(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 3 315 625 A1

(12) **EUROPEAN PATENT APPLICATION**
published in accordance with Art. 153(4) EPC

(43) Date of publication:
02.05.2018 Bulletin 2018/18

(21) Application number: **16817641.0**

(22) Date of filing: **03.06.2016**

(51) Int Cl.:
C22C 38/00 *(2006.01)* ***C21D 1/10*** *(2006.01)*
C21D 9/00 *(2006.01)*

(86) International application number:
PCT/JP2016/066601

(87) International publication number:
WO 2017/002532 (05.01.2017 Gazette 2017/01)

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
MA MD

(30) Priority: **29.06.2015 JP 2015129873**

(71) Applicant: **NTN Corporation**
Osaka-shi, Osaka 550-0003 (JP)

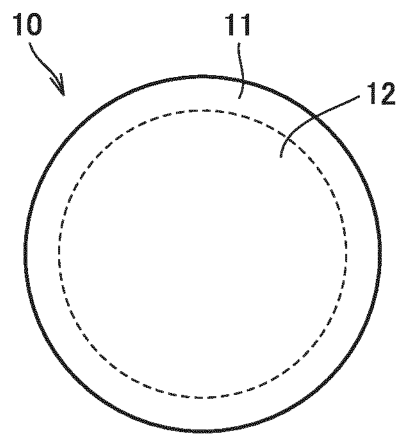
(72) Inventors:
- **SATO, Miyu**
Kuwana-shi
Mie 511-0867 (JP)
- **OHKI, Chikara**
Kuwana-shi
Mie 511-0867 (JP)

(74) Representative: **Bockhorni & Kollegen**
Elsenheimerstraße 49
80687 München (DE)

(54) **MACHINE PART**

(57) There is provided a high-strength steel mechanical component. A mechanical component (10) is a mechanical component composed of a steel having a carbon content of more than or equal to 0.2 mass % and less than or equal to 0.8 mass %, and includes a quench-hardened layer (11) formed in a surface layer of the mechanical component. In the quench-hardened layer (11), a grain size number of prior austenite crystal grains is No. 11 or higher. Moreover, the quench-hardened layer (11) may have a Vickers hardness of more than or equal to 500 HV. In this case, prior austenite crystal grains in the quench-hardened layer (11) become fine, thereby providing the mechanical component (10) with high strength.

FIG.3



EP 3 315 625 A1

Description

TECHNICAL FIELD

[0001] The present invention relates to a mechanical component, more particularly, a mechanical component having a hardened layer formed in a surface layer of the mechanical component.

BACKGROUND ART

[0002] An ECAP (Equal Channel Angular Processing) method is a representative method for applying large strain to a metal material. The ECAP method is drawing attention as a large-strain processing method with which the shape of a material is not much changed before and after the processing. However, in the ECAP method, an amount of strain in one processing is not so large. Therefore, in the ECAP method, the processing has to be performed multiple times in order to exhibit desired fine crystal grains and plasticity. This presents a problem in terms of processing efficiency. Moreover, in the ECAP method, it is difficult to control processing conditions. Due to existence of such problems, it is difficult to use the ECAP method as industrial technology.

[0003] As a metal processing method with improved mass productivity and low cost, the following method has been proposed: a target object composed of a metal material is heated and a formed low deformation resistance region is twisted to cause shear deformation of the region, thereby obtaining a fine metal structure (for example, see Japanese Patent Laying-Open No. 2007-308806 (Patent Document 1)).

CITATION LIST

PATENT DOCUMENT

[0004] PTD 1: Japanese Patent Laying-Open No. 2007-308806

SUMMARY OF INVENTION

TECHNICAL PROBLEM

[0005] However, in the above-described method, no report has been made with regard to: a quenching treatment for a steel material; a condition under which the quenching treatment can be performed; and a condition under which the fine crystalline structure of the steel material can be obtained.

[0006] Here, for example, in the automobile industry, it has been desired to reduce the weight of a vehicle body or the like in order to improve fuel efficiency or traveling performance. As one of measures to achieve this, it can be considered to reduce the weight by using a material having high strength resulting from a fine crystalline structure. Particularly, it is considered that a great contribution to the weight reduction of the vehicle body or the like is made by providing a steel material, which is a main component of a vehicle body or the like, a fine crystalline structure to have high strength.

[0007] The present invention has been made to solve the above-described problem, and has an object to provide a mechanical component composed of a steel having high strength.

SOLUTION TO PROBLEM

[0008] A mechanical component according to the present disclosure is a mechanical component composed of a steel having a carbon content of more than or equal to 0.2 mass % and less than or equal to 0.8 mass %, the mechanical component including a quench-hardened layer formed in a surface layer of the mechanical component. In the quench-hardened layer, a grain size number of prior austenite crystal grains is No. 11 or higher.

ADVANTAGEOUS EFFECTS OF INVENTION

[0009] According to the description above, there can be obtained a mechanical component composed of a steel having high strength.

BRIEF DESCRIPTION OF DRAWINGS

[0010]

Fig. 1 is a flowchart for illustrating a method for manufacturing a mechanical component according to the present embodiment.
Fig. 2 is a schematic view showing a configuration of a processing apparatus used in a heat treatment step shown in Fig. 1.
Fig. 3 is a schematic cross sectional view of the mechanical component according to the present embodiment.
Fig. 4 shows a photograph of an external appearance of a sample used in an experiment.
Fig. 5 shows an enlarged photograph of a cross section of a sample 1.
Fig. 6 shows an enlarged photograph of a cross section of a sample 2.
Fig. 7 shows an enlarged photograph of a cross section of a sample 3.

DESCRIPTION OF EMBODIMENTS

[0011] The following describes an embodiment of the present disclosure with reference to figures. It should be noted that in the below-described figures, the same or corresponding portions are given the same reference characters and are not described repeatedly.

<Method for Manufacturing Mechanical Component>

[0012] With reference to Fig. 1, the following describes a method for manufacturing a mechanical component according to the present embodiment. As shown in Fig. 1, in the method for manufacturing the mechanical component according to the present embodiment, a preparing step (S10) is performed first. In this step (S10), there are prepared: a steel target object 1 (see Fig. 2) to be formed into the mechanical component; and a processing apparatus such as one shown in Fig. 2. Target object 1 may be processed into a general shape for mechanical components. Target object 1 may have a carbon content of more than or equal to 0.2 mass %. Processing object 1 can be processed using any conventionally known method. For the material of target object 1, a steel having any composition can be employed; however, the material has a carbon content of more than or equal to 0.2 mass %, for example. Any shape of target object 1 can be employed; however, target object 1 may have a shape (for example, bar-like shape) with a longitudinal axis extending in a predetermined direction as shown in Fig. 2, for example. Moreover, a cross sectional shape thereof in a direction perpendicular to the longitudinal axis of target object 1 can be any shape, but may be a circular shape, for example.

[0013] Next, a heat treatment step (S20) is performed. In this step (S20), a quenching treatment is performed by heating a surface portion of target object 1 to a heating temperature more than or equal to an A3 transformation point temperature and then cooling the surface portion of target object 1, under application of shear strain to the surface portion of target object 1. In the step (S20) as a step of performing a quenching treatment, the heating temperature is more than or equal to 800°C. Moreover, in the quenching treatment, the surface portion of the target object is cooled at a rate of more than or equal to 35°C/second in a temperature range from 850°C to 300°C. By performing the quenching treatment under application of the shear strain in this way, a high-strength steel mechanical component having a surface portion provided with a quench-hardened layer having a fine crystalline structure can be obtained. It should be noted that a configuration of the processing apparatus used in this step (S20) will be described later.

[0014] Next, a post-treatment step (S30) is performed. In this step (S30), target object 1 having been through the heat treatment step (S20) is subjected to grinding, washing, and/or other processes, thereby obtaining a final mechanical component. It should be noted that any conventionally known method(s) can be used for the grinding, washing, and/or other processes.

<Configuration of Processing Apparatus>

[0015] With reference to Fig. 2, the following describes the configuration of the processing apparatus used in the above-described heat treatment step (S20). As shown in Fig. 2, the processing apparatus mainly includes: a rotating portion 4 that holds one end portion of target object 1; a fixing portion 5 that fixes the other end portion of target object 1; a heating coil 2 for performing induction heating; a cooling nozzle 3 for performing a quenching treatment; a matching board 6; a coolant circulating device 7; a power supply 8; and a coolant circulating device 9 for power supply 8.

[0016] Rotating portion 4 is configured to be capable of rotating to twist the one end portion of target object 1 relative to fixing portion 5. Rotating portion 4 includes a rotating portion side holder that holds the one end portion of target object 1. Any conventionally known configuration can be employed for the configuration of the rotating portion side holder as long as the rotating portion side holder can detachably hold the one end portion of target object 1. Moreover, rotating portion 4 may include a motor and reduction gears, for example. In rotating portion 4, a driving device, such as the motor, may be connected to the above-described rotating portion side holder via the reduction gears. The rotating portion side holder of rotating portion 4 is configured to be rotatable by the driving device described above.

[0017] Fixing portion 5 includes a fixing portion side holder that holds the other end portion of target object 1. Any conventionally known configuration can be employed for the configuration of the fixing portion side holder as long as the fixing portion side holder can detachably hold the other end portion of target object 1.

[0018] Moreover, heating coil 2 is disposed to surround the outer circumference of target object 1 held by rotating portion 4 and fixing portion 5. Cooling nozzle 3 is disposed adjacent to heating coil 2. Cooling nozzle 3 is configured to be capable of spraying coolant to target object 1. For the coolant, any coolant can be used such as a liquid like water or oil. Heating coil 2 and cooling nozzle 3 are movable along an extending direction of target object 1 (for example, direction from fixing portion 5 toward rotating portion 4). As a mechanism for moving heating coil 2 and cooling nozzle 3, any conventionally known mechanism can be used, such as a fluid cylinder or an electric motor.

[0019] Matching board 6 includes, for example, a capacitor and a transformer, and controls power supplied to heating coil 2 so as to control a heating state of target object 1. Matching board 6 is connected to heating coil 2 and power supply 8. Power supply 8 is a power supply for high-frequency induction heating and includes an inverter, for example. As configurations of power supply 8 and matching board 6, any conventionally known configurations can be employed.

[0020] Coolant circulating device 7 supplies heating coil 2 with water, which is the coolant for cooling heating coil 2. Moreover, coolant circulating device 7 may supply matching board 6 with water, which is the coolant for cooling matching board 6. Moreover, coolant circulating device 7 supplies cooling nozzle 3 with water to be sprayed from cooling nozzle 3 to target object 1 for the purpose of cooling.

[0021] Coolant circulating device 9 supplies power supply 8 with water, which is the coolant for cooling power supply 8.

<Operation of Processing Apparatus>

[0022] In the heat treatment step (S20) shown in Fig. 1, the above-described heat treatment is performed using the processing apparatus shown in Fig. 2. Specifically, target object 1 is fixed by rotating portion 4 and fixing portion 5. In this state, target object 1 is fed with stress by rotating portion 4 to rotate (twist) target object 1 around a rotation axis extending in the extending direction of target object 1. On this occasion, the other end portion of target object 1 is fixed by fixing portion 5, with the result that shear strain due to the twisting is applied to the outer circumferential surface of target object 1 (side surface around the rotation axis).

[0023] Moreover, on this occasion, rotating portion 4 may be rotated relative to fixing portion 5 at a rotating speed of more than or equal to 0.05 (rotation/second). In this way, shear strain can be sufficiently generated in the surface of target object 1. Moreover, a strain amount of the shear strain applied to the surface of target object 1 may be more than or equal to 7.1. It should be noted that the strain amount of the shear strain is defined herein as follows. That is, when target object 1 is twisted (twisted and rotated) around the above-described rotation axis (longitudinal axis of target object 1) and target object 1 is heated as described below in the heat treatment step (S20), a linear pattern extending along the circumferential direction is formed in the outer circumferential surface of target object 1. An angle θ between the above-described rotation axis and the direction in which the linear pattern extends is found by measurement. Then, the strain amount of the shear strain is defined as $\tan\theta$.

[0024] Moreover, the strain amount of the shear strain can be adjusted by controlling stress applied from rotating portion 4 to target object 1, for example. For a method for controlling the stress, a conventionally known method can be used, such as controlling an output of the driving device (such as an electric motor) for rotating target object 1 in rotating portion 4.

[0025] Under such application of the shear strain to target object 1, the surface of target object 1 is inductively heated by heating coil 2 disposed to surround the outer circumference of target object 1. Through the induction heating, the surface of target object 1 is heated to the predetermined heating temperature more than or equal to the A3 transformation point.

[0026] Heating coil 2 and cooling nozzle 3 are moved along the surface of target object 1. The movement direction of heating coil 2 and cooling nozzle 3 is a direction from cooling nozzle 3 toward heating coil 2 (direction from fixing portion 5 toward rotating portion 4 in Fig. 2). As a result, cooling nozzle 3 is moved to be located above the surface of target object 1 having been heated by heating coil 2. Then, the coolant, such as water, is sprayed from cooling nozzle 3 to the heated surface of target object 1, thereby providing a quenching treatment to the surface of target object 1. It should be noted that the movement speed of heating coil 2 may be more than or equal to 0.5 mm/second. Further, the movement speed of cooling nozzle 3 may also be more than or equal to 0.5 mm/second. Moreover, the movement speed of cooling nozzle 3 may be the same as the movement speed of heating coil 2. Further, heating coil 2 and cooling nozzle 3 may be in one piece.

[0027] Moreover, by moving heating coil 2 and cooling nozzle 3 as described above, the heating by heating coil 2 and the cooling (quenching treatment) by cooling nozzle 3 can be performed sequentially to the surface of target object 1 in the direction from the fixing portion 5 side toward the rotating portion 4 side. Further, since the quenching treatment is performed under application of the shear strain to the surface of target object 1 by rotating portion 4 providing target object 1 with the force of twisting target object 1, prior austenite crystal grains in the quench-hardened layer of quenched target object 1 can be fine.

<Mechanical Component>

[0028] With reference to Fig. 3, the following describes a configuration of the mechanical component obtained by the method for manufacturing the mechanical component shown in Fig. 1. Fig. 3 is a schematic cross sectional view of mechanical component 10 in a direction perpendicular to the longitudinal axis of mechanical component 10. As shown in Fig. 3, mechanical component 10 includes: a quench-hardened layer 11 formed in the surface layer of mechanical component 10; and a core portion 12 located circumferentially inwardly of quench-hardened layer 11. In quench-hardened layer 11, the grain size number of the prior austenite crystal grains is No. 11 or higher. The grain size number is defined in JIS G0551. Moreover, mechanical component 10 is a mechanical component composed of a steel having a carbon content of more than or equal to 0.2 mass % and less than or equal to 0.8 mass %. Quench-hardened layer 11 has a higher hardness than that of core portion 12. For example, quench-hardened layer 11 may have a Vickers hardness of more than or equal to 500 HV or more than or equal to 400 HV. Moreover, for example, the thickness of quench-hardened layer 11 can be more than or equal to 4 mm (assuming that quench-hardened layer 11 is a region having a Vickers hardness of more than or equal to 400 HV). It should be noted that the thickness of quench-hardened layer 11 can be determined by finding a quench-hardening depth by way of Vickers hardness measurement.

[0029] The characteristic configurations of the embodiment of the present invention will be listed, although a part of the configurations may be repeatedly described.

[0030] Mechanical component 10 according to the present disclosure is a mechanical component composed of a steel having a carbon content of more than or equal to 0.2 mass % and less than or equal to 0.8 mass %, the mechanical component including a quench-hardened layer 11 formed in a surface layer of the mechanical component. In quench-hardened layer 11, a grain size number of prior austenite crystal grains is No. 11 or higher. In this case, the prior austenite crystal grains of quench-hardened layer 11 become fine to provide mechanical component 10 with high strength.

[0031] Here, the carbon content of the mechanical component is more than or equal to 0.2 mass % in order to securely form the quench-hardened layer by the quenching treatment. Moreover, the carbon content of the mechanical component is less than or equal to 0.8 mass % in order to prevent a quenching crack. It should be noted that the lower limit of the carbon content may be 0.3 mass % or 0.35 mass %. On the other hand, the upper limit of the carbon content may be 0.7 mass % or 0.6 mass %. Moreover, the grain size number of the above-described prior austenite crystal grains may be 12 or higher.

[0032] In mechanical component 10, the thickness of the quench-hardened layer may be more than or equal to 4 mm (assuming that the quench-hardened layer is represented by a region having a Vickers hardness of more than or equal to 400 HV). In this case, quench-hardened layer 11 having a sufficient thickness is formed in the surface layer of mechanical component 10, thereby securely increasing the strength of the mechanical component. It should be noted that the thickness of the quench-hardened layer may be more than or equal to 4.5 mm or more than or equal to 5 mm.

[0033] In mechanical component 10, quench-hardened layer 11 may have a Vickers hardness of more than or equal to 500 HV. In this case, a high-strength mechanical component can be securely obtained. It should be noted that quench-hardened layer 11 may have a Vickers hardness of more than or equal to 550 HV or more than or equal to 580 HV. Moreover, the above-described Vickers hardness of quench-hardened layer 11 refers to an average of measured values of the Vickers hardness at multiple positions (for example, five points) in the depth direction of the quench-hardened layer in the cross section of mechanical component 10.

[0034] A method for manufacturing a mechanical component according to the present disclosure includes: preparing a steel target object 1 to be formed into the mechanical component (preparing step (S10)); and performing a quenching treatment by heating a surface portion of target object 1 to a heating temperature more than or equal to an A3 transformation point temperature and then cooling the surface portion, under application of shear strain to the surface portion of target object 1 (heat treatment step (S20)). Target object 1 has a carbon content of more than or equal to 0.2 mass %. In the step (S20) of performing the quenching treatment, the heating temperature is more than or equal to 800°C, and the surface portion of target object 1 is cooled in the quenching treatment at a cooling rate of more than or equal to 35°C/second in a temperature range from 850°C to 300°C.

[0035] In this way, there can be obtained high-strength steel mechanical component 10 having the surface portion provided with quench-hardened layer 11 having a fine crystalline structure.

[0036] It should be noted that the heating temperature is more than or equal to 800°C in order to securely perform the quenching treatment by securely causing the surface portion of target object 1 to have the temperature more than or equal to the A3 transformation point. The heating temperature may be more than or equal to 850°C or more than or equal to 900°C. Moreover, the upper limit of the heating temperature may be 1000°C.

[0037] Moreover, the cooling rate is set at more than or equal to 35°C/second in the temperature range from 850°C to 300°C in view of a possibility of occurrence of a portion with incomplete quenching when the cooling rate is less than 35°C/second. The cooling rate may be more than or equal to 38°C/second or more than or equal to 40°C/second in the temperature range from 850°C to 300°C.

[0038] In the method for manufacturing the mechanical component, in the step (S20) of performing the quenching treatment, two positions in target object 1 may be held by first and second holders (rotating portion 4 and fixing portion 5) and the first holder (rotating portion 4) may be rotated relative to the second holder (fixing portion 5) around a rotation axis extending from the first holder (rotating portion 4) toward the second holder (fixing portion 5) so as to apply shear strain to the surface portion of target object 1.

[0039] In this case, by such a comparatively simple process that the holder (rotating portion 4) is rotated with the two positions in target object 1 being held, the shear strain can be applied to target object 1. Accordingly, the method for manufacturing the mechanical component can be suppressed from being complicated.

[0040] In the method for manufacturing the mechanical component, the rotating speed (twisting speed) may be more than or equal to 0.05 (rotation/second) when the first holder (rotating portion 4) is rotated relative to the second holder (fixing portion 5).

[0041] In this case, sufficient shear strain can be generated in the surface portion of target object 1, whereby the crystalline structure (prior austenite crystal grains) in the surface portion can be securely fine. It should be noted that the rotating speed described above is set at more than or equal to 0.05 (rotation/second) because sufficient shear strain may not be able to be applied to the surface portion of target object 1 if the rotating speed is less than 0.05 (rotation/second). The rotating speed may be more than or equal to 0.07 (rotation/second), or may be more than or equal to 0.1 (rotation/second).

[0042] In the method for manufacturing the mechanical component, in the step (S20) of performing the quenching treatment, a portion of the surface portion is heated and the heated portion may be moved in the surface portion. The heated portion may be moved at a speed of more than or equal to 0.5 mm/second. In this case, operation efficiency of the quenching treatment in the method for manufacturing the mechanical component can be made sufficiently high. It should be noted that the speed of moving the heated portion is more than or equal to 0.5 mm/second due to the following reason: if the speed of moving the heated portion is less than 0.5 mm/second, the operation efficiency of the quenching treatment becomes too low, thus presumably resulting in a practical problem. The speed of moving the heated portion may be more than or equal to 0.7 mm/second, or more than or equal to 1 mm/second.

[0043] In the method for manufacturing the mechanical component, in the step (S20) of performing the quenching treatment, a strain amount of the shear strain may be more than or equal to 7.1. In this case, sufficient shear strain is applied to the surface portion, whereby the crystalline structure in the surface portion can be securely fine. Here, the strain amount of the shear strain is more than or equal to 7.1 because the prior austenite crystal grains of the quench-hardened layer may become insufficiently fine if the strain amount is less than 7.1. The strain amount may be more than or equal to 7.5 or more than or equal to 8.

<Experiment Example>

[0044] The following experiment was conducted in order to confirm the effect of the present embodiment.

(Samples)

[0045] As samples, carbon steel axial materials each having a small amount of boron added therein was used. For the samples, three types of samples ID1 to ID3 were prepared. In each of the samples, the content of carbon was 0.38 mass %. The shape of the sample was a cylindrical shape. The size of the sample was as follows: the length thereof was 500 mm; and the diameter thereof in a cross section was 20.1 mm.

(Heat Treatment)

[0046] The processing apparatus shown in Fig. 2 was used to perform heat treatment to samples ID1 to ID3. Specifically, the samples were heated through high-frequency induction heating using heating coil 2. By moving heating coil 2 and adjacent cooling nozzle 3 along the axial direction of each sample, the surface of the sample was quenched. Heating coil 2 and cooling nozzle 3 were moved at a speed of 0.5 mm/second.

[0047] Moreover, the heat treatment was performed under conditions that the surface temperature of each of the samples was heated to the heating temperature (900°C) more than or equal to the A3 transformation point and then was cooled, thereby performing the quenching treatment. The cooling was performed under conditions that the cooling rate was 37°C/second in a temperature range from 850°C to 300°C.

[0048] Moreover, the heating treatment was performed under different conditions for the samples with regard to the twisting of each sample in the heat treatment. Specifically, for sample ID1, the heat treatment was performed without twisting. For sample ID2, the heat treatment was performed with the rotating speed (twisting speed) of rotating portion 4 relative to fixing portion 5 being 0.025 (rotation/second). For sample ID3, the heat treatment was performed with the rotating speed being 0.05 (rotation/second).

(Measurement Items)

[0049] The external appearance of each of the samples having been through the heat treatment was observed, a cross-sectional photograph of the surface layer (quench-hardened layer) of each of the samples in a cross section was captured, and a microstructure in the cross section was observed. Specifically, the cross section of each of the samples having been through the heat treatment was corroded with AGS and the microstructure was observed using an optical microscope.

[0050] Moreover, an amount of shear strain was measured in sample ID3. The following method was used as a method for measuring the amount of shear strain. That is, in the outer circumferential surface of the sample having been through the heat treatment, a below-described linear pattern extending along the circumferential direction is formed as shown in Fig. 4. An angle θ between the longitudinal axis (rotation axis) of the sample and the direction in which the linear pattern extends was found by measurement. Then, $\tan\theta$ was calculated as the amount of shear strain.

[0051] Moreover, in the cross section, a Vickers hardness was measured in a region from the surface to a depth of 200 μm. Specifically, the Vickers hardness was measured in the depth direction at five positions at an interval of 40 μm within a region from the surface to a depth of 200 μm in the cross section of each sample.

(Results)

Results of Observation of External Appearances:

[0052] Fig. 4 shows respective photos of external appearances of sample ID1 (at the upper side) having been through the heat treatment without twisting and sample ID3 (at the lower side) having been through the heat treatment with sample ID3 being twisted at a rotating speed of 0.05 (rotation/second). As understood from Fig. 4, a linear pattern was generated in sample ID3 to extend in a direction (circumferential direction along the twisting direction) indicated by a white-dot line.

Amount of Shear Strain:

[0053] The amount of shear strain in sample ID3 was about 7.1.

Vickers Hardness Measurements:

[0054] As a result of measuring the Vickers hardness in each of samples ID1 to ID3, the average value of the Vickers hardness in each of samples ID1 to ID3 was more than or equal to 600 HV in the region from the surface to the depth of 200 μm. That is, in each of the samples, the region from the surface to the depth of 200 μm was quench-hardened.

Microstructure Observation in Cross Section:

[0055] Fig. 5 to Fig. 7 respectively show the microstructures of the cross sections of samples ID1 to ID3 after the corrosion with AGS. The microstructures were observed using an optical microscope. Fig. 5 shows the microstructure photograph of the cross section of sample ID1. The grain size number (see JIS G0551) of the prior austenite crystal grains in sample ID1 shown in Fig. 5 was No. 9. The grain size number of the prior austenite crystal grains in sample ID2 shown in Fig. 6 was No. 10. The grain size number of the prior austenite crystal grains in sample ID3 shown in Fig. 7 was No. 12.

[0056] From these, it was confirmed that the quench-hardened layer having the fine crystal grains can be formed by performing the heat treatment while twisting (i.e., while applying shear strain).

[0057] It should be noted that the carbon steel having a small amount of boron added therein was used as the material of each of samples ID1 to ID3; however, a steel having a carbon concentration of more than or equal to 0.2 mass % is effective because a hardness of more than or equal to 500 HV is obtained after hardening.

[0058] Although the embodiments of the present invention have been illustrated, the embodiments described above can be modified in various manners. Further, the scope of the present invention is not limited to the above-described embodiments. The scope of the present invention is defined by the terms of the claims, and is intended to include any modifications within the scope and meaning equivalent to the terms of the claims.

INDUSTRIAL APPLICABILITY

[0059] The present invention is applied particularly advantageously to a mechanical component having a quench-hardened layer formed in a surface of the mechanical component.

REFERENCE SIGNS LIST

[0060] 1: target object; 2: heating coil; 3: cooling nozzle; 4: rotating portion (motor and reduction gears); 5: fixing portion; 6: matching board (capacitor, transformer); 7: coolant circulating device for cooling the matching board/heating coil and for supplying coolant to the cooling nozzle; 8: high-frequency induction heating power supply (inverter); 9: coolant circulating device for cooling the high-frequency induction heating power supply; 10: mechanical component; 11: quench-hardened layer; 12: core portion.

Claims

1. A mechanical component composed of a steel having a carbon content of more than or equal to 0.2 mass % and less than or equal to 0.8 mass %, the mechanical component comprising a quench-hardened layer formed in a surface layer of the mechanical component,
in the quench-hardened layer, a grain size number of prior austenite crystal grains being No. 11 or higher.

2. The mechanical component according to claim 1, wherein the quench-hardened layer has a thickness of more than or equal to 4 mm.

3. The mechanical component according to claim 1 or claim 2, wherein the quench-hardened layer has a Vickers hardness of more than or equal to 500 HV.

FIG.1

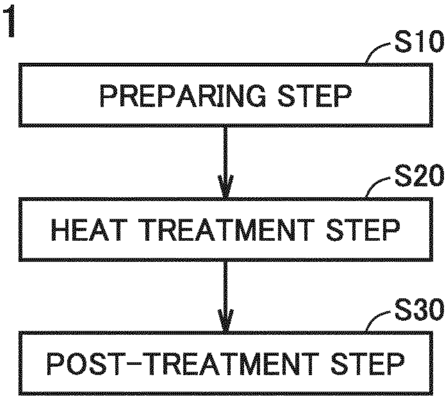

S10
PREPARING STEP
S20
HEAT TREATMENT STEP
S30
POST-TREATMENT STEP

FIG.2

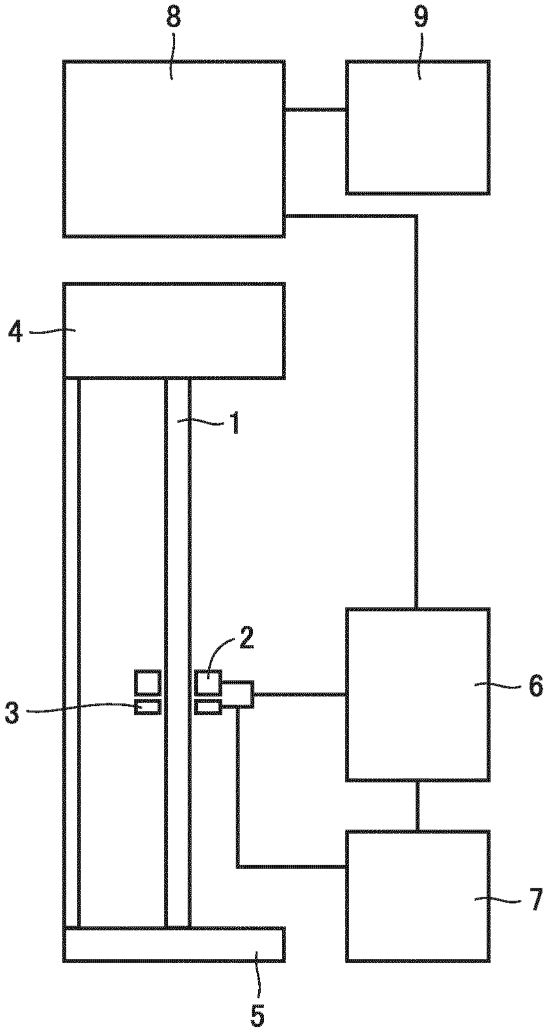

8
9
4
1
2
3
6
7
5

FIG.3

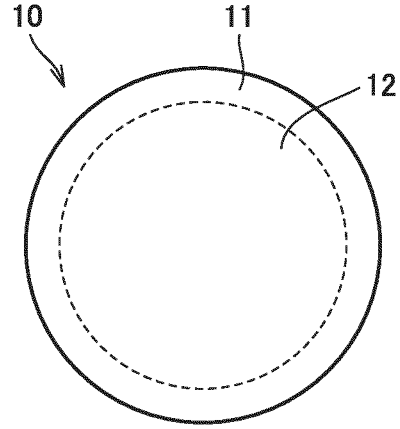


FIG.4

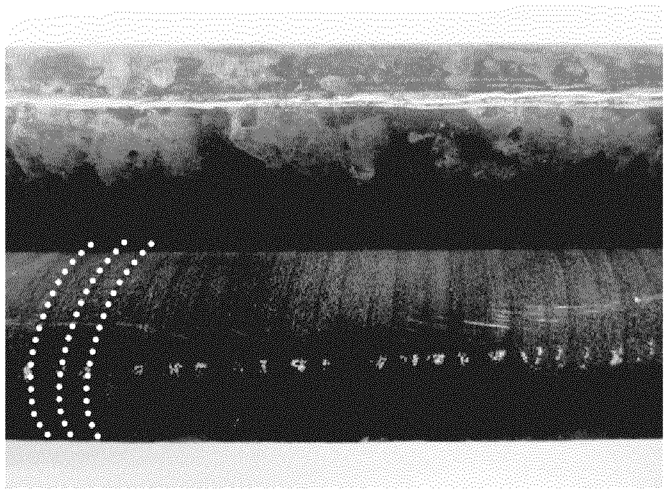


FIG.5

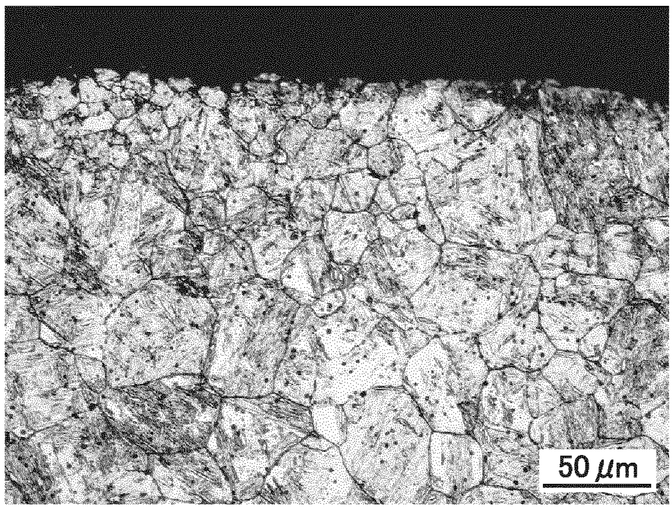


FIG.6

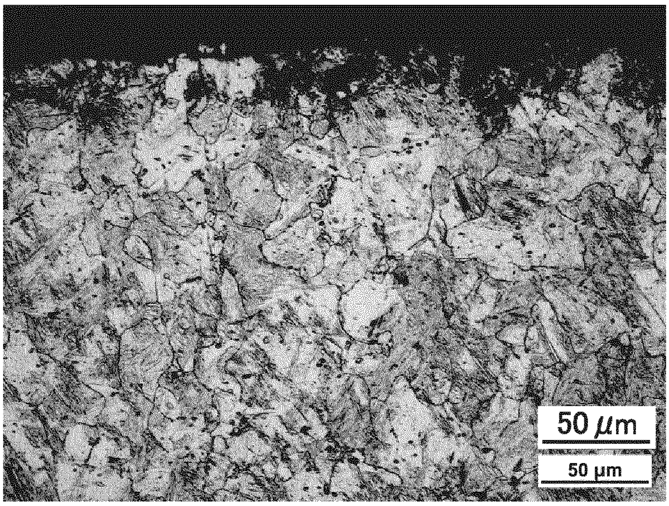
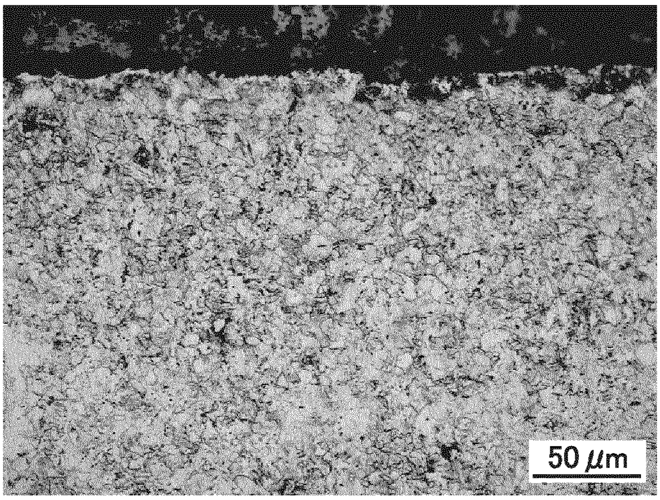


FIG.7



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2016/066601

A. CLASSIFICATION OF SUBJECT MATTER
C22C38/00(2006.01)i, *C21D1/10*(2006.01)n, *C21D9/00*(2006.01)n

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C22C38/00, C21D1/10, C21D9/00

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

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2016
Kokai Jitsuyo Shinan Koho	1971-2016	Toroku Jitsuyo Shinan Koho	1994-2016

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 2004-232669 A (NSK Ltd.), 19 August 2004 (19.08.2004), claims; paragraphs [0022], [0024], [0033], [0035] & US 2005/0141799 A1 paragraphs [0042], [0044], [0447]; tables 15, 16 & WO 2004/007219 A1 & EP 1541377 A1 & CN 1678469 A	1-3
X	JP 2007-321197 A (JFE Steel Corp.), 13 December 2007 (13.12.2007), claims; paragraphs [0010], [0039]; table 3 (Family: none)	1-3

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

Date of the actual completion of the international search
01 August 2016 (01.08.16)

Date of mailing of the international search report
16 August 2016 (16.08.16)

Name and mailing address of the ISA/
Japan Patent Office
3-4-3,Kasumigaseki,Chiyoda-ku,
Tokyo 100-8915,Japan

Authorized officer

Telephone No.

Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2016/066601

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 2009-242918 A (JFE Steel Corp.), 22 October 2009 (22.10.2009), claims; paragraphs [0017], [0032], [0035], [0038] (Family: none)	1-3
X	JP 2007-177275 A (JFE Steel Corp.), 12 July 2007 (12.07.2007), claims; paragraphs [0034], [0049]; table 2 & WO 2007/074705 A1 page 9, lines 24 to 29; examples	1-3
X	JP 2009-242923 A (JFE Steel Corp.), 22 October 2009 (22.10.2009), claims; paragraphs [0018], [0033]; examples (Family: none)	1-3
X	WO 2006/008960 A1 (JFE Steel Corp.), 26 January 2006 (26.01.2006), claims; paragraphs [0029] to [0034]; examples 1, 2 & EP 1770181 A1 claims; paragraphs [0030] to [0035]; examples 1, 2 & CN 1950530 A	1-3
A	JP 2010-185478 A (NHK Spring Co., Ltd.), 26 August 2010 (26.08.2010), (Family: none)	1-3
A	JP 2002-275538 A (Toyota Motor Corp.), 25 September 2002 (25.09.2002), (Family: none)	1-3

Form PCT/ISA/210 (continuation of second sheet) (January 2015)

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- JP 2007308806 A **[0003] [0004]**