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(54) **PROCESS FOR HEAT TREATMENT OF STEEL OR CAST IRON WORKPIECES**

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(57) **ABSTRACT**

A method for the heat treatment of workpieces made of steel or cast iron involves quenching the workpiece to a temperature above the martensite starting temperature (i.e., the temperature below which martensite is formed) after a holding period at or above the austenitizing temperature. In the ensuing time period, austenite is transformed into bainite. The temperature of the workpiece is reduced during the time period when transformation occurs and the transformation of austenite into bainite is thus continued.

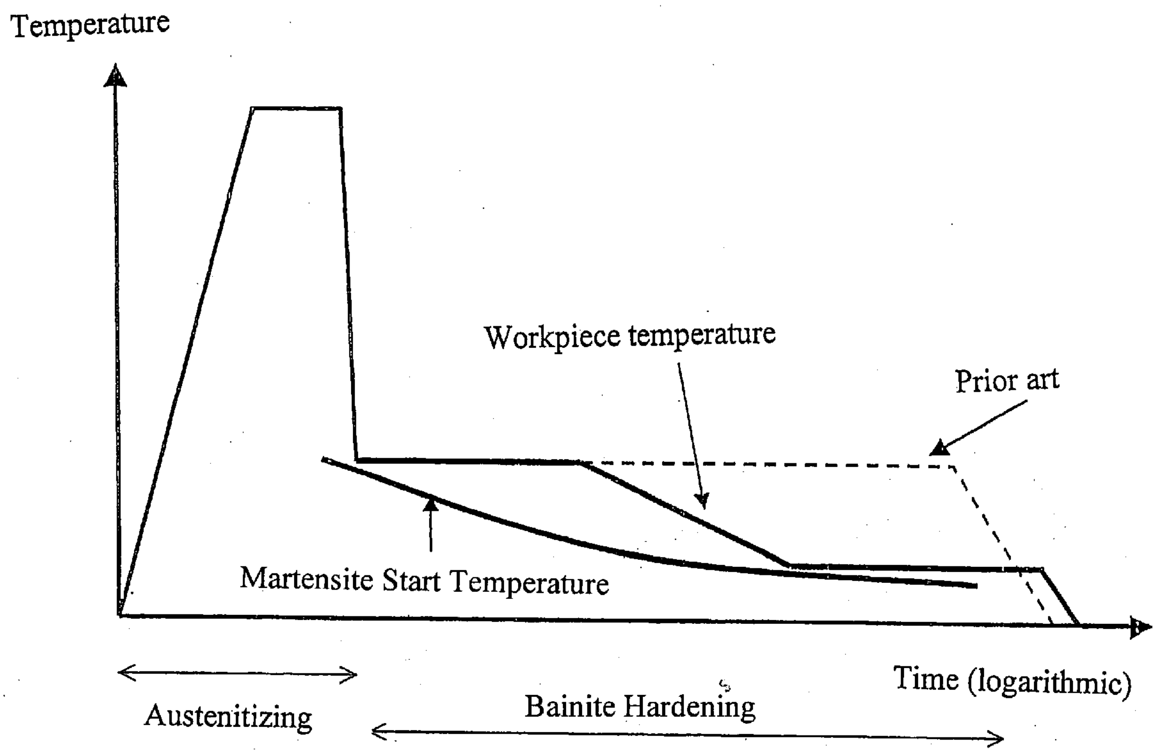
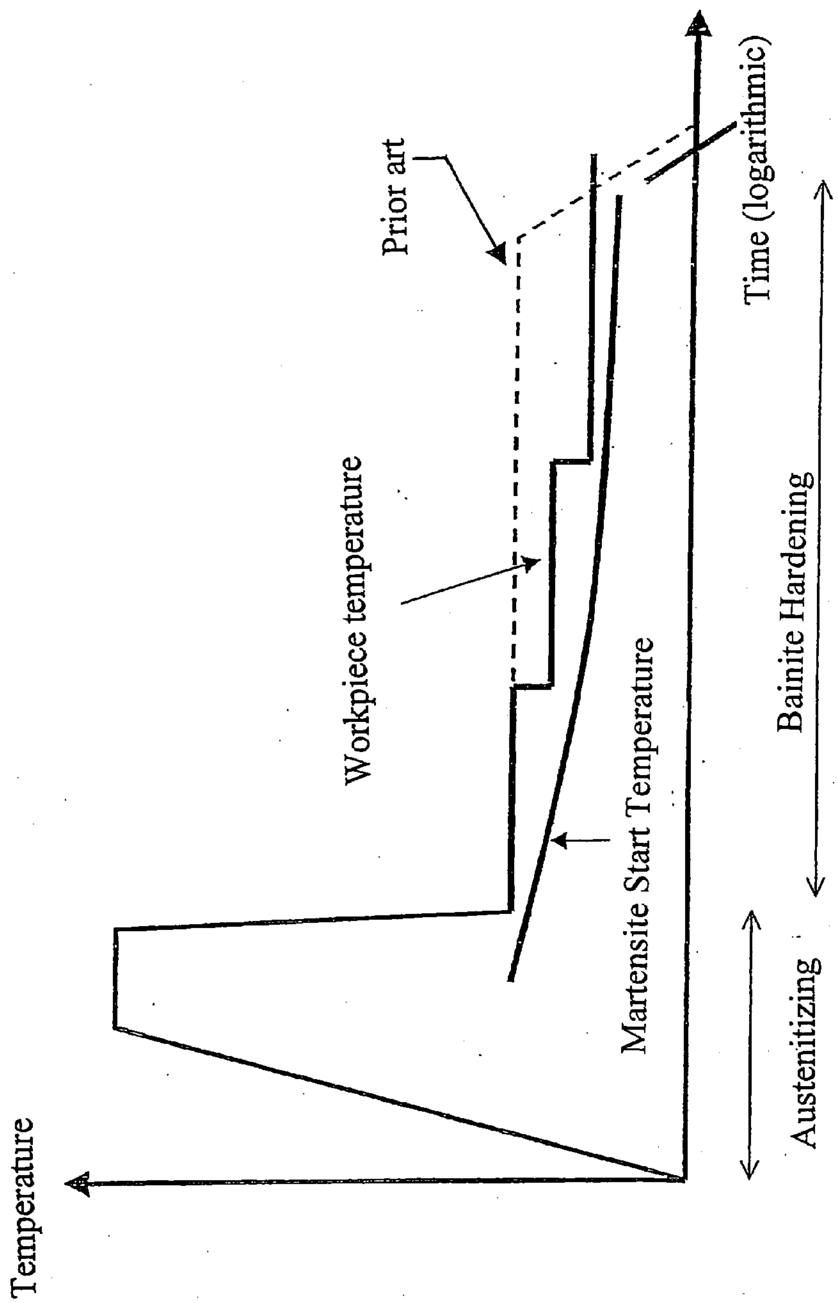


Fig. 1



Temperature
Prior art
Workpiece temperature
Martensite Start Temperature
Time (logarithmic)
Bainite Hardening
Austenitizing

Fig. 2

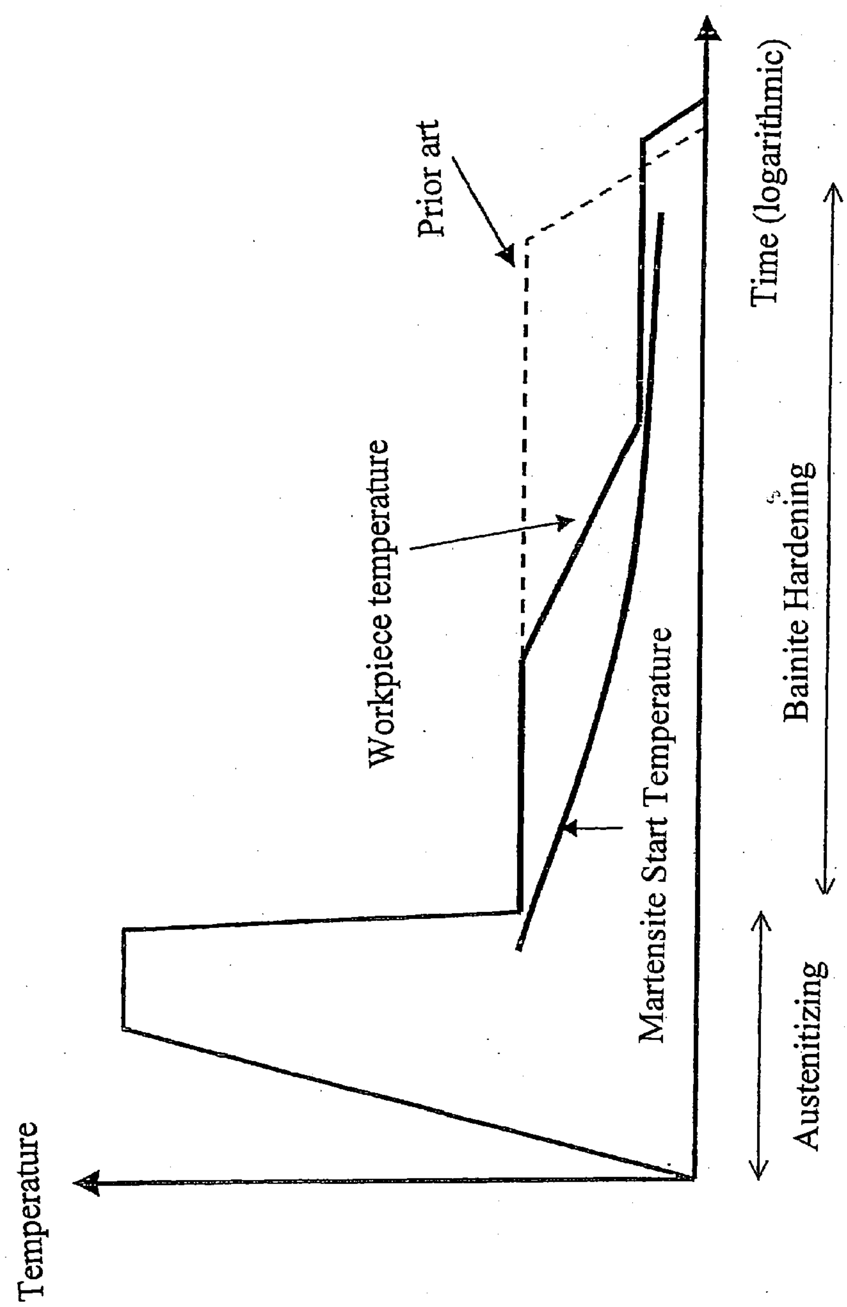

Temperature
Time (logarithmic)
Prior art
Workpiece temperature
Martensite Start Temperature
Bainite Hardening
Austenitizing

Fig. 3

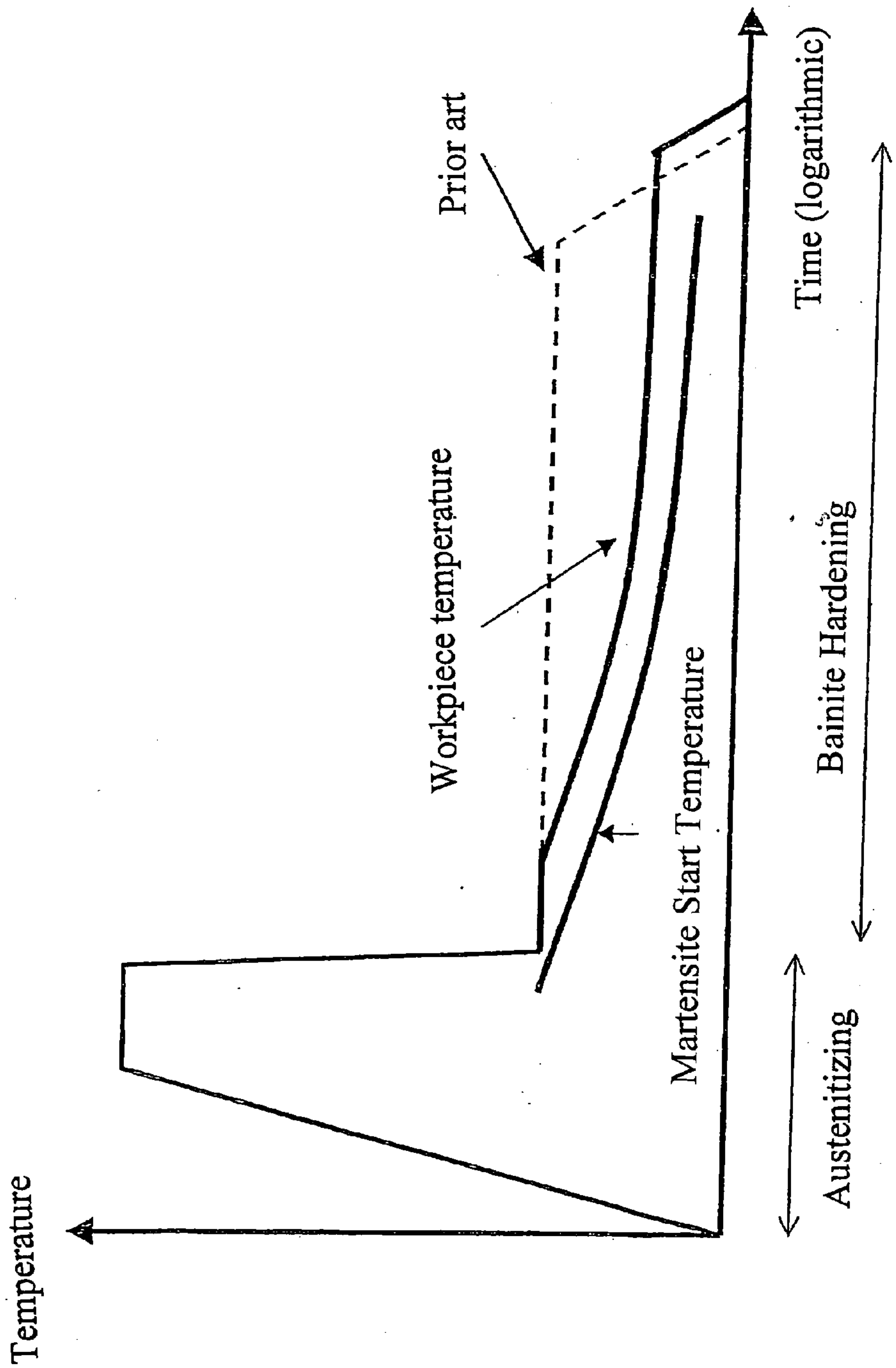
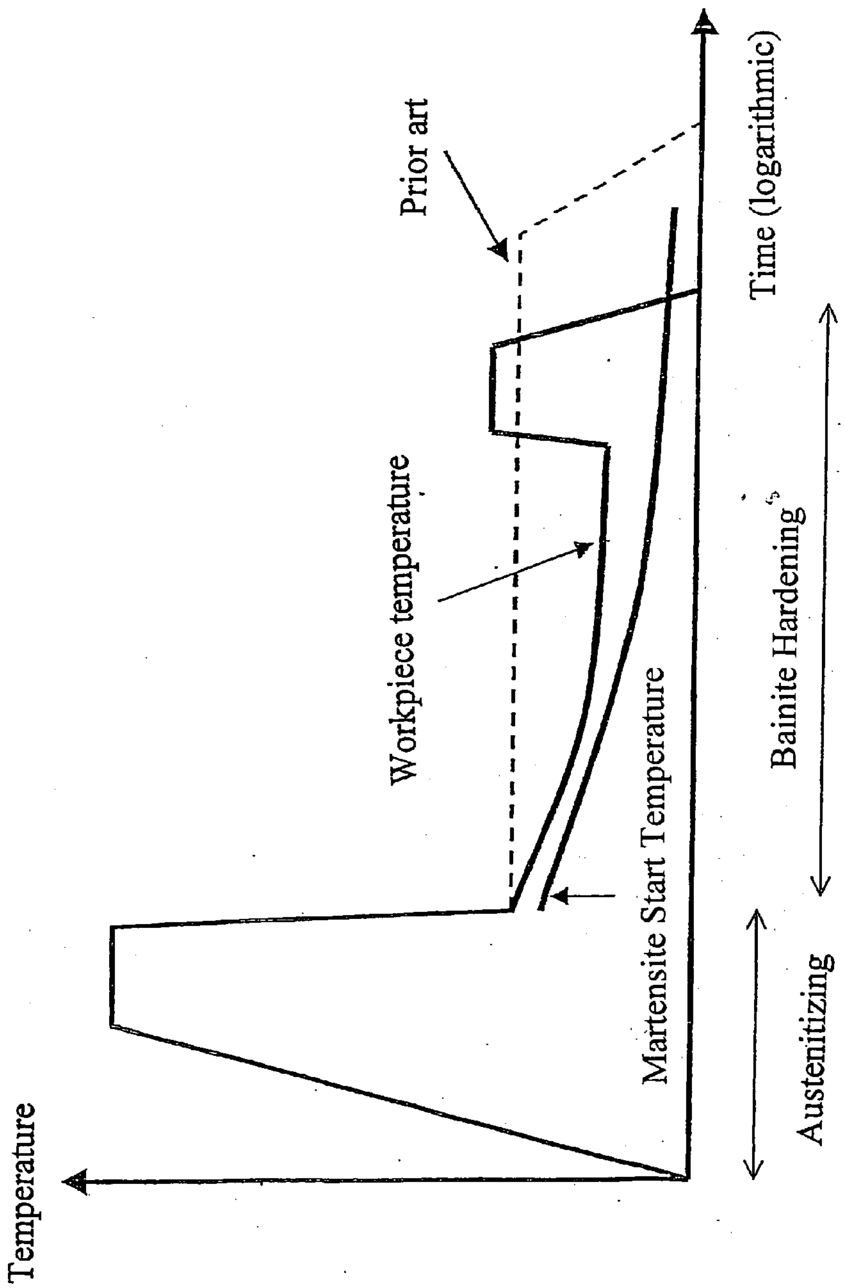
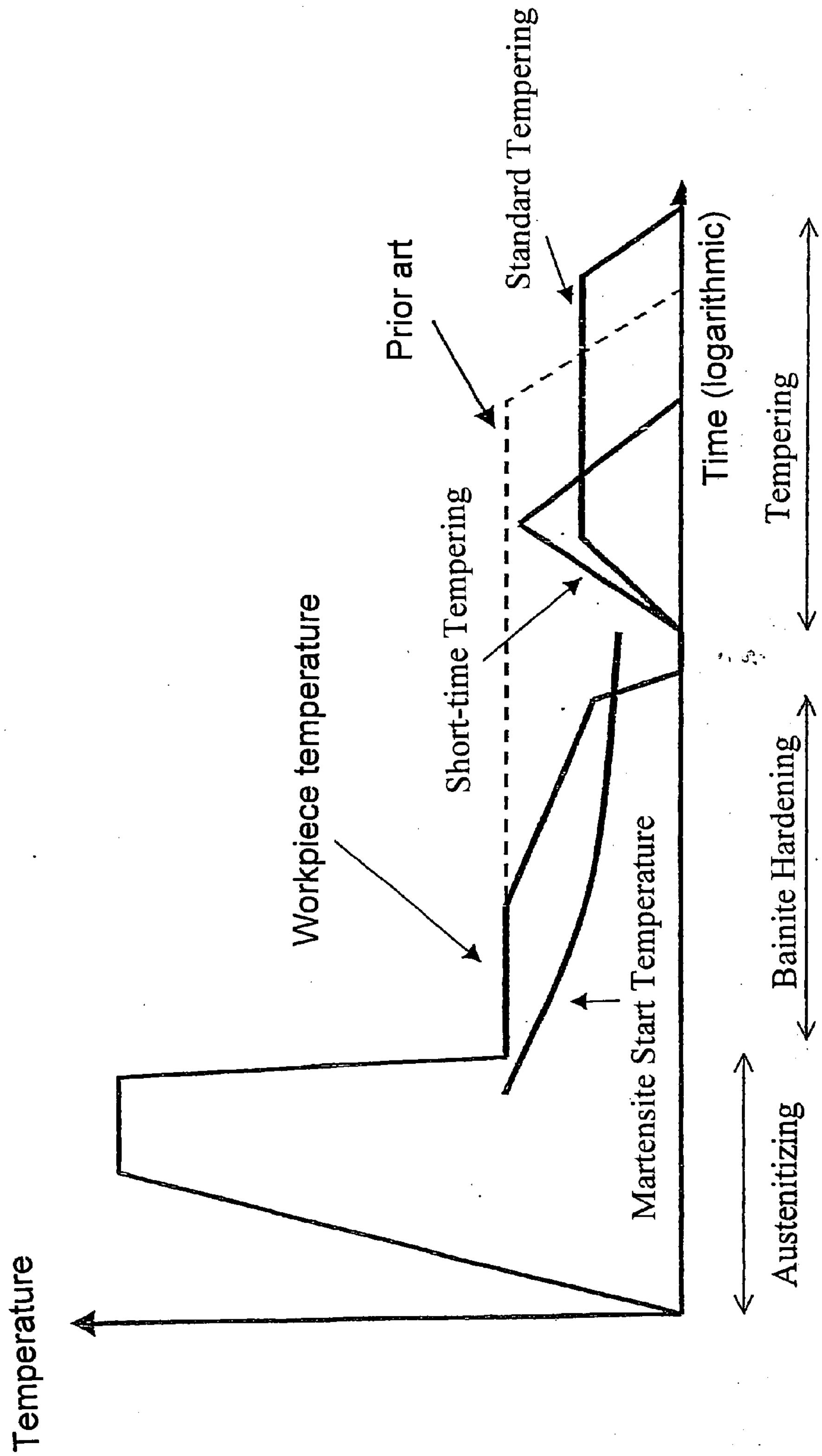

Temperature
Time (logarithmic)
Prior art
Workpiece temperature
Martensite Start Temperature
Bainite Hardening
Austenitizing

Fig. 4



Prior art
Workpiece temperature
Martensite Start Temperature
Temperature
Time (logarithmic)
Bainite Hardening
Austenitizing

Fig. 5


Temperature
Workpiece temperature
Prior art
Standard Tempering
Short-time Tempering
Martensite Start Temperature
Time (logarithmic)
Austenitizing
Bainite Hardening
Tempering

PROCESS FOR HEAT TREATMENT OF STEEL OR CAST IRON WORKPIECES

TECHNICAL FIELD

[0001] The invention relates to a process for heat treatment of steel or cast iron workpieces.

BACKGROUND DISCUSSION

[0002] Various processes for heat treatment of steel or cast iron workpieces are known. Heat treatment is used especially to increase the hardness of the workpieces. In this connection the type of heat treatment has a great effect on the properties of the workpieces so that the choice of a suitable heat treatment process, in addition to choosing a suitable composition of the steel or cast iron, is of major importance for the utility of the workpieces. This applies especially to workpieces such as especially rolling bearing parts which must meet high quality requirements and which are exposed to high stresses over a long time of use. In these workpieces the quality can depend very sensitively on the heat treatment details. Important criteria for assessment of workpiece quality are their strength, service life and structural stability against ageing.

[0003] One current heat treatment process which, for purposes of meeting the aforementioned and/or other quality requirements in a manner as good as possible is diversely combined with other heat treatment measures, is bainite hardening. As is known for example from EP 0 896 068 B1 or DE 198 49 681 C1, the workpieces are heated to the austenitizing temperature and kept at this temperature for a time. Then quenching to a temperature barely above the martensite start temperature takes place. Afterwards the workpieces are kept constantly at this temperature until the end of transformation and finally cooled to room temperature.

[0004] EP 0 896 068 B1 furthermore discloses increasing the temperature of the workpieces before the end of transformation of the austenite into bainite in order to accelerate the conversion of the residual austenite.

[0005] DE 198 49 681 C1 discloses cooling the workpieces quickly to room temperature before the end of transformation of the austenite into bainite. After a short holding time at room temperature, short-time age-hardening follows.

[0006] In spite of the favorable properties which can be achieved with bainite hardening, in many applications it has the adverse effect that the hardness attained is generally less than is the case in martensite hardening.

[0007] The object of the invention is to make the heat treatment of the steel or cast iron workpieces such that high quality requirements can be achieved at reasonable cost and thus a long service life of the workpieces is enabled. In particular, hardness as high as possible and/or a holding time as short as possible will be sufficient for bainite hardening.

SUMMARY

[0008] In the process for heat treatment of steel or cast iron workpieces, the workpieces are quenched, after a holding interval at or above the austenitizing temperature, to a temperature above the martensite start temperature, martensite being formed when going below this temperature. In a following time interval the austenite is transformed into bainite. The temperature of the workpieces is lowered during the time interval of transformation and transformation of austenite into bainite is continued.

[0009] The invention has the advantage that a hardness higher than for isothermal bainite hardening can be achieved. This lengthens the service life of the workpieces which have been treated in this way.

[0010] In particular, the temperature of the workpieces is lowered to values below the temperature which is achieved by quenching at least during a time portion of 20% of the transformation duration.

[0011] The temperature of the workpieces is lowered preferably depending on the martensite start temperature. In particular, the temperature of the workpieces is lowered to values above the martensite start temperature in order to avoid martensite formation. In this way the formation of mixed structures in the workpieces can be avoided.

[0012] It is especially advantageous if the temperature of the workpieces is lowered according to a given temperature profile. In this way, with the heat treatment processes as claimed in the invention optimum and reproducible results can be achieved. For example, the temperature of the workpieces can be lowered incrementally. This version can be implemented with relatively little cost. One possible implementation consists in exposing the workpieces to media of varied temperature to lower the workpiece temperature, especially to place them in baths kept at varied temperatures.

[0013] In another version of the heat treatment process, the temperature of the workpieces is continuously lowered. In particular, the temperature of the workpieces is lowered according to the behavior of the martensite start temperature. In this way, during the entire duration of transformation of austenite into bainite a very short interval to the martensite start temperature can be maintained and transformation can thus be done at a low workpiece temperature. This in turn benefits the attainable hardness of the workpieces. In this and also other versions of the heat treatment process as claimed in the invention the temperature of the workpieces can be lowered by means of one or more controllable facilities, especially furnaces. Thus almost any temperature profiles can be implemented.

[0014] In one development of the heat treatment process as claimed in the invention the workpieces are heated to a higher temperature after partial transformation of austenite into bainite in order to accelerate transformation. This is a very efficient measure for shortening the time required overall for heat treatment of the workpieces. Alternatively, the time interval of transformation can be dimensioned such that complete transformation of austenite into bainite does not take place and the workpieces are cooled to room temperature following the transformation time interval, held briefly there, and then age-hardened.

[0015] The heat treatment process as claimed in the invention can be used especially for workpieces which are made from a through-hardening rolling bearing or heat treatable steel. For example the workpieces are rolling bearing components.

BRIEF DESCRIPTION OF THE DRAWING FIGURES

[0016] The invention is explained below using the embodiments shown in the drawings.

[0017] FIGS. **1** to **5** show schematic time-temperature diagrams to illustrate the different versions of the heat treatment process disclosed herein. The X axis plots the time on a logarithmic scale. The Y axis plots the workpiece temperature.

DETAILED DESCRIPTION

[0018] The heat treatment process disclosed herein is carried out with steel or cast iron workpieces. In particular, workpieces of through-hardening rolling bearing or heat treatable steels are suitable. One typical representative of a rolling bearing steel which is defined in standard DIN EN ISO 683-17 is a steel labelled 100Cr6. This steel, relative to its mass, contains 0.93 to 1.05% carbon, 1.35 to 1.60% chromium, 0.25 to 0.45% manganese, 0.15 to 0.35% silicon and up to 0.1% molybdenum. The phosphorus content is a maximum 0.025%, and the sulfur content is a maximum 0.015%. Moreover small amounts of other elements can be contained, depending on production.

[0019] Before heat treatment, the workpieces are subjected to soft machining, by which the workpieces are brought into the desired form and, for example, are made as rolling bearing components. This form can differ from the final form of the workpieces by additions for further mechanical working after heat treatment.

[0020] FIG. **1** shows a schematic time-temperature diagram for illustration of a first version of the heat treatment process as disclosed herein. The workpieces are first heated proceeding from room temperature to the austenitizing temperature and kept at this temperature for a time. After austenitizing, the workpieces are quenched and thus cooled to a temperature barely above the martensite start temperature. Martensite formation is not desirable within the framework of the heat treatment process, so that falling below the martensite start temperature is avoided as long as this can be combined with the intended process progression. Quenching can advantageously take place by immersion of the workpieces in a salt bath. Salt baths have the advantage that they can easily capture the energy being released by exothermal reactions. In this way the material temperature can be kept within very narrow limits. After quenching, gradual conversion of the austenites into bainite takes place. This conversion is also called bainite transformation, bainite hardening or austempering. As is indicated by the broken line, bainite transformation according to the prior art is carried out at a constant temperature.

[0021] In the heat treatment process disclosed herein, the workpiece temperature is lowered during bainite transformation. This is enabled in that the martensite starting structure which should always be at least maintained likewise decreases during bainite transformation. By lowering the workpiece temperature for through-hardening rolling bearing steels, a hardness of roughly 59 to 64 HRC can be achieved which is greater than is the case for conventional isothermal bainite transformation. In order to achieve a distinct effect, the workpiece temperature preferably during at least a time portion of 20% of the transformation interval intended for bainite transformation is lowered to values which are below the workpiece temperature achieved by quenching. Especially good results can be achieved for a time portion of at least 80% of the transformation interval.

[0022] In the first version of the heat treatment process which is shown in FIG. **1**, the temperature is lowered incrementally. This means that the workpiece temperature is kept for a time at a constant temperature and then quickly lowered to barely above the current value of the martensite start temperature. Then a constant segment and a renewed drop etc. follow. This behavior of the workpiece temperature can be achieved, for example, by several salt baths which are kept at different temperatures and into which the workpieces are placed in succession. Likewise, it is also possible to quench the workpieces first by a salt bath and leave them in the salt bath for a first holding phase. Then the workpieces for each holding phase are placed in a tempering furnace with a different temperature, especially an air tempering furnace. When the time interval intended for bainite transformation has expired, the workpieces are cooled to room temperature.

[0023] The versions of the heat treatment process described below differ from the above described first version with respect to the behavior of the workpiece temperature during bainite transformation, and in the case of the version shown in FIG. **5** also after bainite transformation. Otherwise what was said about the first version applies to the other versions analogously.

[0024] FIG. **2** shows a schematic time-temperature diagram for illustration of a second version of the heat treatment process disclosed herein. In this second version, during bainite transformation immediately after quenching of the workpieces, there is a holding phase with a constant workpiece temperature which is followed by a phase with a continuously decreasing workpiece temperature. Finally, a holding phase with a constant workpiece temperature follows. Outside the time interval intended for bainite transformation, the behavior of the workpiece temperature corresponds to the behavior described for the first version.

[0025] To implement this temperature behavior, the workpieces are in turn quenched again in a salt bath and left for a time in the salt bath. Then the workpieces are each moved for a time into media kept at different temperatures, for example tempering furnaces or salt baths which are controlled such that the workpiece temperature is lowered or kept in the desired manner.

[0026] FIG. **3** shows a schematic time-temperature diagram for illustration of a third version of the heat treatment process disclosed herein. For the third version the workpiece temperature during the bainite transformation is continuously lowered following a short holding phase after the quenching process. Temperature lowering takes place in a manner corresponding to the decrease in the martensite start temperature. For the workpiece temperature during the time interval intended for bainite transformation, this yields a behavior essentially parallel to the martensite start temperature. To implement this temperature behavior, the workpieces after quenching can be placed in a long tempering furnace or temperature-controlled furnace in which the desired temperature profile can be established and controlled. Alternatively it is also possible to treat the workpieces with water-air mixtures with a quenching effect or temperature-reducing effect which can be controlled during bainite transformation such that it follows a given cooling rate.

[0027] FIG. **4** shows a schematic time-temperature diagram to illustrate one development of the third version of the heat treatment process. In this development the workpiece temperature during bainite transformation is first lowered in a manner analogous to FIG. **3**. Even before the end of the time interval intended for bainite transformation, the workpiece temperature is distinctly raised and kept constant for a time. The temperature value reached thereby is preferably higher than the workpiece temperature at the start of bainite transformation. Following the constant phase, the workpiece temperature is lowered to room temperature. By briefly raising the workpiece temperature during bainite transformation, the bainite transformation is greatly accelerated and thus the time required overall for complete bainite transformation is reduced.

[0028] The first and the second version of the heat treatment process disclosed herein can also be developed accordingly.

[0029] FIG. **5** shows a schematic time-temperature diagram to illustrate one development of a second version of the heat treatment process as disclosed herein. In this development, the workpiece temperature is lowered to room temperature after the first holding phase and the first lowering phase which are carried out in the second version during the time interval intended for bainite transformation. A short holding time at room temperature is followed by short-time or standard age-hardening. For this purpose, the workpieces are preferably heated to a temperature which is between the workpiece temperature at the start of bainite transformation and the workpiece temperature immediately before interruption of the bainite transformation and is then cooled again to room temperature. By this procedure, the time required overall for heat treatment is shortened compared to the second version of the heat treatment process as disclosed and shown in FIG. **2**. In this connection it is accepted that martensite occurs as a structural component.

[0030] The development shown in FIG. **5** can be transferred analogously to the first and third version of the heat treatment process as disclosed.

[0031] In addition to the explicitly described behaviors of the workpiece temperature, within the framework of the heat treatment process as disclosed herein, other behaviors are possible which each agree in that the workpiece temperature during the time interval intended for bainite transformation is lowered.

1. Process for heat treatment of a steel or cast iron workpiece, comprising: quenching the workpiece, after a holding interval at or above the austenitizing temperature, to a temperature above a martensite start temperature, martensite being formed at a temperature below this martensite start temperature, and in a following time interval transforming the austenite into bainite, and lowering the temperature of the workpiece during the transformation as the transformation of austenite into bainite is continued.

2. Process as claimed in claim **1**, wherein the temperature of the workpiece is lowered to values below the temperature which is achieved by quenching at least during a time portion of 20% of a duration of the transformation.

3. Process as claimed in claim **1**, wherein the temperature of the workpiece is lowered depending on the martensite start temperature.

4. Process as claimed in claim **1**, wherein the temperature of the workpiece is lowered to values above the martensite start temperature.

5. Process as claimed in claim **1**, wherein the temperature of the workpiece is lowered according to a given temperature profile.

6. Process as claimed in claim **1**, wherein the temperature of the workpiece is lowered in increments.

7. Process as claimed in claim **6**, wherein the workpiece is exposed to media of varied temperature to lower the workpiece temperature.

8. Process as claimed in claim **1**, wherein the temperature of the workpiece is continuously lowered.

9. Process as claimed in claim **8**, wherein the temperature of the workpiece is lowered according to a behavior of the martensite start temperature.

10. Process as claimed in claim **1**, wherein the temperature of the workpiece is lowered by one or more controllable facilities.

11. Process as claimed in claim **1**, wherein the workpiece is heated to a higher temperature after partial transformation of austenite into bainite in order to accelerate transformation.

12. Process as claimed in claim **1**, wherein the time interval of transformation is dimensioned such that complete transformation of austenite into bainite does not take place and the workpiece is cooled to room temperature following the transformation time interval, held briefly there and then tempered.

13. Process as claimed in claim **1**, wherein the workpiece is made from a through-hardening rolling bearing or heat treatment steel.

14. Process as claimed in claim **1**, wherein the workpiece is a rolling bearing component.

15. Process as claimed in claim **6**, wherein the workpiece is placed in baths kept at varied temperatures to lower the workpiece temperature.

16. Process as claimed in claim **1**, wherein the temperature of the workpiece is lowered by one or more controllable furnaces.

17. Process for heat treating a steel or cast iron workpiece comprising:

heating the workpiece to at least an austenitizing temperature;

quenching the workpiece which has been heated to at least the austenitizing temperature to a temperature above a martensite start temperature, the martensite start temperature being a temperature below which martensite is formed;

transforming austenite in the workpiece into bainite; and

lowering the temperature of the workpiece during transformation of the austenite into bainite.

18. Process as claimed in claim **17**, wherein the lowering of the temperature of the workpiece during transformation of the austenite into bainite comprises lowering the temperature of the workpiece to a temperature above the martensite start temperature.

19. Process as claimed in claim **17**, wherein the lowering of the temperature of the workpiece during transformation of the austenite into bainite comprises lowering the temperature of the workpiece in increments.

20. Process as claimed in claim **17**, wherein the lowering of the temperature of the workpiece during transformation of the austenite into bainite comprises continuously lowering the temperature of the workpiece.

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