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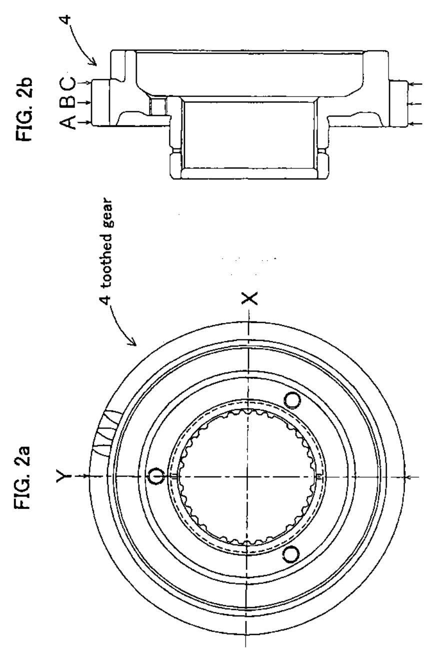
(54) **CARBURIZED AND QUENCHED MEMBER AND METHOD FOR PRODUCTION THEREOF**

(57) Provided are a carburized and hardened member that allows strength enhancement while sufficiently reducing the hardening strain, without increasing the production cost, and a production method for the carburized and hardened member. An alloy steel which contains Fe as a main component and contains 0.10 to 0.50 wt.% of C and 0.50 to 1.50 wt.% of Si and whose hardenability J based on an end quenching test is in a range of 35 to 50 (at 12.5 mm) is used as a raw material. After the material is formed into a member of a desired shape, a carburized layer is formed by performing a carburizing process in an oxidation inhibitive atmosphere. After the carburizing process, a quenching process is performed in a condition that cooling is monotonously performed from a pearlite transformation point (A1 point) to a martensite transformation start point (Ms point), and a condition that a severity of quenching H is in a range of 0.01 to 0.08 (cm^{-1}).

FIG. 2



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Description

TECHNICAL FIELD

[0001] The present invention relates to a carburized and hardened member that is excellent in fatigue strength and dimensional accuracy, and a production method for the member.

BACKGROUND ART

[0002] For example, for power transmission component parts of an automatic transmission, for example, gears and the like, carburized and hardened members subjected to a carburizing and quenching process are often used in order to increase the surface hardness and the toughness.

[0003] Conventional carburized and hardened members are normally produced by forming a case hardening steel (JIS: SCM420H, SCR420H, SNCM220) or the like into a desired shape, and then gas-carburizing the steel in a carburizing atmosphere, and then quenching it in an oil or the like.

[0004] As for the carburized and hardened members, cost cut and performance improvement are demanded more strongly than ever.

[0005] In order to achieve both a cost cut and a performance improvement, it is necessary to remove each of problems of the conventional carburized and hardened members produced from a conventional case hardening steel by an ordinary carburizing and quenching method.

[0006] One of goals regarding the carburized and hardened members is to further improve the post-carburizing and quenching process strength and, at the same time, improve the dimensional accuracy by reducing or suppressing the hardening strain.

[0007] However, improved hardenability normally leads to increased hardening strain, as well known. There is a possibility that the strength prior to the carburizing and quenching process may increase resulting in degraded processability and therefore increased cost of processing.

[0008] The present invention has been accomplished in view of the aforementioned problems of the conventional art. It is an object of the present invention to provide a carburized and hardened member that allows strength enhancement while sufficiently reducing the hardening strain, and a production method for the carburized and hardened member.

DISCLOSURE OF THE INVENTION

[0009] A first aspect of the present invention is a carburized and hardened member production method characterized in: that an alloy steel which contains Fe as a main component and contains 0.10 to 0.50 wt.% of C and 0.50 to 1.50 wt.% of Si and whose hardenability J based on an end quenching test is in a range of 35 to 50 (at 12.5 mm) is used as a raw material; and that after the material is formed into a member of a desired shape, a carburized layer is formed by performing a carburizing process in an oxidation inhibitive atmosphere; and that after the carburizing process, a quenching process is performed in such a condition that cooling is monotonously performed from a pearlite transformation point (A1 point) to a martensite transformation start point (Ms point), and such a condition that a severity of quenching H is in a range of 0.01 to 0.08 (cm^{-1}).

[0010] The aforementioned hardenability J based on an end quenching test is a value acquired by an end quenching test method prescribed in JIS: G0561 (generally termed "Jominy end quench test method"). Furthermore, the indication of (at 12.5 mm) means that the value of hardenability J is a value of hardenability J regarding a position of 12.5 mm from the water cool-side end surface of a rod-like test piece in the Jominy end quench test method.

[0011] The aforementioned severity of quenching H is a widely used index espoused by Grossmann et al. to indicate the strength of quenching, and is defined as in $H=0.5\times(\alpha/\gamma)$ where γ is the heat conductivity (kcal/mh°C) of a steel to be processed, and α is a surface heat transfer factor (kcal/mh^2°C) of the steel in a hardening atmosphere.

[0012] In the present invention, a specific alloy of which the C content and the Si content and the hardenability J are within the specific ranges is used as a raw material. After a carburized layer is formed by performing the carburizing process in the oxidation inhibitive atmosphere, the quenching process is performed so as to fulfill the aforementioned conditions of monotonous cooling and the aforementioned condition of specific severity of quenching H. That is, only after the material characteristics and the production conditions are fulfilled, it becomes possible to provide a carburized and hardened member in which the strength is enhanced while the hardening strain is sufficiently reduced.

[0013] This will be further explained. The setting of the C content within the range of 0.1 to 0.50 wt.% makes it possible to secure an appropriate toughness and an appropriate strength of a non-carburized portion (internal portion) after the carburizing and quenching process. If the C content is less than 0.1 wt.%, the aforementioned effect is not sufficient. If the C content exceeds 0.50 wt.%, the pre-quenching hardness becomes excessively high, thus creating a possibility of increased processing cost and reduced toughness. Furthermore, due to increased structural transformation rate of the interior of the non-carburized portion following the carburizing and quenching process, transformation stress increases, and due to great quenching strain, the component part accuracy may degrade.

[0014] Furthermore, in the present invention, the member positively contains Si as a component, and the content thereof is 0.50 to 1.50 wt.%. The carburizing process is performed in an oxidation inhibitive atmosphere. Therefore, it becomes possible to achieve improved plane fatigue strength, improved hardenability, improved resistance to temper softening, etc. while reducing the intergranular oxidation, which is likely to occur at the time of the carburizing process.

[0015] If the Si content is less than 0.50 wt.%, the aforementioned improvement effect is small; in particular, there is a problem of reduction of intergranular oxidation preventative effect at the time of the carburizing process. Conversely, if the Si content is greater than 1.50 wt.%, the improvement effect becomes saturated, and uniform austenitization prior to quenching is difficult. In order to prevent or curb degradations in the plastic processability, the cutting processability and the formability of the material, it is preferable that the Si content be less than or equal to 0.70 wt.%. Therefore, a preferable range of the Si content is a range greater than 0.50 wt.% and less than or equal to 0.70 wt.%.

[0016] The hardenability J of the material is limited within the range of 35 to 50 (at 12.5 mm). Therefore, excellent hardening effect can be achieved even if the range of the severity of quenching H is limited to the aforementioned range. If the hardenability J is less than 35, it becomes impossible to achieve sufficient hardening effect on the carburized layer and the non-carburized portion (internal portion) in the quenching process following the carburizing process, and it is therefore impossible to achieve a desired strength enhancement. Therefore, it is preferable that the hardenability J be greater than or equal to 38. If the hardenability J exceeds 50, the structural transformation rate of the internal portion, that is, the non-carburized portion, rises, so that the transformation stress increases and the hardening strain becomes more likely. If the hardenability J is higher, the hardness prior to the carburizing and quenching process is correspondingly higher, so that processability, such as the plastic processability prior to the carburizing process, the cutting processability, etc., degrades. Therefore, in order to prevent such degradation of workability, it is preferable that hardenability J be less than or equal to 45.

[0017] The severity of quenching H is limited within the range of 0.01 to 0.08 (cm^{-1}). If the alloy having the specific amount of carbon and having the hardenability is used, it becomes possible to substantially prevent or reduce the hardenability strain at the time of hardening process and therefore secure excellent dimensional accuracy.

[0018] If the severity of quenching H is less than 0.01 (cm^{-1}), it is impossible to achieve sufficient hardening effect on the carburized layer and the non-carburized portion (internal portion) in a hardening process following the carburizing process as in the case where the hardenability J is less than 35. Therefore, desired strength enhancement cannot be accomplished. If the severity of quenching H is greater than 0.08 (cm^{-1}), the transformation stress increases due to, particularly, increased structural transformation rate of the internal portion, that is, the non-carburized portion, and therefore the hardening strain is likely to occur, as in the case where the hardenability J is greater than 50.

[0019] The quenching process is performed under the condition that the cooling monotonously occurs from the A1 point to the Ms point, in addition to the condition of the range of severity of quenching H. The term "monotonously" herein means that re-heating is not performed during the cooling process, that is, there is no rise of the material temperature during the cooling. Therefore, examples of the case where the condition of monotonous cooling is fulfilled include a case where the material temperature continues to fall, and a case where if the temperature stops falling during the process, the temperature remains constant and never rises, and then starts falling again. Furthermore, changes in the cooling rate are allowable.

[0020] As the monotonous cooling is adopted as an essential condition, precipitation of carbides can be substantially prevented or reduced.

[0021] With regard to the monotonous cooling condition, it is possible to select a cooling condition such that the cooling does not enter a region of a nose of an S curve indicated in an isothermal transformation diagram within the carburized portion. This selection secures sufficient martensite transformation.

[0022] Although this may be a repeated statement, the present invention provides a carburized and hardened member in which the strength is enhanced while the hardening strain is sufficiently reduced, as the invention comprises the aforementioned C content, the Si content, the hardenability J, the carburizing process in an oxidation inhibitive atmosphere, and the quenching process that fulfills the condition of the monotonous cooling and the condition of the specific severity of quenching H. If any one of these elements is absent, the intended object cannot be achieved. The present inventors have discovered this through many experiments.

[0023] A second aspect of the present invention is a carburized and hardened member produced by the above-described production method, characterized in that a surface hardness of the carburized layer is in a range of 700 to 900 Hv, and an internal hardness of a non-carburized portion located inward of the carburized layer is in a range of 250 to 450 Hv.

[0024] This carburized and hardened member is produced by adopting the above-described production method and by adjusting the component range processing condition so as to restrict the surface hardness of the carburized layer and the internal hardness of the non-carburized portion within the aforementioned ranges. Therefore, it becomes possible to secure a static strength (tensile strength, flexural strength, torsional strength, etc.) and a dynamic strength (plane fatigue strength, bending fatigue strength, torsion fatigue strength, etc.) in a region from the surface to the internal portion (core portion), with respect to the distribution of stress applied to the member which results from the operating stress caused on the member by load applied to the member and the stress concentrated adjacent to the surface of the member due to bumps and dips, holes, etc. of the member.

[0025] If the surface hardness of the carburized layer is less than 700 Hv, a conceivable problem is that strength cannot be secure corresponding to the stress concentration adjacent to the surfaces of the member. Another conceivable problem is insufficient abrasion resistance in outermost surface. If the surface hardness is greater than 900 Hv, production of carbide, such as cementite and the like, in the surface layer is conceivable. Therefore, a conceivable problem is insufficient strength and, more particularly, reduced toughness.

[0026] If the internal hardness of the non-carburized portion is less than 250 Hv, the problem of insufficient strength and, more particularly, insufficient static strength, can be considered. If the internal hardness is greater than 450 Hv, the following problem is possible, taking the rate of transformation of structure into consideration. That is, when a hardening process is performed so as to secure 450 Hv, a great transformation stress occurs, which causes a great hardening strain and therefore makes a factor of degradation in component parts accuracy.

BRIEF DESCRIPTION OF THE DRAWINGS

[0027]

FIG 1 is an illustration of a rotating bending fatigue test piece.
FIG 2a is a plan view of a toothed gear for evaluation.
FIG 2b is a sectional view the toothed gear for evaluation.

BEST MODES FOR CARRYING OUT THE INVENTION

[0028] In the production method for a carburized and hardened member according to the first aspect of the present invention, it is preferable that the carburizing process be performed in a reduced-pressure atmosphere having a reduced pressure of 1 to 30 hPa. Therefore, it becomes possible to easily provide the oxidation inhibitive atmosphere through pressure reduction, and therefore sufficiently prevent intergranular oxidation at the time of carburization. The value of the reduced pressure of the reduced-pressure atmosphere being less than 1 hPa is excessive for substantial prevention of oxidation. If such value of the reduced pressure is required, the device for the pressure reduction needs to have high capability for pressure reduction, and creates a problem of cost increase. If the value of the reduced pressure is higher than 30 hPa, the oxidation preventing effect degrades, and furthermore, other problems, such as production of soot in the carburizing furnace, and the like, occur.

[0029] It is also preferable that the carburizing process be performed in an atmosphere containing an inert gas as a main component. This also makes it possible to easily form the oxidation inhibitive atmosphere. Examples of the inert gas include nitrogen gas, argon gas, etc.

[0030] It is also preferable that the carburizing process be performed so that a surface carbon amount in the carburized layer becomes 0.6 to 1.5 wt.% (claim 4). The surface carbon concentration in the carburized layer affects the surface hardness of the carburized and hardened member. If the surface carbon amount in the carburized layer is less than 0.6 wt.%, there occurs a problem of insufficient surface hardness. If the surface carbon amount is greater than 1.5 wt.%, the precipitation of carbide becomes great so that the hardenability of the base remarkably degrades and the surface hardness becomes insufficient.

[0031] It is also preferable that intergranular oxidation progressing from a surface of the raw material be at most 3 μm. That is, it is preferable to restrict the intergranular oxidation to 3 μm or less from the surface by adjusting the oxidation inhibitive atmosphere, the heating temperature, the heating time, etc., at the time of carburization.

[0032] The intergranular strength decreases if an intergranular oxide (portion) is produced. Therefore, if intergranular oxidation reaches a depth beyond 3 μm, there is a danger of reduced abrasion resistance due to insufficient strength of the member, reduced hardness, etc. Furthermore, at the time of intergranular oxidation, surrounding alloy elements are also taken up into the intergranular oxide due to chemical reactions. Therefore, the hardenability-improving elements in the carburized and hardened layer around intergranular oxides are taken up and consumed by the intergranular oxides, thereby forming regions where additives are depleted, around the intergranular oxide layer. Therefore, the hardenability of the carburized and hardened layer becomes insufficient. Hence, there is a danger of causing insufficient hardness and insufficient strength.

[0033] It is also preferable that the raw material have a surface compression residual stress of 300 to 800 MPa. That is, it is preferable to set the surface compression residual stress to at least 300 MPa by adjusting the composition of the raw material, the oxidation inhibitive atmosphere for the carburization, the heating temperature, the heating time, etc. Therefore, the tensile stress near the surface can be reduced by the compression residual stress near the surface of the member. In particular, the dynamic strength (planer fatigue strength, bending fatigue strength, torsional fatigue strength) can be improved. If the surface compression residual stress is greater than 800 MPa, it is necessary to increase the cooling rate during the quenching process beyond a limit in order to increase the amount of martensite. Therefore, great hardening strain occurs, and therefore a dimensional accuracy of the member cannot be secured.

[0034] The surface compression residual stress can be produced by forming the martensite via the quenching process of the carburized layer, and creating a compression stress field due to volume expansion involved in the transformation. However, if the amount of martensite produced is small, that is, if the amount of retained austenite is great, or if the troostite structure is great in amount, it is impossible to form a sufficient compression residual stress field. Therefore, the reduction of the retained austenite (specifically, to 25% or less) and the reduction of the troostite structure (specifically, to 10% or less) are effective in view of enhancement of compression residual stress effect. The absorption of volume expansion at the time of martensite transformation does not considerably contribute to enhancement of the surface compression residual stress if the amount of martensite is small. If the amount of martensite is small, plastic deformation of the surrounding retained austenite or troostite structure is involved, and therefore stress reduces. However, if the amount of martensite increases and the retained austenite or troostite structure reduces in amount as mentioned above, the density of dislocation introduced by plastic deformation increases, so that slip is restrained. Therefore, the surface compression residual stress rapidly increases.

[0035] In another possible method, the compression residual stress can be increased by performing a surface process, such as shot peening, after the quenching process. In the latter method, turning the retained austenite into martensite by the shot peening process is more advantageous in increasing the compression residual stress.

[0036] It is also preferable that in the quenching process, quenching be performed with the severity of quenching H being in said range during a transition from a temperature in an austenite region to 300°C. Therefore, sufficient quenching effect can be achieved. If the severity of quenching H in a cooling process from the temperature of the austenite region to 300°C is less than 0.01 (cm^{-1}), the quenching will be insufficient. Thus, desired hardened structure and characteristic cannot be achieved, and the strength of the member will be insufficient. If the severity of quenching H in a cooling process from the temperature of the austenite region to 300°C is greater than 0.08 (cm^{-1}), the quenching will be excessive, so that the structure transformation stress and the thermal stress will increase. Therefore, there is a possibility of increased hardening strain and degraded component part accuracy.

[0037] It is also preferable that in the quenching process, quenching be accomplished by gas cooling. Therefore, it becomes relatively easy to secure the aforementioned severity of quenching H.

[0038] It is also preferable that the quenching by gas cooling use an inert gas. Therefore, a safety can be secured during the quenching.

[0039] It is also preferable that the inert gas be a nitrogen gas. The adoption of nitrogen gas as the aforementioned inert gas is preferable in view of cost, ease of handling, availability at the time of mass-production operation, etc.

[0040] In the carburized and hardened member of the second aspect of the present invention, a retained austenite area rate of the carburized layer preferably is at most 25%. If the retained austenite area rate is greater than 25%, structural transformation from retained austenite into martensite occurs in association with changes in temperature and operating stress during a working process after the carburizing and quenching process, or during the use of the member. Due to the stress of the transformation, strain occurs, and the component parts accuracy will likely degrade. It is more preferable that the retained austenite area rate be 20% or less. The retained austenite area rate can be reduced by other manners. For example, the area rate can be reduced by forcibly turning the retained austenite into martensite via shot peening or the like.

[0041] It is also preferable that a troostite structure area rate of a surface layer of the carburized layer be at most 10%. The troostite is a slack-quenched structure formed in the carburized layer after the carburizing and quenching process, and has a low hardness. Therefore, if the troostite structure area rate is greater than 10%, low-strength troostite will reduce the strength of the component part.

[0042] It is also preferable that an internal structure of the carburized and hardened member be bainite. More specifically, it is desirable that the area rate of bainite in a sectional structure be at least 50%. Unlike the case of martensite, transformation of bainite progresses while iron atoms forming a lattice partially diffuse. Therefore, the strain associated with transformation is less in bainite than in martensite. Furthermore, bainite has a greater hardness than pearlite, which is produced if the cooling rate is lower. Thus, bainite appropriately enhances the strength of the internal non-carburized layer. In order to form an internal layer portion mainly from bainite, it is desirable to select such a composition as to form a structure mainly from bainite by setting the severity of quenching H within the range of 0.01 to 0.08 (cm^{-1}). Therefore, it becomes possible to provide a component part that has high strength and high toughness.

[0043] It is also preferable that the carburized and hardened member be a carburized toothed gear. The toothed gears require various strict conditions. The excellent characteristics achieved by the above-described production method are very effective for the toothed gears.

EXAMPLES

[0044] The carburized and hardened members according to embodiments of the present invention will be described in detail with reference to specific examples.

(Example 1)

[0045] As Example 1, results of experiments conducted to verify advantages of the present invention will be described.

[0046] Steels (Steel 11 to Steel 14) having chemical compositions shown in Table 1, after being melt-formed in an arc furnace, were hot-rolled into round bars having a diameter of 150 mm and a diameter of 32 mm. The round bars were normalized by keeping them at 925°C for an hour and then air-cooling them.

[0047] Steel 11 and Steel 12 are steel grades having new compositions developed in the example. Steel 13 and Steel 14 are steel grades corresponding to case hardening steels SCM420 and SNCM 815 according to JIS.

[0048] Firstly, for each steel grade, a hardenability J was determined by conducting a Jominy end quenching method according to JIS: G0561.

[0049] Results are shown in Table 1. This characteristic is a characteristic of a raw material irrelevant to the production method described below.

(Table 1)

Steel grade	Component element (wt%)												Hardenability J
	C	Si	Mn	S	Ni	Cr	Mo	B	Ti	Mb	A1	N	
11	0.16	0.56	0.38	0.012	0.96	1.47	0.01	0.0022	0.044	0.05	0.013	0.006	38
12	0.18	0.75	0.35	0.009	0.71	2.22	0.01	0.0018	0.035	0.03	0.019	0.005	42
13	0.2	0.21	0.78	0.011	0.02	1.01	0.17	-	-	-	0.027	0.015	25
14	0.15	0.25	0.47	0.009	4.34	0.83	0.27	-	-	-	0.04	0.018	37

[0050] As can be understood from Table 1, Steels 11 and 12 are alloy steels that are applicable as a raw material in the present invention in view of material quality and hardenability J. However, as for Steel 13, the hardenability J and the Si content are outside their respective ranges according to the present invention. As for Steel 14, the Si content is outside the range according the present invention.

[0051] Steels 11 to 14 were formed into round bar test pieces (not shown) of 25 mm in diameter and 50 mm in length, and were also formed into rotating bending fatigue test pieces 1 having a shape as shown in FIG 1.

[0052] Normalized materials of 150 mm in diameter were machined into test spur gears 4 having a pitch radius of 54 mm, 27 teeth, a module of 4, a facewidth of 9 mm, a shaft hole radius of 35 mm (an equivalent round bar diameter of 10.5 mmϕ) as shown in FIG 2.

[0053] The test pieces and the gears produced from Steels 11, 12 and 14 were subjected to low-pressure carburization (vacuum carburization) and gas quenching under the conditions of "Process 1" shown in Table 2.

[0054] The test pieces produced from Steel 13 were gas-carburized and oil-quenched under the conditions of "Process 2" shown in Table 3.

[0055] In the aforementioned "Process 1", the severity of quenching H after the carburization is 0.05 (cm^{-1}) as shown in Table 2, and the elements of the production method of the present invention are included.

[0056] In the aforementioned "Process 2", the severity of quenching H after the carburization is 0.15 (cm^{-1}) as shown in Table 3, and the elements of the production method of the present invention are included.

[0057] The test pieces prepared as described above were subjected to the following tests.

[0058] First, with regard to the round bar test pieces of 25 mm in diameter, a hardness distribution (internal hardness) of a cross section was investigated using a Vickers hardness meter. The surface layer hardness (surface hardness) of each carburized member was measured at a position of 0.02 mm from the surface. Furthermore, at an equivalent position, the troostite area rate was measured by image analysis of scanning electron micrographs.

[0059] As for the intergranular oxidation layer, a greatest depth of the oxidation layer from the superficial metallographic structure was measured by an optical microscope.

[0060] The surface carbon concentration was measured at a position of 50 μm from the surface via an X-ray macroanalyzer.

[0061] The retained austenite area rate was measured at a surface of the member using a Co-Kα ray in an X-ray diffraction apparatus.

[0062] The surface residual stress was measured by a half value breadth midpoint method, using an Fe-Kα ray in an X-ray stress meter.

[0063] Measurement results are shown in Table 4.

(Table 2)

Process 1					
Step	Temperature	Time	Atmosphere	Pressure	Severity of Quenching H
Carburizing	930°C	2 h	Acetylene	20 mbar	-
Diffusion	930°C	1 h	Acetylene	20 mbar	-
Thermal uniforming	850°C	0.5 h	Acetylene	20 mbar	-
Quenching	-	-	Nitrogen	8 bar	0.05 cm^{-1}
Tempering	150°C	2 h	Atmosphere	Atmospheric	-

(Table 3)

Process 2					
Step	Temperature	Time	Atmosphere	Pressure	Severity of Quenching H
Carburizing	930°C	3 h	Mixed gas of CO, H_2, N_2, etc. formed by reaction of butane and air	Atmospheric spheric	-

(Table 3) (continued)

Process 2					
Step	Temperature	Time	Atmosphere	Pressure	Severity of Quenching H
Diffusion	930°C	1 h	Mixed gas of CO, H_2, N_2, etc. formed by reaction of butane and air	Atmospheric spheric	-
Thermal uniforming	850°C	0.5 h	Mixed gas of CO, H_2, N_2, etc. formed by reaction of butane and air	Atmospheric	-
Quenching	120°C	-	Oil	Atmospheric	0.15 cm^{-1}
Tempering	150°C	2 h	Atmosphere	Atmospheric	-

(Table 4)

Steel grade	Carburizing and quenching step	Intergranular oxidation layer (μm)	Surface carbon concentration (%)	Troostite area rate (%)	Surface hardness (%)	Retained austenite area rate (%)	Surface residual stress (MPa)	internal hardness (Hv)	10^7 fatigue limit	
									Bending fatigue (MPa)	Plane fatigue (MPa)
11	(Process 1) vacuum carburizing + gas cooling	1.2	0.68	7.0	779	14.2	-314	393	1098	3750
12		2.2	1.21	2.5	839	19.1	-330	423	1080	4260
13	(Process 2) gas carburizing + oil cooling	10.7	0.78	37.7	631	7.1	-69	267	900	3000
14	(Process 1) vacuum carburizing + gas cooling	5.8	0.66	9.1	729	22.5	-125	384	1053	3090

[0064] As shown in Table 4, all the carburized and hardened specimens "Steel 11, 12 + Process 1" produced from Steels 11 and 12 by Process 1 (hereinafter, combinations of the steel grade and the production process will be indicated in the fashion of "Steel Grade + Process") had a central portion hardness above 250 Hv. The structures in a surface layer and a central portion were martensite, and no remarkable slack-quenched structure existed.

[0065] In contrast, the specimen "Steel 13 + Process 2" had a lower surface layer hardness and a lower central portion hardness than any one of the specimens "Steel 11, 12 + Process 1".

[0066] The specimen "Steel 14 + Process 1" had a surface layer hardness and a central portion hardness that are approximately equal to those of the specimens "Steel 11, 12 + Process 1", but had a greater retained austenite area rate and a smaller surface residual stress. Correspondingly, the member was inferior in the plane fatigue strength.

[0067] As for the rotating bending fatigue test, an Ono-type rotary bending fatigue testing machine was used to determine fatigue strengths with the reference number of repetitions being ten millions. Results are shown as the bending fatigue and the plane fatigue in Table 4.

[0068] As can be understood from Table 4, the specimens "Steel 11, 12 + Process 1" achieved considerably better characteristics in the rotating bending fatigue strength than the specimens "Steel 13 + Process 2" and "Steel 14 + Process 1".

[0069] As for the gears, the gear accuracy and the dimensional accuracy were evaluated as described below.

[0070] To evaluate the gear accuracy, an amount of error in directions of gear pressure and an amount of error in the direction of helix angle were measured on each of the right and left tooth flanks, via a dedicated precision gear accuracy measuring machine. Tooth space heights were measured all round the circumference of each gear, and a value obtained by subtracting a minimum value from a maximum value was determined as a tooth space runout.

[0071] To evaluate the dimensional accuracy, a ball was placed in two tooth spaces of gears facing each other, and an outer periphery thereof was measured via a dedicated OBD measuring device. As for the OBD measurement, circumferential directions were two perpendicular directions (X, Y), and upper, intermediate and lower sites (three sites) (A, B, C) were defined in the direction of facewidth, as indicated in FIGS. 2a and 2b. As an OBD ellipse, an absolute value of the difference in OBD in the two perpendicular directions was determined. As an OBD taper, a difference between an upper OBD and a lower OBD in the direction of facewidth was determined.

[0072] Results are shown in FIG 5.

(Table 5)

Steel grade	Carburizing and quenching step	Gear accuracy (%)				Dimensional accuracy (%)		
		flank Tooth	Variation in characteristics		Tooth space runout	OBD variation	OBD ellipse	OBD taper
			Pressure angle error	Helix angle error				
11	Process 1	Right	45	51	68	70	82	35
		Left	48	49				
12	Process 1	Right	62	65	73	78	81	40
		Left	58	60				
13	Process 2	Right	100	100	100	100	100	100
		Left	100	100				
14	Process 1	Right	47	48	70	65	80	30
		Left	50	55				

[0073] As can be understood from Table 5, the specimens "Steel 11, 12 + Process 1" exhibited better gear accuracies and better dimensional accuracies than the other members.

[0074] The aforementioned results indicate that it is possible to increase the strength while sufficiently reducing the hardening strain in the specimens "Steel 11, 12 + Process 1" in which a specific alloy steel having a C content, an Si content and hardenability J within the aforementioned specific ranges was used as a raw material, and was subjected to a carburizing process in an oxidation inhibitive atmosphere, thereby forming a carburized layer, and then the steel was quenched under the condition of the specific severity of quenching H.

[0075] As for the alloy steel, it is appropriate to make a setting such that the alloy steel contains Fe as a main component and, as subsidiary components, 0.12 to 0.22 wt.% of C, 0.5 to 1.5 wt.% of Si, 0.25 to 0.45 wt.% of Mn, 0.5 to 1.5 wt.% ofNi, 1.3 to 2.3 wt.% of Cr, 0.001 to 0.003 wt.% of B, 0.02 to 0.06 wt.% of Ti, 0.02 to 0.12 wt.% ofNb, and 0.005 to 0.05 wt.% of Al.

[0076] More specifically, it is appropriate to prepare a composition such that a component parameter N defined as below is 95 or less.

$$N \equiv 106\times C(\text{wt.\%}) + 10.8\times Si(\text{wt.\%}) + 19.9\times Mn(\text{wt.\%}) + 16.7\times Ni(\text{wt.\%}) +$$

$$8.55\times Cr(\text{wt.\%}) + 45.5\times Mo(\text{wt.\%}) + 28$$

[0077] In Steel Grades 11, 12, N is 87.6 and 93.4, respectively, whereas in Steel Grades 13, 14, not included in the present invention in terms of the ranges of components, N is greater than 95. If N is greater than 95, the hardness of the steel in the rolled state or the hardness of the steel in the normalized state remarkably increases, so that neither required machine workability nor required cold workability can be achieved. Therefore, if productivity is highly valued, it is necessary to control the composition of the steel so that the component parameter N is less than or equal to 95.

[0078] In the alloy steel satisfying the component ranges according to the present invention, no bainite is produced if the cooling rate is equal to or less than 0.1°C/sec., and no ferrite is produced if the cooling rate is greater than or equal to 12°C/sec. These ranges of the cooling rate can be specified through measurements of continuous cooling transformation diagrams (CCT diagrams) of a steel at various cooling rates.

[0079] In the present invention, the composition of the steel is set so that no ferrite is produced in a range of cooling rate greater than or equal to 12°C/sec. (hereinafter, referred to as "upper limit cooling rate), in order to ensure that the sufficient hardening of the carburized layer can be achieved even by gas cooling. If ferrite is produced although the cooling rate is greater than or equal to 12°C/sec., it is impossible to accomplish the sufficient production of martensite in the carburized layer by gas cooling, leading to insufficient hardness.

[0080] However, excessively high hardenability is disadvantageous, too. That is, if martensite is excessively produced in the internal layer portion where the carburization does not have effect, the production of martensite in the entire member becomes considerably great, leading to degraded dimensional accuracy. Therefore, it is important to select a composition so that at the time of gas quenching, martensite is sufficiently produced in the carburized layer whereas martensite is not excessively produced in the internal layer portion. Specifically, the composition of the steel is set so that if the cooling rate is less than or equal to 0.1°C/sec., no bainite is produced. If bainite is produced even though the cooling rate is less than or equal to 0.1°C/sec., the hardening reaches the internal layer portion, which is not affected by the carburized layer. Thus, strain increases.

[0081] If the setting is made so that no bainite is produced if the cooling rate is less than 0.1°C/sec., production of bainite is sufficiently prevented or reduced in an actual range of annealing cooling rate, so that a highly workable structure with a large amount of ferrite and pearlite can be provided. Therefore, if the rate of cooling from austenite is within a range corresponding to the annealing state, that is, a state where the material is air-cooled or let stand to cool, the material is provided with a hardness that is sufficiently low to improve the workability. Thus, the working prior to the carburizing and quenching process becomes easier.

[0082] Furthermore, it is desirable to select such a composition that an internal layer portion can be provided with a structure in which bainite is major if the cooling rate is set at 0.1 to 10°C/sec. It is particularly desirable to select such a composition that the cooling at 3°C/sec. will provide a structure mainly formed by bainite.

(Example 2)

[0083] In this example, steels indicated in Table 6 (Steels 21 to 24 and Steels 31 to 38) were melted and formed into ingots, which were bloom-rolled and bar-rolled to produce round bars of 70 mm in diameter.

[0084] Subsequently, the round bars of 70 mmϕ were stretched to 120 mmϕ by hot forging. After being normalized at 925°C, the materials were formed into test pieces and toothed gears as in Example 1 (see FIGS. 1 and 2).

[0085] The test pieces and the gears were processed separately by three different production methods (Processes 3 to 5).

[0086] "Process 3" is characterized by gas carburization and oil quenching. In this process, steel is carburized and quenched and then tempered in a carburizing gas atmosphere in the manner of heating at 930°C for 5 hours→diffusion at 850°C for 1 hour→oil-quenching at 130°C→tempering at 180°C for 1 hour. The severity of quenching H in this case is 0.15 (cm^{-1}).

[0087] "Process 4" is characterized by vacuum carburization and gas cooling. In this process, steel is carburized and quenched and then tempered in the manner of heating at 930°C for 5 hours→diffusion at 850°C for 1 hour→nitrogen gas cooling→tempering at 180°C for 1 hour. The severity of quenching H in this case is 0.05 (cm^{-1}).

[0088] "Process 5" is similar to Process 4, except that the nitrogen gas cooling in Process 4 is changed to oil quenching at 130°C. The severity of quenching H in this case is 0.15 (cm^{-1}).

[0089] The test pieces and the gears processed by the above-described process were subjected to measurements, tests, and the like as in Example 1.

[0090] Results are shown in Tables 7 and 8.

[0091] As shown in Tables 7 and 8, Steel Grades 31 to 38 were inferior in the bending fatigue strength and the plane fatigue strength; furthermore, the oil-cooled component parts had great variation in precision due to hardening strain, and therefore would have problems in practical use.

[0092] Steel Grades 31 to 34 had a slack quenched structure due to intergranular oxidation formation at the time of gas carburization, and therefore exhibited low surface hardness and low strengths. Furthermore, since oil cooling causes rapider quenching and greater non-uniformity in cooling than gas cooling, the variation in precision due to hardening strain increased.

[0093] In Steel Grades 37, 38, the quenching by oil-cooling was excessively strong with respect to the hardenability of the steel materials, so that the internal hardness excessively increased. The difference between the proportion of the surface structure transformation and the proportion of the internal structure transformation was relatively small, that is, the difference between the surface hardness and the internal hardness was relatively small. Therefore, the surface layer residual stress was relatively small, and the strengths were relatively low. Furthermore, since oil cooling causes rapider quenching and greater cooling non-uniformity than gas cooling, the variation in precision due to hardening strain increased.

[0094] In contrast, each of Steel Grades 21 to 24 exhibited a high surface hardness and an appropriate value of internal hardness, and reduced strain. Thus, it is apparent that high strengths and low strains were achieved.

[0095] Therefore, this example also indicates that it is possible to increase the strength while sufficiently reducing the hardening strain in the members if a specific alloy steel having a C content, an Si content and hardenability J within the aforementioned specific ranges is used as a raw material, and is subjected to a carburizing process in an oxidation inhibitive atmosphere, thereby forming a carburized layer, and then the steel is quenched under the condition of the specific severity of quenching H.

[0096] As for the alloy steel, it is appropriate to make a setting such that the alloy steel contains Fe as a main component and, as subsidiary components, 0.1 to 0.5 wt.% of C, 0.5 to 1.0 wt.% of Si, 0.3 to 1.0 wt.% of Mn, 0.1 to 1.0 wt.% of Cr, 0.003 to 0.015 wt.% of P, 0.005 to 0.03 wt.% of S, 0.01 to 0·06 wt.% of Al, and 0.005 to 0.03 wt.% ofN, and at least one of 0.3 to 1.3 wt.% of Mo and 0.1 to 1.0 wt.% of Ni. It is also possible to contain, as subsidiary components, at least one of 0.05 to 1.5 wt.% of V, 0.02 to 0.2 wt.% ofNb, 0.01 to 0.2 wt.% ofTi, or 0.0005 to 0.005 wt.% ofB and 0.005 to 0.1 wt.% of Ti, or 0.0005 to 0.005 wt.% of B and 0.11 to 0.2 wt.% of Ti. As still other elements, at least one species selected from the group consisting of at most 0.01% by weigh of Ca, at most 0.01% by weight of Mg, at most 0.05% by weight ofZr and at most 0.1% by weight of Te may be contained.

(Table 6)

Steel grade	Component element (wt%)											Harden-ability J
	C	Si	Mn	P	S	Cr	Al	Mo	Other & fine grain elements	Trace element (ppm)	N (ppm)	
21	0.15	0.50	0.50	0.008	0.015	0.12	0.020	1.00	V:0.10,Nb:0.03, Ti:0.02	Te:20,Zr:20, B:20	142	38
22	0.15	0.50	0.50	0.003	0.011	0.50	0.020	0.95	Ni:0.30,V:0.10, Nb:0.02,Ti:0.02	Ca:20,Zr:50, B:20	132	44
23	0.15	1.00	0.86	0.010	0.014	0.12	0.018	1.00	V:0.10.Nb:0.03, Ti:0.02	Te:15,Zr:10, B:15	135	38
24	0.25	0.50	0.35	0.015	0.012	0.90	0.035	0.91	Nb:0.02	Mg:30	145	31
31	0.21	0.25	0.70	0.015	0.015	1.06	0.030	0.15	-	-	130	28
32	0.19	0.26	0.80	0.019	0.014	1.13	0.035	0.02	-	-	138	26
33	0.15	0.50	0.50	0.010	0.015	0.44	0.035	1.01	V:0.10.Nb:0.03	Ca:20	130	28
34	0.15	0.50	0.50	0.008	0.015	0.12	0.020	1.00	V:0.10,Nb:0.03. Ti:0.02	Te:20,Zr:20, B:20	142	38
35	0.21	0.25	0.70	0.015	0.015	1.06	0.030	0.15	-	-	130	28
36	0.19	0.26	0.80	0.019	0.014	1.13	0.035	0.02	-	-	138	26
37	0.15	0.50	0.50	0.010	0.015	0.44	0.035	1.01	V:0.10,Nb:0.03	Ca:20	130	28
38	0.15	0.50	0.50	0.008	0.015	0.12	0.020	1.00	V:0.10.Nb:0.03. Ti:0.02	Te:20,Zr:20, B:20	142	38

(Table 7)

Steel grade	Carurizing and quenching step	Intergranular oxidation layer (μm)	Surface carbon concentration (%)	Troostite area rate (%)	Surface hardness (Hv)	Retained austenite area rate (%)	Surface residual stress (MPa)	Internal Hardness (Hv)	10^7 fatigue limit	
									Bending fatigue (MPa)	Plane fatigue (MPa)
21	(Process 4) vacuum carburizing + gas cooling	0	0.67	3	845	6	-392	280	1200	3500
22		0	0.61	3	874	8	-370	315	1250	3500
23		0	0.68	3	844	7	-390	275	1200	3500
24		0	0.62	4	840	9	-390	300	1200	3600
31	(Process 3) gas carburizing + oil cooling	15	0.61	41	680	20	50	290	800	2800
32		5	0.66	28	670	22	40	280	750	2800
33		18	0.61	40	780	18	80	350	900	3100
34		20	0.62	43	770	17	90	360	900	3000
35	(Process 4) vacuum carburizing + gas cooling	0	0.68	2	813	12	-360	230	1000	3100
36		0	0.69	3	780	13	-300	220	1000	3200
37	(Process 5) vacuum carburizing + oil cooling	0	0.66	3	780	10	-160	390	1000	3000
38		0	0.64	4	850	10	-100	400	1000	3100

(Table 8)

Steel grade	Carburizing and quenching step	Gear accuracy (%)				Dimensional accuracy (%)		
		Tooth flank	Variation in characteristics		Tooth space runout	OBD variation	OBD ellipse	OBD taper
			pressure angel error	Helix angle error.				
21	(Process 4) vacuum carburizing + gas cooling	Right	48	60	65	55	80	36
		Left	52	54				
22		Right	47	55	70	68	85	48
		Left	48	59				
23		Right	60	67	66	70	77	32
		Left	52	61				
27		Right	51	56	64	60	79	47
		Left	47	52				
31	(Process 3) gas carburizing + oil cooling	Right	103	108	105	98	100	110
		Left	112	105				
32		Right	99	105	100	100	110	105
		Left	18	98				
33		Right	110	105	101	108	106	99
		Left	105	104				
34		Right	102	109	106	111	111	107
		Left	106	110				
35	(Process 4) vacuum carburizing + gas cooling	Right	60	59	70	65	77	43
		Left	51	65				
		Right	59	55	78	64	85	48
36		Left	54	59				
37	(Process 5) vacuum carburizing + oil cooling	Right	99	106	105	97	110	102
		Left	108	111				
38		Right	100	100	100	100	100	100
		Left	100	100				

Claims

1. A carburized and hardened member production method **characterized in:**

   that an alloy steel which contains Fe as a main component and contains 0.10 to 0.50 wt.% of C and 0.50 to 1.50 wt.% of Si and whose hardenability J based on an end quenching test is in a range of 35 to 50 (at 12.5 mm) is used as a raw material; and

   that after the material is formed into a member of a desired shape, a carburized layer is formed by performing

a carburizing process in an oxidation inhibitive atmosphere; and
that after the carburizing process, a quenching process is performed in a condition that cooling is monotonously performed from a pearlite transformation point (A1 point) to a martensite transformation start point (Ms point), and a condition that a severity of quenching H is in a range of 0.01 to 0.08 (cm^{-1}).

2. The carburized and hardened member production method according to claim 1, **characterized in that** the carburizing process is performed in a reduced-pressure atmosphere having a reduced pressure of 1 to 30 hPa.

3. The carburized and hardened member production method according to claim 1, **characterized in that** the carburizing process is performed in an atmosphere containing an inert gas as a main component.

4. The carburized and hardened member production method according to claim 1, **characterized in that** the carburizing process is performed so that a surface carbon amount in the carburized layer becomes 0.6 to 1.5 wt.%.

5. The carburized and hardened member production method according to claim 1, **characterized in that** intergranular oxidation progressing from a surface of the raw material is at most 3 μm.

6. The carburized and hardened member production method according to claim 1, **characterized in that** the raw material has a surface compression residual stress of 300 to 800 MPa.

7. The carburized and hardened member production method according to claim 1, **characterized in that** in the quenching process, quenching is performed with the severity of quenching H being in said range during a transition from a temperature in an austenite region to 300°C.

8. The carburized and hardened member production method according to claim 1, **characterized in that** in the quenching process, quenching is accomplished by gas cooling.

9. The carburized and hardened member production method according to claim 8, **characterized in that** the quenching accomplished by the gas cooling uses an inert gas.

10. The carburized and hardened member production method according to claim 9, **characterized in that** the inert gas is a nitrogen gas.

11. A carburized and hardened member produced by a production method described in claim 1, **characterized in that** a surface hardness of the carburized layer is in a range of 700 to 900 Hv, and an internal hardness of a non-carburized portion located inward of the carburized layer is in a range of 250 to 450 Hv.

12. The carburized and hardened member according to claim 11, **characterized in that** a retained austenite area rate of the carburized layer is at most 25%.

13. The carburized and hardened member according to claim 11, **characterized in that** a troostite structure area rate of a surface layer of the carburized layer is at most 10%.

14. The carburized and hardened member according to claim 11, **characterized in that** an internal structure of the carburized and hardened member is bainite.

15. The carburized and hardened member according to claim 11, **characterized in that** the carburized and hardened member is a carburized toothed gear.

FIG. 1

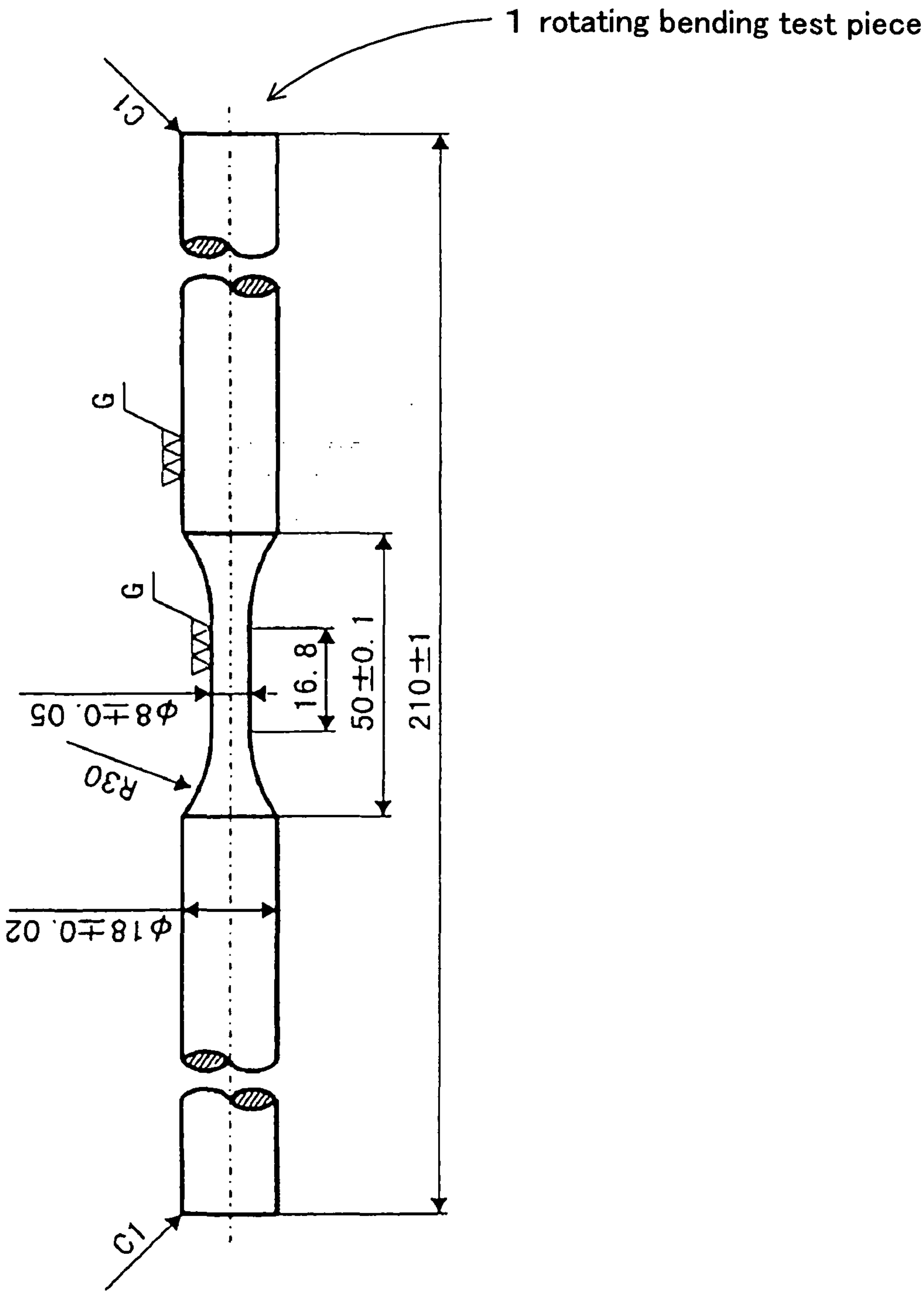
1 rotating bending test piece
C1
G
G
16.8
50±0.1
210±1
φ8±0.05
R30
φ18±0.02
C1

FIG. 2

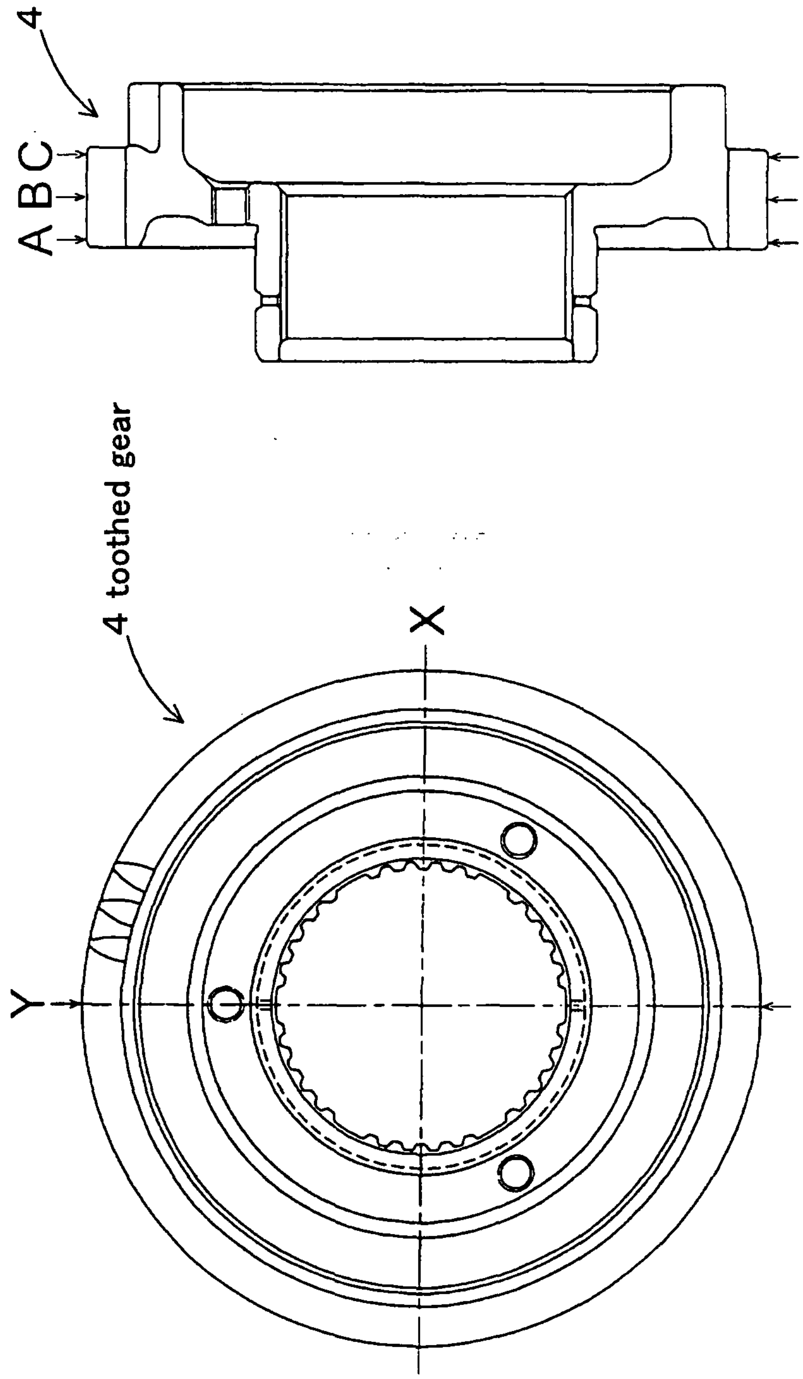

FIG. 2b

FIG. 2a

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP02/13561

A. CLASSIFICATION OF SUBJECT MATTER
Int.Cl[7] C23C8/22

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
Int.Cl[7] C23C8/22

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

Jitsuyo Shinan Koho	1922-1996	Toroku Jitsuyo Shinan Koho	1994-2003
Kokai Jitsuyo Shinan Koho	1971-2003	Jitsuyo Shinan Toroku Koho	1996-2003

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	JP 11-310824 A (Aisin AW Co., Ltd.), 09 November, 1999 (09.11.99), Claims; Par. Nos. [0011], [0014] to [0018]; Fig. 4 (Family: none)	1,4,5,7,11,15 2,3,6,8-10,12-14
Y	US 6258179 B1 (Komatsu Ltd.), 10 July, 2001 (10.07.01), Claims; column 10; table 1; Figs. 11, 18 & JP 11-117059 A	2,3,8-10,14
Y	JP 06-025736 A (Nissan Motor Co., Ltd.), 01 February, 1994 (01.02.94), Claim 1; tables 1, 2 (Family: none)	6,12

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search 05 March, 2003 (05.03.03)	Date of mailing of the international search report 18 March, 2003 (18.03.03)
Name and mailing address of the ISA/ Japanese Patent Office	Authorized officer
Facsimile No.	Telephone No.

Form PCT/ISA/210 (second sheet) (July 1998)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP02/13561

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP 04-032537 A (Nissan Motor Co., Ltd.), 04 February, 1992 (04.02.92), Claims; tables 1, 2 (Family: none)	6,12
Y	JP 09-256102 A (Sumitomo Metal Industries, Ltd.), 30 September, 1997 (30.09.97), Claim 1; table 4 (Family: none)	13

Form PCT/ISA/210 (continuation of second sheet) (July 1998)