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(54) **MACHINE PART AND METHOD FOR MANUFACTURING SAME**

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EP 1 548 141 B1

Description

TECHNICAL FIELD

[0001] The present invention relates to a mechanical component composed of a steel and surface-hardened by nitriding, and a method of fabricating the same, and in more detail, relates to a mechanical component which is surface-hardened and, at the same time, imparted both with strength and bending straightening property, and a method of fabricating the same.

BACKGROUND ART

[0002] There are high levels of demands on wear resistance and fatigue property for mechanical components such as gear, bearing, shaft, crank shaft and connecting rod. Fabrication of these mechanical components generally involves surface hardening for raising strength such as wear resistance and fatigue property. The surface hardening is typically carried out after a material to be forged composed of a carbon steel or an alloyed steel for manufacturing mechanical structures is hot-forged, annealed typically for normalizing, and further machined into a predetermined geometry desired for various mechanical components. After the surface hardening, the material is finished typically through bend straightening, to thereby given as a final product of the mechanical component.

[0003] The surface hardening is carried out by nitriding such as salt bath nitriding and gas soft nitriding. It is generally known that the nitriding causes only a small post-processing distortion as compared with that possibly occurs after surface hardening such as cementation, and is recognized as a particularly effective method (as found in Japanese Laid-Open Patent Publication "Tokkaihei" No. 09-324258, for example).

[0004] The surface hardening through nitriding may, however in some cases, result in an unallowable level of generated distortion, and as a consequence often needs bend straightening after the surface hardening. The bend straightening is carried out so as to straighten the bend to a level allowable by the product, wherein easiness of the process, or bend straightening property depends on the surface hardness achieved after the surface hardening. The lower the surface hardness becomes, the bend straightening property improves. On the other hand, the lower the surface hardness becomes, the component strength such as wear resistance and fatigue property of the mechanical components degrades. Larger surface hardness is therefore preferable for the purpose of raising component strength of the mechanical components. As is known from the above, it is preferable to sufficiently raise the surface hardness by the surface hardening from the viewpoint of component strength of the mechanical components, and it is preferable to suppress as possible the surface hardness achieved by the surface hardening from the viewpoint of bend straightening property, because a larger surface hardness will degrade the bend straightening property and will be more likely to cause micro-cracks on the surface during the bend straightening.

[0005] As described in the above, it is not easy for the mechanical components to harmonize excellent component strength and bend straightening property after being surface-hardened. It is, however, a critical issue to carry out the surface hardening in order to ensure desirable quality of the fabricated mechanical components and to improve the yield ratio of the products, and to improve the component strength and bend straightening property of the mechanical components provided as the products after the surface hardening. The present invention is indeed conceived after considering the above-described problems, and an object thereof resides in providing a mechanical component and a method of fabricating the same, which involve surface hardening by nitriding, and are capable of improving both of component strength and bend straightening property.

[0006] US-A 6 083 455 relates to a method of manufacturing of nitrided steel parts with high strength, high fatigue strength and excellent bending toughness, such as crank shafts, etc...

DISCLOSURE OF THE INVENTION

[0007] A mechanical component aimed at solving the above-described problems is composed of a steel and surface-hardened by nitriding according to claim 1, having a Vickers hardness of the surficial portion measured at a reference position corresponded to a 50 μm depth from the surface of the mechanical component of 340 to 460 HV, having a Vickers hardness of the inner portion being not affected by the nitriding and showing a nearly constant hardness of 190 to 260 HV, and having an effective depth of hardened layer measured from the component surface, where a Vickers hardness of 270 HV is achieved, of 0.3 mm or more.

[0008] A method of fabricating a mechanical component aimed at solving the above-described problems is a method according to claim 3 of fabricating a mechanical component composed of a steel and surface-hardened by nitriding, wherein the nitriding is carried out so as to adjust Vickers hardness of the surficial portion measured at a reference position corresponded to a 50 μm depth from the surface of the mechanical component to 340 to 460 HV, so as to adjust

Vickers hardness of the inner portion being not affected by the nitriding and showing a nearly constant hardness to 190 to 260 HV, and so as to adjust an effective depth of hardened layer measured from the component surface, where a Vickers hardness of 270 HV is achieved, to 0.3 mm or more.

[0009] The above-described mechanical component is targeted at those composed of a steel and surface-hardened by nitriding. The nitriding is a treatment allowing nitrogen component to diffuse from the surface towards the inner portion of the mechanical component so as to nitrify the surficial portion of the mechanical component, to thereby raise the hardness of the surficial portion including the component surface. An essential point in the present invention is not only to improve the surface hardness by nitriding, but also to impart the mechanical component, to be provided after the treatment as the product, both with an excellent component strength and bend straightening property. The foregoing paragraphs have already discussed that the surface hardness of the surficial portion of the mechanical component can be improved by the nitriding. Increase in the surface hardness results in increase in the component strength of the mechanical components such as wear resistance and fatigue property. On the other hand, increase in the surface hardness results in decrease in the bend straightening property which indicates degree of process easiness in the bend straightening carried out after the nitriding. The decrease in the bend straightening property results in generation of nonconformities such as micro-cracks in the component surface, and this fails in product making of desirable mechanical components, and is causative of a lowered yield ratio of the products in the manufacturing.

[0010] As described in the above, carrying-out of the nitriding and achievement of excellent component strength and bend straightening property of the mechanical products seem to result in an inevitable dilemma so far as the treatment is to be conducted. The present inventors, however, derived a conclusion after extensive experiments and discussion that both of excellent strength and bend straightening property can be imparted to the mechanical components even after nitriding, by optimizing a hardness distribution to be imparted by the nitriding in the depth-wise direction from the component surface, or in other words, by optimizing a hardness distribution in the depth-wise direction in the surficial portion of the mechanical component to be provided as the product after nitriding, and by optimizing hardness of the inner portion not affected by the nitriding and showing a nearly constant hardness.

[0011] The mechanical component of the present invention is therefore such as being surface-hardened by nitriding, and having a Vickers hardness of the surficial portion measured at a reference position corresponded to a 50 μ m depth from the surface of the mechanical component (referred to as "surficial reference position", hereinafter) of 340 to 460 HV, having a Vickers hardness of the inner portion being not affected by the nitriding and showing a nearly constant hardness (simply referred to as "inner portion", hereinafter) of 190 to 260 HV, and having an effective depth of hardened layer measured from the component surface, where a Vickers hardness of 270 HV is achieved, of 0.3 mm or more.

[0012] First, a Vickers hardness at the surficial reference position of less than 340 HV may result in only a small surface hardness, and may fail in making the component useful and excellent in the component strength. On the other hand, a Vickers hardness exceeding 460 HV may result in a large surface hardness, may become more likely to induce non-conformities such as causing micro-cracks during bend straightening, and may fail in making the component useful and excellent in the bend straightening property. Next, a Vickers hardness of the inner portion of less than 190 HV may fail in imparting a desired hardness up to a position of a sufficient depth from the component surface, even if the component is subjected to the nitriding so as to adjust the Vickers hardness at the surficial reference position to a desirable range, and this consequently results in only a small surface hardness, and may fail in making the component useful and excellent in the component strength. On the other hand, a Vickers hardness of the inner portion exceeding 260 HV may result in an excessive increase in the hardness of the surficial portion imparted by the nitriding, even if the component is subjected to the nitriding so as to adjust the Vickers hardness at the surficial reference position to a desirable range, and this makes an amount of increase in the hardness of the surficial portion too large, and consequently results in a large surface hardness, and may fail in making the component useful and excellent in the bend straightening property.

[0013] During diffusion of nitrogen component in the depth-wise direction from the component surface, diffusion concentration of the nitrogen component decreases in the increasing direction of depth, and reaches the inner portion which is not affected by the nitriding and therefore shows an almost constant hardness, and this indicates an end of the diffusion of the nitrogen component. In other words, the amount of increase in the hardness given by the nitriding decreases in the increasing direction of depth from the component surface towards the inner portion. The rate of decrease in the amount of increase in the hardness can arbitrarily vary depending on species and contents of constituent elements of the steel composing the mechanical components, and on temperature and process time of the nitriding. It is therefore insufficient to optimize the hardness distribution in the depth-wise direction in the surficial portion after the nitriding only by specifying ranges for the surficial reference position and hardness of the inner portion. Therefore the mechanical component of the present invention is further given with a condition describing that the effective depth of hardened layer (also simply referred to as "effective hardening depth", hereinafter) measured from the component surface, where a Vickers hardness of 270 HV is achieved, is adjusted to 0.3 mm or more. This condition means moderation of the rate of decrease in the amount of increase in the hardness given by the nitriding, which occurs so as to decrease in the depth-wise direction from the component surface towards the inner portion, and this consequently makes it possible to provide the surficial portion of the mechanical component after the nitriding with a larger hardness over a range from

the component surface towards a deeper position. More specifically, an effective depth of hardening from the component surface, where a Vickers hardness of 270 HV is achieved, of less than 0.3 mm may result in a too sharp decrease in the hardness distribution in the depth-wise direction in the surficial portion of the mechanical component, and may sometimes fail in obtaining the surface hardness necessary for making the component useful and excellent in the strength.

[0014] As described in the above, the mechanical component can be made excellent both in the strength and bend straightening property, by appropriately specifying hardness at the surficial reference position, hardness of the inner portion and effective hardening depth, and by optimizing hardness distribution in the depth-wise direction from the component surface.

[0015] Therefore in the method of fabrication, it is made possible to adjust the surficial reference position, hardness of the inner portion and effective hardening depth within the above-described ranges, and to make the mechanical component excellent both in the strength and bend straightening property, by adjusting flow rate of nitrogen component over the surface of the component, temperature and process time of the nitriding, in a manner appropriately adapted to composition of a steel composing the component.

[0016] Next, the mechanical component of the present invention is characterized by having compositions of the individual constituent elements adjusted so as to limit Cr[eq.] to 0.72% or more and 1.0% or less, and C[eq.] to 0.65% or more and 0.86% or less, under definitions of

$$\text{Cr[eq.]} = 0.475 \times \text{C} + 0.164 \times \text{Si} + 0.241 \times \text{Mn} + \text{Cr}$$

and

$$\text{C[eq.]} = \text{C} + 0.07 \times \text{Si} + 0.16 \times \text{Mn} + 0.19 \times \text{Cu} + 0.17 \times \text{Ni} + 0.2 \times \text{Cr},$$

and

having a hardness distribution profile $H(x)$, which is given by plotting, on the H-x plane, Vickers hardness H measured in the depth-wise direction x as viewed from the component surface, fallen in region Z expressed by the equation (1) below:

$$H'(x) = H'0 + (H'1 - H'0) \times \left[1 - \text{erf} \left(\frac{x}{2\sqrt{\alpha Dt}} \right) \right] \quad \dots(1)$$

where,

$$H'0 = \text{C[eq.]} \times 254 + 33.8$$

$$H'1 = \text{Cr[eq.]} \times 392 + 65.8$$

Cr[eq.]: chromium equivalence described in the above

C[eq.]: carbon equivalence described in the above;

$$D = D_0 \times \exp \left(\frac{-Q}{R \times (T + 273)} \right)$$

$D_0: 1.13 \times 10^{-6}$

$$Q : 83 \times \left(1 - \frac{14.03}{T + 273} \right) \times 1000$$

R: 8.314;

$$\alpha = \exp(-1.47 \times \text{Si} - 0.918 \times \text{Mn} + 0.998)$$

Si : Si content (wt%)

Mn: Mn content (wt%); and

region Z is defined as a region in which $H'(x)$ expressed by the equation (1) can move on the H-x plane while satisfying a condition of $H'(0.3 \times 10^{-3}) \geq 270$, when t varies from 3.6×10^3 to 18×10^3 and T varies from 500 to 650.

[0017] In the nitriding, degree of hardening of the surficial layer is affected by composition of a steel material composing the mechanical component. For the purpose of making hardness at the surficial reference position, hardness of the inner portion and effective hardening depth fall within the above-specified ranges in a more reliable manner, an effective method may be such as optimizing steel composition effectively contributable to hardness of the inner portion corresponded to the hardness of the surficial portion before the nitriding, and steel composition effectively contributable to the nitriding. For this purpose, first in the steel material for composing the mechanical component, chromium equivalence $Cr[eq.]$, defined as

$$Cr[eq.] = 0.475 \times C + 0.164 \times Si + 0.241 \times Mn + Cr,$$

is adjusted to 0.72% or more and 1.0% or less in % by weight. The $Cr[eq.]$ herein is understood as an index of compositional components capable of effectively raising hardness at the surficial reference position. Compositional components capable of effectively raising hardness at the surficial reference position of the mechanical component after the nitriding were found to be Cr, C, Mn and Si, enumerated in a decreasing order of the effect. The constant terms expressing degrees of such effect are measured values determined by extensive measurements. A value of thus-defined $Cr[eq.]$ of less than 0.72% may sometimes fail in raising Vickers hardness at the surficial reference position of the mechanical component to as high as 340 HV or more even after the nitriding, and on the other hand, a value of $Cr[eq.]$ exceeding 1.0% may sometimes fail in suppressing Vickers hardness at the surficial reference position of the mechanical component to as low as 460 HV or less due to an excessive hardening of the surficial portion during the nitriding.

[0018] Next, in the steel material for composing the mechanical component, carbon equivalence $C[eq.]$, defined as

$$C[eq.] = C + 0.07 \times Si + 0.16 \times Mn + 0.19 \times Cu + 0.17 \times Ni + 0.2 \times Cr,$$

is adjusted to 0.65% or more and 0.86% or less in % by weight. The $C[eq.]$ herein is understood as an index of compositional components capable of effectively raising hardness of the inner portion. Compositional components capable of effectively raising hardness of the inner portion of the mechanical component were found to be C, Cr, Cu, Ni, Mn and Si, enumerated in a decreasing order of the effect. The constant terms expressing degrees of such effect are values determined by extensive measurements, similarly to as described in the above. A value of thus-defined $C[eq.]$ of less than 0.65% may sometimes fail in raising Vickers hardness of the inner portion of the mechanical component to as high as 190 HV or more, and on the other hand, a value of $C[eq.]$ exceeding 0.86% may sometimes fail in suppressing Vickers hardness of the inner portion of the mechanical component to as low as 260 HV or less due to an excessive hardening of the inner portion.

[0019] The mechanical component is also characterized by having a hardness distribution profile $H(x)$, which is given by plotting, on the H-x plane, Vickers hardness H measured in the depth-wise direction x as viewed from the component surface, fallen in region Z expressed by the equation (1) below:

$$H'(x) = H'0 + (H'1 - H'0) \times \left[1 - \operatorname{erf} \left(\frac{x}{2\sqrt{\alpha Dt}} \right) \right] \quad \dots(1)$$

where,

$$H'0 = C[\text{eq.}] \times 254 + 33.8$$

$$H'1 = Cr[\text{eq.}] \times 392 + 65.8$$

Cr[eq.]: chromium equivalence described in the above

C[eq.]: carbon equivalence described in the above;

$$D = D_0 \times \exp \left(\frac{-Q}{R \times (T + 273)} \right)$$

D_0 : 1.13×10^{-6}

$$Q: 83 \times \left(1 - \frac{14.03}{T + 273} \right) \times 1000$$

R: 8.314;

$$\alpha = \exp(-1.47 \times \text{Si} - 0.918 \times \text{Mn} + 0.998)$$

Si : Si content (wt%)

Mn: Mn content (wt%); and

region Z is defined as a region in which $H'(x)$ expressed by the equation (1) can move on the H-x plane while satisfying a condition of $H'(0.3 \times 10^{-3}) \geq 270$, when t varies from 3.6×10^3 to 18×10^3 and T varies from 500 to 650.

[0020] The nitriding is a treatment allowing nitrogen component to diffuse in the depth-wise direction from the component surface. Diffusion equation $C(x)$ expressing diffusion concentration C of the nitrogen component with respect to the depth-wise direction x can generally be given by the equation (2) below:

$$C(x) = C0 + (C1 - C0) \times \left[1 - \operatorname{erf} \left(\frac{x}{2\sqrt{Dt}} \right) \right] \quad \dots(2)$$

where,

D: diffusion coefficient and

t: time elapsed from start of diffusion

According to the equation (2), and assuming now that concentration of the nitrogen component in a region of $x > 0$ ($x = 0$ is the surface of the component, and the depth-wise direction x as viewed from the component surface defined as positive) at time $t = 0$ (start time of the nitriding) as C_0 ($C_0 = 0$ in this nitriding), $C(0)$ at $x = 0$ is understood as an equation expressing changes in diffusion concentration of the nitrogen component in the depth-wise direction x as viewed from the surface ($x = 0$) of the component, assuming that the surface of the component always has a constant nitrogen component concentration C_1 . A basic concept of the present invention is to adopt the equation in an approximated manner, so as to optimize the hardness distribution in the depth-wise direction in the surficial portion of the mechanical component.

[0021] The nitriding is a treatment allowing nitrogen component to diffuse in the depth-wise direction from the component surface so as to harden the surficial portion through nitriding. Diffusion concentration of the nitrogen component at a certain depth from the component surface is, therefore, closely related to a degree of hardness attained at the depth by the nitriding, and allows an approximated substitution. First, $C(x)$ in the equation (2) is substituted by hardness distribution $H'(x)$ in the depth-wise direction x as viewed from the component surface after the nitriding. Next, C_0 in the equation (2) is substituted by H'_0 expressing hardness of the inner portion of the mechanical component, that is, hardness of the surficial portion at the start time of the nitriding is assumed as hardness of the inner portion. H'_0 is further defined as $H'_0 = C[\text{eq.}] \times 254 + 33.8$, to which, together with $C[\text{eq.}]$, a measured value based on results of hardness measurement is adopted. Next, C_1 in the equation (2) is substituted by H'_1 expressing hardness at the surficial reference position of the mechanical component, wherein H'_1 is supposed to have a value expressing hardness at the surficial reference position of the mechanical component because the hardness of the true surface of the mechanical component cannot be measured. H'_1 is further defined as $H'_1 = Cr[\text{eq.}] \times 392 + 65.8$, to which, together with $Cr[\text{eq.}]$, a measured value based on results of hardness measurement is adopted. This mode of approximated use of the equation (2) gives the equation (1).

[0022] D in the equation (1) is a diffusion coefficient in metal or alloy, and is generally expressed as $D = D_0 \times \exp(-Q/(R \times (T + 273)))$, where D_0 is a term of number of vibration frequency, Q is activation energy, R is the gas constant, and T is temperature in degrees centigrade. In the present invention, diffusion coefficient D was determined assuming that nitrogen as a diffusing element diffuses in a pure Fe, because the mechanical component is composed of a steel, and content of a major component Fe contained therein is supposed to be at least 50 wt% or more. Specific values adopted herein are values described in a literature (Metal Data Book, 3rd Edition, published by Maruzen; p.21), defined for the case where N as a diffusing element diffuses in α - δ -Fe, which are $D_0 = 1.13 \times 10^{-6}$, $Q = 83 \times (1 - 14.03/(T + 273)) \times 1000$ and $R = 8.314$.

[0023] Next, α in the equation (1), not found in the equation (2), is a correction diffusion coefficient correcting diffusion coefficient D used in the equation (1). The correction diffusion coefficient α herein was defined as $\alpha = \exp(-1.47 \times \text{Si} - 0.918 \times \text{Mn} + 0.998)$. The correction diffusion coefficient α is used for incorporating any influences of constituent elements other than Fe contained in the steel exerted on the diffusion of N into $H'(x)$. Again α is a measured value based on results of extensive hardness measurement. What is worth attracting an attention is that Si and Mn contained in the steel, in particular Si, are constituent elements suppressing the diffusion of N. In other words, α sharply decreases as the contents of Si and Mn increase. Optimization of the Si content is, therefore, understood as one essential point in reliably optimizing the hardness distribution in the depth-wise direction of the surficial portion of the mechanical component. It is preferable to adjust the Si and Mn contents so as to make α fall within a range from 0.3 to 1.6, for example.

[0024] In $H'(x)$, t represents process time of the nitriding, and a value thereof generally falls within a range from 3.6×10^3 to 18×10^3 seconds. T represents process temperature of the nitriding, and a value thereof generally falls within a range from 500 to 650°C.

[0025] $H'(x)$ is determined as described in the above. The $H'(x)$ is a function having arbitrary variables of t and T with respect to process conditions of the nitriding, given when a composition of the steel used for composing the mechanical component is uniquely determined. Hardness distribution profile, which is obtained by plotting, on the H - x plane, Vickers hardness H measured in the depth-wise direction x as viewed from the component surface, is now given as $H(x)$. $H(x)$ is restricted to reside only in region Z, wherein the region Z is defined as a region in which $H'(x)$ can move on the H - x plane when t is arbitrarily varied from 3.6×10^3 to 18×10^3 and T is arbitrarily varied from 500 to 650, while satisfying a condition that a Vickers hardness of 270 HV is attained at a depth from the component surface of 0.3 mm or more, or in other words, under a condition that a position of 0.3 mm deep from the component surface will show a hardness of 270 HV or more as expressed by $H'(0.3 \times 10^{-3}) \geq 270$. A region of the hardness distribution $H(x)$ as viewed from the surface of the mechanical component restricted to as described in the above makes it possible to reliably optimize the hardness distribution in the depth-wise direction in the surficial portion of the mechanical component, and to impart both of excellent component strength and bend straightening property to the mechanical component. The region of $H(x)$ restricted herein in the region Z means that all requirements on the composition of the steel material for the mechanical component, such as $Cr[\text{eq.}]$, $C[\text{eq.}]$, Si content and Mn content, are optimized within ranges for general process conditions of the nitriding. This mode of optimization of the composition of the steel material makes it possible to more reliably impart excellent strength and bend straightening property to the mechanical component.

[0026] In the method of fabrication, it is made possible to more reliably impart excellent strength and bend straightening property to the mechanical component, by adjusting the ranges of $Cr[\text{eq.}]$ and $C[\text{eq.}]$ to the ranges similar to those

described in the above, and also by adjusting the nitriding conditions to those described in the next. The nitriding conditions adopted to gas soft nitriding or salt bath nitriding include a process time of 3.6×10^3 to 18×10^3 seconds and nitriding temperature of 500 to 650°C. Other nitriding conditions adopted herein are same as those adopted by the general gas soft nitriding or salt bath nitriding. A nitriding temperature of less than 500°C may sometimes excessively reduce the diffusion of the nitrogen component, and may consequently fail in imparting, by the nitriding, a desired profile of surface hardness in the depth-wise direction to the mechanical component. On the contrary, a nitriding temperature exceeding 650°C may excessively accelerate the diffusion of the nitrogen component, and may sometimes excessively raise the surface hardness than desired. Next, as for the process time, a time less than 3.6×10^3 seconds, or one hour, may sometimes fail in imparting, by the nitriding, a desirable surface hardness profile in the depth-wise direction to the mechanical component. On the contrary, a process time of the nitriding exceeding 18×10^3 seconds, or five hours, may sometimes result in a too large surface hardness than desired. Ranges of the process time and process temperature of the nitriding are thus set in consideration of these situations, wherein these ranges can be said as more general ones than those set from viewpoints such as operation efficiency in the manufacture. The conditions for the nitriding are set based on these reasons, and this is consequently successful in imparting excellent strength and bend straightening property to the mechanical component in a more reliable manner.

[0027] Next, the mechanical component of the present invention is characterized by having the composition as defined by claim 1.

[0028] Major component thereof is therefore Fe. As one of the constituent elements other than Fe, C is contained in an amount of 0.35 to 0.5% by weight. C is an element useful for effectively raising the hardness in the inner portion and at the surficial reference position of the mechanical component, wherein a content of 0.35% or more makes the effect more distinct. On the contrary, the content exceeding 0.5% may sometimes result in an excessive effect, and may fail in adjusting the hardness of the surficial layer of the mechanical component to a desired level. It may also be causative of degradation in the machinability when the mechanical component is machined into a desired geometry, for example when a forged material composed of a steel is machined. Next, Si is contained in an amount of 0.01 to 0.3% by weight. Si is used as a deoxidizer element in steel melting, so that it is necessarily contained at least in an amount of 0.01% or more. Si is, however, also a constituent element suppressing the N diffusion in the nitriding. In view of reliably imparting a desired hardness profile to the mechanical component, it is preferable to suppress the content thereof to as low as 0.3% or less. Next, Mn is contained in an amount of 0.6 to 1.8% by weight. Mn is an element useful for effectively raising the hardness of the inner portion and at the surficial reference position, wherein a content of 0.6% or more makes the effect more distinct. On the contrary, the content exceeding 1.8% may sometimes result in generation of bainite during operations such as hot forging and normalizing before the nitriding. Also Mn is a constituent element suppressing the N diffusion in the nitriding, although to a lesser degree as compared with Si. Also from this point of view, the content of Mn is preferably suppressed to as small as 1.8% or less.

[0029] Both of Cu and Ni are contained in an amount of 0.01 to 0.5% by weight. Both of Cu and Ni are contained as inevitable impurities in an amount of 0.01% or more, and are useful for effectively raising the hardness of the inner portion of the mechanical component. The content exceeding 0.5% may, however, be disadvantageous from an economical point of view, and may raise cost of the mechanical component, so that the content is adjusted to 0.5% or less. Next, Cr is contained in an amount of 0.01 to 0.5% by weight. Cr is an element useful for effectively raising the hardness of the inner portion and at the surficial reference position of the mechanical component. The content adjusted to 0.01% or more is successful in making the effect more distinct. On the contrary, the content exceeding 0.5% may sometimes result in an excessive effect, and may fail in adjusting the hardness of the surficial layer of the mechanical component to a desired level. Next, Al is contained in an amount of 0.001 to 0.01% by weight. Similarly to Si, also Al is used as a deoxidizer element in steel melting, so that it is necessarily contained at least in an amount of 0.001% or more. However in some cases, Al may excessively raise the hardness at the surficial reference position of the mechanical component, so that the content thereof is preferably limited to 0.01% or less. Next, N is contained in an amount of 0.005 to 0.025% by weight. N is an element useful for effectively suppressing crystal grain growth of the steel component typically during hot forging, through formation of nitride with Al. The content thereof is preferably set to as much as 0.005% or more, but a content of 0.025% may be enough for the upper limit thereof, because the effect saturates above 0.025%.

[0030] The mechanical component of the present invention is further characterized by containing any one species, or two or more species of constituent elements with the individual contents, in % by weight, of Pb: 0.30% or less, S: 0.20% or less, Ca: 0.01% or less, Bi: 0.30% or less, Ti: 0.02 or less, Zr: 0.02% or less and Mg: 0.01% or less.

[0031] Pb, S, Ca and Bi described in the above are elements useful for effectively improving machinability when a forged material composed of a steel is machined into a desired geometry. Without a desirable level of machinability, an excessive machining distortion or the like may generate on the surface of the component during machining, and may fail in reliably imparting a desired level of bend straightening property to the mechanical component. As for the individual contents of Pb, S, Ca and Bi, any contents exceeding the above-described upper limits may degrade the hot workability or component strength such as fatigue property of the mechanical component, so that it is preferable to adjust, in % by weight, Pb to 0.30% or less, S to 0.20% or less, Ca to 0.01% or less and Bi to 0.30% or less. Next, Ti, Zr and Mg are

known to promote micro-dispersion of MnS and so forth in steel melting, through formation of their oxides. The effect also makes it possible to improve the machinability in the machining, and to micronize a crystal texture of the steel after annealing such as normalizing in the succeeding step of hot forging, for example, and further to reliably impart necessary component strength and bend straightening property to the mechanical component. As for the individual contents of Ti, Zr and Mg, any contents exceeding the above-described upper limits may saturate the effect, so that it is preferable to adjust, in % by weight, Ti to 0.02% or less, Zr to 0.02% or less, and Mg to 0.01 % or less.

[0032] The foregoing paragraphs have described the essential points of the mechanical component of the present invention to which both of strength and bend straightening property should be imparted. Mechanical component targeted at by the present invention is not specifically limited, and is applicable to any publicly-known mechanical components such as gear, bearing, shaft, crank shaft and connecting rod. Among others, a special limitation is placed on crank shaft. This is because the crank shaft is a mechanical component used under high-speed rotation and needs a precise control of decentering by bend straightening. The crank shaft can improve its usefulness by being applied with the mechanical component of the present invention which can be made excellent both in strength and bend straightening property.

BRIEF DESCRIPTION OF THE DRAWINGS

[0033]

Fig. 1 is a schematic side elevation of one embodiment of the mechanical component of the present invention; Fig. 2 is a sectional view taken along line II-II in Fig. 1; and Fig. 3 is a drawing showing hardness profiles based on measured results and theoretical calculation.

BEST MODES FOR CARRYING OUT THE INVENTION

[0034] The following paragraphs will explain a best embodiment of the mechanical component of the present invention referring to the attached drawings.

[0035] Fig. 1 is a schematic side elevation of a fillet portion of one essential portion of a crank shaft, which is one embodiment of the mechanical component. Fig. 2 is a schematic sectional view of the fillet portion taken along line II-II in Fig. 1. In the drawing, the fillet portion 1 is understood as a mechanical component 1. Because the crank shaft is formed by assembling separately-manufactured constituents, assumption of the fillet portion as the mechanical component of the present invention will never depart from the spirit of the present invention. The fillet portion 1 is composed of a steel and is nitrided. As shown in Fig. 2, the fillet portion 1 comprises a surficial portion 2 raised in the surface hardness by the nitriding, and an inner portion 3 not affected by the nitriding and showing a nearly constant hardness. In the surficial portion 2, the hardness decreases in the depth-wise direction from a component surface 4 towards the inner portion 3. The inner portion 3 is adjusted to have a Vickers hardness of 190 to 260 HV, the surficial portion 2 is adjusted to have a Vickers hardness of 340 to 460 HV at the reference position corresponded to a 50 μ m depth from the component surface, and is further adjusted to have an effective depth of hardened layer measured from the component surface 4, where a Vickers hardness of 270 HV is achieved, of 0.3 mm or more. This way of adjustment of the hardness distribution in the surficial portion 2 in the depth-wise direction from the component surface 4 makes it possible to improve component strength of the mechanical component 1, such as wear resistance and fatigue property, and to improve the bend straightening property in bend straightening in the succeeding step of the nitriding.

[0036] By imparting both of excellent strength and bend straightening property to the mechanical component as described in the above, it is made possible to effectively suppress generation of micro-cracks in bend straightening, and to make the mechanical component excellent in the strength.

[0037] Next paragraphs will explain an exemplary method of fabricating the mechanical component of the present invention, including the fillet portion shown in Fig. 1. First, a steel material having a predetermined composition is prepared by melting so as to attain a steel composition necessary for the mechanical component, and is then hot-forged to yield a forged material. The forged material composed of the steel is then thermally refined by annealing such as normalizing, quenching and tempering, and is machined according to a desired geometry of the mechanical component. After the machining, the mechanical component is subjected to surface hardening by nitriding to so as to improve the strength. Next, bend straightening is carried out in order to make any bend, including those ascribable to distortion generated by the nitriding, fall within a desired allowable range. After a series of such manufacturing steps, the mechanical component is provided as a product. For any mechanical components composed of two or more types of constituents manufactured in a separate manner, each of the constituents is assumed as the mechanical component, respectively manufactured according to the above-described process flow, and assembled to thereby obtain the mechanical component of a desired geometry. In this sense, the mechanical component of the present invention is essentially targeted at publicly-known mechanical components such as gear, bearing, shaft, crank shaft and connecting rod, but any of those composed of two or more constituents can be assumed that each of the constituents is understood as the mechanical component of

the present invention.

[0038] It is to be noted that the above-described fabrication method is only one example, and the present invention also allows a non-refining process from which the refining by annealing after hot forging is omitted. An essential point is that any fabrication method can be adopted as the fabrication method so far as it involves at least surface hardening by nitriding, which is followed by bend straightening to thereby finish the mechanical component as a product. The nitriding may be carried out by publicly-known method such as salt bath nitriding and gas soft nitriding. Appropriate adjustment of conditions for the nitriding, such as process temperature, process time and flow rate of nitrogen to be supplied to the component surface, makes it possible to achieve a desired depth-wise hardness distribution in the surficial portion of the mechanical component.

[0039] Next paragraphs will describe embodiments as confirmation of the effects of the present invention.

(Embodiment)

[0040] Steels having chemical compositions (in wt%) listed in Table 1 were melted, and hot-forged to thereby fabricate rod-formed forged materials of 40 mm in diameter. The forged materials were then kept under heating at 880°C for 60 minutes, and then normalized by allowing them to cool down to room temperature. The forged materials were then machined into a geometry of the fillet portion of the crank shaft shown in Fig. 1. The machined fillet portions were nitrided by gas soft nitriding. Conditions adopted herein include a process time of 2 hours (7.2×10^3 seconds) and a process temperature of 600°C, which fall in general ranges. Thus-fabricated embodied products 1 to 10 and comparative products 1 to 12 were subjected to measurements shown below. Table 1 shows also chromium equivalence Cr[eq.] and carbon equivalence C[eq.] of the individual steels composing the individual test pieces. Table 1 still also shows calculated results of $H'(0.3 \times 10^{-3})$, which are values of Vickers hardness at a 0.3 mm deep from the component surface based on the theoretical formula $H'(x)$ given as the equation (1) in the above.

Table 1

	C	Si	Mn	Cu	Ni	Cr	Al	N	Others	Cr[eq.]	C[eq.]	H'(0.3×10 ⁻³)
Embodied product 1	0.4	0.05	1.45	0.05	0.05	0.2	0.005	0.023		0.75	0.69	273
Embodied product 2	0.35	0.28	0.65	0.45	0.45	0.48	0.002	0.012		0.85	0.73	312
Embodied product 3	0.5	0.12	1.75	0.15	0.15	0.04	0.008	0.008		0.72	0.85	282
Embodied product 4	0.45	0.1	1.2	0.1	0.1	0.45	0.002	0.02		0.97	0.78	330
Embodied product 5	0.4	0.08	1.48	0.1	0.1	0.2	0.005	0.005	Pb:0.18, S:0.062	0.76	0.72	277
Embodied product 6	0.42	0.1	1.44	0.08	0.08	0.18	0.003	0.003	S:0.121, Ca:0.0025	0.74	0.72	275
Embodied product 7	0.41	0.12	1.45	0.1	0.1	0.21	0.004	0.004	Bi:0.1, S:0.052, Ca:0.0042	0.77	0.73	279
Embodied product 8	0.42	0.09	1.51	0.07	0.08	0.19	0.006	0.006	S:0.065, Ca:0.0026, Ti:0.006	0.77	0.73	279
Embodied product 9	0.39	0.12	1.49	0.14	0.15	0.21	0.003	0.003	S:0.068, Ca:0.0031, Zr:0.005	0.77	0.73	278
Embodied product 10	0.41	0.11	1.45	0.11	0.12	0.2	0.005	0.005	S:0.055, Mg:0.0025	0.76	0.73	278
Comparative product 1	0.3	0.1	1.5	0.1	0.1	0.2	0.004	0.021		0.72	0.62	254
Comparative product 2	0.54	0.11	1.43	0.11	0.11	0.21	0.005	0.022		0.82	0.86	309
Comparative product 3	0.41	0.75	1.42	0.08	0.09	0.2	0.004	0.021		0.86	0.76	260
Comparative product 4	0.41	0.12	2	0.1	0.1	0.2	0.004	0.018		0.9	0.81	290
Comparative product 5	0.42	0.15	1.5	0.15	0.15	0.75	0.003	0.023		1.34	0.87	383
Comparative product 6	0.41	0.12	1.43	0.12	0.11	0.21	0.015	0.02		0.77	0.73	279
Comparative product 7	0.42	0.25	1.53	0.23	0.22	0.45	0.003	0.021		1.06	0.85	329
Comparative product 8	0.35	0.1	0.8	0.05	0.05	0.45	0.004	0.022		0.83	0.59	295
Comparative product 9	0.4	0.11	1.45	0.1	0.1	0.19	0.005	0.021	Pb:0.32, S:0.21	0.75	0.71	273
Comparative product 10	0.41	0.09	1.4	0.09	0.09	0.18	0.004	0.023	S:0.215, Ca:0.032	0.73	0.71	271
Comparative product 11	0.4	0.1	1.48	0.1	0.1	0.21	0.005	0.021	Bi:0.31, S:0.051, Ca:0.0021	0.77	0.72	278
Comparative product 12	0.48	0.25	0.8	0.05	0.05	0.15	0.004	0.008		0.61	0.67	255

(Sectional Hardness)

[0041] Sectional hardness of the test pieces was measured by a 0.1 mm pitch in the depth-wise direction over an 1 mm depth from the component surface to the inner portion, using a Vickers hardness tester under a load of 2.9 kN and a test period of 15 seconds. It is noted herein that hardness of the real component surface cannot be measured, so that Vickers hardness measured at a position 50 μ m deep from the component surface was assumed as the hardness of the component surface (depth=0 mm).

(Fatigue Property)

[0042] The test pieces were subjected to fatigue test using an Ono-type rotating-bending fatigue tester, and measured values of fatigue strength (MPa) were used as indices of fatigue property as component strength.

(Bend Straightening Property)

[0043] The test pieces were subjected to three-point bending test using a universal testing machine, wherein measured values of amount of indentation (mm) causative of cracks in the component surface were used as indices of the bend straightening property.

[0044] Table 2 shows results of these measurements which include Vickers hardness at the surficial reference position (at a position 50 μ m deep from the component surface), Vickers hardness at a position 0.3 mm deep from the component surface (referred to as "effective hardening depth position", hereinafter), fatigue strength as an index of the fatigue property, and amount of indentation as an index of the bend straightening property. It is to be noted that the individual measurements for the sectional hardness, fatigue property and bend straightening property were made using separate test pieces individually fabricated under the same conditions.

[0045] Evaluation was also made on the machinability in machining such as being carried out for fabricating the test pieces. Steels having chemical compositions listed in Table 1 were melted similarly to as described in the above, hot-forged to thereby obtain rod-formed forged materials of 40 mm in diameter, kept under heating at 880°C for 60 minutes, and then normalized by allowing them to cool down to room temperature. Machinability of thus-normalized products was evaluated by subjecting them to machining test using a carbide tool. The machining test was carried out under a cutting speed of 200 m/minute, a feed speed of 2 mm/rotation and a cutting width of 2 mm, wherein cutting time elapsed before the wear width of the side clearance surface of the carbide tool reached 0.2 mm was measured. Assuming now that measured cutting time of the normalized product corresponded to embodied product 1 as 100, based on which the measured values of the cutting time of the other normalized products corresponded to other test pieces were standardized and listed in Table 2 as cutting efficiency expressing the machinability.

Table 2

	Vickers hardness (HV)			Fatigue property	Bend straightening property	Machinability
	Surficial reference position	Inner portion	Depth of effective hardening	Fatigue strength (MPa)	Amount of indentation (mm)	Cutting efficiency
Embodied product 1	355	211	271	432	5.7	100
Embodied product 2	407	212	306	504	3.8	100
Embodied product 3	350	249	283	431	5.9	87
Embodied product 4	448	231	334	539	2.6	94
Embodied product 5	364	225	274	462	4.8	120
Embodied product 6	347	221	271	450	5.7	853

EP 1 548 141 B1

(continued)

5		Vickers hardness (HV)			Fatigue property	Bend straightening property	Machinability
		Surficial reference position	Inner portion	Depth of effective hardening	Fatigue strength (MPa)	Amount of indentation (mm)	Cutting efficiency
10	Embodied product 7	375	220	282	445	4.5	723
	Embodied product 8	369	225	277	448	5.2	1065
15	Embodied product 9	365	224	275	433	5.2	1002
	Embodied product 10	367	220	278	434	5.3	913
20	Comparative product 1	357	188	246	390	5.1	125
	Comparative product 2	388	252	305	491	4.2	68
25	Comparative product 3	402	224	264	398	3.8	92
	Comparative product 4	-	-	-	-	-	-
30	Comparative product 5	586	265	391	617	0.5	78
	Comparative product 6	471	212	273	447	1.5	100
35	Comparative product 7	482	249	337	551	0.8	86
	Comparative product 8	385	185	296	398	3.8	145
40	Comparative product 9	364	211	273	413	5.1	212
	Comparative product 10	360	220	271	415	4.7	1680
45	Comparative product 11	375	221	278	421	4.1	1129
	Comparative product 12	296	206	249	358	6.3	103

50 **[0046]** As shown in Table 1 and Table 2, embodiment products 1 to 10 showed values of Vickers hardness at the surficial reference position of 340 to 460 HV, Vickers hardness of the inner portion of 190 to 260 HV, and Vickers hardness at the effective hardening depth position of 270 HV or above. They were confirmed to be excellent both in the fatigue property and bend straightening property. It is to be noted herein that in the present embodiment, the mechanical components excellent both in the strength and bend straightening property are defined as those having a fatigue strength which gives an index of fatigue property of 400 MPa or above, and an amount of indentation which gives an index of bend straightening property of 2 mm or more. In the steel compositions listed in Table 1, the residual portion other than those listed therein is essentially composed of Fe.

55 **[0047]** On the contrary, comparative product 1 showed a hardness of the inner portion of less than 190 HV, and a

hardness at the effective hardening depth position is less than 270 HV, although the hardness at the surficial reference position was maintained at 355 HV. This consequently resulted in only an insufficient surface hardness of the surficial portion, and in considerably lowered fatigue strength as compared with that of the embodied products, in other words, this failed in obtaining a desirable level of component strength. As discussed from the viewpoint of steel composition, comparative product 1 has C[eq.] smaller than that of the embodied products, due to the C content. The present embodiment adopts process conditions (process temperature, process time) of nitriding which fall in general ranges, and this reaches a conclusion that C[eq.] is adjusted to 0.65 or more in view of reliably adjusting hardness at the surficial reference position and at the effective hardening depth position to desirable levels, and raising the hardness of the inner portion, which is necessary for ensuring a sufficient level of the component strength. As for the C content, it is adjusted to 0.35 wt% or more (see embodied product 2).

[0048] Next, comparative product 8 showed a hardness of the inner portion of less than 190 HV, and showed hardness both at the surficial reference position and at the effective hardening depth position of the desired levels, but a reduction rate of the hardness towards the inner portion was high similarly to comparative product 1, and this consequently resulted in only an insufficient surface hardness of the surficial portion, and in considerably lowered fatigue strength as compared with that of the embodied products. As discussed from the viewpoint of steel composition of comparative product 8, C[eq.] is adjusted to 0.65 or more in view of reliably raising the hardness of the inner portion, which is necessary for ensuring a sufficient level of the component strength, based on the same reason with comparative product 1.

[0049] Comparative product 3 showed desirable level of hardness values at the surficial reference position and of the inner portion, but showed a hardness at the effective hardening depth position of less than 270 HV, proving a large reduction rate of the hardness towards the inner portion, and this consequently resulted in only an insufficient surface hardness of the surficial portion, and in considerably lowered fatigue strength as compared with that of the embodied products. As discussed from the viewpoint of steel composition of comparative product 3, it can be said that the reduction rate of the hardness towards the inner portion was excessively increased because the Si content thereof became excessively large as compared with those of the embodied products. In view of reliably raising the hardness at the effective hardening depth position necessary for ensuring a sufficient level of the component strength, the Si content is adjusted to 0.3 wt% or less (see embodied product 2), for example.

[0050] Comparative product 12 showed a desired hardness for the inner portion, but showed hardness smaller than desired for the surficial reference position and effective hardening depth position. This consequently resulted in only an insufficient surface hardness of the surficial portion, and in considerably lowered fatigue strength as compared with that of the embodied products. As discussed from the viewpoint of steel composition of comparative product 12, Cr[eq.] is adjusted to 0.72 or more in view of reliably raising the surface hardness required for ensuring a sufficient level of the component strength.

[0051] Comparative product 5 showed a hardness of the inner portion exceeding 260 HV, and a desirable level of hardness at the effective hardening depth position of as high as 270 HV, but also showed a hardness at the surficial reference position exceeding 460 HV. This resulted in an excessively large surface hardness of the surficial portion, an amount of indentation considerably lowered from that of the embodied products, and consequently resulted in only an insufficient bend straightening property. As discussed from the viewpoint of steel composition of comparative product 5, the excessively large surface hardness of the surficial portion was supposed to be ascribable to the Cr[eq.] larger than that of the embodied products, due to the Cr content. Cr[eq.] is therefore adjusted to 1.0 or less in view of reliably obtaining a desired level of surface hardness at the surficial reference position required for ensuring a sufficient level of bend straightening property. Another possible reason for the excessively large surface hardness was also supposed to be the large Cr content, which was ascribable to the large C[eq.] and the hardness of the inner portion larger than desired. It is therefore necessary to limit C[eq.] to as low as 0.86 or less in view of reliably ensuring a sufficient level of bend straightening property. From the viewpoint of Cr content, it is adjusted to 0.5 wt% or less (see embodied product 2).

[0052] Comparative products 6 and 7 showed desirable levels of hardness of the inner portion and at the effective hardening depth position, but showed hardness values exceeding 460 HV at the surficial reference position. This resulted in an excessively large surface hardness, an amount of indentation considerably lowered from that of the embodied products, and consequently resulted in only an insufficient bend straightening property. From the viewpoint of steel composition, comparative product 7 was supposed to be excessively raised in the surface hardness of the surficial portion due to Cr[eq.] larger than that of the embodied products. It is therefore necessary to limit Cr [eq.] to 1.0 or less in view of reliably obtaining a desired level of hardness at the surficial reference position required for ensuring a sufficient level of bend straightening property. Comparative product 6 was supposed to be excessively raised in the surface hardness due to an excessively large Al content. It is therefore necessary to limit the Al content to 0.01 wt% or less (see embodied product 3) in view of reliably obtaining a desired level of bend straightening property.

[0053] Next paragraphs will describe the machinability. Comparative product 2 was found to be excellent both in the component strength and bend straightening property, but suppressed in the machinability due to a large C content. For the case where there are demands for an improved machinability, and for both of excellent component strength and bend straightening property, it is therefore necessary to limit the C content to, 0.5 wt% or less (see embodied product

3). Embodied products 5 to 10 contain any one or more of Pb, S, Ca, Bi, Ti, Zr and Mg which are machinability-improving elements. Embodied products 5 to 10 are thus successfully raised in the machinability as compared with the others. Addition of the machinability-improving elements to the steel composition is understood as an effective measure, because suppression of the machinability may sometimes result in the component strength. It was found from comparison, for example, between embodied products 1 and 6 that the both showed an equivalent amount of indentation, but embodied product 6 containing the machinability-improving elements certainly showed a larger fatigue limit.

[0054] Also comparative products 9 to 11 were found to be excellent both in the component strength and bend straightening property, similarly to the embodied products. The machinability-improving elements are contained in these steel compositions. The fatigue limit as an index for the component strength was, however, conversely lowered from those of the embodied products, due to large contents of these machinability-improving elements. It is therefore necessary to limit the contents such as Pb: 0.30 wt% or less, S: 0.20 wt% or less, Ca: 0.01 wt% or less, Bi: 0.30 wt% or less, Ti: 0.02 or less, Zr: 0.02 wt% or less and Mg: 0.01 wt% or less.

[0055] Comparative product 4 showed an excessive generation of bainite due to an excessively large Mn content in the steel composition. Comparative product 4 was found to be inappropriate as a product as early as when it was made into a forged material. It is therefore necessary to limit the Mn content to 1.8 wt% or less.

[0056] From the discussion referring to Table 1 and Table 2, it was confirmed that adjustment of Vickers hardness individually at the surficial reference position, effective hardening depth position and inner portion so as to fall them within the optimized ranges of the present invention is essential for making the component strength and bend straightening property excellent. Next, in relation to Claim 2, data obtained based on the above-described equation (1) will be shown in Fig. 3.

[0057] The individual data points in Fig. 3 express results of the measurement of the sectional hardness of the representative test pieces, selected from those of the individual test pieces. The individual curves (broken lines) almost fitted to the individual data points were obtained based on the equation (1). It is obvious that the equation (1) is a good approximate expression based on a better reflection of the measured values of the sectional hardness. As is clear from the drawing, the sectional hardness reduces from the component surface towards the inner portion, and reaches plateau at the inner portion. It is to be noted herein that the inner portion is defined by a region 1 mm deep or more from the component surface. The individual curves based on the equation (1) shown in the drawing are obtained under $T=600^{\circ}\text{C}$, which corresponds to the nitriding temperature, and $t=7.2 \times 10^3$ seconds, which corresponds to the process time.

[0058] In Fig. 3, filled plots represent the embodied products, and blank plots represent the comparative products. A region surrounded by the data points of the embodied products (vertical hatched region in the drawing) is included in region Z defined by using the equation (1). More specifically, further increase in the process temperature and process time of the nitriding for embodied product 1 results in increase in the sectional hardness so as to come closer to that of embodied product 4. On the other hand, decrease in the process temperature and process time of the nitriding for embodied product 4 results in decrease in the sectional hardness so as to come closer to that of embodied product 1. It is accordingly obvious that adjustment of the measured hardness distribution profile so as to fall within region Z defined by using the equation (1) makes the mechanical component excellent both in the component strength and bend straightening property. A numerical range of $H'1$ in the equation (1), expressing hardness at the surficial reference position, is based on $\text{Cr}[\text{eq.}]$, showing a range of Vickers hardness defined thereby from 348 HV to 458 HV, and on the other hand, a numerical range of $H'0$, expressing hardness of the inner portion, is based on $\text{C}[\text{eq.}]$, showing a range of Vickers hardness defined thereby from 199 HV to 252 HV. In other words, by making the measured hardness distribution profile fall within the region Z defined by the equation (1), both of the component strength and bend straightening property are made excellent. It is made possible to obtain desired levels of component strength and bend straightening property by appropriately varying the hardness distribution profile within the region Z.

[0059] The above-described results proved that the effects and desired ends of the present invention can successfully be achieved. It is to be noted that the above-described embodiment and examples are only for the purpose of exemplification, by which the present invention is never limited, allowing any modifications to be included within a concept of the present invention without departing from the claims.

Claims

1. A mechanical component composed of a steel and surface-hardened by nitriding, having a Vickers hardness of the surficial portion measured at a reference position corresponded to a $50\text{ }\mu\text{m}$ depth from the surface of said mechanical component of 340 to 460 HV, having a Vickers hardness of the inner portion being not affected by the nitriding and showing a nearly constant hardness of 190 to 260 HV, and having an effective depth of hardened layer measured from the surface of said component, where a Vickers hardness of 270 HV is achieved, of 0.3 mm or more, wherein the mechanical component consists of a steel with the individual contents of constituent elements C: 0.35 to 0.5%, Si : 0.01 to 0.3%, Mn: 0.6 to 1.8%, Cu: 0.01 to

EP 1 548 141 B1

0.6%, Ni: 0.01 to 0.5%, Cr: 0.01 to 0.5%, Al: 0.001 to 0.01% and N: 0.005 to 0.025%,
and any one, or two or more species of constituent elements with the individual contents, in % by weight, of Pb:
0.30% or less, S: 0.20% or less, Ca: 0.01 % or less, Bi: 0.30% or less, Ti: 0.02 or less, Zr: 0.02% or less and Mg:
0.01 % or less, the balance being Fe and unavoidable impurities and wherein the mechanical component has the
composition of the individual constituent elements adjusted so as to limit Cr[eq.] to 0.72% or more and 1.0% or less,
and C[eq.] to 0.65% or more and 0.86% or less, under definitions of

$$\text{Cr[eq.]}=0.475\times\text{C}+0.164\times\text{Si}+0.241\times\text{Mn}+\text{Cr}$$

$$\text{C[eq.]}=\text{C}+0.07\times\text{Si}+0.16\times\text{Mn}+0.19\times\text{Cu}+0.17\times\text{Ni}+0.2\times\text{Cr},$$

and
having a hardness distribution profile $H(x)$, which is given by plotting, on H - x plane, Vickers hardness H measured
in the depth-wise direction x as viewed from the component surface, fallen in region Z expressed by the equation
(1) below:

$$H'(x) = H'0 + (H'1 - H'0) \times \left[1 - \text{erf} \left(\frac{x}{2\sqrt{\alpha Dt}} \right) \right] \quad \dots(1)$$

where,

$$H'0 = \text{C[eq.]} \times 254 + 33.8$$

$$H'1 = \text{Cr[eq.]} \times 392 + 65.8$$

Cr[eq.]: chromium equivalence described in the above
C[eq.]: carbon equivalence described in the above;

$$D = D_0 \times \exp \left(\frac{-Q}{R \times (T + 273)} \right)$$

D_0 : 1.13×10^{-6}

$$Q : 83 \times \left(1 - \frac{14.03}{T + 273} \right) \times 1000$$

R : 8.314;

$$\alpha = \exp(-1.47 \times \text{Si} - 0.918 \times \text{Mn} + 0.998)$$

Si : Si content (wt%)

Mn: Mn content (wt%); and

region Z is defined as a region in which $H'(x)$ expressed by the equation (1) can move on the H-x plane while satisfying a condition of $H'(0.3 \times 10^{-3}) \geq 270$, when t varies from 3.6×10^3 to 18×10^3 and T varies from 500 to 650.

2. The mechanical component as claimed in Claim 1, wherein said mechanical component is a crank shaft.
3. A method of fabricating a mechanical component according to Claim 1, comprising the step of nitriding the surface of a steel component by gas soft nitriding or salt-bath nitriding under conditions of a process time of 3.6×10^3 to 18×10^3 seconds, and a process temperature of 500 to 650°C, said nitriding being carried out so as to adjust Vickers hardness of the surficial portion measured at a reference position corresponded to a 50 μm depth from the surface of said mechanical component to 340 to 460 HV, so as to adjust Vickers hardness of the inner portion being not affected by the nitriding and showing a nearly constant hardness to 190 to 260 HV, and so as to adjust an effective depth of hardened layer measured from the surface of said component, where a Vickers hardness of 270 HV is achieved, to 0.3 mm or more.

Patentansprüche

1. Mechanische Komponente zusammengesetzt aus einem Stahl und durch Nitrierung Oberflächen-gehärtet, mit einer Vickershärte des Oberflächen-Teils, gemessen an einer Referenzposition entsprechend einer 50 μm Tiefe von der Oberfläche der mechanischen Komponente, von 340 bis 460 HV, mit einer Vickershärte des Innen-Teils, der durch die Nitrierung nicht beeinflusst ist und eine nahezu konstante Härte von 190 bis 260 HV zeigt und mit einer effektiven Tiefe von einer gehärteten Schicht, gemessen von der Oberfläche der Komponente, wo eine Vickershärte von 270 HV erreicht wird, von 0,3 mm oder mehr; wobei die mechanische Komponente aus einem Stahl mit den einzelnen Gehalten von den konstituierenden Elementen C: 0,35 bis 0,5%, Si: 0,01 bis 0,3%, Mn: 0,6 bis 1,8%, Cu: 0,01 bis 0,5%, Ni: 0,01 bis 0,5%, Cr: 0,01 bis 0,5%, Al: 0,001 bis 0,01% und N: 0,005 bis 0,025%, und aus irgendeiner oder zwei oder mehr Spezies von konstituierenden Elementen mit den einzelnen Gehalten, in Gewichtsprozent, von Pb: 0,30% oder weniger, S: 0,20% oder weniger, Ca: 0,01% oder weniger, Bi: 0,30% oder weniger, Ti: 0,02 oder weniger, Zr: 0,02% oder weniger und Mg: 0,01% oder weniger, wobei das Gleichgewicht Fe und unvermeidbare Verunreinigungen sind, besteht und wobei die mechanische Komponente die Zusammensetzung der einzelnen konstituierenden Elemente hat, die angepasst sind um Cr[äq.] bis 0,72% oder mehr und 1,0% oder weniger und C[äq.] bis 0,65% oder mehr und 0,86% oder weniger mit den Definitionen von

$$\text{Cr}[\text{äq.}] = 0,475 \times \text{C} + 0,164 \times \text{Si} + 0,241 \times \text{Mn} + \text{Cr}$$

$$\text{C}[\text{äq.}] = \text{C} + 0,07 \times \text{Si} + 0,16 \times \text{Mn} + 0,19 \times \text{Cu} + 0,17 \times \text{Ni} + 0,2 \times \text{Cr}$$

zu begrenzen, und

mit einem Härte-Verteilungsprofil $H(x)$, welches gegeben ist durch das Auftragen, auf die H-x-Ebene, der Vickershärte H, gemessen in der TiefenRichtung x, wie von der Komponenten-Oberfläche gesehen, in Region Z fallend, ausgedrückt durch die Gleichung (1) unten:

$$H'(x) = H'_0 + (H'_1 - H'_0) \times \left[1 - \text{erf} \left(\frac{x}{2\sqrt{\alpha Dt}} \right) \right] \quad \dots(1)$$

wobei,

$$H'_0 = \text{C}[\text{äq.}] \times 254 + 33,8$$

$$H'1 = Cr[\text{äq.}] \times 392 + 65,8$$

Cr[äq.]: Chrom-Äquivalenz oben beschrieben
C[äq.]: Kohlenstoff-Äquivalenz oben beschrieben;

$$D = D_0 \times \exp\left(\frac{-Q}{R \times (T + 273)}\right)$$

D_0 : $1,13 \times 10^{-6}$

$$Q : 83 \times \left(1 - \frac{14,03}{T + 273}\right) \times 1000$$

R: 8,314

$$\alpha = \exp(-1,47 \times Si - 0,918 \times Mn + 0,998)$$

Si: Si-Gehalt (Gew.-%)
Mn: Mn-Gehalt (Gew.-%); und

Region Z ist definiert als eine Region in welcher $H'(x)$, das durch die Gleichung (1) ausgedrückt wird, sich auf der H-x-Ebene bewegen kann während eine Bedingung von $H'(0,3 \times 10^{-3}) \geq 270$ erfüllt wird, wenn t von $3,6 \times 10^3$ bis 18×10^3 variiert und T von 500 bis 600 variiert.

2. Mechanische Komponente gemäß Anspruch 1, wobei die mechanische Komponente eine Kurbelwelle ist.

3. Verfahren zur Anfertigung einer mechanischen Komponente gemäß Anspruch 1, umfassend den Schritt der Nitrierung der Oberfläche von einer Stahl Komponente durch weiche Gas-Nitrierung oder Salzbad-Nitrierung unter Bedingungen einer Prozesszeit von $3,6 \times 10^3$ bis 18×10^3 Sekunden und einer Prozesstemperatur von 500 bis 650°C , wobei die Nitrierung so ausgeführt wird so dass die Vickershärte des Oberflächenteils, gemessen an einer Referenzposition entsprechend einer $50 \mu\text{m}$ Tiefe von der Oberfläche der mechanischen Komponente, von 340 bis 460 HV angepasst wird, so dass die Vickershärte des Innen-Teils, der durch die Nitrierung nicht beeinflusst ist und eine nahezu konstante Härte von 190 bis 260 HV zeigt, angepasst wird und so dass eine effektive Tiefe von gehärteter Schicht, gemessen von der Oberfläche der Komponente, angepasst wird, wobei eine Vickershärte von 270 HV erreicht wird, bis 0,3 mm oder mehr.

Revendications

1. Composant mécanique composé d'un acier et durci en surface par nitruration, ayant une dureté Vickers de la portion superficielle mesurée à une position de référence correspondant à une profondeur de $50 \mu\text{m}$ depuis la surface dudit composant mécanique de 340 à 460 HV, ayant une dureté Vickers de la portion interne non affectée par la nitruration et présentant une dureté presque constante de 190 à 260 HV, et ayant une profondeur effective de la couche durcie mesurée depuis la surface dudit composant, où une dureté Vickers de 270 HV est atteinte, de 0,3 mm ou plus, dans lequel le composant mécanique est constitué d'un acier avec les teneurs individuelles suivantes des éléments constitutifs : C : 0,35 à 0,5 %, Si : 0,01 à 0,3 %, Mn : 0,6 à 1,8 %, Cu : 0,01 à 0,5 %, Ni : 0,01 à 0,5 %, Cr : 0,01 à 0,5 %, Al : 0,001 à 0,01 % et N : 0,005 à 0,025 %, et une ou deux ou plusieurs espèces quelconques des éléments constitutifs avec les teneurs individuelles, en % en poids, de Pb : 0,30 % ou moins, S : 0,20 % ou moins, Ca : 0,01 % ou moins, Bi : 0,30 % ou moins, Ti : 0,02 % ou moins, Zr : 0,02 % ou moins et Mg : 0,01 % ou moins, le reste étant du Fe et des impuretés inévitables et dans

EP 1 548 141 B1

lequel le composant mécanique a la composition des éléments constitutifs individuels ajustée de façon à limiter Cr [eq] à 0,72 % ou plus et 1,0 % ou moins, et C[eq] à 0,65 % ou plus et 0,86 % ou moins, dans le cadre des définitions suivantes

$$\text{Cr[eq]} = 0,475 \times \text{C} + 0,164 \times \text{Si} + 0,241 \times \text{Mn} + \text{Cr}$$

et

$$\text{C[eq]} = \text{C} + 0,07 \times \text{Si} + 0,16 \times \text{Mn} + 0,19 \times \text{Cu} + 0,17 \times \text{Ni} + 0,2 \times \text{Cr},$$

ayant un profil de distribution de dureté H(x), qui est donné en traçant, sur un plan H-x, la dureté Vickers H mesurée dans le sens de la profondeur x vue depuis la surface du composant, entrant dans la région Z exprimée par l'équation (1) ci-dessous :

$$H'(x) = H'0 + (H'1 - H'0) \times \left[1 - \text{erf} \left(\frac{x}{2\sqrt{\alpha Dt}} \right) \right] \quad \dots(1)$$

où

$$H'0 = \text{C[eq]} \times 254 + 33,8$$

$$H'1 = \text{Cr[eq]} \times 392 + 65,8$$

Cr[eq] = équivalence chrome décrite dans ce qui précède

C[eq] = équivalence carbone décrite dans ce qui précède

$$D = D_0 \times \exp \left(\frac{-Q}{R \times (T + 273)} \right)$$

$$D_0 : 1,13 \times 10^{-6}$$

$$Q : 83 \times \left(1 - \frac{14.03}{T + 273} \right) \times 1000$$

$$R : 8,314 ;$$

$$\alpha = \exp(-1,47 \times \text{Si} - 0,918 \times \text{Mn} + 0,998)$$

Si : teneur en Si (% en poids)

EP 1 548 141 B1

Mn : teneur en Mn (% en poids) ; et

la région Z est définie comme une région dans laquelle $H'(x)$ exprimé par l'équation (1) peut se déplacer sur le plan H-x tout en vérifiant la condition $H'(0,3 \times 10^{-3}) \geq 270$, lorsque t varie de $3,6 \times 10^3$ à 18×10^3 et T varie de 500 à 650.

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2. Composant mécanique selon la revendication 1, dans lequel ledit composant mécanique est un vilebrequin.
3. Procédé de fabrication d'un composant mécanique selon la revendication 1, comprenant l'étape de nitruration de la surface d'un composant en acier par nitruration douce au gaz ou nitruration au bain de sel dans des conditions d'un temps de traitement de $3,6 \times 10^3$ à 18×10^3 secondes, et une température de traitement de 500 à 650 °C, ladite nitruration étant réalisée de façon à ajuster la dureté Vickers de la portion superficielle, mesurée en une position de référence correspondant à une profondeur de 50 μm depuis la surface dudit composant mécanique à 340 à 460 HV, de façon à ajuster la dureté Vickers de la portion interne qui n'est pas affectée par la nitruration et présentant une dureté presque constante de 190 à 260 HV, et de façon à ajuster une profondeur effective de la couche durcie mesurée depuis la surface dudit composant, où une dureté Vickers de 270 HV est atteinte, à 0,3 mm ou plus.
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Fig.1

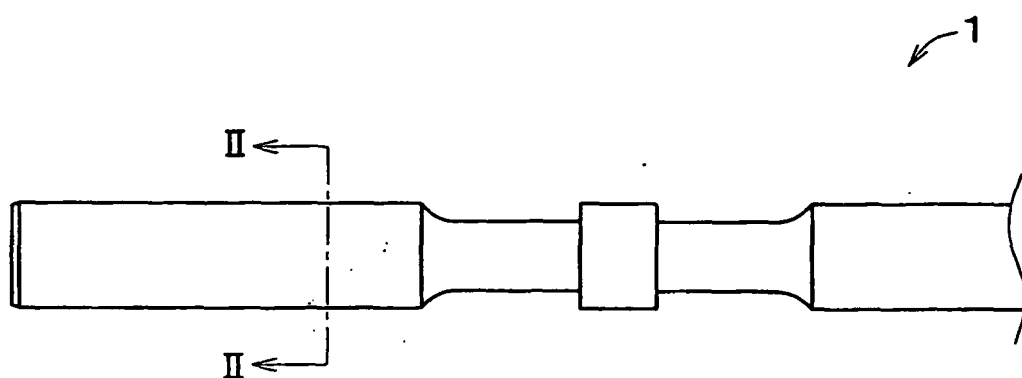


Fig.2

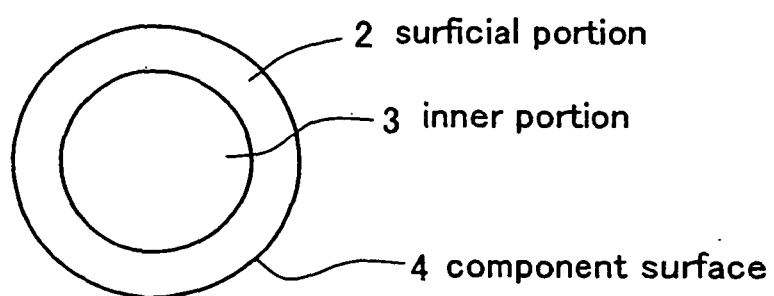
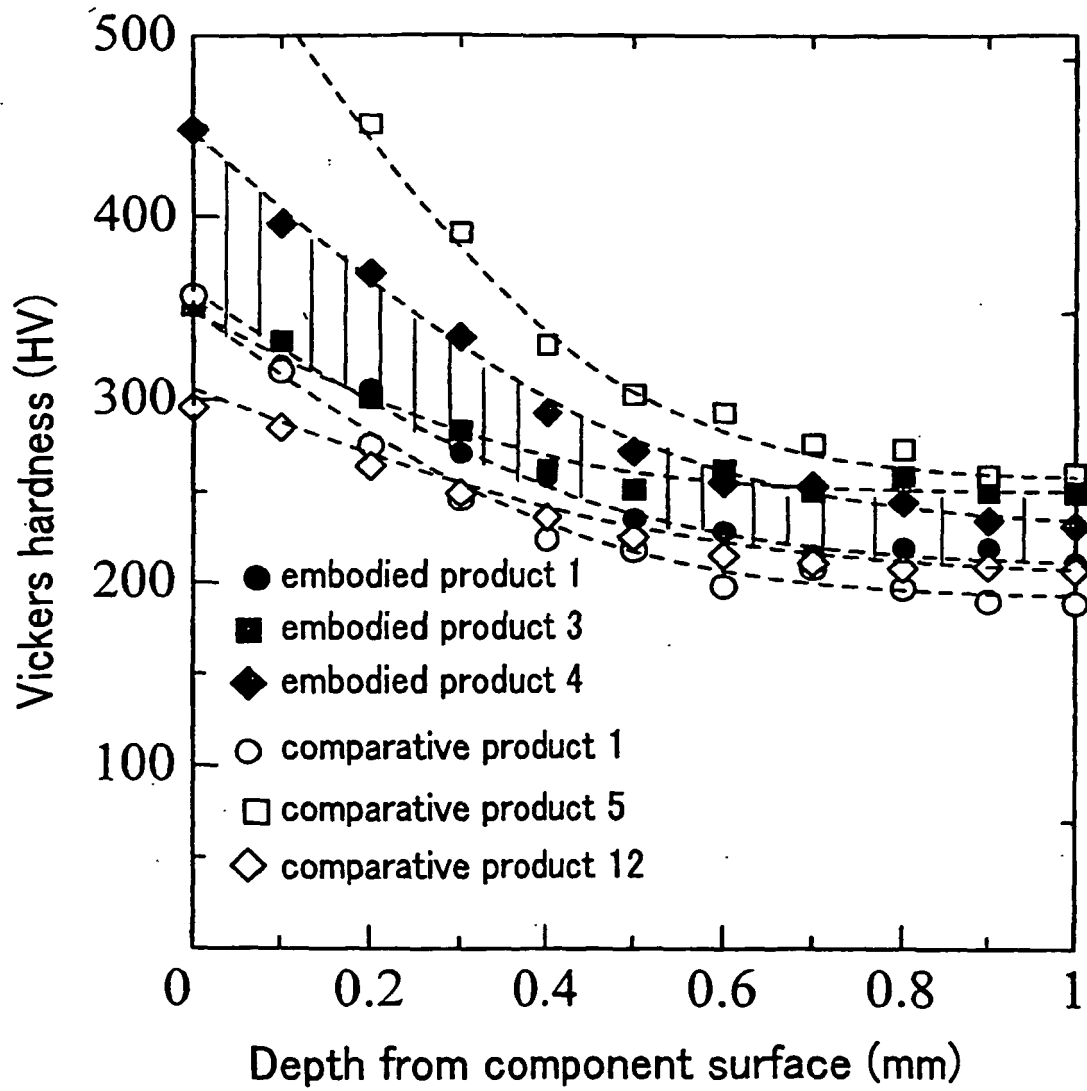


Fig.3



REFERENCES CITED IN THE DESCRIPTION

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