as well as S can facilitate the amount of formed MgO and MgS in an alloy in the cooling solidification process, and formation of MgS and MgO, in one aspect, can take effects of further refining the crystal grains and stabilizing austenite crystal grains, and in the other aspect, can also reduce hazards of O and S in the alloy to a crystal boundary so as to improve the impact toughness of the steel for the alloy structure in the invention.

[0026] Further, in the steel for the alloy structure according to the present invention, a microstructure thereof is ferrite + pearlite, and the steel for the alloy structure contains ZrC, ZrN, MgO, and MgS particles.

[0027] The ZrC, ZrN, MgO, and MgS particles mean that ZrC, ZrN, MgO, and MgS exist in a form of fine particles in the steel for the alloy structure. The particles can further refine and stabilize the size of the austenite crystal grains in the process of continuous casting and cooling solidification, and the hot rolling process so as to avoid formation of defects on the surface of a blank or a finished product and meanwhile, the mechanical properties of the product is also improved.

[0028] Further, in the steel for the alloy structure according to the present invention, the sum of the number of the ZrC and ZrN particles is 3-15 pieces/mm^2.

[0029] In the solution, the inventor of the invention finds that controlling the sum of the number of the ZrC and ZrN particles within a range of 3-15 pieces/mm^2 takes better effects of refining the crystal grains, improving the mechanical properties and the stamping performance of the steel and solidifying part of N in the steel, and reducing the mass percentage of solutionized N.

[0030] Further, in the steel for the alloy structure according to the present invention, the sum of the number of the MgO and MgS particles is 5-20 pieces/mm^2.

[0031] In the solution, the inventor of the invention finds that controlling the sum of the number of the MgO and MgS particles within a range of 5-20 pieces/mm^2 takes better effects of further refining the crystal grains, stabilizing the austenite crystal grains, and reducing hazards of O and S in the alloy to the crystal boundary so as to improve the impact toughness of the steel for the alloy structure of the invention.

[0032] Further, in the steel for the alloy structure according to the present invention, the grains of ZrC, ZrN, MgO, and MgS particles have a diameter of 0.2-7μm.

[0033] Further, in the steel for the alloy structure according to the present invention, the yield strength is 755MPa or more, the tensile strength is 900MPa or more, the elongation percentage is 12% or more, and the impact toughness is 100J or more.

[0034] Correspondingly, another objective of the present invention is to provide a manufacturing method for the steel

for the alloy structure. By the manufacturing method, the steel for the alloy structure, which is higher in mechanical property, better in impact toughness, and more reasonable in cost, can be obtained.

[0035] In order to achieve the objective above, the present invention provides a manufacturing method for the steel for the alloy structure, including steps of:

(1) smelting, refining, and casting;
(2) blooming and cogging;
(3) secondary hot rolling to form a product; and
(4) heat treatment including quenching and tempering.

[0036] It should be noted that in the manufacturing method provided by the present invention, electric furnace smelting and LF and VD (or RH) refining may be adopted in the step (1), and in the final stage of VD (or RH) refining, a small amount of ferrozirconium and a small amount of magnesium aluminum alloy may be sequentially added, soft stirring with argon blowing is carried out after the mass percentage of each chemical element in the steel meets the range defined by the invention, and an argon flow rate is controlled within a range of 5-8L/min.

[0037] In some preferred embodiments, in the step (1), casting may adopt bloom continuous casting, and a casting speed is controlled within a range of 0.45-0.65m/min; mould fluxes are adopted, mould electromagnetic stirring is adopted, the current is 500A, the frequency is 2.5-3.5Hz, and a proportion of equiaxed grains of a continuously cast bloom is 20% or more.

[0038] In some preferred embodiments, in the step (2), a blank may be preprocessed before blooming and cogging and for example, may be subjected to surface finishing and polishing to remove visible surface defects so as to ensure high surface quality.

[0039] Further, in the manufacturing method provided by the invention, in the steps (2) and (3), a heating temperature is 1,150-1,250°C during blooming and cogging; and a heating temperature is 1,150-1,250°C during secondary hot rolling to form the product.

[0040] Further, in the manufacturing method provided by the invention, in the step (4), a heating temperature is controlled within a range of 855-890°C during quenching, and a cooling speed is controlled within a range of 50-90°C/s during quenching; and a heating temperature is controlled within a range of 645-670°C during tempering, and a cooling speed is controlled within a range of 50-90°C/s during tempering.

[0041] It should be noted that in the step (4), a cooling agent adopted for quenching may be mineral oil, and a cooling agent adopted for tempering may be mineral oil or water.

[0042] According to the present invention, compared with the prior art, the steel for the alloy structure and the manufacturing method therefor have the following advantages and beneficial effects that:

[0043] according to the present invention, the steel for the alloy structure is designed by adding the trace alloy elements; by adding the proper amount of Zr and Mg, controlling the low content of total oxygen, and utilizing the characteristics of the added trace alloy elements, the steel for the alloy structure is further strengthened and toughened, so that the steel for the alloy structure has high strength and the material cost is low.

[0044] In addition, by the manufacturing method provided by the present invention, the steel for the alloy structure, which is ultrahigh in mechanical property, good in impact toughness, and low in manufacturing cost, can be obtained.

Detailed Description of the Embodiments

[0045] A steel for an alloy structure and a manufacturing method therefor, which are provided by the present invention, will be further explained and illustrated below in combination with specific embodiments, but the explanation and illustration do not constitute improper limitation to the technical solution of the present invention.

Embodiments 1-6 and Comparative Examples 1-3

[0046] A steel for an alloy structure, which is provided by Embodiment 1-6, is prepared by adopting the following steps:

(1) carrying out smelting by an electric furnace, LF refining, and casting.
(2) blooming and cogging: the heating temperature is 1,150-1,250°C.
(3) carrying out secondary hot rolling to form a product: the heating temperature is 1,150-1,250°C.
(4) heat treatment including quenching and tempering, wherein a heating temperature is controlled within a range of 855-890°C during quenching, a cooling speed is controlled within a range of 50-90°C/s during quenching, and a cooling agent adopts mineral oil; and a heating temperature is controlled within a range of 645-670°C during tempering, a cooling speed is controlled within a range of 50-90°C/s during tempering, and a cooling agent adopts mineral oil or water.

[0047] It should be noted that in some other embodiments, refining may also adopt RH refining, and in the final stage of VD (or RH) refining, a small amount of ferrozirconium-iron and a small amount of magnesium aluminum alloy may be sequentially added, soft stirring with argon blowing is carried out after the mass percentage of each chemical element in the steel meets a range defined by the invention, and an argon flow rate is controlled within a range of 5-8L/min.

[0048] In some preferred embodiments, in the step (1), casting may adopt bloom continuous casting, and a casting speed is controlled within a range of 0.45-0.65m/min; mould fluxes are adopted, mould electromagnetic stirring is adopted, the current is 500A, the frequency is 2.5-3.5Hz, and a proportion of equiaxed grains of a continuously cast bloom is 20% or more.

[0049] In some preferred embodiments, in the step (2), a blank may be preprocessed before blooming and cogging and for example, may be subjected to surface finishing and polishing to remove visible surface defects so as to ensure high surface quality.

[0050] Comparative examples 1-3 are obtained by adopting ingredients and a manufacturing process in the prior art.

[0051] Table 1 lists the mass percentage of each chemical element of the steel for the alloy structure in Embodiments 1-6 and an existing steel for an alloy structure in comparative examples 1-3.

Table 1 (wt%, the balance of Fe and other inevitable impurities)

Nu mbe r	C	Si	Mn	V	P	s	N	Al	Zr	O	Mg	Ce	La	Zr/ N	Zr/ C	Zr/ V	Mg /S	Mg/ O
Emb odi men t 1	0. 4 0	0. 3 5	0.8	0. 1	0.0 15	0.0 15	0.0 05	0.0 5	0.3	0.0 01	0.0 04	0.1	-	60	0.7 5	3	0.2 7	4
Emb odi men t2	0. 4 4	0. 2 7	0.6	0. 0 6	0.0 25	0.0 08	0.0 03	0.0 2	0.20	0.0 00 8	0.0 02	-	0.2	67	0.4 5	3.3	0.2 5	2.5
Emb odi men t 3	0. 4 3	0. 3 2	0.7	0. 0 8	0.0 16	0.0 08	0.0 04	0.0 4	1.0	0.0 01 0	0.0 05	-	-	25 0	2.3 3	12. 5	0.6 25	5.0
Emb odi men t4	0. 3 5	0. 2 9	0.5	0. 0 6	0.0 18	0.0 05	0.0 02	0.0 15	0.88	0.0 01 0	0.0 03	-	-	44 0	2.5	14. 7	0.6	3.0
Emb odi men t 5	0. 4 2	0. 3 4	0.6	0. 0 9	0.0 13	0.0 07	0.0 03	0.0 3	0.73	0.0 00 7	0.0 05	-	-	24 3.3 33 3	1.7 4	8.1	0.7 1	7.14
Emb odi men t 6	0. 4 3	0. 2 8	0.5	0. 0 7	0.0 07	0.0 05	0.0 04	0.0 35	0.58	0.0 00 9	0.0 01	-	-	14 5	1.3 5	8.3	0.2	1.11
Com para tive exa mpl e 1	0. 4 0	0. 2 8	***0.5***	***0. 1 3***	0.0 04	0.0 15	0.0 05	0.0 18	-	0.0 00 8	-	0	0	0	0	0	0	0
Com para tive	0. 4 1	0. 3 5	***0.4***	***0. 1 7***	0.0 16	0.0 12	0.0 04	0.0 4	-	0.0 00 7	-	0	0	0	0	0	0	0
exa mpl e 2																		
Com para tive exa mpl e 3	0. 4 2	0. 3 2	0.7	***0. 1 1***	0.0 25	0.0 05	0.0 04	0.0 35	-	0.0 00 9	-	0	0	0	0	0	0	0

[0052] Table 2 lists conditions of microstructures in the obtained steel for the alloy structure in Embodiments 1-6 and microstructures in the obtained existing steel for the alloy structure in Comparative examples 1-3.

Table 2

Number	Mi crostructure	Sum of Number of ZrC and ZrN particles (pieces/mm^2)	Sum of Number of MgO and MgS particles (pieces/mm^2)	Diameter of ZrC, ZrN, MgO and MgS particles (μm)
Embodiment 1	ferrite and pearlite	3	20	0.2-5
Embodiment 2	ferrite and pearlite	12	5	0.2-6
Embodiment 3	ferrite and pearlite	15	12	0.2-7
Embodiment 4	ferrite and pearlite	5	8	0.2-4
Embodiment 5	ferrite and pearlite	8	16	0.2-7
Embodiment 6	ferrite and pearlite	10	10	0.2-5
Comparative example 1	ferrite and pearlite	0	0	-
Comparative example 2	ferrite and pearlite	0	0	-
Comparative example 3	ferrite and pearlite	0	0	-

[0053] Table 3 lists specific process parameters of the steel for the alloy structure in Embodiments 1-6 and the existing steel for the alloy structure in Comparative examples 1-3.

Table 3

Number	Step (2)	Step (3)	Step (4)			
	Heating temperat ure during bloomin g and cogging (°C)	Heating temperatur e during secondary hot rolling to form a product (°C)	Heating temperature during quenching (°C)	Cooling speed during quenching (°C/s)	Heating temperature during tempering (°C)	Cooling speed during tempering (°C/S)
Embodiment 1	1150	1250	855	50	645	82
Embodiment 2	1180	1220	890	85	670	50
Embodiment 3	1220	1180	860	66	650	90
Embodiment 4	1250	1150	870	90	660	78
Embodiment 5	1190	1180	865	78	655	66

(continued)

Number	Step (2)	Step (3)	Step (4)			
	Heating temperature during blooming and cogging (°C)	Heating temperature during secondary hot rolling to form a product (°C)	Heating temperature during quenching (°C)	Cooling speed during quenching (°C/s)	Heating temperature during tempering (°C)	Cooling speed during tempering (°C/S)
Embodiment 6	1230	1200	855	83	645	88
Comparative example 1	1250	1250	*850*	*40*	*640*	*35*
Comparative example 2	1230	1210	860	*35*	650	45
Comparative example 3	1200	1230	870	45	655	*40*

[0054] In order to verify the implementation effect of the invention and meanwhile, prove the excellent effects of the invention with respect to the prior art, the steel for the alloy structure in Embodiments 1-6 and the existing steel for the alloy structure in comparative examples 1-3 are subjected to mechanical testing. A steel with a thickness of 25mm is adopted for testing.

[0055] According to the present invention, a tensile test (test on the yield strength R_{el}, the tensile strength R_m, and the elongation percentage) adopts a zwick/roell Z330 tensile testing machine to carry out testing, and the testing standard adopts the national standard GB/T 228.1-2010, wherein tests on the yield strength R_{el}, the tensile strength R_m, and the elongation percentage are respectively carried out according to standards defined by 3.10.1, 3.10.2 and 3.6.1 in this standard.

[0056] The impact toughness is tested by a Zwick/Roell PSW 750 impact testing machine, the testing standard adopts the national standard GB/T 229-2007, and the value of the impact toughness is obtained by testing the energy absorbed by the steel for the alloy structure in a charpy impact test.

[0057] A statistics and testing method of the number of the ZrC and ZrN particles, the number of the MgO and MgS particles, and the diameters of the grains of ZrC, ZrN, MgO and MgS particles is carried out by a scanning electron microscope (SEM) matched with an Oxford energy disperse spectroscopy oxford X-max 20, wherein a model of the scanning electron microscope is a Zeiss scanning electron microscope EVO 18, and a testing standard adopts the standard GB/T30834-2014.

[0058] Table 4 lists testing results of the embodiments and comparative examples.

Table 4

Number	Yield Strength R_{el} (MPa)	Tensile Strength R_m (MPa)	Elongation Percentage (%)	Impact Toughness (J)
Embodiment 1	755	900	12	123
Embodiment 2	765	905	13	125
Embodiment 3	763	910	12	108
Embodiment 4	770	908	14	137
Embodiment 5	767	912	13	117
Embodiment 6	758	907	12	100
Comparative example 1	735	885	10	78
Comparative example 2	730	890	11	85

(continued)

Number	Yield Strength R_{el} (MPa)	Tensile Strength R_m (MPa)	Elongation Percentage (%)	Impact Toughness (J)
Comparative example 3	732	893	10	73

[0059] It can be seen in combination with Table 2 and Table 4 that according to the steel for the alloy structure in the embodiments of the invention, the microstructure is ferrite + pearlite, the steel contains the grains of ZrC, ZrN, MgO and MgS particles, and these particles take effects of refining and stabilizing austenite crystal grains and are beneficial for improving the mechanical properties of the material, and thus, compared with the existing steel for the alloy structure in comparative examples 1-3 in the prior art, the steel for the alloy structure in the embodiments of the invention shows better mechanical properties, and for the steel for the alloy structure in the embodiments, the yield strength is 755MPa or more, the tensile strength is 900MPa or more, the elongation percentage is 12% or more, and the impact toughness is 100J or more.

[0060] To sum up, according to the present invention, the steel for the alloy structure is designed by adding trace alloy elements; by adding the proper amount of Zr and Mg, controlling the low content of total oxygen, and utilizing the characteristics of the added trace alloy elements, the steel for the alloy structure is further strengthened and toughened, so that the steel for the alloy structure has high strength and low material cost.

[0061] In addition, by the manufacturing method provided by the present invention, the steel for the alloy structure, which is ultrahigh in mechanical property, good in impact toughness, and low in manufacturing cost, can be obtained.

[0062] It should be noted that the prior art part in the scope of protection of the present invention is not limited to the embodiments given out by the application documents, and all the prior art, without conflict with the solution of the present invention, including, but are not limited to, the prior patent literatures, the prior publications, the prior public use and the like, shall fall within the scope of the protection of the present invention.

[0063] In addition, the combination modes of all the technical characteristics in the invention are not limited to the combination modes recorded in claims of the invention or the combination modes recorded in the specific embodiments, and all the technical characteristics recorded in the invention can be freely combined or integrated in any mode, unless there are conflicts therebetween.

[0064] It also should be noted that the embodiments listed above are merely specific embodiments of the present invention. It is obvious that the present invention is not limited to the embodiments above, and similar changes or modifications made therewith could be directly obtained from the contents disclosed by the present invention or very easily thought of by those skilled in the art, and all shall fall within the scope of protection of the present invention.

Claims

1. A steel for an alloy structure, comprising the following chemical elements in percentage by mass: 0.35-0.45% of C, 0.27-0.35% of Si, 0.6-0.8% of Mn, 0.015-0.05% of Al, 0.06-0.1% of V, 0.2-1.0% of Zr, 0.001-0.005% of Mg, 0.025% or less of P, 0.015% or less of S, 0.005% or less of N, 0.001% or less of O, the balance being Fe and other inevitable impurities.

2. The steel for the alloy structure according to claim 1, further comprising at least one selected from the following chemical elements: Ce, Hf, La, Re, Sc, and Y, wherein the total addition amount of these elements is 1% or less.

3. The steel for the alloy structure according to claim 1, wherein the content by mass percentage of chemical elements satisfies at least one of the following:

   0.08-0.1% of V;
   0.3-0.7% Zr; and
   0.001-0.003% of Mg.

4. The steel for the alloy structure according to claim 1, wherein a ratio of the content by mass of chemical elements further satisfies at least one of the following:

$$Zr/N=40\sim200;$$

$$Zr/V=2\sim16.7;$$

and

$$Zr/C=0.4\sim2.8.$$

5. The steel for the alloy structure according to claim 1, wherein a ratio of the content by mass of chemical elements further satisfies at least one of the following:

$$Mg/O=0.5\sim3;$$

and

$$Mg/S=0.6\sim5.0.$$

6. The steel for the alloy structure according to claim 1, wherein a microstructure of the steel for the alloy structure is ferrite + pearlite, and the steel for the alloy structure contains ZrC, ZrN, MgO, and MgS particles.

7. The steel for the alloy structure according to claim 6, wherein the sum of the number of the ZrC and ZrN particles is 3-15 pieces/mm^2.

8. The steel for the alloy structure according to claim 6, wherein the sum of the number of the MgO and MgS particles is 5-20 pieces/mm^2.

9. The steel for the alloy structure according to claim 6, wherein the ZrC, ZrN, MgO, and MgS particles have a diameter of 0.2-7μm.

10. The steel for the alloy structure according to any one of claims 1-9, wherein the steel for alloy structure has a yield strength of 755 MPa or more, a tensile strength of 900 MPa or more, an elongation percentage of 12% or more, and an impact toughness of 100J or more.

11. A manufacturing method for the steel for the alloy structure according to any one of claims 1-10, comprising steps of:

(1) smelting, refining, and casting;
(2) blooming and cogging;
(3) secondary hot rolling to form a product; and
(4) heat treatment comprising quenching and tempering.

12. The manufacturing method according to claim 11, wherein a heating temperature is 1,150-1,250°C in the step of blooming and cogging; and a heating temperature is 1,150-1,250°C in the step of secondary hot rolling to form the product.

13. The manufacturing method according to claim 11, wherein in the step of heat treatment, a heating temperature is controlled within a range of 855-890°C during quenching, and a cooling speed is controlled within a range of 50-90°C/s during quenching; and a heating temperature is controlled within a range of 645-670°C during tempering, and a cooling speed is controlled within a range of 50-90°C/s during tempering.

INTERNATIONAL SEARCH REPORT

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A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/04(2006.01)i; C22C 38/06(2006.01)i; C22C 38/12(2006.01)i; C22C 38/14(2006.01)i; C21D 8/00(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)

C22C

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)

VEN; CNABS; CNTXT; CNKI; WOTXT; JPTXT; EPTXT; USTXT: 合金钢, 结构钢, steel, 锰, Mn, magnesium, 铝, Al, aluminum, Si , 硅, silicon, C , 碳, carbon, 锆, Zr, zirconium, 镁, Mg, manganese, 钒, vanadium, V

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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

Date of the actual completion of the international search	Date of mailing of the international search report
16 November 2020	**08 December 2020**
Name and mailing address of the ISA/CN **China National Intellectual Property Administration (ISA/CN)** **No. 6, Xitucheng Road, Jimenqiao Haidian District, Beijing 100088** **China**	Authorized officer
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C. DOCUMENTS CONSIDERED TO BE RELEVANT

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