US 20160076130A1

(19) United States
(12) Patent Application Publication
UEMATSU et al.
(10) Pub. No.: US 2016/0076130 A1
(43) Pub. Date: Mar. 17, 2016

(54) **SURFACE MODIFICATION APPARATUS FOR ALLOY STEEL COMPONENT, SURFACE MODIFICATION METHOD FOR ALLOY STEEL COMPONENT, AND METHOD FOR MANUFACTURING ALLOY STEEL COMPONENT**

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(21) Appl. No.: **14/785,453**

(22) PCT Filed: **Mar. 20, 2014**

(86) PCT No.: **PCT/JP2014/057717**

§ 371 (c)(1),
(2) Date: **Oct. 19, 2015**

(30) **Foreign Application Priority Data**

Apr. 25, 2013 (JP) 2013-092633

Publication Classification

(51) **Int. Cl.**
C23C 8/26 (2006.01)
C21D 1/74 (2006.01)
C21D 6/00 (2006.01)

(52) **U.S. Cl.**
CPC ... *C23C 8/26* (2013.01); *C21D 6/00* (2013.01); *C21D 1/74* (2013.01)

(57) **ABSTRACT**

Provided are a surface modification apparatus for an alloy steel component, a surface modification method for an alloy steel component, and a method for manufacturing an alloy steel component, which can provide a deep and homogeneous hard layer for a steel component with a wide shape or a large amount of such steel components. A surface modification apparatus **100** includes a process furnace **101**, and the process furnace **101** performs a surface modification process on an alloy steel component **90** including an alloy steel material to which at least one kind of nitride formation element such as chromium, molybdenum, or aluminum is added. The surface modification apparatus **100** forms a compound layer on a surface of the alloy steel component **90** by exposing the alloy steel component **90** for at least 180 minutes to an atmosphere in the process furnace **101** maintained to have an ammonia gas concentration of 80% or more and a temperature of 620° C.

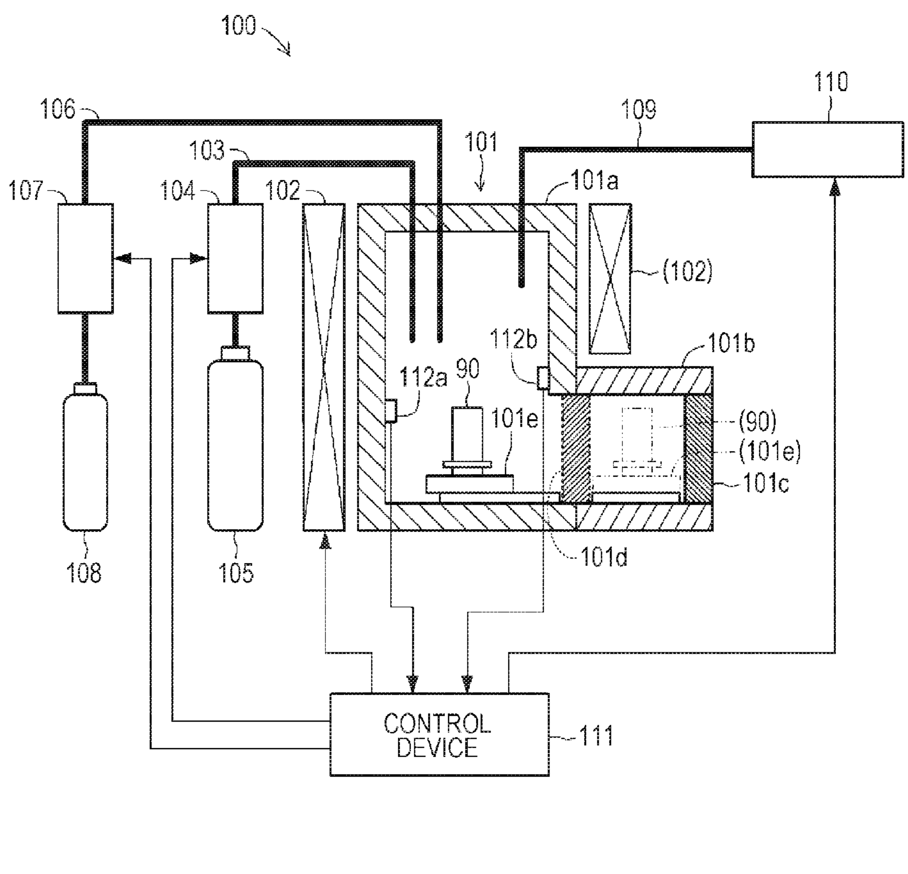


FIG. 1

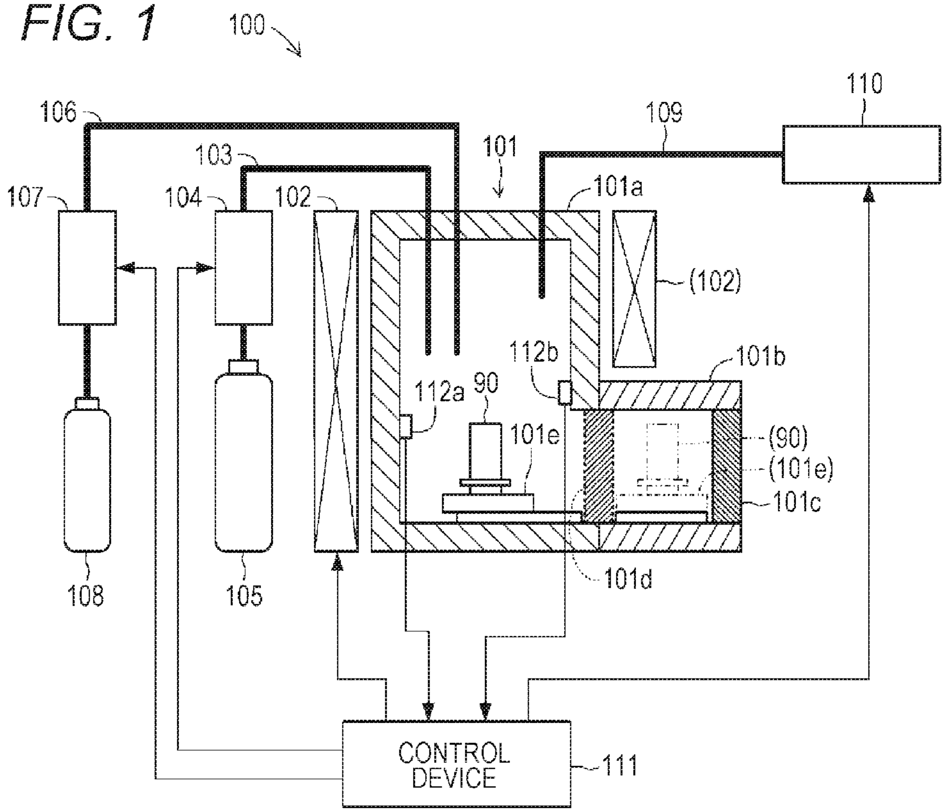

100
106
103
101
109
110
107
104
102
101a
(102)
112b
101b
112a
90
101e
(90)
(101e)
101c
108
105
101d
CONTROL DEVICE
111

FIG. 2

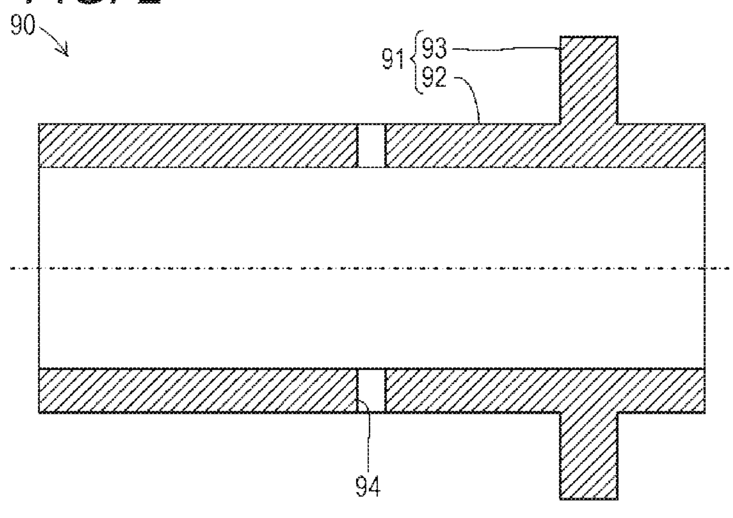

90
91
93
92
94

FIG. 3

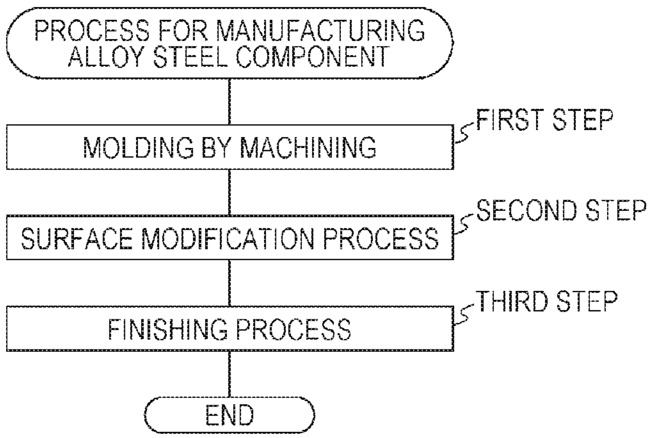

PROCESS FOR MANUFACTURING ALLOY STEEL COMPONENT
FIRST STEP
MOLDING BY MACHINING
SECOND STEP
SURFACE MODIFICATION PROCESS
THIRD STEP
FINISHING PROCESS
END

FIG. 4

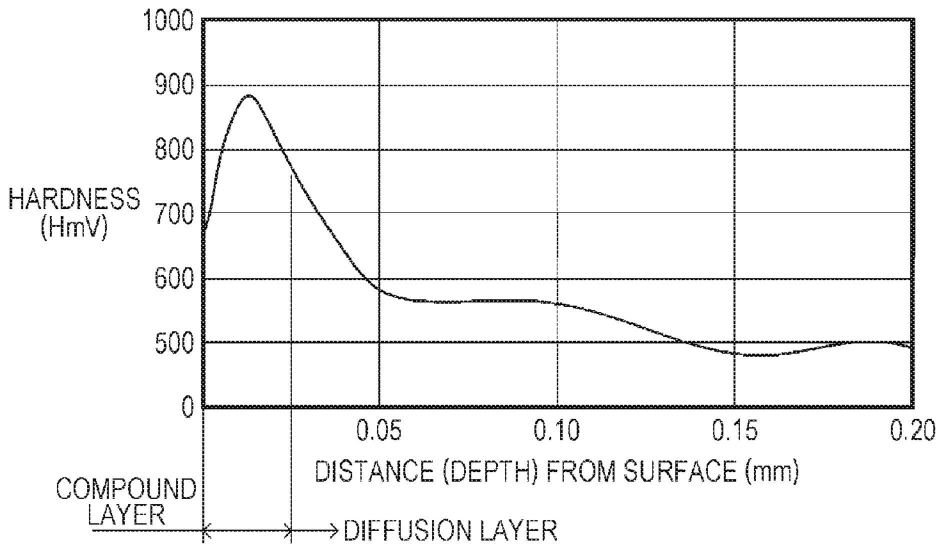

1000
900
800
700
600
500
0
HARDNESS (HmV)
0.05
0.10
0.15
0.20
DISTANCE (DEPTH) FROM SURFACE (mm)
COMPOUND LAYER
DIFFUSION LAYER

FIG. 5

(wt%)

	C	Si	Mn	P	S	Cu	Ni	Cr	Mo	Al
A	0.36	0.21	0.73	0.011	0.015	0.01	0.01	0.14	0.01	0.02
B	0.23	0.24	0.78	0.020	0.016	0.14	0.08	0.98	0.05	0.04
C	0.33	0.19	0.72	0.014	0.012	0.13	0.08	0.99	0.15	0.02
D	0.49	0.49	0.29	0.027	0.011	0.18	0.10	1.43	0.16	0.70
E	0.24	0.62	0.90	0.022	0.020	0.18	0.16	1.00	0.03	0.19

FIG. 6

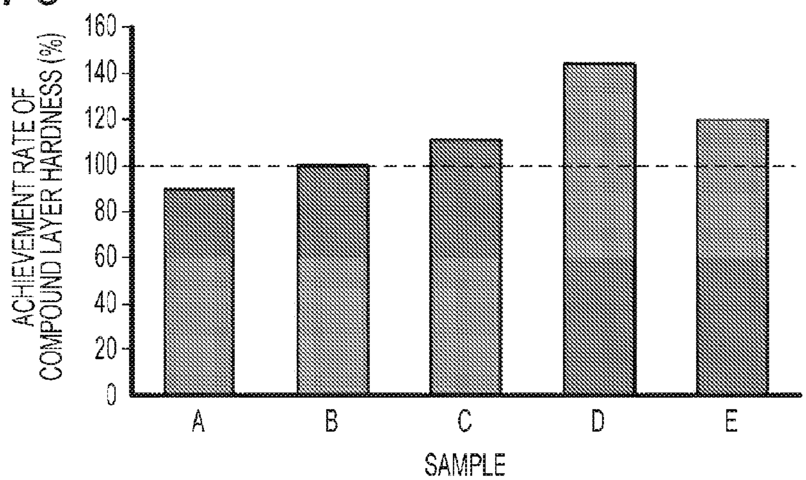


FIG. 7

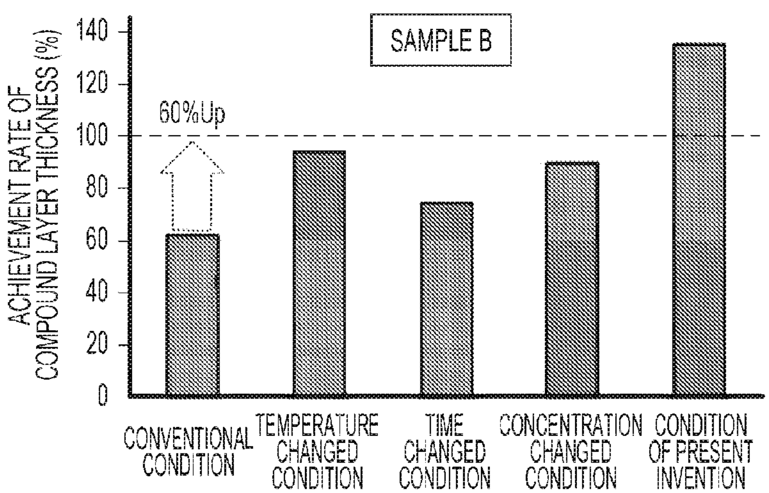


FIG. 8

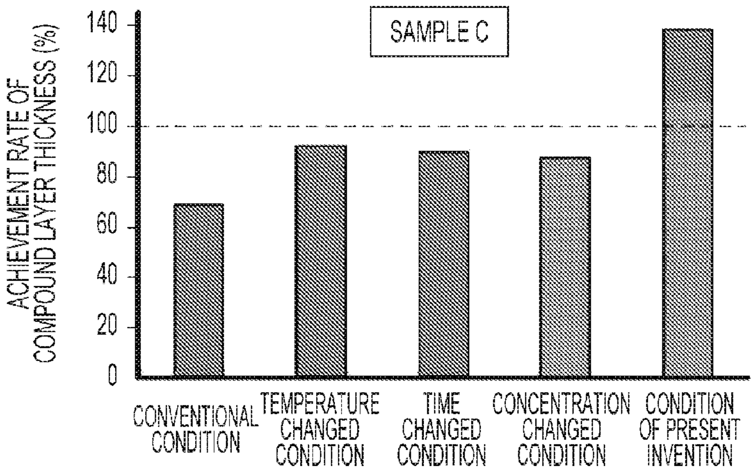


FIG. 9

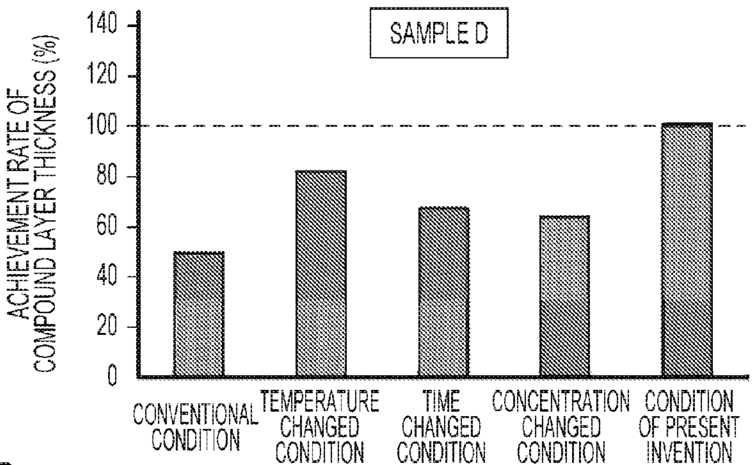
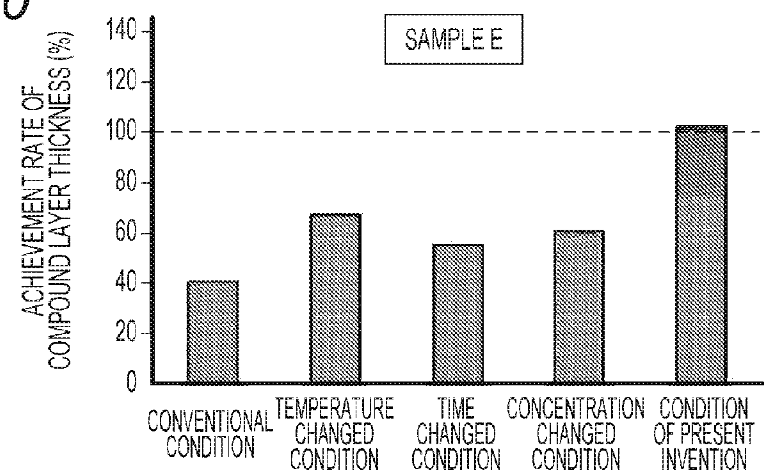


FIG. 10



SURFACE MODIFICATION APPARATUS FOR ALLOY STEEL COMPONENT, SURFACE MODIFICATION METHOD FOR ALLOY STEEL COMPONENT, AND METHOD FOR MANUFACTURING ALLOY STEEL COMPONENT

TECHNICAL FIELD

[0001] The present invention relates to a surface modification apparatus for an alloy steel component including an alloy steel material containing a nitride formation element, a surface modification method for an alloy steel component, and a method for manufacturing an alloy steel component.

BACKGROUND ART

[0002] Conventionally, various mechanical components made of alloy steel included in vehicles such as four-wheeled vehicles and bicycles are subjected to a surface modification process for enabling the portion of the component that mechanically slides to have higher wear and abrasion resistance. For example, Patent Literature 1 has disclosed the thermal processing method for improving the wear and abrasion resistance and the shock resistance by modifying the surface of the steel component through a so-called ion nitration process (also referred to as "plasma nitration process").

CITATION LIST

Patent Literature

[0003] PATENT LITERATURE 1: JP-A-09-125225

[0004] In the surface modification method according to Patent Literature 1, the surface of the steel component is modified by the ion nitration process. This has led to a problem that it is difficult to form a surface modification layer (hard layer) homogeneously and the surface-modifiable component is limited due to the hollow-cathode effect or the edge effect. Here, the hollow-cathode effect refers to the phenomenon that, if the alloy steel component has a hole portion with small diameter, discharge within this hole is so difficult that the surface modification layer becomes inhomogeneous. The edge effect refers to the phenomenon that, if the alloy steel component has a corner portion with an acute, right, or obtuse angle, discharge concentrates on this corner portion to make the surface modification layer inhomogeneous. In the ion nitration process, the steel components to be processed need to be disposed apart from each other in a process furnace. This has led to another problem that the ion nitration process is not suitable for the surface modification process for a large amount of steel components.

[0005] The present invention has been made in view of the above problems. An object of the present invention is to provide a surface modification apparatus for an alloy steel component, a surface modification method for an alloy steel component, and a method for manufacturing an alloy steel component, which can provide a deep and homogeneous hard layer for a steel component with a wide shape or a large amount of such steel components.

SUMMARY OF INVENTION

[0006] An aspect of the present invention for achieving the above object is a surface modification apparatus for an alloy steel component, which performs the surface modification on an alloy steel component including an alloy steel material containing a nitride formation element. The apparatus includes a surface modification processing unit for modifying a surface of the alloy steel component by exposing the alloy steel component for at least 180 minutes to the atmosphere with an ammonia gas concentration of 80% or more and a temperature of 610° C. or more and 630° C. or less. In this case, the nitride formation element refers to an element which forms a hard nitride due to the permeation and diffusion of nitrogen, and specifically corresponds to at least one of chromium, molybdenum, and aluminum. The alloy steel material containing a nitride formation element is obtained by adding at least the minimum amount, which is defined by JIS (Japanese Industrial Standard), of the nitride formation element to the carbon steel, and specifically 0.3 wt % or more of chromium, 0.08 wt % of molybdenum, and 0.1 wt % of aluminum.

[0007] According to the aspect of the present invention described above, the surface modification apparatus for an alloy steel component is structured to include the surface modification processing unit for exposing the alloy steel component for at least 180 minutes to the atmosphere with an ammonia gas concentration of 80% or more and a temperature of 610° C. or more and 630° C. or less. According to the experiments by the present inventors, it has been confirmed that the compound layer with a thickness of 25 μm or more can be formed stably on the surface of the alloy steel component. In other words, by a surface modification method for an alloy steel component according to the present invention, the surface modification process is performed in an atmosphere where nitrogen generated by the thermal decomposition of ammonia gas floats. This can form a deep and homogenous hard layer for the alloy steel component with a wide shape. In the surface modification apparatus for an alloy steel component according to the present invention, the alloy steel components to be processed are disposed in the process furnace with a space therebetween large enough for the ammonia gas to spread. This enables the efficient surface modification process to be performed on a large amount of alloy steel components as compared to the ion nitration process. According to the experiments by the present inventors, the ammonia gas concentration is preferably constant during the surface modification process for the alloy steel component.

[0008] Another aspect of the present invention is the surface modification apparatus for an alloy steel component wherein the temperature is set to 620° C. by the surface modification processing unit.

[0009] In the other aspect of the surface modification apparatus for an alloy steel component according to the present invention as described above, the temperature of the atmosphere to which the alloy steel component is exposed is set to 620° C. Therefore, according to the experiments by the present inventors, the hard layer can be formed more stably. According to the experiments by the present inventors, the temperature of the atmosphere to which the alloy steel component is exposed is preferably 610° C. or more and 630° C. or less, more preferably 615° C. or more and 625° C. or less, and the most preferably 620° C. In any of these cases, the temperature of the atmosphere to which the alloy steel component is exposed is desirably maintained constant during the process.

[0010] In another aspect of the surface modification apparatus for an alloy steel component according to the present invention, the alloy steel component includes at least one of a corner portion with an acute shape and a hole portion with a diameter of 8 mm or less. In this case, the corner portion may include, for example, a portion with an acute angle, a right angle, or an obtuse angle or an acute shape like a spindle.

[0011] According to the other aspect of the surface modification method for an alloy steel component according to the present invention as described above, the homogeneous hard layer can be formed even though the alloy steel component is formed to have a corner portion with an acute shape or a hole portion with a diameter of 8 mm or less.

[0012] The present invention can be implemented not just as the invention of the surface modification apparatus for an alloy steel component but also as the invention of the surface modification method for an alloy steel component and the invention of a method for manufacturing an alloy steel component.

[0013] Specifically, the surface modification method for an alloy steel component may be a surface modification apparatus for an alloy steel component for performing the surface modification on an alloy steel component including an alloy steel material containing a nitride formation element, and the method may include a surface modification processing step of modifying a surface of the alloy steel component by exposing the alloy steel component for at least 180 minutes to the atmosphere with an ammonia gas concentration of 80% or more and a temperature of 610° C. or more and 630° C. or less.

[0014] In this case, in the surface modification processing step, the temperature is more preferably 615° C. or more and 625° C. or less, and the most preferably 620° C.

[0015] In this case, the alloy steel component preferably includes at least one of the corner portion with an acute shape and the hole portion with a diameter of 8 mm or less.

[0016] The method for manufacturing an alloy steel component may be a method for manufacturing an alloy steel component including an alloy steel material containing a nitride formation element, and the method may include a surface modification processing step of modifying a surface of the alloy steel component by exposing the alloy steel component for at least 180 minutes to the atmosphere with an ammonia gas concentration of 80% or more and a temperature of 610*C or more and 630° C. or less.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] FIG. **1** is a schematic view illustrating the outline of an apparatus structure of a surface modification apparatus for an alloy steel component used in a surface modification method for an alloy steel component according to the present invention.

[0018] FIG. **2** is a sectional view illustrating the outline of a structure of an alloy steel component to which a surface modification method for an alloy steel component according to the present invention is applied.

[0019] FIG. **3** is a flowchart illustrating a manufacturing process for an alloy steel component by a surface modification method for an alloy steel component according to an embodiment of the present invention.

[0020] FIG. **4** is a graph expressing the relation between the hardness and the depth of a hard layer formed on a surface layer of an alloy steel component by the surface modification method for an alloy steel component according to the present invention.

[0021] FIG. **5** is a table showing the chemical composition values of Samples A to E which have been subjected to the surface modification process by the surface modification method for an alloy steel component according to the present invention.

[0022] FIG. **6** is a graph expressing the hardness of a compound layer formed on a surface layer of each of Samples A to E by the surface modification method for an alloy steel component according to the present invention.

[0023] FIG. **7** is a graph relatively expressing the thickness of the compound layer formed on the surface layer of Sample B for each of different process conditions including the surface modification method for an alloy steel component according to the present invention.

[0024] FIG. **8** is a graph relatively expressing the thickness of the compound layer formed on the surface layer of Sample C for each of different process conditions including the surface modification method for an alloy steel component according to the present invention.

[0025] FIG. **9** is a graph relatively expressing the thickness of the compound layer formed on the surface layer of Sample D for each of different process conditions including the surface modification method for an alloy steel component according to the present invention.

[0026] FIG. **10** is a graph relatively expressing the thickness of the compound layer formed on the surface layer of Sample E for each of different process conditions including the surface modification method for an alloy steel component according to the present invention.

DESCRIPTION OF EMBODIMENTS

[0027] An embodiment of a surface modification apparatus for an alloy steel component, a surface modification method for an alloy steel component, and a method for manufacturing an alloy steel component according to the present invention will be described below with reference to drawings. FIG. **1** is a schematic view illustrating the outline of an apparatus structure of a surface modification apparatus **100** for an alloy steel component, which is used in a surface modification method for an alloy steel component according to the present invention. In each drawing in the present specification, some elements are illustrated schematically, for example, drawn exaggerated in order to help the understanding of the present invention. Therefore, the size, ratio, etc. among the elements may be different. This surface modification apparatus **100** corresponds to a thermal processing apparatus for performing a surface modification process to improve the wear and abrasion resistance by forming a hard layer on a surface layer of an alloy steel component **90** such as a cylindrical boss component included in an alloy steel mechanical component, for example, a power transmission device such as a clutch in a vehicle like a four-wheeled vehicle or a bicycle.

[0028] First, description is made of the alloy steel component **90** molded by the surface modification apparatus **100** according to the present invention. This alloy steel component **90** is a component included in a power transmission device such as a clutch in a vehicle, and is formed of an alloy steel material corresponding to carbon steel to which a nitride formation element has been added. In this case, the nitride formation element added to the carbon steel is at least one kind of element that combines with nitrogen to form a nitride, and corresponds to, for example, chromium, molybdenum, or aluminum. The amount of the nitride formation element to be added is more than or equal to the minimum amount defined by JIS (Japanese Industrial Standard), and specifically, if the element is chromium, the amount is 0.3 wt % or more, if the element is molybdenum, the amount is 0.08 wt % or more, and if the element is aluminum, the amount is 0.1 wt % or more.

[0029] As specifically illustrated in FIG. **2**, the alloy steel component **90** includes a main body portion **91** formed to have an approximately cylindrical shape. The main body portion **91** includes a cylindrical sliding portion **92** on which another member of the power transmission device slides, and a flange portion **93** that extends in a circular-plate shape outward in the radial direction from one end (right side in the figure) of the sliding portion **92**. The sliding portion **92** of the main body portion **91** is provided with a penetration hole **94** in a state of penetrating in the radial direction of the main body portion **91**. The penetration hole **94** is formed to have a diameter of 8 mm.

[0030] The surface modification apparatus **100** includes a process furnace **101**. The process furnace **101** is a vessel with an approximately cylindrical shape formed to be airtight so that the surface modification process is performed on the alloy steel component **90**. The process furnace **101** is formed of a material that can resist 620° C. corresponding to the process temperature of the alloy steel component **90**, for example, a ceramic material. This process furnace **101** is mainly formed of a main chamber **101***a* and a stand-by chamber **101***b*.

[0031] The main chamber **101***a* is a space where the surface modification process is performed on the alloy steel component **90**. The stand-by chamber **101***b* is a space where the alloy steel component **90** is set before or after the alloy steel component **90** is taken in or out of the main chamber **101***a*, and is formed to have a release door **101***c* that is opened and closed toward the outside. Between the main chamber **101***a* and the stand-by chamber **101***b* is provided a partition wall **101***d* that partitions between both chambers in a manner that the partition wall **101***d* can freely connect or disconnect the chambers. Moreover, a conveyance mechanism **101***e* is provided between the main chamber **101***a* and the stand-by chamber **101***b*. The conveyance mechanism **101***e* conveys the alloy steel component **90** between the stand-by chamber **101***b* and the main chamber **101***a* under the operation control by a control device **111** to be described below. In FIG. **1**, the partition wall **101***c* is illustrated by a dashed line, and the conveyance mechanism **101***e* and the alloy steel component **90** in the stand-by chamber **101***b* are each illustrated by a two-dot chain line.

[0032] A heater **102** is provided outside the outer peripheral surface of the process furnace **101**. The heater **102** is an electric heater used for heating the main chamber **101***a* in the process furnace **101** up to 620° C. corresponding to the process temperature and moreover for maintaining this temperature. The operation of the hater **102** is controlled by the control device **111**.

[0033] The process furnace **101** is connected to a main gas supply pipe **103**, a sub-gas supply pipe **106**, and an exhaust pipe **109**. The main gas supply pipe **103** is a pipe for guiding ammonia gas (not shown) into the process furnace **101**. On the upstream side of the main gas supply pipe **103**, a main gas cylinder **105** is connected through a flow rate adjuster **104**. The flow rate adjuster **104** is a device for adjusting the flow rate of the ammonia gas to be introduced into the process furnace **101**. The flow rate adjuster **104** includes, for example, a gasifier (not shown) for gasifying liquid ammonia and a flow rate adjustment valve (not shown) for adjusting the flow rate of the gasified ammonia gas. The operation of the flow rate adjuster **104** is controlled by the control device **111**. The main gas cylinder **105** is a vessel for storing the liquid ammonia.

[0034] The sub-gas supply pipe **106** is a pipe for guiding the nitrogen gas (not shown) into the process furnace **101**. On the upstream side of the sub-gas supply pipe **106**, a sub-gas cylinder **108** is connected through a flow rate adjuster **107**. The flow rate adjuster **107** is similar to the flow rate adjuster **104** and is a device for adjusting the flow rate of the nitrogen gas to be introduced into the process furnace **101**. The flow rate adjuster **107** includes, for example, a gasifier (not shown) for gasifying liquid nitrogen and a flow rate adjustment valve (not shown) for adjusting the flow rate of the gasified nitrogen gas. The operation of the flow rate adjuster **107** is controlled by the control device **111**. The sub-gas cylinder **108** is a vessel for storing the liquid nitrogen.

[0035] The exhaust pipe **109** is a pipe for guiding the gas in the process furnace **101** to the outside of the process chamber **101**. On the downstream side of the exhaust pipe **109**, an exhaust gas process device **110** for deodorizing and burning the exhaust gas led out of the process furnace **101** is connected.

[0036] The control device **111** is configured by a microcomputer including a CPU, a ROM, a RAM, and the like. The control device **111** further includes an input device (not shown) for an operator to input an instruction, and a display device (not shown) to show the operator the operation status of the surface modification apparatus **100**. The control device **111** executes the programs stored in advance in the storage device such as the ROM in accordance with the operator's instruction, thereby controlling the operation of the surface modification apparatus **100**. Specifically, the control device **100** controls the operation of each of the heater **102**, the flow rate adjusting devices **104** and **107**, and the exhaust gas process device **110** in accordance with the operator's instruction. The surface modification apparatus **100** is further provided with a temperature sensor **112***a* and a concentration sensor **112***b*. These sensors **112***a* and **112***b* measure the temperature of the furnace **101** and the ammonia gas concentration, respectively and output the results to the control device **111**.

(Operation of Surface Modification Apparatus **100**)

[0037] Next, the surface modification process performed on the alloy steel component **90** by the surface modification apparatus **100** with the above structure is described with reference to the flowchart of FIG. **3**. FIG. **3** is the flowchart illustrating a process for manufacturing the alloy steel component **90**.

[0038] The operator who manufactures the alloy steel component **90** molds the alloy steel component **90** in a first step. Specifically, the operator molds the main body portion **91**, the sliding portion **92**, the flange portion **93**, and the penetration hole **94** through cutting, welding, and grinding of the alloy steel material using the machining equipment including a machine tool, which is not shown. In this case, in this embodiment, the alloy steel component **90** is not subjected to a heat treatment including a quenching process. However, the heat treatment including quenching may be performed before or after the surface modification process according to the present invention.

[0039] Next, the operator performs the surface modification process on the alloy steel component **90** in a second step. In this case, the surface modification process corresponds to a process of forming a hard layer made of a nitride on a surface layer of the alloy steel component **90**. Specifically, the operator manipulates the control device **111** to close the partition wall **101***d* in the process furnace **101** so as to make the main chamber **101***a* airtight. After that, the operator disposes the alloy steel component **90** molded by the machining in the stand-by chamber **101***b* through the opening and closing door **101***c*. If the operator disposes a plurality of alloy steel components **90**, the operator disposes the alloy steel components **90** with a space therebetween so that the ammonia gas can spread in the space.

[0040] Next, the operator manipulates the control device **111** to introduce the ammonia gas and the nitrogen gas into the main chamber **101***a* in the process furnace **101** and heats the process furnace **101**. In this case, the operator introduces the ammonia gas and the nitrogen gas into the main chamber **101***a* so that 80% or more of the gas in the main chamber **101***a* of the process furnace **101** is constituted by ammonia gas while the remainder is constituted by the nitrogen gas. In addition, the operator heats the main chamber **101***a* of the process furnace **101** so that the chamber has a temperature of 620° C.

[0041] Next, if the main chamber **101***a* of the process furnace **101** has an atmosphere with an ammonia gas concentration of 80% and with a temperature of 620° C. or more, the operator manipulates the control device **111** to move the alloy steel component **90** from the stand-by chamber **101***b* to the main chamber **101***a*. After that, the operator manipulates the control device **111** to expose the alloy steel component **90** for at least 180 minutes to the maintained atmosphere of the main chamber **101***a* of the process furnace **101**, specifically the atmosphere of the main chamber **101***a* maintained to have an ammonia gas concentration of 80% and a temperature of 620° C. In other words, this process furnace **101** corresponds to the surface modification processing unit according to the present invention.

[0042] This causes the nitrogen, which is generated by the thermal decomposition of the ammonia gas, to permeate into the surface layer of the alloy steel component **90** in the main chamber **101***a* of the process chamber **101**, thereby forming the hard layer. Specifically, on the surface layer of the alloy steel component **90**, the hard layer formed of a compound layer and a diffusion layer in the order from the outermost surface is generated. In this case, the surface modification process for the alloy steel component **90** is performed by having the nitrogen floating in the main chamber **101***a* in contact with the alloy steel component **90**. Thus, the hard layer is generated homogeneously without unevenness for the inside of the penetration hole **94** and the corner portion of the flange portion **92**.

[0043] After the alloy steel component **90** is exposed to the atmosphere in the main chamber **101***a* of the process furnace **101** for at least 180 minutes, the operator manipulates the control device **111** to stop the supply of the ammonia gas and the nitrogen gas to the process furnace **101** and stop the heating of the process furnace **101**. The operator extracts the alloy steel component **90** out of the process furnace **101** after the temperature in the process furnace **101** has decreased to be less than a predetermined temperature (for example, 150° C.).

[0044] Here, description is made of the hardness of the surface layer of the alloy steel component **90** extracted from the process furnace **101**. FIG. **4** is a graph expressing an example of how the hardness changes relative to the distance from the surface layer of the alloy steel component **90** containing the so-called nitride formation element. According to FIG. **4**, it has been confirmed that the compound layer with a hardness of 780 HmV through 660 HmV to 880 HmV is formed in the range of thicknesses from the surface up to approximately 25 μm in the alloy steel component **90** and the diffusion layer is formed to a depth of 0.2 mm from this compound layer toward the lower layer. This means that the compound layer with a hardness (750 HmV or more) more than or equal to the hardness of chromium plating defined in JIS (Japanese Industrial Standard) is formed on the surface of the alloy steel component **90**.

[0045] Next, the operator performs a finishing process in a third step. Specifically, the operator performs a grinding process on the outer surface of the alloy steel component **90** extracted from the process furnace **101** so that the alloy steel component **90** has a predetermined size or a predetermined surface roughness. In this case, since the compound layer with a thickness of 25 μm or more is formed on the surface of the alloy steel component **90**, the operator can easily achieve the predetermined size or the predetermined surface roughness by a sufficient process margin.

[0046] Here, the results of experiments by the present inventors are described. FIG. **5** shows the values of the chemical compositions of Samples A to E used in the present experiments. FIG. **6** shows the results of measuring the surface hardness of Samples A to E in FIG. **5** that have been subjected to the surface modification process similar to the process in the above embodiment. In FIG. **6**, the hardness of Sample B satisfying the hardness required in the specification of the alloy steel component **90** is regarded as 100%, based on which the hardness of the other Samples A and C to E are shown. According to the experiment results in FIG. **6**, it has been confirmed that the alloy steel component **09** needs to be formed of the alloy steel material containing a nitride formation element in order for the compound layer to have the required hardness.

[0047] Next, FIG. **7** to FIG. **10** show the results of measuring the thickness of the compound layer of each of Samples B to E, among Samples A to E in FIG. **5**, which have been subjected to the surface modification process according to the conventional condition, the temperature changed condition, the time changed condition, the concentration changed condition, and the condition of the present invention. In FIG. **7** to FIG. **10**, the thicknesses of the compound layers of Samples C to E are expressed assuming the thickness of the compound layer that has been increased by 60% of the thickness of the compound layer of Sample B subjected to the conventional surface modification process is the target value (achievement rate 100%).

[0048] In this experiment, the conventional technique corresponds to the conventional nitration process, specifically the gas soft-nitriding process performed on the alloy steel component **90** in the atmosphere with a temperature of 530 to 580° C., a process time of 60 to 180 minutes, and an ammonia gas concentration of 30 to 50% in the furnace. The conventional technique provides the compound layer with a hardness of 350 HmV or more in general and with a thickness of approximately 8 μm to 15 μm.

[0049] In regard to the temperature changed condition, the conventional condition is changed into a process condition where just the temperature condition is changed to 620° C. corresponding to the temperature condition according to the present invention; under this process condition, the alloy steel component **90** is processed. In regard to the time changed condition, the conventional condition is changed into a process condition where just the time condition is changed to 180 minutes or more corresponding to the time condition according to the present invention; under this condition, the alloy steel component **90** is processed. In regard to the concentration changed condition, the conventional condition is changed into a process condition where just the concentration condition of the gas confined in the main chamber **101***a* is changed to 80% or more of ammonia gas corresponding to the gas concentration condition according to the present invention; under this condition, the alloy steel component **90** is processed. In regard to the condition according to the present invention, the alloy steel component **90** is processed under the process condition in the above embodiment, i.e., the temperature is set to 620° C., the process time is 180 minutes or more, and the ammonia concentration is 80% or more.

[0050] According to the results of the experiments shown in FIG. **7** to FIG. **10**, it has been confirmed that the thickness of the compound layer formed based on the process condition of the present invention is clearly larger than that of the compound layer formed by any process condition that has employed part of the temperature condition, the time condition, and the ammonia concentration condition in the process condition in the present invention. In other words, the thickness of the compound layer formed based on the present invention cannot be achieved by the process condition that has employed part of the process condition in the present invention, and can be achieved only by executing the process condition including all the temperature condition, the time condition, and the ammonia concentration condition in the present invention.

[0051] In regard to how much the thickness of the hard layer formed by the surface modification process according to the present invention has increased relative to the conventional thickness, the experiment results from Samples B to E indicate that the thickness of the compound layer has increased 1.9 times to 2.5 times and the thickness of the diffusion layer has increased 1.2 times to 1.6 times. In this case, along with the increase of the compound layer, the diffusion layer is increased but in regard to the increase rate, the increase rate of the diffusion layer is smaller than that of the compound layer. In other words, through the surface modification process according to the present invention, the thickness of the compound layer formed on the surface of the alloy steel component **90** can be increased while the modification of the mother material inside the alloy steel component **90**, more specifically the tough part thereof is suppressed. Therefore, the surface modification process according to the present invention is particularly effective in mechanical parts required to have the toughness on the inside and have the wear and abrasion resistance on the surface.

[0052] The thickness of the compound layer formed on the surface of each of Samples B to E through the surface modification process according to the present invention is 25 μm to 33 μm. This thickness is as large as the depth of each hard layer in the thermally processed product obtained by carburizing and quenching a conventional chromium molybdenum steel material and plating the material with chromium and the thermally processed product obtained by hardening a medium carbon steel material with high frequency and plating the material with chromium as compared to the thickness of the compound layer obtained from the conventional gas nitration process.

[0053] As can be understood from the above description about the operation, the surface modification apparatus **100** for the alloy steel component in the above embodiment is structured to have the process furnace **101** where the alloy steel component **90** is exposed for at least 180 minutes to the atmosphere with an ammonia gas concentration of 80% or more and a temperature of 620° C. According to the experiments by the present inventors, it has been confirmed that the compound layer with a thickness of 25 μm or more can be formed stably on the surface of the alloy steel component **90**. In other words, the surface modification apparatus **100** for the alloy steel component **90** according to the present invention performs the surface modification process in the atmosphere containing nitrogen generated by the thermal decomposition of the ammonia gas. This can form the hard layer that is deep and homogeneous in the alloy steel component **90** with a wide shape. In the surface modification apparatus **90** for an alloy steel component according to the present invention, the alloy steel components **90** to be processed are disposed in the process furnace **101** with a space between the components **90** so that the ammonia gas spreads in the space. This enables the efficient surface modification process on a large amount of alloy steel components **90** as compared to the ion nitration process.

[0054] In the implementation of the present invention, various changes can be made without departing from the purpose of the present invention and without being limited to the above embodiment.

[0055] For example, in regard to the concentration of the gas in the main chamber **101***a* of the process furnace **101** in the above embodiment, the ammonia gas constitutes 80% or more with the remainder constituted by the nitrogen gas. However, the concentration of the gas in the main chamber **101***a* is not limited to that in the above embodiment as long as the ammonia gas constitutes at least 80%. Therefore, the main chamber **101***a* may be formed to contain the ammonia gas only. Alternatively, 80% or more of the gas concentration in the main chamber **101***a* may be constituted by the ammonia gas with the remainder constituted by other gas than the nitrogen gas, such as carbon gas or hydrogen gas. In these cases, according to the experiments by the present inventors, the ammonia gas concentration is preferably maintained constant during the surface modification process on the alloy steel component **90**.

[0056] In the above embodiment, the alloy steel component **90** may be subjected to the surface modification process while the inside of the main chamber **101***a* of the process furnace **101** is maintained to be heated at 620° C. According to the experiments by the present inventors, however, it has been confirmed that the effect of the present invention is achieved if the temperature condition in the surface modification process in the present invention is in the range of ±10° C. from 620° C., i.e., from 610° C. to 630° C. and that the effect of the present invention cannot be fully achieved if the temperature is out of that range. Moreover, according to the experiments by the present inventors, it has been confirmed that the temperature of the atmosphere to which the alloy steel component is exposed is more appropriate to be 615° C. or more and 625° C. or less, and the most appropriate to be 620° C. It has also been confirmed that in those cases, the temperature of the atmosphere to which the alloy steel component is exposed is desirably maintained to be constant during the process.

[0057] In the above embodiment, the alloy steel component **90** is one of parts constituting the power transmission device such as a clutch in a self-propelled vehicle. However, the surface modification apparatus **100** for the alloy steel component **90** according to the present invention is widely applicable to the mechanical parts formed of alloy steel. In this case, the surface modification apparatus **100** for the alloy steel component **90** according to the present invention is appropriate because the thick and homogeneous compound layer can be formed even for the alloy steel component **90** including at least one of a corner portion with the shape having a narrowing end, such as a conical shape or an acute angle, a right angle, or an obtuse angle and a hole portion with a diameter of 8 mm or less, preferably 5 mm or less, and more preferably 4 mm or less. In regard to the alloy steel component **90** including a mechanically slidable portion partly or entirely in the alloy steel component **90**, the hard layer (compound layer) formed by the surface modification apparatus **100** for the alloy steel component **90** according to the present invention is effective because the hard layer can be formed more easily and in a shorter time than the hard layer formed by the conventional process for forming the hard layer, specifically the hard layer formed by the hard chromium plating process after the high-frequency hardening or the carburizing and quenching.

[0058] In the above embodiment, the surface modification apparatus **100** exposes the alloy steel component **90** for at least 180 minutes to the atmosphere maintained to have an ammonia gas concentration of 80% and a temperature of 620° C. in the main chamber **101***a*. This is based on the experiments by the present inventors, which have confirmed that the effect of the present invention cannot fully be achieved if the surface modification process on the alloy steel component **90** is less than 180 minutes. Thus, the surface modification apparatus **100** needs to expose the alloy steel component **90** for at least 180 minutes to the atmosphere maintained to have an ammonia gas concentration of 80% and a temperature of 610° C. or more and 630° C. or less.

[0059] The surface modification method for an alloy steel component according to the present invention is widely applicable to the alloy steel material containing the nitride formation element. In this case, examples of the alloy steel material containing the nitride formation element include steel materials containing more than or equal to the minimum amount, which is defined by JIS (Japanese Industrial Standard), of at least one element of chromium, molybdenum, and aluminum, such as chromium alloy steel, chromium molybdenum steel, nitride steel, and carbon steel, chromium alloy steel, or chromium molybdenum steel containing 0.1 to 0.3 wt % of aluminum.

DESCRIPTION OF REFERENCE SIGNS

[0060] **90** Alloy steel component
[0061] **91** Main body portion
[0062] **92** Sliding portion
[0063] **93** Flange portion
[0064] **94** Penetration hole
[0065] **100** Surface modification apparatus
[0066] **101** Process furnace
[0067] **101***a* Main chamber
[0068] **101***b* Stand-by chamber
[0069] **101***c* Opening and closing door
[0070] **101***d* Partition wall
[0071] **101***e* Conveyance mechanism
[0072] **102** Heater
[0073] **103** Main gas supply pipe
[0074] **104** Flow rate adjuster
[0075] **105** Main gas cylinder
[0076] **106** Sub-gas supply pipe
[0077] **107** Flow rate adjuster
[0078] **108** Sub-gas cylinder
[0079] **109** Exhaust pipe
[0080] **110** Exhaust gas process device
[0081] **111** Control device
[0082] **112***a* Temperature sensor
[0083] **112***b* Concentration sensor

1. A surface modification apparatus for an alloy steel component, which performs surface modification on an alloy steel component including an alloy steel material containing a nitride formation element, the apparatus comprising

a surface modification processing unit for modifying a surface of the alloy steel component by exposing the alloy steel component for at least 180 minutes to an atmosphere with an ammonia gas concentration of 80% or more and a temperature of 610° C. or more and 630° C. or less.

2. The surface modification apparatus for an alloy steel component according to claim **1**, wherein the temperature is set to 620° C. by the surface modification processing unit.

3. The surface modification apparatus for an alloy steel component according to claim **1**, wherein the alloy steel component includes at least one of a corner portion with an acute shape and a hole portion with a diameter of 8 mm or less.

4. A surface modification method for an alloy steel component including an alloy steel material containing a nitride formation element, the method comprising

a surface modification processing step of modifying a surface of an alloy steel component by exposing the alloy steel component for at least 180 minutes to an atmosphere with an ammonia gas concentration of 80% or more and a temperature of 610° C. or more and 630° C. or less.

5. The surface modification method for an alloy steel component according to claim **4**, wherein the temperature is set to 620° C. in the surface modification processing step.

6. The surface modification method for an alloy steel component according to claim **4**, wherein the alloy steel component includes at least one of a corner portion with an acute shape and a hole portion with a diameter of 8 mm or less.

7. A method for manufacturing an alloy steel component including an alloy steel material containing a nitride formation element, the method comprising

a surface modification processing step of modifying a surface of an alloy steel component by exposing the alloy steel component for at least 180 minutes to the atmosphere with an ammonia gas concentration of 80% or more and a temperature of 610° C. or more and 630° C. or less.

8. The surface modification apparatus for an alloy steel component according to claim **2**, wherein the alloy steel component includes at least one of a corner portion with an acute shape and a hole portion with a diameter of 8 mm or less.

9. The surface modification method for an alloy steel component according to claim **5**, wherein the alloy steel component includes at least one of a corner portion with an acute shape and a hole portion with a diameter of 8 mm or less.

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