METHOD OF CARBONITRIDING A STEEL COMPONENT, THE STEEL COMPONENT AND THE USE OF THE COMPONENT

Fig. 2

Abstract: Method for heat treating a steel component (28, 36) to provide the steel component (28, 36) with a surface having improved wear resistance. The method comprises the steps of carbonitriding the steel component (28, 36) at a temperature of 930-970°C, cooling the steel component (28, 36), re-heating the steel component (28, 36) to a temperature of 780-820°C and either quenching the steel component (28, 36) to form martensite and tempering, or quenching the steel component (28, 36) to form bainite and tempering.
TECHNICAL FIELD

The present invention concerns a method for heat treating a steel component to provide the steel component with a surface having improved wear resistance. The invention also concerns a steel component having a carbonitrided layer and the use of such a steel component under contaminated and/or poor lubricant conditions.

BACKGROUND OF THE INVENTION

Carbonitriding is a metallurgical surface modification technique that is used to increase the surface hardness of a metal component, thereby reducing the wear of the component during use. During the carbonitriding process, atoms of carbon and nitrogen diffuse interstitially into the metal, creating barriers to slip and increasing the hardness near the surface, typically in a layer that is 0.1 to 0.3 mm thick. Carbonitriding is usually carried out at a temperature of 850-860 °C.

Carbonitriding is normally used to improve the wear resistance of steel components comprising low or medium carbon steel, and not high carbon steel. Although steel components comprising high carbon steel are stronger, they have been found to be more susceptible to cracking in certain applications. Components may for example be used in typically dirty environments where lubricating oil is easily contaminated, such as in a gear box, and it is well known that the service life of components can decrease considerably under such conditions. Particles in the lubricant can namely get in between the various moving parts of a gear box, for example, and make indentations in their contact surfaces. Stress is concentrated around the edges of these indentations and the contact stress concentrations may eventually lead to fatigue cracking. Using components damaged in this way may also result in an increase in the noise generated by the components.

SUMMARY OF THE INVENTION

An object of the invention is to provide a method for heat treating a steel component to provide the steel component with a surface having improved wear resistance.

This object is achieved by a method that comprises the steps of: a) carbonitriding the steel component at a temperature of 930-970°C, i.e. a temperature higher than the usual
carbonitriding temperature, in order to dissolve all carbides, b) cooling the steel component to a temperature below the \( A_1 \) transformation temperature, c) re-heating (re-hardening) the steel component to a temperature of 780-820°C i.e. a temperature higher than the \( A_1 \) transformation temperature, lower than the carbonitriding temperature and lower than the temperatures used in the prior art, and either d) quenching the steel component, in oil for example, to form martensite and tempering, or d) quenching the steel component, in a quenching medium bath, such as a salt bath, polymer solution or oil, to form bainite.

The surface of steel components subjected to a method according to the present invention will have a Rockwell hardness HRC of at least 60 and comprise a considerable quantity of fine carbides, i.e. carbides having a maximum longitudinal dimension of 0.2-0.3 \( \mu \text{m} \). Changing the microstructure of the surface of the steel component in this way improves its wear resistance and enhances its ability to relax stress concentration at the edges of any indentations in its surface.

By carrying out the carbonitriding step at a temperature in the given temperature range, and the subsequent (re-hardening) heat treatment, the steel component may be provided with a carbonitrided layer having a depth measured from the surface of the steel component of 0.3-1.5 mm, whereby the carbonitrided layer contains only carbides having a maximum longitudinal dimension of 0.2-0.3 \( \mu \text{m} \) and no carbides having a longer maximum longitudinal dimension.

According to an embodiment of the invention the method comprises the step of low temperature tempering the steel component at a temperature in the range 150-260 °C. Tempering is carried out to toughen the steel component by transforming brittle martensite or bainite into a combination of ferrite and cementite. The brittle material becomes tough and ductile after it has been tempered.

According to an embodiment of the invention the method comprises the step of tempering the steel component at a temperature of approximately 290 degrees Celsius for 4 hours. This will lead to an increased hardness of the steel component and also the steel component can be used, such as a bearing, under higher operating temperatures with maintained high hardness of the component. In this embodiment, the operating temperature is up to 250 degrees Celsius. This can be done for both a bainite and
martensite structure. In an embodiment of the steel component, when the steel component has been subjected to bainite quenching and followed by tempering at 290 degrees Celcius for 4 hours, the hardness of the component will be approximately 61.5 HRC. In an embodiment of the steel component, when the steel component has been subjected to martensite quenching and followed by tempering at 290 degrees Celcius for 4 hours, the hardness of the component will be approximately 57.6 HRC.

According to another embodiment of the invention the method comprises the step of tempering the steel component at a temperature of approximately 340 degrees celcius for 4 hours. This will lead to an increased hardness of the steel component and also the steel component can be used, such as a bearing, under higher operating temperatures with maintained high hardness of the component. In this embodiment, the operating temperature is up to 300 degrees Celcius. This can be done for both a bainite and martensite structure. In an embodiment of the steel component, when the steel component has been subjected to bainite quenching and followed by tempering at 340 degrees Celcius for 4 hours, the hardness of the component will be approximately 59.5 HRC. In an embodiment of the steel component, when the steel component has been subjected to martensite quenching and followed by tempering at 340 degrees Celcius for 4 hours, the hardness of the component will be approximately 55.5 HRC.

According to another embodiment of the invention the method comprises the step of tempering the steel component at a temperature of approximately 390 degrees celcius for 4 hours. This will lead to an increased hardness of the steel component and also the steel component can be used, such as a bearing, under higher operating temperatures with maintained high hardness of the component. In this embodiment, the operating temperature is up to 350 degrees Celcius. This can be done for both a bainite and martensite structure. In an embodiment of the steel component, when the steel component has been subjected to bainite quenching and followed by tempering at 390 degrees Celcius for 4 hours, the hardness of the component will be approximately 58 HRC. In an embodiment of the steel component, when the steel component has been subjected to martensite quenching and followed by tempering at 390 degrees Celcius for 4 hours, the hardness of the component will be approximately 52.5 HRC.

According to another embodiment of the invention step a) comprises carbonitriding the steel component at a temperature of 930-970°C for 5-10 hours. In another embodiment of
the invention, step a) comprises carbonitriding the steel component at a temperature of 930-970 °C for at least 8 hours. This will lead to that the carbonitried layer will go deep into the surface of the steel component, approximately 1-1.5 mm. This is advantageous especially for large steel components, such as large rolling bearings.

According to an embodiment of the invention the steel component comprises or constitutes a rolling element or roller, or a steel component for an application in which is subjected to alternating Hertzian stresses, such as rolling contact or combined rolling and sliding, such as a slewing bearing or a raceway for a bearing. The component may include or constitute gear teeth, a cam, shaft, bearing, fastener, pin, automotive clutch plate, tool, or a die. The steel component may for example constitute at least part of a roller bearing, a needle bearing, a tapered roller bearing, a spherical roller bearing, a toroidal roller bearing or a thrust bearing. The component may be used in automotive, wind, marine, metal producing or other machine applications which require high wear resistance and/or increased fatigue and tensile strength.

According to a further embodiment of the invention the steel component comprises steel with a carbon content of 0.6 to 1.20 weight %, such as a high carbon bearing steel such as SAE 52100/Gd3. Compared with the prior art, the hardness of both the carbonitried layer and the core of a high carbon steel component is greater than is the case with known components comprising steel having a low carbon content. The wear resistance and fatigue strength for rolling contact are improved as a result. Furthermore, the loading capacity of a component, such as a bearing, will be increased, whereby the bearing may be of smaller construction for a particular application. The fatigue resistance on rolling contact also increases, so that the service life of the bearing can be extended. Additionally, the disadvantage that through cracking occurs, described in the prior art, is not found.

According to a further embodiment of the invention, the steel component comprises steel with a carbon content of 0.6 to 1.20 weight %, such as a high carbon bearing steel such as SAE 52100 (high carbon chromium steel), wherein the steel before the heat treating process is spherodized annealed with approximately 15 % carbides, which all will be dissolved when carburizing the steel at 930-970 °C. In another embodiment the steel component comprises steel with a carbon content of 0.7-1.20 weight %. In another embodiment of the invention, step c) comprises re-heating (re-hardening) the steel
component to a temperature of 780-820°C which will result in 3-5 % residual carbides in
the core of the steel component. It has been found that by using a high carbon steel of
0.6-1.20 weight % carbon, the reheating step will create residual carbides in the core. This
will increase the hardness and strength of the core, and the risk that cracking occurs is
reduced significantly.

According to a further embodiment of the invention, as a result of said method, the steel
component is provided with a carbonitrided layer having a ratio (d:D) of depth (d) of the
carbonitrided layer measured from the surface of the steel component to maximum
transverse dimension (D) of said steel component of 1: 4000 to 1: 17,000 or more. The
method according to the present invention may be used to provide a component of any
size with a carbonitrided layer. The method is however particularly suitable for providing a
large component, having a maximum transverse dimension of a few metres for example,
with a carbonitrided layer since the higher carbonitriding temperature provides a
carbonitrided layer with greater depth, whereby part of the carbonitrided layer may be
ground away during the manufacture of the component without substantially affecting the
wear resistance of the component.

The present invention also concerns a steel component that comprises a carbonitrided
layer having a depth of the carbonitrided layer measured from the surface of the steel
component of 0.3-1.5 mm whereby the carbonitrided layer contains only carbides having a
maximum longitudinal dimension of 0.2-0.3 μm.

According to an embodiment of the invention the steel component comprises steel with a
carbon content of 0.6 to 1.2 weight %, such as a high carbon bearing steel such as SAE
52100/Gd3.

According to an embodiment of the invention the steel component comprises or
constitutes a rolling element or roller, or a steel component for an application in which is
subjected to alternating Hertzian stresses.

According to another embodiment of the invention the steel component comprises a
carbonitrided layer having a ratio (d:D) of depth (d) of the carbonitrided layer of the
carbonitrided layer measured from the surface of the steel component to maximum
transverse dimension (D) of said steel component of 1: 4000 to 1: 17,000 or more.
The present invention further concerns the use of a steel component according to any of the embodiments of the invention under contaminated and/or poor lubricant conditions.

5 BRIEF DESCRIPTION OF THE DRAWINGS
The present invention will hereinafter be further explained by means of non-limiting examples with reference to the appended figures where;

Figure 1 shows a heat treatment cycle according to the prior art,
Figure 2 shows a method according to an embodiment of the invention,
Figure 3 shows the carbonitriding layer depth of a component according to an embodiment of the invention,
Figure 4 shows micrographs of carbonitriding layers of components according to an embodiment of the invention and schematic representations thereof, and
Figures 5 & 6 show components according to embodiments of the invention.

It should be noted that the drawings have not been drawn to scale and that the dimensions of certain features have been exaggerated for the sake of clarity.

DETAILED DESCRIPTION OF EMBODIMENTS
Figure 1 shows a heat treatment cycle according to the prior art. A steel component is subjected to a carbonitriding (CN) process at a temperature of 850°C. The process environment is provided by the introduction of methane/propane/natural gas (for carbon) and ammonia (for nitrogen) into a furnace in the presence of a controlled carrier gas. By maintaining the proper ratios of the working gases, the component is provided with a thin carbonitrided layer of carbon- and nitrogen-rich steel. The component is then re-heated to 820°C and subsequently quenched to achieve the full case hardness. Quenching may be carried out in an oil or salt bath with bath temperatures selected to achieve the optimum properties with acceptable levels of dimensional change. Hot oil/salt bath quenching can
be used to minimize distortion of intricate parts. Low temperature tempering may be carried out to toughen the steel component.

Figure 2 shows a method according to the present invention. The method comprises the steps of a) carbonitriding a steel component at a temperature of 930-970°C for 5-10 hours.

According to an embodiment of the invention the method includes supplying a higher concentration of ammonia at the beginning of the carbonitriding step a) to boost the carbonitriding process. For example, 9.5% ammonia may be used initially; this may be lowered to 6.5% ammonia and then 0%. 9.5% ammonia may be used for about 70% of the carbonitriding step a).

The method then comprises the steps b) cooling the steel component to a temperature below the A₁ transformation temperature, c) re-heating the steel component to a temperature of 780-820°C i.e. a temperature higher than the A₁ transformation temperature, lower than the carbonitriding temperature and lower than the re-heating temperatures used in the prior art, and d) quenching the steel component to form martensite, and low temperature tempering the steel component at a temperature in the range 150-260 °C. After tempering, the component is cooled to room temperature and may then be used in any application in which it is likely to be subjected to stress, strain, impact and/or wear under a normal operational cycle, such as in under contaminated and/or poor lubricant conditions.

Alternatively, after step c), in which the steel component is re-heated to a temperature of 780-820°C, the steel component may be quenched, in a salt bath for example, to form bainite. This will induce compressive residual stresses in the subsurface of the steel component. In an embodiment, the compressive residual stress in the subsurface of the steel component is 250-300 MPa. A standard bainitic steel may have a compressive residual stress of approximately 50-75 MPa. Compressive residual stress is good for fatigue life, e.g. the fatigue life of a bearing component which is subjected to alternating Hertzian stresses. Alternatively, the steel component may subsequently be followed by a tempering step.
Components subjected to a method according to an embodiment of the present invention may be used with or without subsequent grinding operations.

Steel components comprising steel with a carbon content of 0.6 to 1.20 weight % may be subjected to a method according to the present invention.

Figure 3 shows the carbonitriding depth in µm from the surface (x-axis) of a component according to an embodiment of the invention against hardness (y-axis) of the carbonitriding layer. Figure 3 shows measured hardness values for the carbonitriding layers of components comprising SAE 52100/Gd3 steel which have been subjected to a method according to the present invention.

Figure 3 namely shows the hardness profile of:

- a component subjected to carbonitriding at 930°C for 8 hours, and re-hardened martensitically and tempered at 160 °C for 1.5 hours and 350°C for 5 hours (profile 10),
- a component subjected to carbonitriding at 970°C for 6 hours and re-hardened martensitically and tempered at 160 °C for 1.5 hours and 350°C for 5 hours (profile 12),
- a component subjected to carbonitriding at 930°C for 8 hours and re-hardened bainitically at 215°C for 4 hours and 240°C for 4 hours and tempered at 350°C for 5 hours (profile 14), and
- a component subjected to carbonitriding at 970°C for 6 hours and re-hardened bainitically at 215°C for 4 hours and 240°C for 4 hours and tempered at 350°C for 5 hours (profile 16).

Figure 3 also shows the nitriding depth 18 achieved in bainite and the nitriding depth 20 achieved in martensite. The profiles 10-16 show that the depth of a carbonitriding layer may be tailored to a specific application by the selection of a suitable carbonitriding and re-hardening temperatures and times.

The method according to the present invention may be used to provide a steel component with a carbonitrided layer having a thickness of 0.3-1.2 mm whereby all of the carbides in the carbonitrided layer have a maximum longitudinal dimension of 0.2-0.3 µm.
Figure 4 shows a micrograph of a carbonitriding layer of a component according to the present invention which has been subjected to carbonitriding at 930°C, cooled to 70°C in an oil bath, tempered at 320°C, re-heated to 820°C, quenched in a 215°C salt bath for four hours followed directly by transferring to a 240°C salt bath for four hours and cooling to room temperature and finally a 350°C tempering. The white structures in the micrograph and the black structures in the schematic representation are carbides.

Figure 4 also shows a micrograph of a carbonitriding layer of a component according to another embodiment of the present invention and a schematic representation thereof. The component has been subjected to carbonitriding at 970°C, cooled to 70°C in an oil bath, tempered at 320°C, re-heated to 820°C, quenched in a 215°C salt bath for four hours followed by directly transferring to a 240°C salt bath for four hours and cooling to room temperature and finally a 350°C tempering. The white structures in the micrograph and the black structures in the structures in the schematic representation are carbides.

As can be seen, the carbides in the micrograph are more coarse than the fine carbides in micrograph 22. The coarse carbides in micrograph are more remotely spaced than the fine carbides in micrograph 22, and there are fewer of them per unit area of the carbonitrided layer. The carbonitrided layer of components according to the present invention, which contains more carbides, finer carbides and more closely spaced carbides than the carbonitrided layers of prior art components, has been found to have superior wear resistance compared to the carbonitrided layer of prior art components which have fewer, larger and more remotely spaced carbides. The distribution of carbides and 26 in a carbonitrided layer of a component may be tailored to a specific application by selection of suitable carbonitriding temperature and time.

Figure 5 shows an example of a component according to an embodiment of the invention, namely a rolling element bearing that may range in size from 10 mm diameter to a few metres diameter and have a load-carrying capacity from a few tens of grams to many thousands of tonnes. The bearing according to the present invention may namely be of any size and have any load-carrying capacity. The bearing has an inner ring and an outer ring and a set of rolling elements. The inner ring, the outer ring and/or the rolling elements of the rolling element bearing, and preferably at least part of the
surface of all of the rolling contact parts of the rolling element bearing 28 may be subjected to a method according to the present invention.

Figure 6 shows a component 36, namely a shaft shown in cross section, according to an embodiment of the invention. The component 36 has been provided with a carbonitrided layer 38 on its outer surface using a method according to an embodiment of the invention. The depth of the carbonitrided layer 38 measured from the surface of the component 36 is d and the maximum transverse dimension of the component 36 (the diameter of the shaft in this case) is D. The ratio (d:D) of the thickness d of the carbonitrided layer 38 to the maximum transverse dimension D of the component 36 is 1:4000-17,000 or more.

EXAMPLES

- Steel components were subjected to a method according to the present invention comprising the steps of: carbonitriding the steel components at a temperature of 930°C or 970°C (step a)), cooling the steel components to 70°C using an oil bath (step b)), tempering the components at 320°C, re-heating (bainite re-hardening) the steel components to 820°C (step c)), quenching the steel components in a 215°C salt bath (step e)) for four hours followed directly by quenching in a 240°C salt bath for four hours and air cooling to room temperature. The measured hardness for the steel components subjected to this method was 61.5 to 62.0 HRC.

- Steel components were also subjected to a method according to the present invention comprising the steps of: carbonitriding the steel components at a temperature of 930°C or 970°C (step a)), cooling the steel components to 70°C using an oil bath (step b)), tempering the components at 320°C, re-heating (martensite re-hardening) the steel components to 820°C (step c)), quenching the steel components in a 70°C oil bath (step d)), air cooling to room temperature, post-quenching in a 5°C water bath, tempering at 160°C for 90 minutes and air cooling to room temperature. The measured hardness for the steel components subject to this method was 64.5 to 65.5 HRC.

- SAE 52100/ Gd 2 steel components were subjected to carbonitriding at 970°C for 3 hours; carbon potential (Cp) 1.4, NH₃ 9.5% and CO 20% (both the carbon
potential and the nitrogen potential (Np) was boosted during the carbonitriding process), SAE 52100/Gd 3 steel components were subjected to carbonitriding at 970°C for 13 hours: Cp 1.2, NH₃ 9.5% and CO 20% (the nitrogen potential (Np) was boosted during the carbonitriding process), SAE 52100/Gd 6 steel components were subjected to carbonitriding at 970°C for 1.5 hours, Cp 1.2, NH₃ 6.5% and CO 20%, SAE 52100/Gd 70 steel components were subjected to carbonitriding at 970°C for 4.5 hours, Cp 1.2, NH₃ 3.0% and CO 20%. The components were then quenched in a 320°C salt bath and re-heated (bainite re-hardening) at 805°C for 1 hour, quenched in a 215°C salt bath for 18.5 hours followed directly by quenching in a 240°C salt bath for six hours and cooled to room temperature. The measured hardness for the SAE 52100/Gd 2 steel components subjected to this method was 60.0 HRC. The measured hardness for the SAE 52100/Gd 6 steel components subjected to this method was 61.7 HRC. The depth of the carbonitrided layer was 2.5-3 mm.

Further modifications of the invention within the scope of the claims would be apparent to a skilled person.
CLAIMS

1. Method for heat treating a steel component (28, 36) to provide the steel component (28, 36) with a surface having improved wear resistance, characterized in that it comprises the steps of:
   a) carbonitriding the steel component (28, 36) at a temperature of 930-970°C
   b) cooling the steel component (28, 36),
   c) re-heating the steel component (28, 36) to a temperature of 780-820°C and either
   d) quenching the steel component (28, 36) to form martensite, and tempering,
   or
   d) quenching the steel component (28, 36) to form bainite.

2. Method according to claim 1, characterized in that step a) comprises carbonitriding the steel component (28, 36) at a temperature of 930-970°C for 5-10 hours.

3. Method according to any of the preceding claims, characterized in that said steel component (28, 36) comprises steel with a carbon content of 0.6 to 1.20 weight %.

4. Method according to any of the preceding claims, wherein step d) comprises quenching the steel component to form bainite, and tempering.

5. Method according to any of the preceding claims, characterized in that said steel component (28, 36) comprises or constitutes a rolling element or roller, or a steel component (28, 36) for an application in which is subjected to alternating Hertzian stresses.

6. Method according to any of the preceding claims, characterized in that as a result of said method, said steel component (28, 36) is provided with a carbonitrided layer (38) having a thickness (d) of 0.3-1.5 mm whereby all of the carbides (24, 26) in said carbonitrided layer (38) have a maximum longitudinal dimension of 0.2-0.3 μm.

7. Method according to any of the preceding claims, characterized in that as a result of said method, said steel component (28, 36) is provided with a carbonitrided layer (38) having a ratio (d:D) of depth (d) of the carbonitrided layer (38) measured from the
surface of the steel component (28, 36) to maximum transverse dimension (D) of said steel component (28, 36) of 1:4000 to 1:17,000 or more.

8. Steel component (28, 36), characterized in that it comprises a carbonitrided layer (38) having a depth of the carbonitrided layer measured from the surface of the steel component (28, 36) of 0.3-1.2 mm whereby all of the carbides (24, 26) in said carbonitrided layer (38) have a maximum longitudinal dimension of 0.2-0.3 μm.

9. Steel component (28, 36) according to claim 8, characterized in that it comprises steel with a carbon content of 0.6 to 1.2 weight %.

10. Steel component (28, 36) according to claim 8 or 9, characterized in that it comprises or constitutes a rolling element or roller, or a steel component (28, 36) for an application in which it is subjected to alternating Hertzian stresses.

11. Steel component (28, 36) according to any of claims 8-10, characterized in that it comprises a carbonitrided layer (38) having a ratio (d:D) of depth (d) of the carbonitrided layer (38) of the carbonitrided layer measured from the surface of the steel component (28, 36) to maximum transverse dimension (D) of said steel component (28, 36) of 1:4000 to 1:17,000 or more.

12. Use of a steel component (28, 36) according to any of claims 8-11 under contaminated and/or poor lubricant conditions.
**INTERNATIONAL SEARCH REPORT**

A. **CLASSIFICATION OF SUBJECT MATTER**

IPC: see extra sheet

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

B. **FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

IPC: C23C, F16C

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

SE, DK, FI, NO classes as above

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

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C. **DOCUMENTS CONSIDERED TO BE RELEVANT**

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<td>X</td>
<td>EP 1273672 A1 (KOMATSU MFG CO LTD), 8 January 2003 (2003-01-08); abstract; paragraphs [0006], [0037], [0017], [0018]</td>
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International Patent Classification (IPC)

C23C 8/32 (2006.01)
F16C 33/00 (2006.01)

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