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(54) HIGH TOUGHNESS BAINITIC STEEL WHEEL FOR RAIL TRANSIT, AND MANUFACTURING METHOD THEREFOR

(57) The present invention provides a high-toughness bainitic steel wheel for rail transit and a manufacturing method therefor. The steel wheel includes elements with the following weight percents: carbon C: 0.10-0.40%, silicon Si: 1.00-2.00%, manganeseMn: 1.00-2.50%, nickel Ni: 0.20-1.00%, rare earth RE: 0.001-0.040%, phosphorus P ≤ 0.020%, and sulphur S≤0.020%, where the remaining is iron and unavoidable residual elements, and 2.00%≤Si+Mn ≤4.00%. Compared with the prior technology, in the present invention, by using design of chemical compositions of steel and production and manufacturing processes, especially a heat treatment process and technology, a rim of the wheel obtains a carbide-free bainitic structure, and a web and a wheel hub obtain a metallographic structure based on granular bainitic and supersaturated ferritic. The wheel has comprehensive mechanical properties such as high yield strength, toughness, and low-temperature toughness, and good service performance. In addition, costs are reduced, thereby improving a service life and comprehensive efficiency of the wheel, bringing specific economic and social benefits.

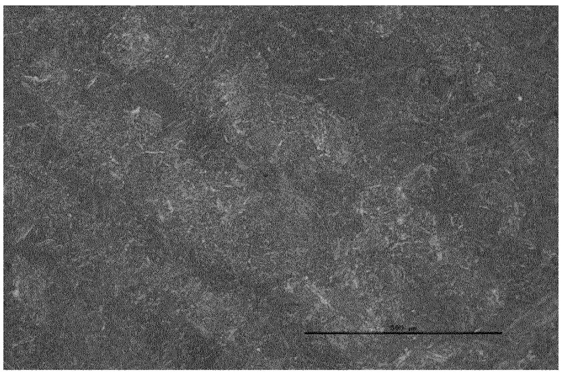


FIG. 3 (3a)

Description

Technical Field

[0001] The present invention belongs to the field of design of chemical compositions of steel and wheel manufacturing, and specifically, to a high-toughness bainitic steel wheel for rail transit, and a manufacturing method therefor, and steel design of other elements and similar elements in rail transit and a production and manufacturing method therefor.

Related Art

[0002] "High speed, heavy load, and low noise" are a main development direction of world rail transit. Wheels are "shoes" of the rail transit, which are one of most important runner elements and directly affect traveling safety. In a normal train traveling process, wheels bear a full load weight of a vehicle, and are subject to wear and rolling contact fatigue (RCF) damage. In addition, more importantly, wheels have a very complex interaction relationship with steel rails, brake shoes, axletrees, and surrounding media, and are in a dynamic alternating stress state. Especially, the wheels and the steel rails, and the wheels and the brake shoes (except for disc brakes) are two pairs of friction couples that always exist and cannot be ignored. In an emergency or during running on a special road, brakes are subject to significant thermal damage and friction damage. In addition, thermal fatigue is generated, also affecting wheel safety and a service life.

[0003] In rail transit, when wheels satisfy basic strength, particular attention is paid to a roughness indicator of the wheels, to ensure safety and reliability. Freight transport wheels are seriously worn and have serious rolling contact fatigue (RCF) damage. In addition, tread braking is used for the wheels, which causes serious thermal fatigue damage, leading to defects such as peeling, flaking, and rim cracking. More attention is paid to toughness and low-temperature toughness of passenger transport wheels. Because disc brakes are used in passenger transport, thermal fatigue during braking is reduced.

[0004] Currently, national and international wheel steel for rail transit, for example, Chinese wheel standards GB/T8601 and TB/T2817, European wheel standard EN13262, Japanese wheel standard JRS and JISB5402, and North American wheel standard AARM107, uses medium-to-high carbon steel or medium-to-high carbon microalloyed steel, where microstructures of both are of a pearlite-ferritic structure.

[0005] CL60 wheel steel is rolled wheel steel mainly used in Chinese current rail transit vehicles (for passenger and freight transport), and BZ-L wheel steel is cast wheel steel mainly used in Chinese current rail transit vehicles (for freight transport), where metallographic structure of both are of a pearlite-ferritic structure.

[0006] For a schematic diagram of names of wheel elements, refer to FIG. 1, and for main technical indicators of CL60 wheel steel, refer to Table 1.

Table 1 Main technical requirements for CL60 wheel steel

Material	Component, wt%			Rim performance requirement			
	C	Si	Mn	R_m,MPa	A%	Z%	Hardness, HB
CL60	0.55-0.65	0.17-0.37	0.50-0.80	≥910	≥10	≥14	265-320

[0007] In a production and manufacturing process, to ensure good quality of a wheel, content of harmful gas and content of harmful residual elements in steel need to be slow. When the wheel is in a high-temperature state, a rim tread is intensively cooled with a water spray, to improve strength and hardness of a rim. This is equivalent to that normalizing heat treatment is performed on a web and a wheel hub, so that the rim has high strength-roughness matching, and the web has high roughness, thereby finally realizing excellent comprehensive mechanical properties and service performance of the wheel.

[0008] In wheel steel having pearlite and a small amount of ferritic, the ferritic is a soft domain material, has good roughness and low yield strength. The ferritic is soft and therefore, has poor rolling contact fatigue (RCF) resistance performance. Generally, higher content of the ferritic leads to better impact toughness of the steel. Compared with the ferritic, the pearlite has higher strength and poorer roughness, and therefore has poorer impact performance. The rail transit develops towards a high speed and a heavy load. During running, load borne by a wheel will be significantly increased. An existing wheel made of pearlite and a small amount of ferritic has more problems exposed in a running service process. Several main disadvantages are as follows:

(1) A rim has low yield strength, which generally does not exceed 600 MPa. During wheel running, because a rolling contact stresses between a wheel and a rail is relatively large, which sometimes exceeds yield strength of wheel

steel, plastic deformation is caused to the wheel during a running process, leading to plastic deformation of a tread sub-surface. In addition, because brittle phases such as inclusions and cementite exist in steel, the rim is prone to micro-cracks. The micro-cracks cause detects such as peeling and rim cracking under the action of rolling contact fatigue during wheel running.

(2) High carbon content in the steel causes a poor thermal damage resistance capability. When tread braking is used or friction damage is caused during wheel slipping, temperature of a part of the wheel is increased to the austenitizing temperature of the steel. Then the steel is chilled to produce martensite. By such repeated thermal fatigue, thermal cracks on a brake are generated and detects such as flaking and spalling are caused.

(3) The wheel steel has poor hardenability. The rim of the wheel has a particular hardness gradient and hardness is uneven, which easily causes defects such as wheel flange wear and non-circularity.

[0009] With development and breakthrough of the research on a bainitic phase change in steel, especially the research on theories and application of carbide-free bainitic steel, good matching between high-strength and high-toughness can be realized. The carbide-free bainitic steel has an ideal microstructure, and also has excellent mechanical properties. A fine microstructure of the carbide-free bainitic steel is carbide-free bainitic, namely, supersaturated lathy ferritic in nanometer scale, in the middle of which film-shaped carbon-rich residual austenite in nanometer scale exists, thereby improving the strength and toughness of the steel, especially the yield strength, impact toughness, and fracture toughness of the steel, and reducing notch sensitivity of the steel. Therefore, by using a bainitic steel wheel, rolling contact fatigue (RCF) resistance performance of the wheel is effectively increased, phenomena of wheel peeling and flaking are reduced, and safety performance and service performance of the wheel are improved. Because the bainitic steel wheel has low carbon content, thermal fatigue resistance performance of the wheel is improved, generation of thermal cracks on the rim is prevented, the number of times of repairing by turning and an amount of repairing by turning are reduced, the service efficiency of the rim metal is improved, and a service life of the wheel is prolonged.

[0010] Chinese Patent Publication No. CN1800427A published on July 12, 2006 and entitled with "Bainitic Steel For Railroad Carriage Wheel" discloses that chemical compositions (wt%) of steel are: carbon C: 0.08-0.45%, silicon Si: 0.60-2.10%, manganese Mn: 0.60-2.10%, molybdenum Mo: 0.08-0.60%, nickel Ni: 0.00-2.10%, chromium Cr: <0.25%, vanadium V: 0.00-0.20%, and copper Cu: 0.00-1.00%. A typical structure of the bainitic steel is carbide-free bainitic, which has excellent strength and toughness, low notch sensitivity, and good hot-crack resistance performance. The addition of the element Mo can increase hardenability of the steel. However, for a wheel having a large cross-section, there is a great difficulty in controlling production, and costs are relatively high.

[0011] British Steel Corporation Patent No. CN1059239C discloses bainitic steel and a production process thereof. Chemical compositions (wt%) of the steel are: carbon C: 0.05-0.50%, silicon Si and/or aluminium Al: 1.00-3.00%, manganese Mn: 0.50-2.50%, and chromium Cr: 0.25-2.50%. A typical structure of the bainitic steel is carbide-free bainitic, which has high wearability and rolling contact fatigue resistance performance. Although the steel has good strength and toughness, a cross section of a steel rail is relatively simple, impact toughness performance at 20°C is not high, and costs of the steel are high.

The Invention Content

[0012] An objective of the present invention is to provide a high-toughness bainitic steel wheel for rail transit, using a C-Si-Mn-Ni-RE system, without particularly adding alloying elements such as Mo, V, Cr, and B. In this way, a typical structure of a rim is carbide-free bainitic, so that the wheel has characteristics such as excellent strength and toughness and low notch sensitivity.

[0013] The present invention further provides a manufacturing method for the high-toughness bainitic steel wheel for rail transit, so that by using a heat treatment process and technology, the wheel obtains good comprehensive mechanical properties, and production is relatively easy to control.

[0014] The high-toughness bainitic steel wheel for rail transit provided in the present invention contains elements with the following weight percents:

carbon C: 0.10-0.40%, silicon Si: 1.00-2.00%, manganese Mn: 1.00-2.50%,

nickel Ni: 0.20-1.00%, rare earth RE: 0.001-0.040%,

phosphorus P≤0.020%, and sulphur S≤0.020%, where the remaining is iron and unavoidable residual elements; and

1.50%≤Si+Ni≤2.50%, and 2.00%≤Si+Mn≤4.00%.

[0015] Preferably, the high-toughness bainitic steel wheel for rail transit contains elements with the following weight percents:

carbon C: 0.15-0.25%, silicon Si: 1.20-1.80%, manganese Mn: 1.60-2.10%,

nickel Ni: 0.20-0.80%, rare earth RE: 0.010-0.040%, phosphorus P ≤ 0.020%, and sulphur S ≤

0.020%, where the remaining is iron and unavoidable residual elements, 1.50%≤Si+Ni≤2.50%, and 2.00%≤Si+Mn≤4.00%.

[0016] Preferably, the high-toughness bainitic steel wheel for rail transit contains elements with the following weight percents:

carbon C: 0.20%, silicon Si: 1.45%, manganese Mn: 1.92%,

nickel Ni: 0.35%, rare earth RE: 0.018%, phosphorus P: 0.013%, and sulphur S: 0.008%, where the remaining is iron and unavoidable residual elements.

[0017] When total content of Si and Mn is lower than 2%, hardenability of the steel is reduced, and a carbide is easily produced in the steel, which is adverse to obtaining a carbide-free bainitic structure having good strength and toughness. When total content of Si and Mn is higher than 4%, hardenability of the steel is excessively high, undesirable structures such as martensite are easily formed, and there is a great difficulty in controlling production.

[0018] When total content of Si and Ni is lower than 1.5%, a carbide is easily produced in the steel, which is adverse to obtaining a carbide-free bainitic structure having good strength and toughness. When total content of Si and Ni is higher than 2.5%, functions of the elements cannot be effectively played, and costs are increased.

[0019] An obtained microstructure of the wheel is: a metallographic structure within 40 millimetre below a rim tread of the wheel is a carbide-free bainitic structure, namely, supersaturated lathy ferritic in nanometer scale, where film-shaped carbon-rich residual austenite in nanometer scale exists in the middle of the supersaturated lathy ferritic in nanometer scale, and a volume percent of the residual austenite is 4%-15%. A rim microstructure is a multiphase structure formed by supersaturated ferritic and carbon-rich residual austenite, and a size of the rim microstructure is in nanometer scale and ranges from 1 nanometer to 999 nanometers.

[0020] The wheel provided in the present invention may be used for production of freight car wheels and passenger car wheels, and other elements and similar elements in rail transit.

[0021] The manufacturing method for the high-toughness bainitic steel wheel for rail transit provided in the present invention includes smelting, refining, molding, and heat treatment processes. The smelting and molding processes use the prior art, and the heat treatment process is:

heating a molded wheel to the austenite temperature, intensively cooling a rim tread with a water spray to a temperature below 400°C, and performing temperingtreatment. The heating to the austenite temperature is specifically: heating to 860-930°C and maintaining at the temperature for 2.0-2.5 hours. The temperingtreatment is: performing tempering at medium orlow temperature for more than 30 minutes when the temperature of the wheel is less than 400°C, and air cooling the wheel to room temperature after the tempering; or intensively cooling the rim tread with the water spray to the temperature below 400°C, and air cooling to room temperature, during which self-tempering is performed by using waste heat of a web and a wheel hub.

[0022] The heat treatment process may alternatively be: heating treatment of the wheel with high-temperature waste heat after the molding, and directly intensively cooling a rim tread of a molded wheel with a water spray to a temperature below 400°C, and performing tempering treatment. The temperingtreatment is: performing tempering at medium or low temperature for more than 30 minutes when the temperature of the wheel is less than 400°C, and air cooling the wheel to room temperature after the tempering; or intensively cooling the rim tread with the water spray to the temperature below 400°C, and air cooling to room temperature, during which self-tempering is performed by using waste heat of a web and a wheel hub.

[0023] The heat treatment process may alternatively be: air cooling the wheel to a temperature below 400°C after the wheel is molded, and performing temperingtreatment. The temperingtreatment is: performing tempering at medium orlow temperature for more than 30 minutes when the temperature of the wheel is less than 400°C, and air cooling the wheel to room temperature after the tempering; or air cooling to a temperature below 400°C, and air cooling to room temperature, during which self-tempering is performed by using waste heat of a web and a wheel hub.

[0024] Specifically, the heat treatment process is any one of the following:

heating the wheel to the austenite temperature, intensively cooling the rim tread with the water spray to the temperature below 400°C, and air cooling to room temperature, during which self-tempering is performed by using waste heat; or

heating the wheel to the austenite temperature, intensively cooling the rim tread with the water spray to the temperature below 400°C, performing tempering at medium or low temperature for more than 30 minutes when the temperature of the wheel is less than 400°C, and air cooling to room temperature after the tempering, where the heating to the austenite temperature is specifically: heating to 860-930°C and maintaining at the temperature for 2.0-2.5 hours; or

heating treatment of the wheel with high-temperature waste heat after the molding, the rim tread with the water spray to the temperature below 400°C, and air cooling to room temperature, during which self-tempering is performed by using waste heat of the web and the wheel hub; or

heating treatment of the wheel with high-temperature waste heat after the molding, and the rim tread with the water spray to the temperature below 400°C, performing tempering at medium or low temperature for more than 30 minutes when the temperature of the wheel is less than 400°C, and air cooling to room temperature after the tempering; or

after the wheel is molded, air cooling the wheel to the temperature below 400°C, during which performing self-tempering is performed by using the waste heat of the web and the wheel hub; or after the wheel is molded, air cooling the wheel to the temperature below 400°C, performing tempering at medium or low temperature for more than 30 minutes when the temperature of the wheel is less than 400°C, and air cooling to room temperature after the tempering.

[0025] Functions of the elements in the present invention are as follows:

C content: is a basic element in the steel and has strong functions of interstitial solution hardening and precipitation strengthening. As the carbon content increases, strength of the steel is improved and toughness of the steel is reduced. A solubility of carbon in austenite is far greater than that in ferritic, and carbon is a valid austenite-stabilizing element. A volume fraction of carbide in the steel is in direct proportion to the carbon content. To obtain a carbide-free bainitic structure, it needs to be ensured that particular C content dissolves in supercooled austenite and supersaturated ferritic, thereby effectively improving strength and hardness of the material, especially yield strength of the material. When the C content is higher than 0.40%, cementite is precipitated, reducing roughness of the steel. When the C content is lower than 0.10%, supersaturation of ferritic is reduced, and the strength of the steel is reduced. Therefore, a proper range of the carbon content is preferably 0.10-0.40%.

Si content: is a basic alloying element in the steel, and is a common deoxidizer. An atomic radius of Si is less than an atomic radius of iron, and Si has a strong solution strengthening function on austenite and ferritic. In this way, shear strength of the austenite is improved. Si is a noncarbide former, which prevents precipitation of cementite, facilitates formation of a bainitic-ferritic carbon-rich austenite film and (M-A) island-type structure, and is a main element for obtaining the carbide-free bainitic steel. Si can further prevent precipitation of cementite, thereby preventing precipitation of carbide due to decomposition of supercooled austenite. When tempering is performed at 300-400°C, precipitation of cementite is completely suppressed, thereby improving thermal stability and mechanical stability of the austenite. When the Si content in the steel is higher than 2.00%, a tendency of precipitating proeutectoid ferritic is increased, an amount of residual austenite is increased, and strength and toughness of the steel are reduced. When the Si content is lower than 1.00%, cementite is easily precipitated from the steel, and a carbide-free bainitic structure is not easily obtained. Therefore, the Si content should be controlled from 1.00-2.00%.

Ni content: Ni is a noncarbide former, and can inhibit precipitation of carbide in a bainitic conversion process. In this way, a stable austenite film is formed between bainitic ferritic laths, facilitating formation of a carbide-free bainitic structure. Ni can improve strength and toughness of the steel, is an inevitable alloying element for obtaining high impact toughness, and lowers impact toughness conversion temperature. When the Ni content is lower than 0.20%, it is adverse to forming carbide-free bainitic. When the Ni content is higher than 1.00%, contribution rates of the strength and toughness of the steel are greatly reduced, and production costs are increased. Therefore, the Ni content should be controlled from 0.20-1.00%.

Mn content: Mn is an austenite stabilization element, improves hardenability of the steel, and improves mechanical properties of the steel. By properly adjusting alloying content of Si and Mn, a film-shaped austenite structure, that is, carbide-free bainitic, precipitated from noncarbide and spaced between bainitic ferritic laths is obtained. Mn can also improve a diffusion coefficient of P and improve brittleness of the steel. When the Mn content is lower than 1.00%, the hardenability of the steel is poor, which is adverse to obtaining carbide-free bainitic. When the Mn content is higher than 2.50%, the hardenability of the steel is significantly improved. In addition, a diffusion tendency of P is also greatly improved, and toughness of the steel is reduced. Therefore, the Mn content should be controlled from 1.00-2.50%.

RE content: An RE element is added to refine austenite grains, which has functions of purification and modification, and can reduce segregation of harmful impurity elements along a grain boundary and improve and strengthen the grain boundary, thereby improving strength and toughness of the steel. In addition, RE can facilitate spheroidization of inclusions, to further improve the toughness of the steel and reduce notch sensitivity of the material. When the RE content is excessively high, a beneficial effect is reduced, and production costs of the steel are increased. When the RE content is lower than 0.001%, tough rare earth inclusions are generated by using harmful elements that cannot completely removed. When the RE content is higher than 0.040%, RE elements are redundant, and a function of the RE elements cannot be effectively played. Considering all conditions, the RE content is controlled from 0.001-0.040%.

P content: P is prone to grain boundary segregation in medium and high carbon steel, to weaken a grain boundary and reduce strength and toughness of the steel. As a harmful element, when P≤ 0.020%, the performance is not greatly adversely affected.

S content: S is prone to grain boundary segregation, and easily forms an inclusion together with other elements, to reduce strength and toughness of the steel. As a harmful element, when S≤ 0.020%, the performance is not greatly adversely affected.

[0026] In the design of the components of the steel, the present invention uses the C-Si-Mn-Ni-RE system, without particularly adding the alloying elements such as Mo, V, Cr, and B, and combining the heat treatment process, the typical structure of the rim is carbide-free bainitic, namely, the supersaturated lathy ferritic in nanometer scale, in the middle of which the film-shaped carbon-rich residual austenite in nanometer scale exists, where the residual austenite is 4%-15%. The wheel has characteristics such as excellent strength and toughness and low notch sensitivity. The steel has medium hardenability, and is relatively easy to produce and control, having relatively low costs. The rare earth element can spheroidize the inclusions in the steel, and strengthen the grain boundary, so that the steel has relatively high impact toughness performance at 20°C. The addition of Ni enables the obtained bainitic steel to obtain higher impact toughness performance at 20°C.

[0027] In the present invention, through the component design and the manufacturing process, matching between high strength and high toughness of the wheel is realized, and comprehensive mechanical properties of the wheel are provided, so as to achieve the objective of improving the service performance of the wheel. The steel can also be used for production and manufacturing of other key elements and similar elements in rail transit.

[0028] According to the present invention, the noncarbide formers such as Si and Ni are mainly used to improve activity of carbon in ferritic, and defer and inhibit precipitation of carbide. By using a proper molding process (including forging and rolling, mold casting, or the like), especially the heat treatment process, the rim tread is intensively cooled with the water spray according to a formulation of the steel, so that the rim of the wheel obtains the carbide-free bainitic structure. Alternatively, self-tempering using the waste heat or tempering at medium or low temperature is performed on a composite structure based on the carbide-free bainitic structure, to further improve structure stability of the wheel and the comprehensive mechanical properties of the wheel. In addition, the Mn element has a good austenite stabilization function, to improve the hardenability and the strength of the steel. The rare earth element has a function of absorbing harmful gas such as hydrogen in the steel, to spheroidize the unavoidable inclusions in the steel, so as to further improve the toughness of the steel. By properly adjusting the content of Si, Ni, Mn, and RE, the rim obtains the carbide-free bainitic structure precipitated from noncarbide, to further improve strength and toughness of the wheel. Characteristics such as good solution strengthening of the element Si is used to further improve the strength and the toughness without lowering a toughness indicator. Moreover, corrosion resistance performance of the element Ni is used to realize atmospheric corrosion resistance of the wheel, thereby improving a service life of the wheel, realizing a high-toughness bainitic steel wheel, and satisfying a strict running condition of rail transit.

[0029] Compared with the CL60 wheel in the prior art, for the bainitic steel wheel prepared in the present invention, matching between the strength and the toughness of the rim is obviously improved, so as to effectively improve, while ensuring safety, the yield strength, the toughness, and the low-temperature toughness of the wheel, the rolling contact fatigue (RCF) resistance performance of the wheel, the hot-crack resistance performance of the wheel, and the corrosion resistance performance of the wheel, reduce the notch sensitivity of the wheel, reduce a probability of peeling or flaking of the wheel in use, implement even wear and less repairing by turning of the tread of the wheel, improve the service efficiency of the rim metal of the wheel, and improve the service life and comprehensive efficiency of the wheel, bringing specific economic and social benefits.

Brief Description of The Drawings

[0030]

FIG. 1 is a schematic diagram of names of parts of a wheel, where
1: wheel hub hole; 2: outer side face of a rim; 3: rim; 4: inner side face of the rim; 5: web; 6: wheel hub; and 7: tread;

FIG. 2a is a diagram of a 100x optical metallographic structure of a rim according to Embodiment 1;

FIG. 2b is a diagram of a 500x optical metallographic structure of a rim according to Embodiment 1;

FIG. 3a is a diagram of a 100x optical metallographic structure of a rim according to Embodiment 2;

FIG. 3b is a diagram of a 500x optical metallographic structure of a rim according to Embodiment 2;

FIG. 3c is a diagram of a 500x dyed metallographic structure of a rim according to Embodiment 2;

FIG. 3d is a diagram of a transmission electron microscope structure of a rim according to Embodiment 2;

FIG. 4a is a diagram of a 100x optical metallographic structure of a rim according to Embodiment 3;

FIG. 4b is a diagram of a 500x optical metallographic structure of a rim according to Embodiment 3;

FIG. 5 is a continuous cooling transformation curve (CCT curve) of steel according to Embodiment 2;

FIG. 6 shows a relationship comparison between a friction coefficient and the number of revolutions in a friction and wear test of a wheel according to Embodiment 2 and a CL60 wheel; and

FIG. 7 shows structures of deformation layers on surfaces of samples of a wheel according to Embodiment 2 and a CL60 wheel after a friction and wear test.

Detailed Description

[0031] Weight percents of chemical components of wheel steel in Embodiments 1, 2, and 3 are shown in Table 2. In Embodiments 1, 2, and 3, a φ380 mm round billet directly cast after electric furnace smelting, and LF+RH refining and vacuum degassing is used. Then, the round billet forms a car wheel having a diameter of 915 mm after ingot cutting, heating and rolling, heat treatment, and finishing.

Embodiment 1

[0032] A high-toughness bainitic steel wheel for rail transit contains elements with the following weight percents shown in Table 2.

[0033] A manufacturing method for the high-toughness bainitic steel wheel for rail transit includes the following steps: forming the wheel by using liquid steel in Embodiment 1 with chemical components shown in Table 2 through an electric furnace steelmaking process, an LF refining process, an RH vacuum treatment process, a round billet continuous casting process, an ingot cutting and rolling process, a heat treatment process, processing, and a finished product detection process. The heat treatment process is: heating to 860-930°C and maintaining at the temperature for 2.0-2.5 hours; cooling a rim tread with a water spray to a temperature below 400°C, and performing temperingtreatment at 280°C for 4.5-5.0 hours.

[0034] As shown in FIG. 2a and FIG. 2b, a metallographic structure of a rim of the wheel prepared in this embodiment is mainly a carbide-free bainitic structure. Mechanical properties of the wheel in this embodiment are shown in Table 3, and matching between strength and toughness of the wheel is superior to that of a CL60 wheel.

Embodiment 2

[0035] A high-toughness bainitic steel wheel for rail transit contains elements with the following weight percents shown in Table 2.

[0036] A manufacturing method for the high-toughness bainitic steel wheel for rail transit includes the following steps: forming the wheel by using liquid steel in Embodiment 2 with chemical components shown in Table 2 through an electric furnace steelmaking process, an LF refining process, an RH vacuum treatment process, a round billet continuous casting process, an ingot cutting and rolling process, a heat treatment process, processing, and a finished product detection process. The heat treatment process is: heating to 860-930°C and maintaining at the temperature for 2.0-2.5 hours; cooling a rim tread with a water spray to a temperature below 400°C, and performing temperingtreatment at 240°C for 4.5-5.0 hours.

[0037] As shown in FIG. 3a, FIG. 3b, FIG. 3c, and FIG. 3d, a metallographic structure of a rim of the wheel prepared in this embodiment is mainly carbide-free bainitic. Mechanical properties of the wheel in this embodiment are shown in Table 3, and matching between strength and toughness of the wheel is superior to that of a CL60 wheel.

Embodiment 3

[0038] A high-toughness bainitic steel wheel for rail transit contains elements with the following weight percents shown in Table 2.

[0039] A manufacturing method for the high-toughness bainitic steel wheel for rail transit includes the following steps: forming the wheel by using liquid steel in Embodiment 3 with chemical components shown in Table 2 through an electric furnace steelmaking process, an LF refining process, an RH vacuum treatment process, a round billet continuous casting process, an ingot cutting and rolling process, a heat treatment process, processing, and a finished product detection process. The heat treatment process is: heating to 860-930°C and maintaining at the temperature for 2.0-2.5 hours; cooling a rim tread with a water spray to a temperature below 400°C, and performing temperingtreatment at 200°C for 4.5-5.0 hours.

[0040] As shown in FIG. 4a and FIG. 4b, a metallographic structure of a rim of the wheel prepared in this embodiment is mainly carbide-free bainitic. Mechanical properties of the wheel in this embodiment are shown in Table 3, and matching between strength and toughness of the wheel is superior to that of a CL60 wheel.

Table 2 Chemical components (wt%) of wheels in Embodiments 1, 2, and 3 and comparison examples

Embodiment and example	C	Si	Mn	Ni	RE	P	s
Embodiment 1	0.13	1.79	2.15	0.48	0.035	0.009	0.009
Embodiment 2	0.20	1.45	1.92	0.35	0.018	0.013	0.008
Embodiment 3	0.33	1.39	1.28	0.41	0.006	0.015	0.011
CL60 wheel	0.63	0.24	0.71	/	/	0.010	0.001
Chinese Patent CN100395366C	0.20	1.5	1.8	0.2	/	/	/
UK Patent CN1059239C	0.22	0.5-3.0	0.5-2.5	/	/	/	/

Table 3 Mechanical properties of rims of wheels in Embodiments 1, 2, and 3 and comparison examples

Embodiment and example	$RP_{0.2}$ MPa	Rm MPa	A %	Z %	Cross-section hardness HB	Room temperature KUJ	K_QMPa·$m^{1/2}$
Embodiment 1	653	1062	16	43	323	95	100.2
Embodiment 2	718	1114	15	41	335	82	91.5
Embodiment 3	727	1148	14	38	340	71	84.3
CL60 wheel	630	994	15.5	39	290	25	56.3
Chinese Patent CN100395366C	779	1198	16	40	360	52	/

(continued)

Embodiment and example	$RP_{0.2}$ MPa	Rm MPa	A %	Z %	Cross-section hardness HB	Room temperature KUJ	K_QMPa·$m^{1/2}$
UK Patent CN1059239C	730	1250	17	55	400	39	60 (-20°C)

Claims

1. A high-toughness bainitic steel wheel for rail transit, wherein the high-toughness, bainitic steel wheel for rail transit contains elements with the following weight percents:

   carbon C: 0.10-0.40%, silicon Si: 1.00-2.00%, manganese Mn: 1.00-2.50%,
   nickel Ni: 0.20-1.00%, rare earth RE: 0.001-0.040%,
   phosphorus P ≤ 0.020%, and sulphur S≤0.020%, wherein the remaining is iron and unavoidable residual elements; and
   1.50%≤Si+Ni≤2.50%, and 2.00%≤Si+Mn≤4.00%.

2. The high-toughness bainitic steel wheel for rail transit according to claim 1, wherein the high-toughness, bainitic steel wheel for rail transit contains elements with the following weight percents:

   carbon C: 0.15-0.25%, silicon Si: 1.20-1.80%, manganese Mn: 1.60-2.10%,
   nickel Ni: 0.20-0.80%, rare earth RE: 0.010-0.040%, phosphorus P ≤ 0.020%, and sulphur S≤ 0.020%, wherein the remaining is iron and unavoidable residual elements,1.50%≤Si+Ni≤2.50%, and 2.00%≤Si+Mn≤4.00%.

3. The high-toughness bainitic steel wheel for rail transit according to claim 1 or 2, wherein the high-toughness, bainitic steel wheel for rail transit contains elements with the following weight percents:
   carbon C: 0.20%, silicon Si: 1.45%, manganese Mn: 1.92%, nickel Ni: 0.35%, rare earth RE: 0.018%, phosphorus P: 0.013%, and sulphur S: 0.008%, wherein the remaining is iron and unavoidable residual elements.

4. The high-toughness bainitic steel wheel for rail transit according to claim 1 or 2, wherein a metallographic structure within 40 millimetre below a rim tread of the bainitic steel wheel is a carbide-free bainitic structure, namely, supersaturated lathy ferritic in nanometer scale, wherein film-shaped carbon-rich residual austenite in nanometer scale exists in the middle of the supersaturated lathy ferritic in nanometer scale, and a volume percent of the residual austenite is 4%-15%.

5. The high-toughness bainitic steel wheel for rail transit according to claim 1 or 2, wherein a rim microstructure of the wheel is a multiphase structure formed by supersaturated ferritic and carbon-rich residual austenite, and a size of the rim microstructure is in nanometer scale ranging from 1-999 nm.

6. A manufacturing method for the high-toughness bainitic steel wheel for rail transit according to any one of claims 1 to 5, comprising smelting, refining, molding, and heat treatment processes, wherein the heat treatment process is: heating a molded wheel to austenite temperature, intensively cooling a rim tread with a water spray to a temperature below 400°C, and performing temperingtreatment.

7. The manufacturing method for the high-toughness bainitic steel wheel for rail transit according to claim 6, wherein the heating to austenite temperature is specifically: heating to 860-930°C and maintaining at the temperature for 2.0-2.5 hours.

8. The manufacturing method for the high-toughness bainitic steel wheel for rail transit according to claim 6 or 7, wherein the temperingtreatment is: performing tempering at medium or low temperature for more than 30 minutes when the temperature of the wheel is less than 400°C, and air cooling the wheel to room temperature after the tempering; or intensively cooling the rim tread with the water spray to the temperature below 400°C, and air cooling to room temperature, during which self-tempering is performed by using waste heat.

9. The manufacturing method for the high-toughness bainitic steel wheel for rail transit according to claim 6, wherein the heat treatment process can alternatively be: heating treatment of the wheel with high-temperature waste heat after the molding, and directly intensively cooling a rim tread of a molded wheel with a water spray to a temperature below 400°C, and performing tempering treatment.

10. The manufacturing method for the high-toughness bainitic steel wheel for rail transit according to claim 6, wherein the heat treatment process can alternatively be: air cooling a wheel to a temperature below 400°C after the wheel is molded, and performing temperingtreatment.

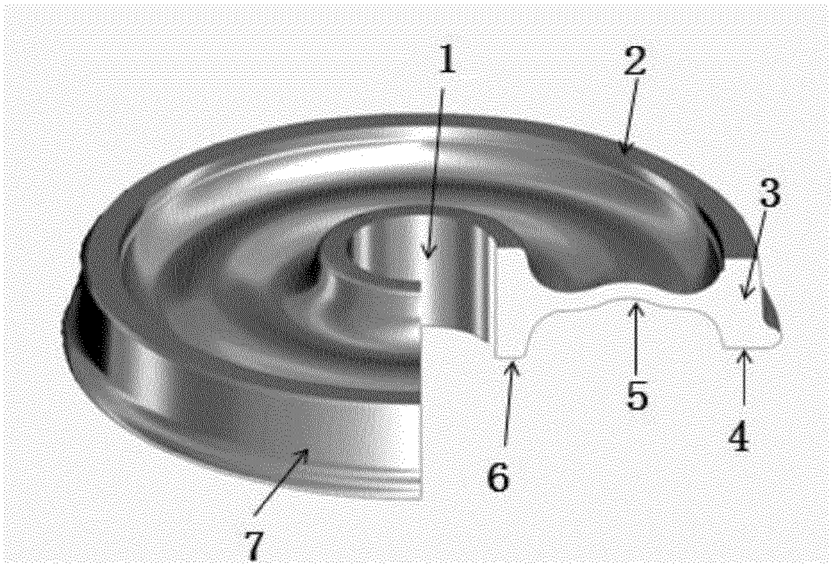


FIG. 1

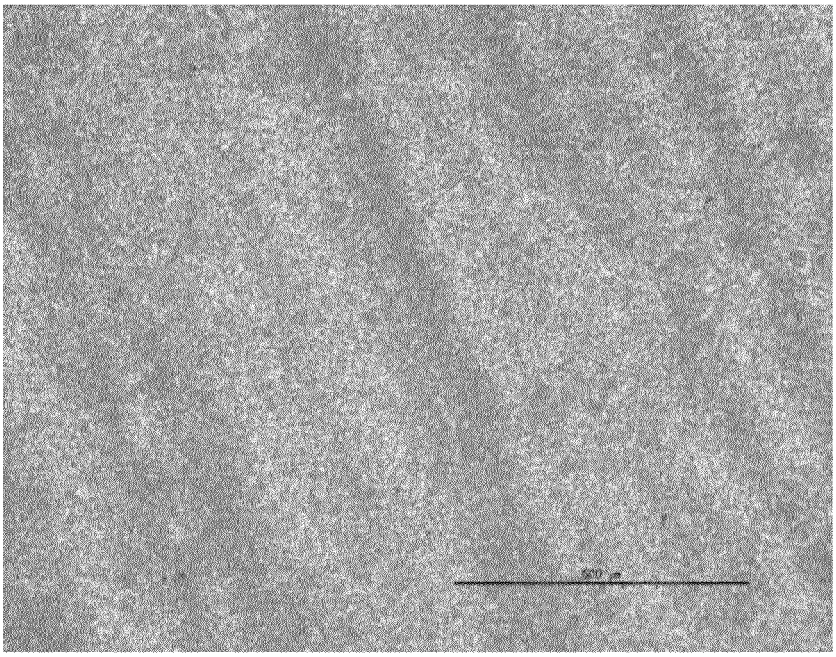


FIG. 2 (2a)

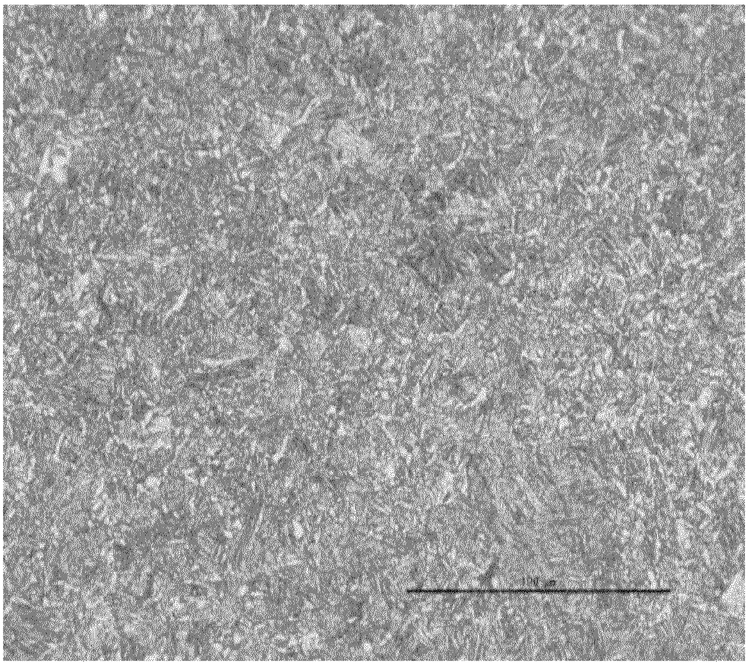


FIG. 2 (2b)

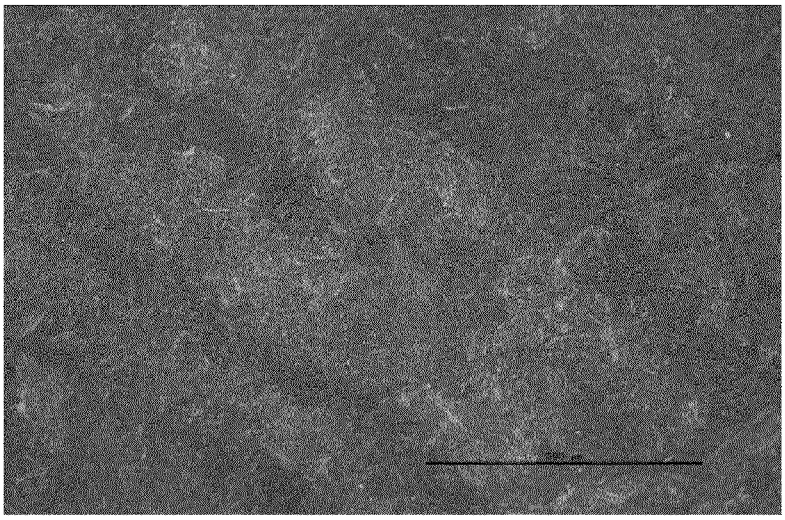


FIG. 3 (3a)

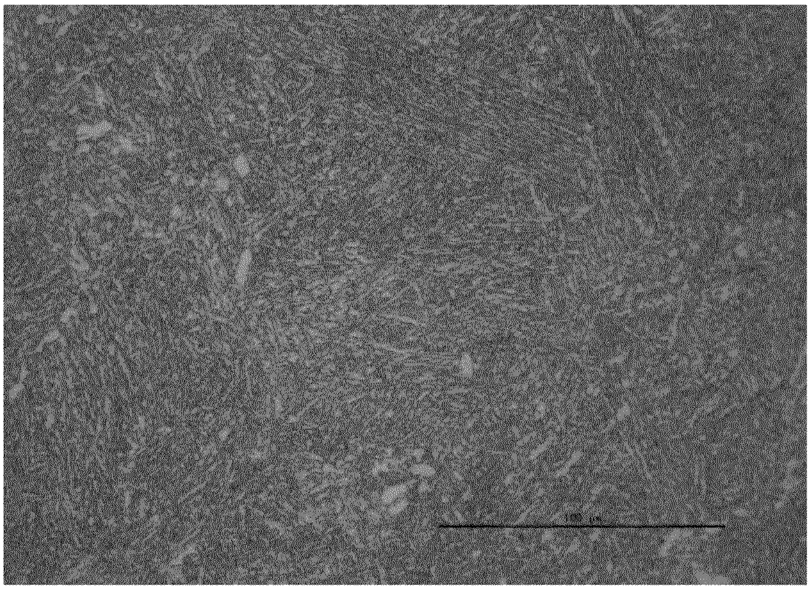


FIG. 3 (3b)

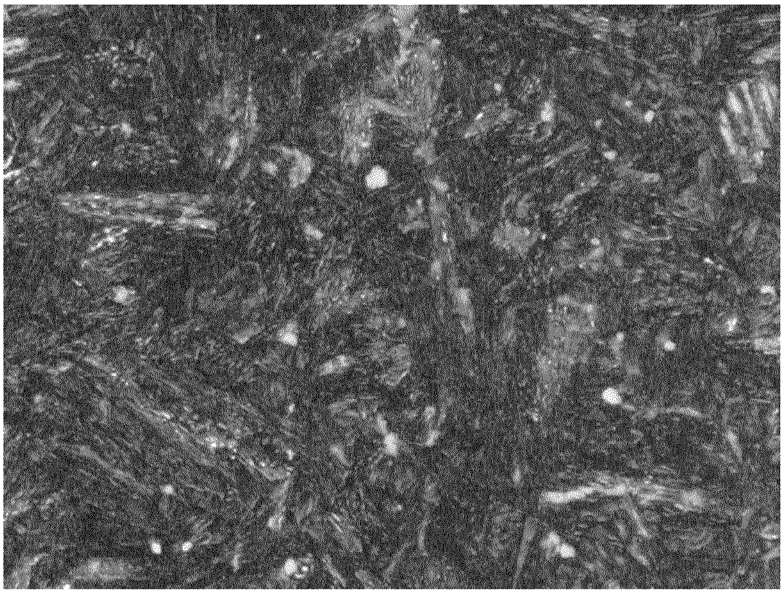


FIG. 3 (3c)

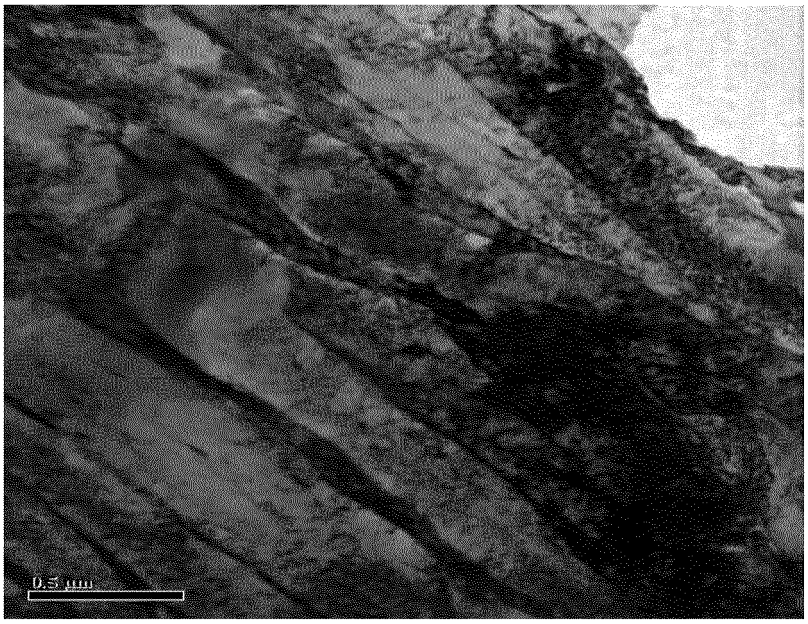


FIG. 3 (3d)

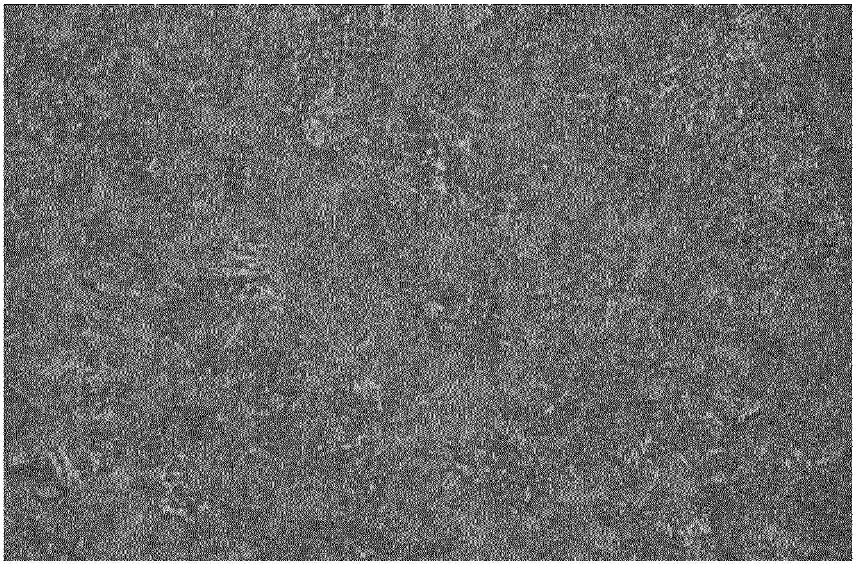


FIG. 4 (4a)

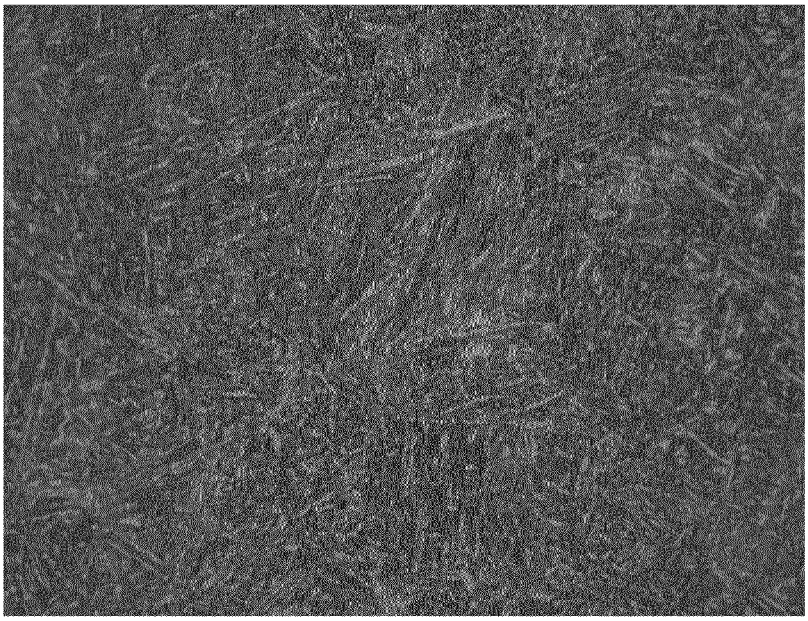


FIG. 4 (4b)

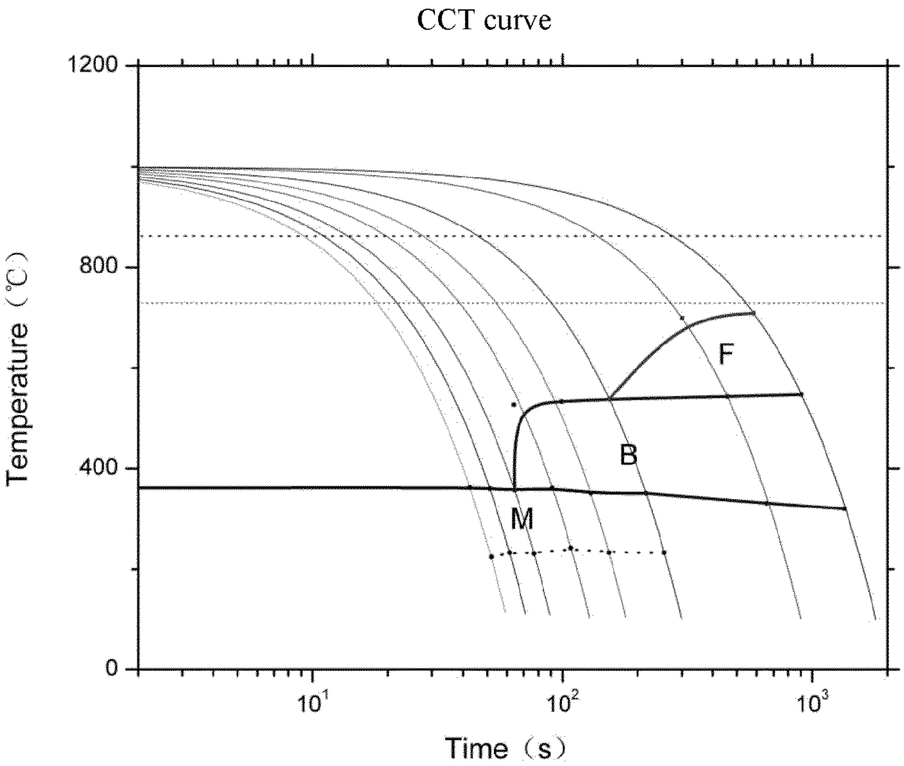


FIG. 5

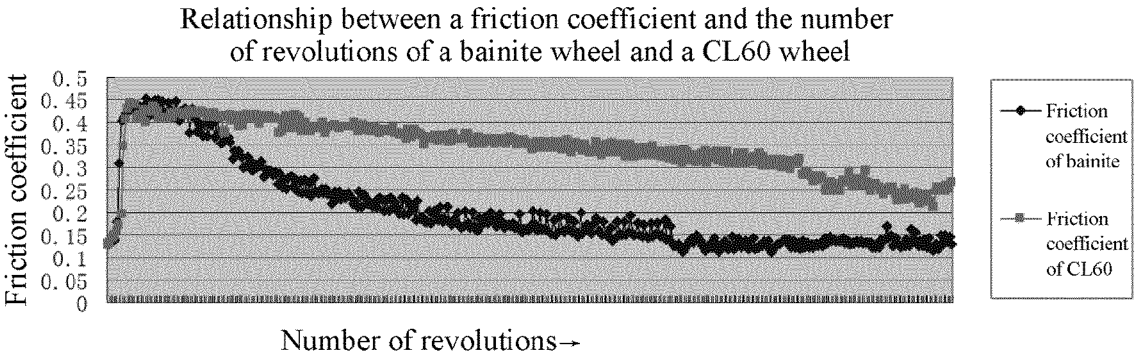
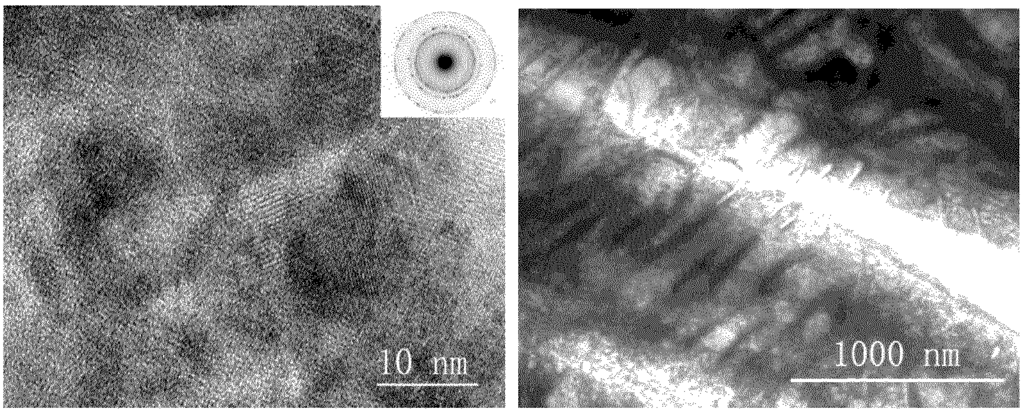


FIG. 6



Bainite wheel

CL60 wheel

FIG. 7

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2017/091930

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/08 (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 38/-

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)

EPODOC, JPABS, CNABS, CNKI: carbon, silicon, manganese, nickel, rare earth, bainitic carbide-free steel, TBF steel, bainitic ferrite steel, C, Si, Mn, Ni, RE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
PX	CN 106048430 A (MAGANG (GROUP) HOLDING CO., LTD. et al.), 26 October 2016 (26.10.2016), claims 1-10	1-10
X	CN 1800427 A (MAANSHAN IRON & STEEL CO., LTD.), 12 July 2006 (12.07.2006), description, page 3, paragraphs 2-5	1-10
A	CN 101338399 A (NANJING IRON & STEEL CO., LTD.), 07 January 2009 (07.01.2009), the whole document	1-10
A	WO 2012048841 A1 (CORUS STAAL BV et al.), 19 April 2012 (19.04.2012), the whole document	1-10

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

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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

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"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
22 August 2017 (22.08.2017)	**12 October 2017 (12.10.2017)**

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Authorized officer
PENG, Min
Telephone No.: (86-10) **62084744**

Form PCT/ISA/210 (second sheet) (July 2009)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2017/091930

Patent Documents referred in the Report	Publication Date	Patent Family	Publication Date
CN 106048430 A	26 October 2016	None	
CN 1800427 A	12 July 2006	CN 100395366 C	18 June 2008
CN 101338399 A	07 January 2009	CN 100567549 C	09 December 2009
WO 2012048841 A1	19 April 2012	EP 2627790 B1	08 October 2014
		JP 2013545890 A	26 December 2013
		EP 2627790 A1	21 August 2013
		CN 103154279 A	12 June 2013
		CN 103154279 B	23 September 2015
		WO 2012048841 A8	25 April 2013
		US 2013192726 A1	01 August 2013
		IN 201303610 P4	10 June 2016

Form PCT/ISA/210 (patent family annex) (July 2009)

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- CN 1800427 A **[0010]**
- CN 1059239 C **[0011] [0040]**
- CN 100395366 C **[0040]**