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(54) Title: DUAL STEP QUENCHED MARTENSITE FOR BEARING APPLICATIONS, AND BEARING PRODUCED ACCORDING TO THIS METHOD

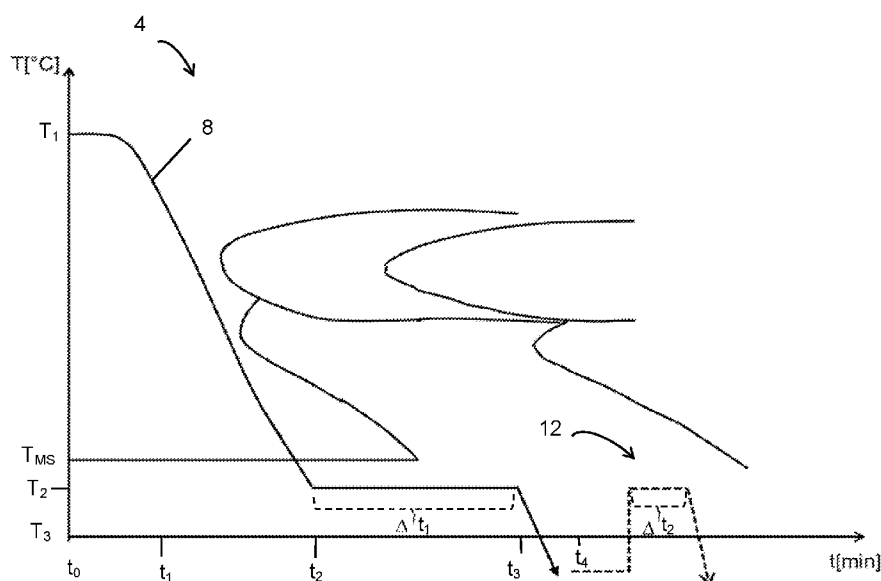


Fig. 1

(57) Abstract: A heat treatment process for through hardening results in improved rolling contact fatigue (RCF) resistance. The method includes austenitizing a steel component, quenching the steel component to a first quench temperature below the martensite start temperature (Ms), holding the steel component at the first quench temperature for a duration of 0.5 hours to 8 hours, and quenching the steel component to a second quench temperature below 100 degrees C. The resulting component has a through hardness of at least 50 HRC, a retained austenite content of at least 10% to a depth of at least 1 mm from a surface of the steel component, residual tensile stresses to a depth of at least 1 mm from the surface of the steel component, and a microstructure of 5-30% bainite, 10-35% retained austenite, less than 7% carbides, and a remainder of martensite throughout a cross-section of the steel component.



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DUAL STEP QUENCHED MARTENSITE FOR BEARING APPLICATIONS, AND BEARING PRODUCED ACCORDING TO THIS METHOD

[0001] The present invention relates to through hardening and case hardening steel components, and more particularly to methods to achieve improved rolling contact fatigue (RCF) resistance characteristics in through hardened and case hardened steel components, and the components that are through hardened and case hardened using such methods.

BACKGROUND

[0002] Through hardening is a heat treatment process that includes heating a steel component to a high temperature as an austenitizing step to change the microstructure of the steel to a pure austenite microstructure. The austenitizing process may include one or more heating cycles or one or more austenitization cycles. The component is then rapidly quenched to increase a hardness throughout a steel component, which increases the strength of the component. Different quench mediums include forced air or gas, still air or gas, quench oil, water and a liquid salt. The component may be quenched to a temperature, such as near or below a martensite start temperature (T_{MS}), which enables further transformation of the microstructure of the component. For example, the microstructure can be transformed from austenite to martensite, bainite, pearlite, or a combination of these microstructures. Additionally, the component may be tempered after the component is quenched by re-heating the component to decrease a brittleness of the component.

[0003] Case hardening is another known heat treatment process in which a hardened, “case region” is created only at the surface of the component and to a depth extending at most to two centimeters below the surface of the component. The case hardening can be done in two different manners. A first is by preferentially enriching the steel surface with carbon and/or nitrogen followed by a quenching step. A second is by preferentially austenitizing the near surface material (case region) by induction heating followed by a quench step.

SUMMARY

[0004] In one aspect, the improved heat treating process provides improved rolling contact fatigue (RCF) resistance, which has been found to improve the life of bearings used in high-debris applications, such as earth-moving and drilling equipment. In those applications, debris (e.g., sand, grit, etc.) gets into the bearing and dents the races and/or rollers. It has been found that bearing steel heat treated with the process described below

increases the life expectancy of these bearings that see significant debris denting. To be clear, the process does not necessarily prevent or reduce the denting, but rather improves the rolling contact fatigue (RCF) resistance such that even when heavily dented by debris, the bearings still last longer.

[0005] The present disclosure provides, in one aspect, a method for through hardening steel, and particularly bearing steel components. The method includes austenitizing a steel component, quenching the steel component to a first quench temperature below the martensite start temperature (M_s) and within a range of $0.8M_s$ to $0.98M_s$, holding the steel component at the first quench temperature for a duration of 0.5 hours to 8 hours, and quenching the steel component to a second quench temperature below 100 degrees C. The resulting component has a through hardness of at least 50 HRC, a retained austenite content of at least 10% to a depth of at least 1 mm from a surface of the steel component, residual tensile stresses to a depth of at least 1 mm from the surface of the steel component, and a microstructure of 5-30% bainite, 10-35% retained austenite, less than 7% carbides, and a remainder of martensite throughout a cross-section of the steel component.

[0006] The present disclosure provides, in another aspect, a method for case hardening steel, and particularly bearing steel components. The method includes preferentially austenitizing a near surface material of the steel component by induction heating and quenching the steel component to a first quench temperature to create a case region. Because of preferential austenitizing and quenching, the case region has a higher hardness than the material in the core, and in this context, the case has hardness of at least 50HRC. The case region has a depth from a surface of the steel component ranging from 100 microns to 1 cm, and the first quench temperature is below a martensite start temperature (M_s) of material in the case region and within a range of $0.8M_s$ to $0.98M_s$. The method further includes holding the steel component at the first quench temperature for a duration of 0.5 hours to 8 hours, and quenching the steel component to a second quench temperature below 100 degrees C. The resulting steel component has a hardness of at least 50 HRC in the case region of the steel component, a retained austenite content of at least 10% to a depth of at least 100 microns from the surface of the steel component, residual compressive stresses to a depth of at least 100 microns to 2 cm from the surface of the steel component, and a microstructure of 5-30% bainite, 10-35% retained austenite, less than 7% carbides, and a remainder of martensite in the case region of the steel component.

[0007] The present disclosure provides, in another aspect, a method for case hardening steel, and particularly bearing steel components. The method includes diffusing carbon and/or nitrogen into a surface of the steel component while austenitizing the steel component and quenching the steel component to a first quench temperature to create a case region. Because of enriched carbon and/or nitrogen in the near surface material, the case region has higher hardness than the material in the core, and in this context, the case has a hardness of at least 50HRC. The case region has a depth from a surface of the steel component ranging from 100 microns to 1 cm, and the first quench temperature is below a martensite start temperature (M_s) of material in the case region and within a range of $0.8M_s$ to $0.98M_s$. The method further includes holding the steel component at the first quench temperature for a duration of 0.5 hours to 8 hours, and quenching the steel component to a second quench temperature below 100 degrees C. The resulting steel component has a hardness of at least 50 HRC to a depth of at least 100 microns from the surface of the steel component, a retained austenite content of at least 10% to a depth of at least 100 microns from the surface of the steel component, residual compressive stresses to a depth of at least 100 microns to 2 cm from the surface of the steel component, and a microstructure of 5-30% bainite, 10-35% retained austenite, less than 7% carbides, and a remainder of martensite in the case region of the steel component.

[0008] Other features and aspects of the invention will become apparent by consideration of the following detailed description and accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] Fig. 1 is a time-temperature-transformation chart of the austenite to martensite+bainite+retained austenite conversion in various stages.

[0010] Figs. 2 illustrates the microstructure of an example component that has been heat treated using the method described herein.

[0011] Fig. 3 is an alternative time-temperature-transformation chart of the austenite to martensite+bainite+retained austenite conversion in various stages.

[0012] Fig. 4 illustrates a graph of bearing life for bearings produced by the heat treating processes of Figs. 1 and 3 as compared to other conventional heat treating processes.

[0013] Before any embodiments of the invention are explained in detail, it is to be understood that the invention is not limited in its application to the details of construction and the arrangement of components set forth in the following description or illustrated in the following drawings. The invention is capable of other embodiments and of being practiced or of being carried out in various ways. Also, it is to be understood that the phraseology and terminology used herein is for the purpose of description and should not be regarded as limiting.

DETAILED DESCRIPTION

[0014] The present disclosure is related to a heat treatment process explained using an example of austempering of bearing steel grades, such as 100CrMo7-3 or 100CrMnSi6-4, or any other steel grade having a carbon composition of at least 0.7 weight% (wt%). However, those of ordinary skill in the art would understand that the inventive heat treatment process could be applied to other steels as well. The typical chemical composition of 100CrMo7-3 steel includes 0.9 wt% carbon, 0.3 wt% silicon, 0.7 wt% manganese, 1.8 wt% chromium, 0.3 wt% molybdenum. The typical chemical composition of 100CrMnSi6-4 steel includes 0.9 wt% carbon, 0.6 wt% silicon, 1.1 wt% manganese, 1.5 wt% chromium. Typical through hardening bearing steels with carbon content of more than 0.7% can be found in the ISO standard ISO 683-17:2014(en).

[0015] The through hardening process described herein is a dual step quenched martensite process for a bearing steel component (e.g., a bearing race or roller, such as a bearing steel component 20 represented in the microstructure view of Fig. 2). As shown in Fig. 1, the steel component may first be austenitized throughout its cross section by heating the component to an initial temperature T_1 , which in the illustrated embodiment is a temperature from 700 degrees Celsius to 1000 degrees Celsius. To fully austenitize, the component is held at the temperature T_1 for a duration of time 5 minutes to 240 minutes. One or more heating cycles may be used to austenitize the component or one or more austenitizing cycles may be used. After the austenitization is complete and the component has a microstructure of austenite and some carbide particles, the component is then heat treated using the dual step quenched martensite process described herein beginning at an initial time t_0 , which is shown in Fig. 1.

[0016] Fig. 1 depicts a time-temperature-transformation (TTT) chart 4 showing a transformation curve 8 of the heat treatment process described herein. Beginning at a time t_1 , the component is quenched from the initial temperature T_1 to a temperature T_2 by a time t_2 . In some instances, the quench rate from T_1 to T_2 also touches and/or crosses the noses of the C-shaped curves. If that were the case, the microstructure could contain small amounts of pearlite and/or upper bainite. The temperature T_2 is below the martensite start temperature T_{MS} of the material, such as from $0.8 \cdot T_{MS}$ to $0.98 \cdot T_{MS}$, and in some instances from $0.8 \cdot T_{MS}$ to $0.9 \cdot T_{MS}$. For the example type of bearing steel described herein, T_{MS} is about 200 degrees Celsius, and the temperature T_2 ranges from 160 degrees C to 195 degrees C. For other steels having higher a higher T_{MS} temperature, the T_2 range would also be correspondingly higher. The initial amount of martensite formed upon reaching the quench temperature T_2 is typically about 5% to about 40%. The component is then held at the temperature T_2 for a time interval Δt_1 from time t_2 to time t_3 . The quench and holding medium includes a liquid salt bath or a quench oil bath. The time interval Δt_1 may be any length of time from 0.5 hours to 8 hours, and alternatively may be from 0.5 hours to 4 hours. During the time interval Δt_1 , the component is held at temperature T_2 , and during this time, isothermal tempering of the formed martensite occurs. In addition, some formation of bainite (e.g., 5-30%) has been observed during this isothermal tempering.

[0017] At time t_3 , the component is quenched to a temperature at or below a room temperature, 100 degrees Celsius, or an ambient temperature. The quench medium includes water, oil, still air or gas, forced air or gas. After quenching, the resulting microstructure has been found to contain 5-30% bainite (lower bainite), 10-35% retained austenite, less than 7% carbides, and the remainder being martensite. Fig. 2 illustrates the microstructure, with areas labeled “B” for bainite, “RA” for retained austenite, and “M” for martensite. Carbides are also indicated. The component has a through hardness of at least 50 HRC and retained austenite content of at least 10% to a depth of at least 1 mm from the surface of the steel component. The component also exhibits residual tensile stresses to a depth of at least 1mm from the surface of the steel component. Those residual stresses range from 10 to 150 MPa.

[0018] The component may be tempered after the second quench or may be used without tempering. To temper the steel component, the steel component may be heated to a fourth temperature that is from 100 degrees Celsius to 350 degrees Celsius and quenched to an ambient or room temperature. The through hardness of the steel part remains at least 50

Rockwell C (HRC) throughout the cross-section of the component after the quench tempering heat treatment (i.e., after t_4). The quench tempering heat treatment 12 after t_4 can be done to reduce the amount of retained austenite to less than 15%. The quench tempering heat treatment 12 begins at time t_4 and includes heating the component to a temperature T_4 for a short period of time Δt_2 , after which the component is again quenched to a temperature at or below a room temperature, 100 degrees Celsius, or an ambient temperature. The quench tempering heat treatment 12 is optional.

[0019] The resulting microstructure increase the rolling contact fatigue life of the component, thus enabling the components to last longer. The increased rolling contact fatigue life is evident from the bearing life testing as shown in Fig. 4. Rolling contact surfaces were dented by debris as per standard procedures and then life tested in viscosity grade 10 mineral oil. Fig. 4 shows the life of bearings made using conventional heat treats that are used in the field as compared to the inventive dual quench martensite heat treatment described above. The improved fatigue resistance properties are attributed to martensite forming at the second quench step and the bainite formed during the isothermal tempering.

[0020] Fig. 3 is an alternative time-temperature-transformation chart 30 of the austenite to martensite+bainite+retained austenite conversion in various stages. The steel used in the illustrated example is bearing steel grades, such as 100CrMo7-3 or 100CrMnSi6-4, or any other steel having a carbon composition of at least 0.7 wt%. The heat treatment process shown in the alternative time-temperature-transformation chart 30 of Fig. 3 includes an additional heating and quenching cycle 34 that may be added to the heat treatment process 4 described above. In the illustrated example, the component is first heated to a high temperature of T_2 , which is a carbide dissolution temperature of approximately 900 to 1100 degrees Celsius. This heating stage has a duration Δt_3 of at least 30 minutes. In one example, the duration Δt_3 is from 30 minutes to 300 minutes. The duration Δt_3 is inclusive of the heating time, holding time, and cooling time of the heating stage. The temperature T_2 is above the A_1 and the A_{CM} temperatures for the steel component. The A_1 transformation temperature is the temperature at which the ferritic phase of the steel starts to transform into austenite. The A_{CM} temperature is the temperature at which the ferritic phase of the steel is completely transformed into austenite. During this heat treatment stage 34 at least some of the carbides in the component are dissolved. After the heating stage 34, the component is

quenched to a temperature T_{-1} . The temperature T_{-1} is less than 500 degrees Celsius, but in one embodiment may be less than 300 degrees Celsius.

[0021] Next, the component is then reheated to a temperature above the A_1 temperature, and may also be above the A_{CM} temperature. The A_{CM} transformation temperature is the temperature at which the ferrite phase of the steel completely transforms into austenite. In the illustrated example, this temperature is the same as the temperature T_1 of the heat treatment cycle described in Fig. 1. Alternatively, the temperature of the second heating stage may be within the range of 750 to 900 degrees Celsius. Following the second heating stage, the heat treatment cycle of Fig. 3 is identical to the heat treatment cycle of Fig. 1. However, the additional heating stage results in components with improved fatigue resistance and refined microstructures. Thus, the heat treatment cycle of Fig. 3 may be better for some applications than the heat treatment cycle of Fig. 1.

[0022] Fig. 4 illustrates the results of bearing life testing conducted for bearings heat-treated using the Dual Quench Martensite processes of Fig. 1, as compared to bearings that underwent different heat treat processes. Rolling contact surfaces of all the bearings were debris dented first as per a standard procedure, and then life tested in a viscosity grade 10 mineral oil. In contrast to smoother bearing surfaces, the dented bearing surfaces decrease the bearing lives drastically. This testing is done typically to evaluate the durability of bearings used in high-debris applications, such as earth-moving and drilling equipment. In Fig. 4, the illustrated Heat Treat 2 results depict results from an austempering process. The illustrated Heat Treat 3 results depict results from a dual step austempering process. The illustrated Heat Treat 4 results depict a case carburized bearing with martensitic microstructure. Also shown for comparison purposes is the estimated bearing life without debris denting of the bearing races.

[0023] The above-described processes described with respect to Fig. 1 can also be performed in conjunction with, or after, a case hardening process is performed on the bearing component. For example, in a case carburizing process, only the near surface material can be hardened by diffusing carbon and/or nitrogen into the steel surface during the austenitization step followed by quenching. With case carburizing, the case region can be created in a separate process prior to the Dual Quench Martensite process 4 described above with respect to Fig. 1, or simultaneously during the austenitizing step of the Dual Quench Martensite processes described above with respect to Fig. 1. When quenching below the M_s

temperature, the Ms temperature is based on the material in the case region. It should also be noted that a lower carbon steel (i.e., lower than 0.7 wt. %) may be used as the base material for this case carburized bearing component, but that the additional diffused carbon in the case region will lead to similar results observed in the case region.

[0024] Alternatively to case carburizing, only the near surface material can be hardened to create the case region by selectively heating the near surface material via induction heating followed by quenching. In this case, the induction heating of the near surface region functions as the austenitizing step(s) of the Dual Quench Martensite processes 4 or 30 described above with respect to Figs. 1 and 3. With this induction hardening process, when quenching below the Ms temperature, the Ms temperature is based on the material in the case region.

[0025] In either method of case hardening, the case-hardened region typically has a depth of 100 microns to 1 cm, a hardness of at least 50 HRC in that case-hardened region, and the microstructure has at least 10% retained austenite in that case hardened region. The overall resulting microstructure in the case region has been found to contain 5-30% bainite, 10-35% retained austenite, less than 7% carbides, and the remainder being martensite. In these case-hardened components, residual compressive stresses at the surface region to a depth of at least 100 microns to 2 cm have been observed.

[0026] Although the invention has been described in detail with reference to certain preferred embodiments, variations and modifications exist within the scope and spirit of one or more independent aspects of the invention as described.

CLAIMS

What is claimed is:

1. A method of through hardening a bearing steel component with at least 0.7% weight of carbon, the method comprising:
 - austenitizing the steel component to an austenitizing temperature;
 - quenching the steel component to a first quench temperature below a martensite start temperature (Ms) and within a range of 0.8Ms to 0.98Ms;
 - holding the steel component at the first quench temperature for a duration of 0.5 hours to 8 hours; and
 - quenching the steel component to a second quench temperature below 100 degrees C;wherein the resulting steel component has
 - a through hardness of at least 50 HRC;
 - a retained austenite content of at least 10% to a depth of at least 1 mm from a surface of the steel component;
 - residual tensile stresses to a depth of at least 1 mm from the surface of the steel component;
 - and a microstructure of 5-30% bainite, 10-35% retained austenite, less than 7% carbides, and a remainder of martensite throughout a cross-section of the steel component.
2. The method of claim 1, wherein the austenitizing temperature is from 700 to 1000 degrees Celsius.
3. The method of claim 1, wherein the first quench temperature ranges from 160 degrees Celsius to 195 degrees Celsius.
4. The method of claim 1, wherein the residual tensile stresses range from 10 to 150 MPa.
5. The method of claim 1, further comprising tempering the steel component after quenching the steel component to the second quench temperature.
6. A bearing component through-hardened according to the method of claim 1.

7. A method of case hardening a bearing steel component, the method comprising:
 - preferentially austenitizing a near surface material of the steel component by induction heating;
 - quenching the steel component to a first quench temperature to create a case region, the case region having a depth from a surface of the steel component ranging from 100 microns to 1 cm, the first quench temperature being below a martensite start temperature (Ms) of material in the case region and within a range of 0.8Ms to 0.98Ms;
 - holding the steel component at the first quench temperature for a duration of 0.5 hours to 8 hours; and
 - quenching the steel component to a second quench temperature below 100 degrees C; wherein the resulting steel component has
 - a hardness of at least 50 HRC in the case region;
 - a retained austenite content of at least 10% to a depth of at least 100 microns from the surface of the steel component;
 - residual compressive stresses to a depth of at least 100 microns to 2 cm from the surface of the steel component; and
 - a microstructure of 5-30% bainite, 10-35% retained austenite, less than 7% carbides, and a remainder of martensite in the case region of the steel component.
8. The method of claim 7, wherein the first quench temperature ranges from 160 degrees Celsius to 195 degrees Celsius.
9. The method of claim 7, further comprising tempering the steel component after quenching the steel component to the second quench temperature.
10. A bearing component case-hardened according to the method of claim 7.

11. A method of case hardening a bearing steel component, the method comprising:
 - diffusing carbon and/or nitrogen into a surface of the steel component while austenitizing the steel component;
 - quenching the steel component to a first quench temperature to create a case region, the case region having a depth from a surface of the steel component ranging from 100 microns to 1 cm, the first quench temperature being below a martensite start temperature (Ms) of material in the case region and within a range of 0.8Ms to 0.98Ms;
 - holding the steel component at the first quench temperature for a duration of 0.5 hours to 8 hours; and
 - quenching the steel component to a second quench temperature below 100 degrees C; wherein the resulting steel component has
 - a hardness of at least 50 HRC in the case region;
 - a retained austenite content of at least 10% to a depth of at least 100 microns from the surface of the steel component;
 - residual compressive stresses to a depth of at least 100 microns to 2 cm from the surface of the steel component; and
 - a microstructure of 5-30% bainite, 10-35% retained austenite, less than 7% carbides, and a remainder of martensite in the case region of the steel component.
12. The method of claim 11, further comprising tempering the steel component after quenching the steel component to the second quench temperature.
13. The method of claim 11, wherein the method further provides quenching the steel component after diffusing carbon into the surface of the steel component, and austenitizing the steel component again prior to quenching the steel component to the first quench temperature.
14. A bearing component case-hardened according to the method of claim 11.
15. A bearing component case-hardened according to the method of claim 13.

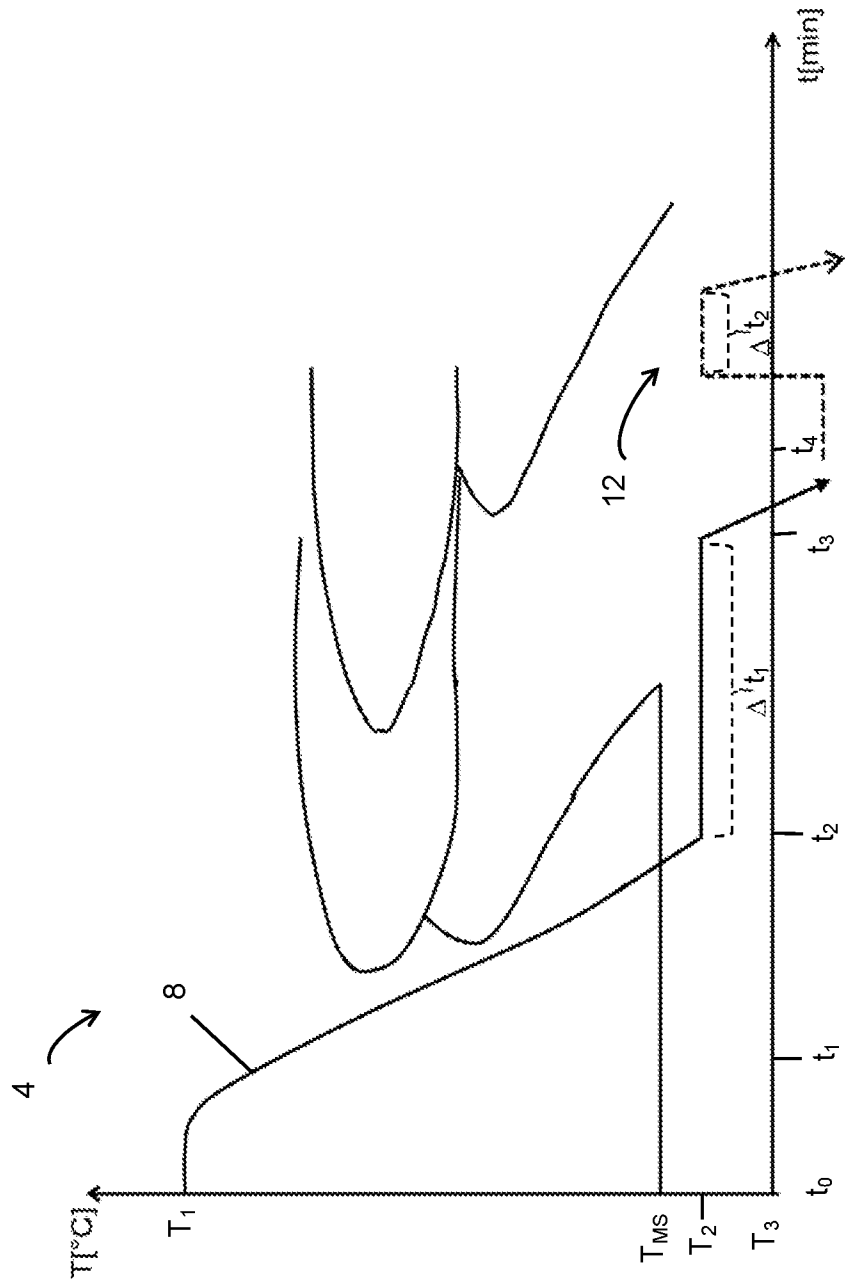


Fig. 1

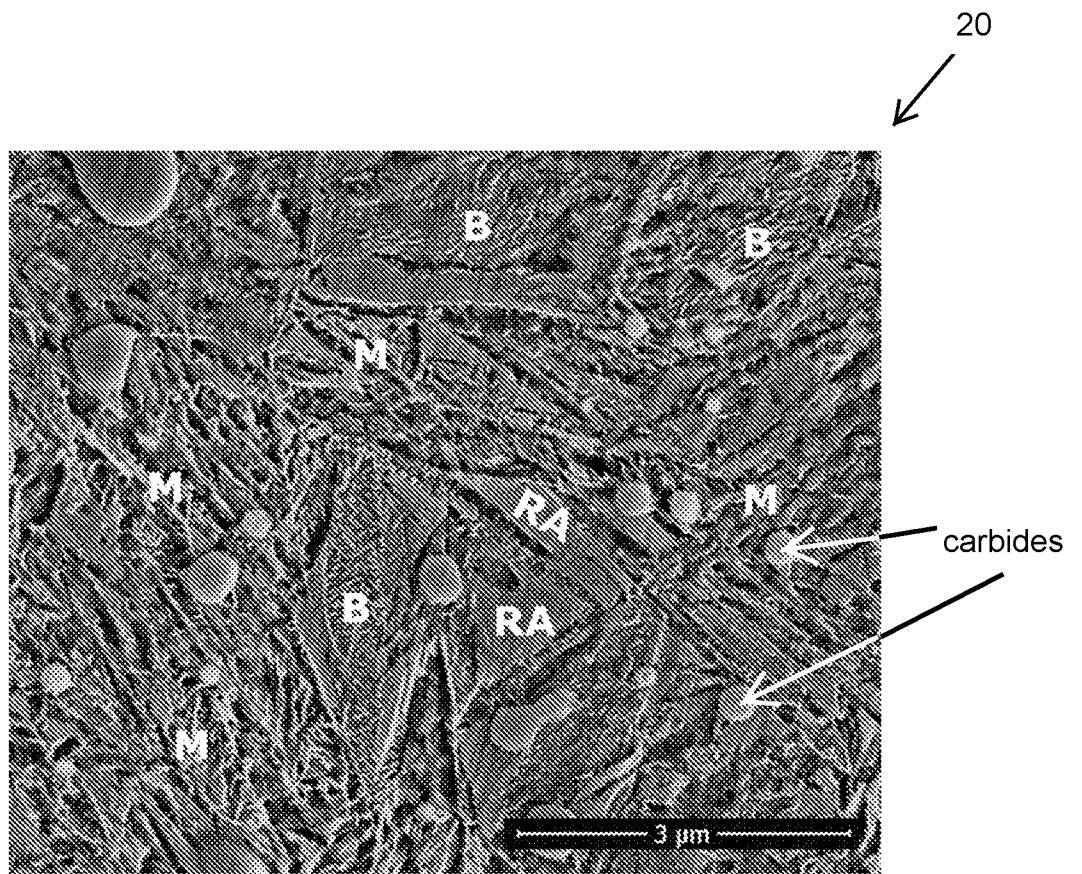


Fig. 2

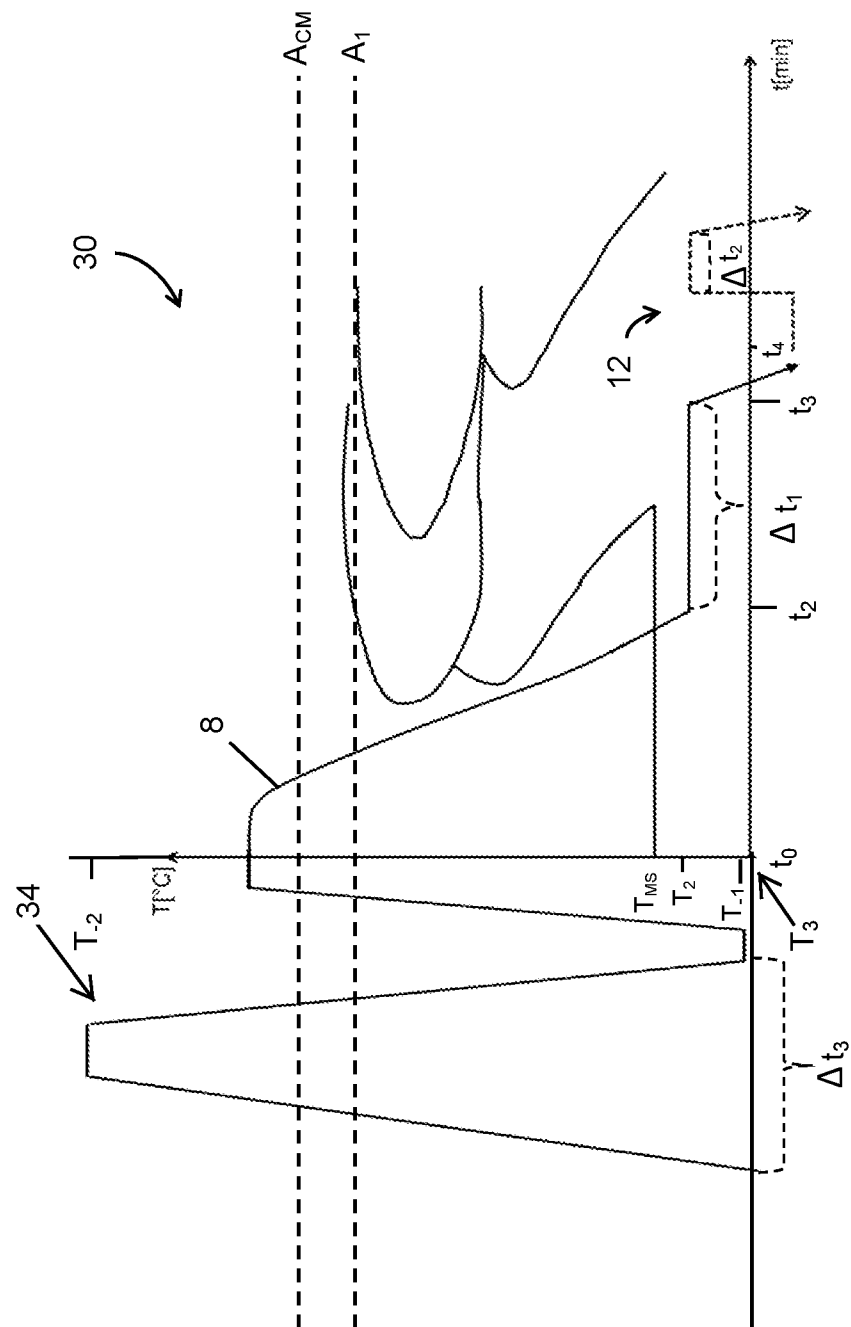


Fig. 3

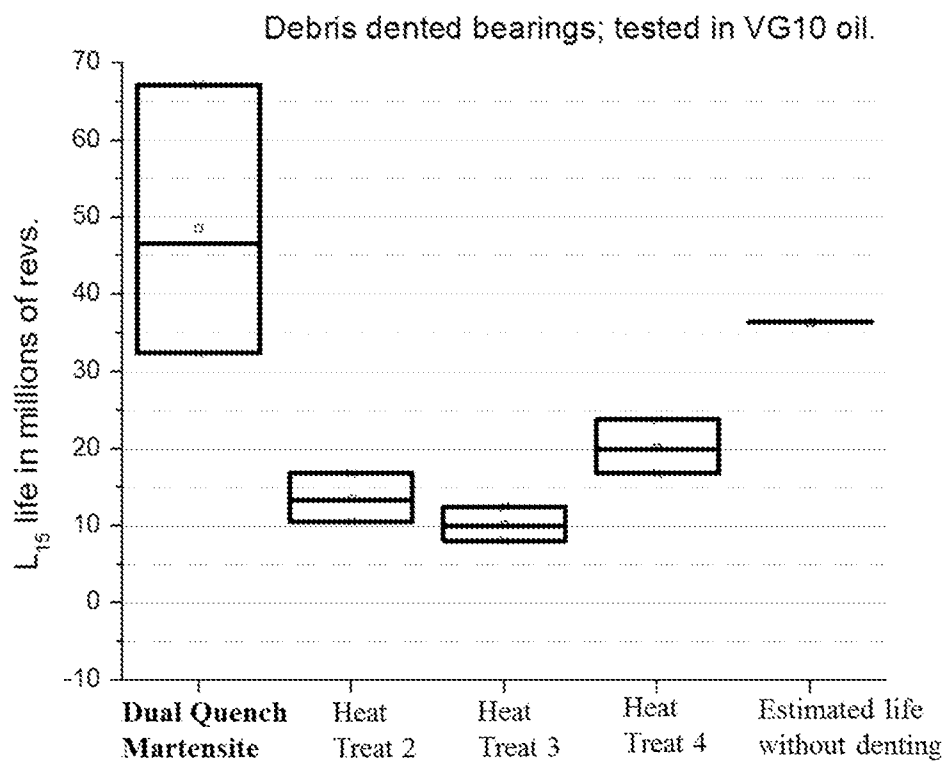


Fig. 4

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2021/013797

A. CLASSIFICATION OF SUBJECT MATTER INV. C21D1/19 C21D1/20 C21D1/25 C21D1/32 C21D6/00 C21D9/40 C23C8/32 F16C33/64 ADD. 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) C21D F16C C23C Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal, WPI Data											
C. DOCUMENTS CONSIDERED TO BE RELEVANT <table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 10%;">Category*</th> <th style="width: 70%;">Citation of document, with indication, where appropriate, of the relevant passages</th> <th style="width: 20%;">Relevant to claim No.</th> </tr> </thead> <tbody> <tr> <td style="text-align: center; vertical-align: top;">X</td> <td>DE 198 49 681 C1 (SKF GMBH) 5 January 2000 (2000-01-05) abstract</td> <td style="text-align: center; vertical-align: top;">1-6</td> </tr> <tr> <td style="text-align: center; vertical-align: top;">A</td> <td>CN 108 285 965 A (TECHNICAL INST PHYSICS & CHEMISTRY CAS) 17 July 2018 (2018-07-17) abstract ----- -/--</td> <td style="text-align: center; vertical-align: top;">1-6</td> </tr> </tbody> </table>			Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.	X	DE 198 49 681 C1 (SKF GMBH) 5 January 2000 (2000-01-05) abstract	1-6	A	CN 108 285 965 A (TECHNICAL INST PHYSICS & CHEMISTRY CAS) 17 July 2018 (2018-07-17) abstract ----- -/--	1-6
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* 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 26 September 2021		Date of mailing of the international search report 29/11/2021									
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer Vermeulen, Yves									

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2021/013797

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	PLATL JAN ET AL: "Determination of Martensite Start Temperature of High-Speed Steels Based on Thermodynamic Calculations", STEEL RESEARCH INTERNATIONAL., vol. 91, no. 8, 3 June 2020 (2020-06-03), page 2000063, XP055837930, DE ISSN: 1611-3683, DOI: 10.1002/srin.202000063 Retrieved from the Internet: URL:https://onlinelibrary.wiley.com/doi/full-xml/10.1002/srin.202000063> [retrieved on 2021-09-09] abstract Formulas (1) to (5); page 91 (2/8) -----	1-6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2021/013797

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-6-----

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-6

A first inventive concept is defined by independent method claim 1 and independent product claim 6, as well as dependent claims 2-5.

The inventive concepts is:

- (1) through hardening a bearing steel component with at least 0.7% weight of carbon;
- (2) austenitizing the steel component to an austenitizing temperature;
- (3) quenching the steel component to a first quench temperature below a martensite start temperature (M_s) and within a range of $0.8M_s$ to $0.98M_s$;
- (4) holding the steel component at the first quench temperature for a duration of 0.5 hours to 8 hours; and
- (5) quenching the steel component to a second quench temperature below 100 degrees C;

The resulting steel component has: a through hardness of at least 50 HRC; a retained austenite content of at least 10% to a depth of at least 1 mm from a surface of the steel component; residual tensile stresses to a depth of at least 1 mm from the surface of the steel component; and a microstructure of 5-30% bainite, 10-35% retained austenite, less than 7% carbides, and a remainder of martensite throughout a cross-section of the steel component.

The independent method discloses a bearing made according to method claim 1.

2. claims: 7-10

A second inventive concept is defined by independent method claim 7 and independent product claim 10, as well as dependent claims 8-9

The inventive concepts is:

- (1) case hardening a bearing steel component, the method comprising:
 - (2) preferentially austenitizing a near surface material of the steel component by induction heating;
 - (3) quenching the steel component to a first quench temperature to create a case region, the case region having a depth from a surface of the steel component ranging from 100 microns to 1 cm,
 - (4) the first quench temperature being below a martensite start temperature (M_s) of material in the case region and within a range of $0.8M_s$ to $0.98M_s$;
 - (5) holding the steel component at the first quench temperature for a duration of 0.5 hours to 8 hours; and
 - (6) quenching the steel component to a second quench temperature below 100 degrees C;
- wherein the resulting steel component has: a hardness of at least 50 HRC in the case region; a retained austenite

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

content of at least 10% to a depth of at least 100 microns from the surface of the steel component; residual compressive stresses to a depth of at least 100 microns to 2 cm from the surface of the steel component; and a microstructure of 5-30% bainite, 10-35% retained austenite, less than 7% carbides, and a remainder of martensite in the case region of the steel component. The independent product claim 7 describes a bearing made according to method claim 7.

3. claims: 11-15

A third inventive concept is defined by independent method claim 11 and independent products claim 14 and 15, as well as dependent claims 12-13.

The inventive concepts is:

- (1) a method of case hardening a bearing steel component, the method comprising:
 - (2) diffusing carbon and/or nitrogen into a surface of the steel component while austenitizing the steel component;
 - (3) quenching the steel component to a first quench temperature to create a case region, the case region having a depth from a surface of the steel component ranging from 100 microns to 1 cm, the first quench temperature being below a martensite start temperature (M_s) of material in the case region and within a range of $0.8M_s$ to $0.98M_s$;
 - (4) holding the steel component at the first quench temperature for a duration of 0.5 hours to 8 hours; and
 - (5) quenching the steel component to a second quench temperature below 100 degrees C;
- wherein the resulting steel component has a hardness of at least 50 HRC in the case region; a retained austenite content of at least 10% to a depth of at least 100 microns from the surface of the steel component; residual compressive stresses to a depth of at least 100 microns to 2 cm from the surface of the steel component; and a microstructure of 5-30% bainite, 10-35% retained austenite, less than 7% carbides, and a remainder of artensite in the case region of the steel component.
- Independent product claim 14 describes a bearing made according to the method of claim 11.
- Independent product claim 15 describes a bearing made according to the method of claim 13.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2021/013797

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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