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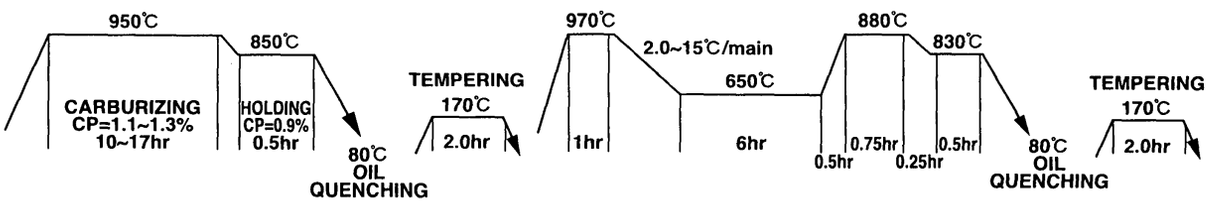
(54) Contact pressure-resistant member and method of making the same

(57) A contact pressure-resistant member including a rolling contact portion having a carbon concentration ranging from 0.8 to 1.2%. The contact pressure-resistant member is made of a steel material containing 0.15 to 0.40% by mass of C, 0.50 to 1.50% by mass of Si, 0.20 to 1.50% by mass of Mn, 0.50 to 1.50% by mass of Cr, and 0.05 to 0.50% by mass of Mo, 0.010% by mass or less of P, at least one element selected from the group consisting of 0.50 to 3.50% by mass of Ni, 0.03 to 0.20% by mass of Ti, 0.03 to 0.15% by mass of Nb and 0.01 to 0.10% by mass of Al, and the balance of Fe and inevitable impurities.

FIG.1A



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Description

BACKGROUND OF THE INVENTION

[0001] The present invention relates to an element useable as a power transmission part such as gears, bearings and rolling elements for a toroidal continuously variable transmission, which necessitates a high contact pressure strength. More specifically, this invention relates to a contact pressure-resistant member that is suitably used under relatively high contact pressure at a relatively high temperature ranging from about 120°C to about 300°C and in hydrogen generating atmosphere, and relates to a method of making the contact pressure-resistant member.

[0002] There have been proposed power transmission parts such as gears, bearings and rolling elements which are made of steels for machine structural use, for instance, JIS SCM420H (C: 0.17-0.23%, Si: 0.15-0.35%, Mn: 0.55-0.90%, P: not more than 0.030%, S: not more than 0.030%, Cr:0.85-1.25%, Mo: 0.15-0.35%, the substantial balance of Fe) and JIS SNCM420H. The power transmission parts are formed by forging and machining, and heat-treated by carburizing, nitriding and carbonitriding for providing enhanced surface fatigue strength, and then case-hardened by quenching and tempering.

[0003] Further, Japanese Patent Application First Publication No. 11-293392 discloses a carburized steel capable of preventing deterioration of its fatigue strength which is caused due to hydrogen. The steel material contains C: 0.10-0.40 wt %, Si: 0.05-0. 50 wt %, Mn: 0.2-2.0 wt %, Ti: 0.05-0.20 wt %, A1: 0.010-0.50 wt %, N: not more than 0.0120 wt % and O: not more than 0.12 ppm and the balance of Fe and inevitable impurities. If necessary, the steel material may further contain at least one element selected from the group consisting of Ni: 0.10-2.0 wt %, Cr: 0.20-2.0 wt %, and Mo: 0.05-1.0 wt %. The steel material has a microstructure in which Ti carbide and Ti carbonitride particles of not more than 70 nm in size are finely dispersed in the matrix. These precipitates trap hydrogen so that the steel material is improved in resistance to delayed fracture.

SUMMARY OF THE INVENTION

[0004] There is a demand to provide power transmission parts having reduced size and weight and therefore provide power transmission parts having improved surface fatigue strength for enduring an increase in contact pressure applied to the power transmission parts which is caused due to the size and weight reduction. Further, in recent years, a continuously variable transmission (CVT) using traction drive or friction drive is widely applied to automobiles for the purpose of meeting a public requirement to improve fuel economy. There is a demand to provide power transmission parts for use in the traction drive of the CVT which are enhanced in surface fatigue strength to meet a need for improvement in torque capacity.

[0005] During a relative rolling movement of power transmission parts under high contact pressure condition, a temperature rise occurs at a rolling contact portion of power transmission parts which is in rolling contact with a counterpart. In order to improve surface fatigue strength of the rolling contact portion of the parts, it is required to suppress internal structure change, namely, white etching constituent (WEC), which is caused in a high stress-exerted portion beneath the rolling contact portion due to rolling fatigue. At the same time, it is required to suppress deterioration of surface fatigue strength of the rolling contact portion of the parts which is caused due to infiltration of hydrogen into a material steel of the parts during the relative rolling movement therebetween. The deterioration of surface fatigue strength is hereinafter referred to as hydrogen embrittlement. The hydrogen is generated by chemical decomposition of components of lubricating oil used for the parts, and infiltrates into the material steel of the parts.

[0006] Conventionally, there have been proposed carburized steels capable of preventing softening of a hardened layer by increasing amounts of Si, Cr and Mo to be blended, in order to enhance surface fatigue strength. However, in a case where hydrogen infiltrates into the material steel, high surface fatigue strength cannot be maintained. Further, the conventionally proposed carburized steels has such a problem that hydrogen trapped by precipitates (trap site) containing Ti is dissociated therefrom in a relatively-high to high temperature range, and therefore, deterioration of surface fatigue strength cannot be sufficiently suppressed.

[0007] It has been difficult to prevent both of WEC and hydrogen embrittlement. As a result of studies on main causes of occurrence of the WEC and the hydrogen embrittlement, the following technical findings have been obtained.

(1) When a power transmission part is used at high contact pressure and in a relatively-high to high temperature range under condition that hydrogen is generated, wherein the power transmission part has a microstructure in which cementite precipitated by carburizing or carbonitriding remains at previous austenite grain boundaries in which amounts of Ni and Mn segregated are small in a microsegregation band of components appearing during cooling subsequent to forging, hydrogen can infiltrate to an interface between the cementite and the previous austenite grain boundaries are separated from each other by. This causes reduction and deterioration of surface fatigue strength of the power transmission part.

(2) In order to prevent the component segregation, a sum of the amounts of Ni and Mn to be added can be reduced. However, the component segregation cannot be completely avoided. Then, a suitable amount of Mo can be added, so that deterioration of interfacial cohesion of the previous austenite grain boundaries can be restrained.
(3) In order to prevent the cementite from remaining upon carburizing and carbonitriding, a suitable amount of Si as an element having a function of inhibiting carburizing, can be added depending upon an amount of Cr as an element forming a carbide.
(4) If a suitable amount of V is added, carbide and carbonitride containing V precipitated during heat treatment can strengthen a matrix. This produces an effect of suppressing the WEC and an effect of preventing deterioration caused due to the hydrogen embrittlement by more effectively trapping hydrogen than precipitates containing Ti.
(5) In the production process of the power transmission part, a whole carbon concentration, a carbon concentration allowing formation of a solid solution, and an area ratio and a mean particle diameter of the remaining carbide, can be controlled to suitable ranges. This suppresses the WEC without damaging the effect of preventing deterioration caused due to the hydrogen embrittlement.

[0008] An object of the present invention is to provide a contact pressure-resistant member for use in power transmissions including rolling elements such as gearings and bearings, and CVTs, which has excellent surface fatigue strength as compared to the conventionally proposed contact pressure-resistant members to thereby realize reduction of the size and weight and improvement in the torque capacity. Also, another object of the present invention is to provide a method of making the contact pressure-resistant member.

[0009] According to one aspect of the present invention, there is provided a contact pressure-resistant member, comprising:

a rolling contact portion having a carbon concentration ranging from 0.8 to 1.2%, the rolling contact portion being located on a surface of the contact pressure-resistant member and adapted to come into rolling contact with a counterpart,
the contact pressure-resistant member being made of a steel material containing 0.15 to 0.40% by mass of C, 0.50 to 1.50% by mass of Si, 0.20 to 1.50% by mass of Mn, 0.50 to 1.50% by mass of Cr, and 0.05 to 0.50% by mass of Mo, 0.010% by mass or less of P, at least one element selected from the group consisting of 0.50 to 3.50% by mass of Ni, 0.03 to 0.20% by mass of Ti, 0.03 to 0.15% by mass of Nb and 0.01 to 0.10% by mass of A1, and the balance of Fe and inevitable impurities.

[0010] According to a further aspect of the present invention, there is provided a method of making a contact pressure-resistant member having a rolling contact portion on a surface thereof, the rolling contact portion being adapted to come into rolling contact with a counterpart, the method comprising:

subjecting a workpiece made of a steel material containing 0.15 to 0.40% by mass of C, 0.50 to 1.50% by mass of Si, 0.20 to 1.50% by mass of Mn, 0.50 to 1.50% by mass of Cr, and 0.05 to 0.50% by mass of Mo, 0.010% by mass or less of P, at least one element selected from the group consisting of 0.50 to 3.50% by mass of Ni, 0.03 to 0.20% by mass of Ti, 0.03 to 0.15% by mass of Nb and 0.01 to 0.10% by mass of A1, and the balance of Fe and inevitable impurities, to either carburizing or carbonitriding to control a carbon concentration on a surface of the workpiece to a range of 0.8 to 1.2%; and
subjecting the workpiece to quenching and tempering.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] Figs. 1A to 1D are explanatory diagrams illustrating heat treatment patterns used in examples of the present invention.

[0012] Fig. 2 is a schematic diagram illustrating a thrust rolling fatigue tester used in examples of the present invention.

[0013] Fig. 3 is a schematic diagram illustrating a ball thrust bearing tester used in the examples of the present invention.

[0014] Figs. 4A and 4B are flowcharts illustrating a method of analyzing carbon concentration and nitrogen concentration, and a method of calculating a carbide area ratio and a mean carbide particle size, respectively.

DETAILED DESCRIPTION OF THE INVENTION

[0015] A contact pressure-resistant member of the present invention is made of a steel material containing 0.15 to 0.40% by mass of C, 0.50 to 1.50% by mass of Si, 0.20 to 1.50% by mass of Mn, 0.50 to 1.50% by mass of Cr, and

0.05 to 0.50% by mass of Mo, 0.010% by mass or less of P, at least one element selected from the group consisting of 0.50 to 3.50% by mass of Ni, 0.03 to 0.20% by mass of Ti, 0.03 to 0.15% by mass of Nb and 0.01 to 0.10% by mass of A1, and the balance of Fe and inevitable impurities. The contact pressure-resistant member has a rolling contact portion located on a surface thereof and adapted to come into rolling contact with a counterpart. The rolling contact portion has a carbon concentration ranging from 0.8 to 1.2%.

[0016] Further, in the steel material of the contact pressure-resistant member of the present invention, a concentration ratio Cr/Si between Cr and Si may be in a range of 0.8 to 2.0% by mass, and a concentration ratio (Mn+Ni)/Mo of Mn+Ni to Mo may be 20 or less.

[0017] Further, in the steel material of the contact pressure-resistant member of the present invention, a V content may be in the range of 0.05 to 0.5% by mass.

[0018] Functions and effects of these main elements contained in the steel material of the pressure-resistant member of the present invention is now explained. C forms a solid-solution with ferrite to thereby enhance strength of the steel material and ensure quenching hardness of the steel material. Si can act as a deoxidizing agent upon producing molten steel. Si increases hardenability of the steel material and maintains fatigue strength of the matrix under a relatively-high to high temperature condition. Si also enhances resistance to temper softening. Namely, Si inhibits deterioration of hardness of the steel material which is caused by tempering, to thereby improve fatigue strength of the steel material. Mn can act as a deoxidizing agent upon producing molten steel, and increase hardenability of the steel material. Cr increases hardenability and carburizing ability of the steel material. Mo increases hardenability of the steel material. P segregates along the previous austenite grain boundaries upon carburizing or carbonitriding to thereby reduce interfacial cohesion of the previous austenite grain boundaries.

[0019] Ni maintains surface fatigue strength of the steel material. Ti, Nb and A1 form precipitates for preventing coarse growth of crystal grains during carburizing or carbonitriding. Further, the precipitate containing Ti can trap hydrogen. V forms one or both of carbide and carbonitride during heat treatment and effectively acts for strengthening the matrix microstructure of the steel material of the members subjected to quenching and tempering, to thereby suppress WEC. The carbide and carbonitride of V more effectively traps hydrogen than the Ti-containing precipitate, and therefore, delays diffusion and accumulation of hydrogen in a stress-concentration portion of the members and prevents hydrogen embrittlement.

[0020] In order to obtain the above-described function and effect of C in the steel material of the contact pressure-resistant member of the present invention, the C content is controlled to the range of 0.15 to 0.40% by mass. The C content is preferably in the range of 0.16 to 0.40% by mass. If the C content is more than 0.40% by mass, the material will become too hard and thereby tends to be deteriorated in machinability. In order to obtain the above-described function and effect of Si in the steel material of the contact pressure-resistant member of the present invention, the Si content is controlled to the range of 0.50 to 1.50% by mass. The Si content is preferably in the range of 0.50 to 1.25% by mass. If the Si content is more than 1.25% by mass, the material will become too hard and thereby tends to be deteriorated in workability. In order to obtain the above-described function and effect of Mn in the steel material of the contact pressure-resistant member of the present invention, the Mn content is controlled to the range of 0.20 to 1.50% by mass. The Mn content is preferably in the range of 0.20 to 1.31% by mass. If the Mn content is more than 1. 31% by mass, the material will become too hard and thereby tends to be deteriorated in workability. Further, in the case where the Mn content is more than 1. 31% by mass, a transformation termination time in which the material is subjected to annealing will be prolonged so that the production cost will be increased. In order to obtain the above-described function and effect of Cr in the steel material of the contact pressure-resistant member of the present invention, the Cr content is controlled to the range of 0.50 to 1.50% by mass. The Cr content is preferably in the range of 0.50 to 1.31% by mass. If the Cr content is more than 1.31% by mass, the material will become too hard and thereby tends to be deteriorated in workability. In order to obtain the above-described function and effect of Mo in the steel material of the contact pressure-resistant member of the present invention, the Mo content is controlled to the range of 0.05 to 0.50% by mass. The Mo content is preferably in the range of 0.05 to 0.45% by mass. If the Mo content is more than 0.45% by mass, the material will become too hard and thereby tends to be deteriorated in workability. In view of the function of P as described above, the P content is limited to 0.010% by mass or less.

[0021] In order to obtain the above-described function and effect of Ni in the steel material of the contact pressure-resistant member of the present invention, the Ni content is controlled to the range of 0.50 to 3.50% by mass. The Ni content is preferably in the range of 0.50 to 3.00% by mass. If the Ni content is more than 3.00% by mass, the material will become too hard and thereby tends to be deteriorated in workability. Further, in order to obtain the above-described functions and effects of Ti, Nb and A1 in the steel material of the contact pressure-resistant member of the present invention, the Ti content is controlled to the range of 0.03 to 0.20% by mass, the Nb content is controlled to the range of 0.03 to 0.15% by mass, and the A1 content is controlled to the range of 0.01 to 0.10% by mass. If the Ti content, the Nb content and the A1 content are larger than the respective ranges, coarse precipitates will be grown to thereby cause deterioration in workability of the material. Here, if any one of Ni, Ti, Nb and A1 is selected, the content of the selected one must be controlled to the range described above. Further, a combination of Ni, Ti, Nb and Al can be used.

In such a case, the contents of the respective elements used in combination must be controlled to the range described above.

[0022] Further, in order to suppress WEC without deteriorating the effect of preventing hydrogen embrittlement in the steel material of the contact pressure-resistant member of the present invention, the C concentration of the rolling contact portion of the member must be controlled to the range of 0.8-1.2%. In addition, a total concentration of C and N of the rolling contact portion is preferably in the range of 0.8-1.2%. This can suppress the WEC without deteriorating the effect of preventing hydrogen embrittlement.

[0023] In the steel material of the contact pressure-resistant member of the present invention, the addition of Cr is essentially required as described above. As the addition amount of Cr increases, precipitation of cementite at the grain boundaries of austenite grains will remarkably occur during carburizing or carbonitriding. The precipitation of cementite can be avoided by adding Si that serves for suppressing carburizing ability or carbonitriding ability of the material. Therefore, it is preferred to control a concentration ratio Cr/Si between Cr and Si to the range of 0.8-2.0. Further, Mo exhibits an effect of preventing embrittlement that occurs in a region of the previous austenite grain boundaries where the amount of microsegregation of Mn and Ni is small. However, if a total content of Mn and Ni is too large relative to the Mo content, the effect of the Mo will not be exhibited. The concentration ratio (Mn + Ni)/Mo of Mn and Ni to Mo is preferably 20 or less. Furthermore, in order to obtain the above-described effect of V, the V content is preferably in the range of 0.05-0.40% by mass. If the V content is larger than the range, coarse precipitates will be grown in the matrix to thereby deteriorate workability of the material.

[0024] In the contact pressure-resistant member of the present invention, a concentration of carbon in the rolling contact portion which forms a solid solution of carbon and Fe may be in a range of 0.60 to 0.95% by mass. The concentration of carbon forming a solid solution of carbon and Fe is hereinafter referred to as a solid-solution carbon concentration. The solid-solution carbon concentration on the surface of the contact pressure-resistant member gives influences on the shape and grain size of a quenched structure, specifically, a martensite structure. Particularly, in order to suppress WEC, it is effective to produce a fine martensite structure containing a lath-shaped martensite and a lens-shaped martensite in a mixed state, by controlling the solid-solution carbon concentration to the range of 0.60 to 0.95% by mass. If the solid-solution carbon concentration is less than 0.60% by mass, the martensite structure is composed almost exclusively of the lath-shaped martensite so that the martensite structure is deteriorated in hardness due to a low hardness of the lath-shaped martensite. If the solid-solution carbon concentration is more than 0.95% by mass, the martensite structure is composed almost exclusively of the lens-shaped martensite so that the grain size of the martensite structure becomes coarse. As a result, in these cases where the solid-solution carbon concentration is out of the above-described range, WEC will occur, thereby causing deterioration of the rolling fatigue life of the contact pressure-resistant member. Here, the solid-solution carbon concentration (%) is calculated by the following formula (1). [carbon concentration (%) obtained by electron probe microanalyzer (EPMA)]-[carbide area ratio X 6.67 (%)]/ 100 ..... (1)

Meanwhile, the calculation of the solid-solution carbon concentration will be in detail explained later.

[0025] In the contact pressure-resistant member of the present invention, the surface of the contact pressure-resistant member may contain carbide particles or carbonitride particles having a mean particle diameter of 1.2 μm or less. In such a case, the carbide particles or carbonitride particles effectively trap hydrogen to thereby cause delay in diffusion and accumulation of hydrogen to a stress-concentration portion of the contact pressure-resistant member. This can suppress rolling fatigue of the contact pressure-resistant member which is caused by hydrogen. As a result of experiment made by the inventors, it was found that when the mean particle diameter of the carbide particles or carbonitride particles is larger than 1.2 μm, substantially no effect of suppression of the rolling fatigue is exhibited. Further, the surface of the contact pressure-resistant member may have a carbide area ratio of a carbide-precipitated portion to the whole surface, in a range of 2 to 8%. If the carbide area ratio lies within the above-specified range, a rolling fatigue life of the contact pressure-resistant member can be increased. If the carbide area ratio is out of the above-specified range, the effect of increasing the rolling fatigue life will not be exhibited.

[0026] In the contact pressure-resistant member of the present invention, the rolling contact portion may have a Ni plating layer on at least a part thereof. Namely, a part of the rolling contact portion or the whole rolling contact portion may be formed with the Ni plating layer. The Ni plating layer can prevent a neo-surface from being newly produced on the rolling contact portion by the catalytic action of a microscopic metal catalyst. In addition, the Ni plating layer can act as a protective coat protecting the rolling contact portion from hydrogen infiltration.

Hydrogen is generated by tribochemical reaction occurring during a relative rolling movement between the contact pressure-resistant member and a counterpart. The Ni plating layer can prevent the hydrogen from infiltrating into the matrix of the steel material. A thickness of the Ni plating layer is preferably in the range of 0.1 to 20 μm.

[0027] The contact pressure-resistant member may be applied to a rolling bearing for an automobile and a rolling element of a toroidal CVT.

[0028] Next, a method of making the above-described contact pressure-resistant member of the present invention, is explained. The contact pressure-resistant member has the rolling contact portion on the surface which is brought

into rolling contact with a counterpart during a relative rolling movement therebetween. The method includes: subjecting a workpiece made of a steel material containing 0.15 to 0.40% by mass of C, 0.50 to 1.50% by mass of Si, 0.20 to 1.50% by mass of Mn, 0.50 to 1.50% by mass of Cr, and 0.05 to 0.50% by mass of Mo, 0.010% by mass or less of P, at least one element selected from the group consisting of 0.50 to 3.50% by mass of Ni, 0.03 to 0.20% by mass of Ti, 0.03 to 0.15% by mass of Nb and 0.01 to 0.10% by mass of A1, and the balance of Fe and inevitable impurities, to either carburizing or carbonitriding to control a carbon concentration on a surface of the workpiece, to a range of 0.8 to 1.2%; and subjecting the workpiece to quenching and tempering. In this method, the carbon concentration on the surface of the workpiece, the solid-solution carbon concentration, and the carbide area ratio and the mean particle diameter of carbides can be respectively controlled to the desired ranges by carburizing or carbonitriding. The nitrogen concentration on the surface of the workpiece also can be controlled to the desired range by carbonitriding.

[0029] Further, the method may further include: holding at least a surface of the workpiece at a first temperature ranging from an Ac_1 transformation point to less than a temperature of an Acm transformation point plus 150°C, after the carburizing or carbonitriding; heating the workpiece to a second temperature ranging from 550°C to less than an Ar_1 transformation point, after holding the at least the surface of the workpiece at the first temperature; holding the workpiece at the second temperature; holding the workpiece at a third temperature ranging from the Ac_1 transformation point to less than the Acm transformation point; and subjecting the workpiece to rapid cooling. The method may further include forming a Ni plating layer on at least a part of the surface of the workpiece which is adapted to act as the rolling contact portion of the contact pressure-resistant member.

EXAMPLES

[0030] The present invention is described in more detail by way of examples and comparative examples by referring to the accompanying drawings. However, these examples are only illustrative and not intended to limit a scope of the present invention thereto.

Examples 1-12 and Comparative Examples 1-11

[0031] Sixteen specimens respectively made of steel materials 1-16 each having a chemical composition as shown in Table 1, were prepared in the following manner. The respective steel materials were formed into a disk shape for a thrust rolling test, as well as shapes of an inner race and an outer race of a thrust ball bearing, for a thrust ball bearing test. The disk-shaped specimen has a diameter of 60 mm and a thickness of 5 mm.

TABLE 1

Steel Material	Chemical Composition (mass %)							
	C	Si	Mn	Cr	Mo	Ni	Ti	Nb
	0.15-0.4	0.5-1.5	0.2-1.5	0.5-1.5	0.05-0.5	0.5-3.5	0.03-0.2	0.03-0.15
1	0.35	1.0	0.33	1.30	0.21	2.1	-	-
2	0.23	1.18	0.35	1.03	0.25	2.25	-	-
3	0.19	1.05	0.32	1.35	0.41	2.28	-	-
4	0.25	0.98	0.31	1.35	0.22	2.37	0.03	-
5	0.20	1.23	1.29	1.16	0.35	2.54	0.18	-
6	0.2	0.75	1.24	1.15	0.25	3.04	-	0.05
7	0.2	1.1	0.31	1.14	0.45	1.17	-	0.14
8	0.21	0.61	0.77	0.87	0.35	1.1	-	-
9	0.34	0.55	0.45	0.66	0.31	2.44	0.09	0.03
10	0.2	0.25	0.78	1.05	0.15	0	-	-
11	0.27	0.88	1.33	0.4	0.75	2.12	0.03	-
12	0.21	0.8	1.82	1.03	0.12	3.9	0.3	-
13	0.34	0.82	0.26	1.68	0.31	1.35	0.3	0.21
14	0.21	0.65	0.67	1.27	0.2	2.06	-	0.21
15	0.23	0.85	0.22	0.96	0.54	1.03	-	-
16	0.22	0.66	0.35	1.28	0.78	0.15	0.11	-

Steel Material	Chemical Composition (mass %)				
	Al	P	V	Cr/Si	(Mn+Ni)/Mo
	0.01-0.1	0.01 ↓	0.05-0.5	0.8-2.0	20↓
1	0.020	0.009	-	1.30	11.67
2	0.023	0.005	0.25	0.87	10.40
3	0.026	0.006	0.25	1.29	6.34
4	0.018	0.007	0.20	1.38	12.18
5	0.020	0.006	0.19	0.94	10.94
6	0.051	0.008	0.11	1.53	17.12
7	0.027	0.005	0.25	1.04	3.29
8	0.092	0.008	0.45	1.43	5.34
9	0.023	0.003	0.15	1.20	9.32
10	0.019	0.009	-	4.20	5.20
11	-	0.008	-	0.45	4.60
12	-	0.008	-	1.29	47.67
13	0.018	0.006	-	2.05	5.19
14	0.019	0.007	-	1.95	13.65
15	0.021	0.009	-	1.13	2.31
16	0.02	0.023	-	1.94	0.64

[0032] Next, the disk-shaped specimens and the inner and outer race-shaped specimens were subjected to carburizing or carbonitriding and quenching and tempering according to heat treatment patterns A-D as shown in Figs. 1A-1D. The heat treatment patterns will be explained in detail later. Then, a rolling contact portion on a surface of each of the specimens which come into rolling contact with a counterpart of a rolling fatigue tester as described later, was subjected to grinding and superfinishing to provide a surface roughness of about Ra 0.03 μm. Subsequently, if required, a Ni plating layer was formed on the rolling contact portion of the specimens in the following manner. First, in order to increase adhesion of the Ni plating layer to the matrix, a Ni strike plating coat is formed on the rolling contact portion

in Ni-based strike plating bath for 10 minutes at a current density of $2A/dm^2$. Subsequently, the Ni plating layer was formed on the Ni strike plating coat in a Ni-based plating bath for 10 minutes at a current density of $2A/dm^2$ until a thickness of the Ni plating layer reached 5 μm. Thus, the specimens were obtained.

[0033] Referring to Fig. 1A-1D, the heat treatment patterns A-D are explained. Figs. 1A-1D illustrate the heat treatment patterns A-D, respectively. In the heat treatment pattern A of Fig. 1A, carburizing is performed within a gas carburizing furnace under the following conditions: temperature of 950°C, carbon potential (CP) of 1.1-1.3%, and carburizing time of 10-17 hours. Next, the temperature is lowered to 850°C and held at 850°C for 0.5 hour at CP of 0.9%. Then, oil quenching is performed in a 80°C oil, followed by tempering at 170°C for 2 hours. Subsequently, the temperature is raised to 970°C in a vacuum atmosphere within a vacuum furnace and held at 970°C for 1 hour. The temperature is then lowered to 650°C at a rate of 2.0°C to 15.0°C per minute and held at 650°C for 6 hours. Thereafter, the temperature is raised to 880°C and held at 880°C for 0.75 hour, and then lowered to 830°C and held at 830°C for 0.5 hour. Oil quenching is performed in an oil at 80°C, followed by tempering at 170°C for 2 hours.

[0034] The heat treatment pattern B shown in Fig. 1B is the same as described in the heat treatment pattern A, except that, instead of carburizing, carbonitriding is performed within a gas carburizing furnace under the following conditions: temperature of 950°C, CP of 1.1-1.3%, NH_3 of 3 vol %, and carburizing time of 10-17 hours.

[0035] The heat treatment pattern C shown in Fig. 1C differs in heat treatment subsequent to the tempering after the holding at 850°C, from the heat treatment pattern A. As shown in Fig. 1C, subsequent to the tempering at 170°C after the holding at 850°C, the temperature is raised to 550°C in a vacuum atmosphere within a vacuum furnace and held at 550°C for 6 hours. Then, the temperature is raised to 880°C and held at 880°C for 0.75 hour, and then lowered to 830°C and held at 830°C for 0.5 hour. After that, oil quenching is performed in an oil at 80°C, followed by tempering at 170°C for 2 hours.

[0036] The heat treatment pattern D shown in Fig. 1D differs in heat treatment subsequent to the tempering after the holding at 850°C, from the heat treatment pattern A. As shown in Fig. 1D, subsequent to the tempering at 170°C after the holding at 850°C, the temperature is raised to 880°C and held at 880°C within a gas carburizing furnace at CP of 1.0% for 1 hour. Then, secondary oil quenching is performed in an oil at 80°C, followed by tempering at 170°C for 2 hours.

[0037] The steel materials, the heat treatment patterns and the Ni plating layer of the specimens used in Examples 1-12 and Comparative Examples 1-11 are shown in Table 2.

TABLE 2

	Steel Material	Heat Treatment	Ni Plating Layer	Surface C Concentration (%)	Surface N Concentration (%)	Mean Carbide Particle Diameter (μm)
Ex. 1	1	A	None	0.88	-	0.25
Ex. 2	2	A	None	0.92	-	0.22
Ex. 3	3	A	None	1.18	-	0.28
Ex. 4	1	A	Formed	1.05	-	0.21
Ex. 5	2	A	Formed	1.15	-	0.34
Ex. 6	3	A	Formed	1.11	-	0.24
Ex. 7	4	B	Formed	0.89	0.26	0.19
Ex. 8	5	B	Formed	0.87	0.29	0.16
Ex. 9	6	A	Formed	0.85	-	0.19
Ex. 10	7	A	Formed	1.05	-	0.18
Ex. 11	8	A	Formed	0.98	-	0.20
Ex. 12	3	D	Formed	1.15	-	2.9
Com. Ex. 1	10	A	None	1.15	-	0.21
Com. Ex. 2	10	A	Formed	1.08	-	0.19
Com. Ex. 3	11	A	Formed	1.12	-	0.18
Com. Ex. 4	12	A	Formed	1.13	-	0.24
Com. Ex. 5	13	A	Formed	1.10	-	2.89
Com. Ex. 6	14	A	Formed	1.26	-	3.11
Com. Ex. 7	15	A	Formed	1.03	-	3.09
Com. Ex. 8	16	A	Formed	1.01	-	0.25
Com. Ex. 9	3	A	Formed	1.32	-	2.34
Com. Ex. 10	11	C	Formed	1.08	-	0.22
Com. Ex. 11	11	C	Formed	0.89	-	0.21

TABLE 2 (continued)

	Carbide Area Ratio (%)	Solid-Solution Carbon Concen-tration (%)	WEC Life (cycle)	Hydrogen Embrittlement Life (cycle)
Ex. 1	4.55	0.60	7.00E+06	2.50E+07
Ex. 2	5.14	0.61	1.10E+07	3.40E+07
Ex. 3	8.35	0.68	1.90E+07	2.30E+07
Ex. 4	5.67	0.71	2.10E+07	2.90E+08
Ex. 5	5.29	0.84	4.80E+07	3.60E+08
Ex. 6	6.22	0.74	5.30E+07	3.20E+08
Ex. 7	4.67	0.61	5.40E+07	3.90E+08
Ex. 8	3.83	0.64	5.50E+07	4.00E+08
Ex. 9	2.58	0.70	5.30E+07	3.90E+08
Ex. 10	2.12	0.93	5.20E+07	4.20E+08
Ex. 11	1.99	0.86	4.30E+07	4.60E+08
Ex. 12	10.2	0.52	2.20E+06	3.30E+06
Com. Ex. 1	3.72	0.94	3.40E+06	1.30E+06
Com. Ex. 2	2.45	0.94	3.50E+06	1.40E+07
Com. Ex. 3	1.45	1.04	1.20E+06	5.50E+07
Com. Ex. 4	4.2	0.89	8.75E+05	3.50E+06
Com. Ex. 5	9.6	0.51	7.50E+06	8.90E+06
Com. Ex. 6	12.1	0.52	8.20E+06	9.80E+06
Com. Ex. 7	9.9	0.41	8.40E+06	1.05E+07
Com. Ex. 8	8.2	0.46	6.50E+06	4.80E+06
Com. Ex. 9	12.3	0.57	8.80E+06	3.40E+06
Com. Ex. 10	2.51	0.94	9.70E+06	4.60E+08
Com. Ex. 11	2.75	0.73	5.60E+07	4.20E+08

Evaluation of Performance

[0038] The thus-prepared specimens were set to a thrust rolling fatigue tester and a thrust ball bearing tester and subjected to rolling fatigue test under the following conditions to evaluate the rolling fatigue life.

WEC Test

[0039]

Testing Machine : Thrust rolling fatigue tester
Contact Pressure : 5.2 GPa
Maximum Shearing Stress Depth: 0.1 mm from outer surface Lubricating Oil : Traction oil
Lubricating Oil Temperature: 150°C
Revolution Number : 2000 rpm
Counterpart Steel Ball: 3 balls, made of SUJ2 steel carbonitrided and having 3/8-inch diameter

Hydrogen Embrittlement Test

[0040]

Testing Machine : Thrust ball bearing tester
Contact Pressure : 3.6 GPa
Maximum Shearing Stress Depth: 0.3 mm from outer surface
Lubricating Oil : Traction oil
Lubricating Oil Temperature: 150°C
Revolution Number : 6000 rpm
Counterpart Steel Ball: 12 balls, made of SUJ2 steel carbonitrided and having 3/8-inch diameter

[0041] The evaluation of the rolling fatigue life was conducted using a vibration sensor to detect vibrations during rolling of the specimens, and measuring a time elapsed until flaking was caused on the disk-shaped specimen and either one of the inner race- and outer race-shaped specimens. When flaking was caused on power rollers of the testers during the rolling fatigue test, the power rollers were replaced with new ones and the rolling fatigue test was continued.

[0042] Fig. 2 shows the thrust rolling fatigue tester 1 to which disk-shaped specimen 10 is set to undergo the rolling fatigue test. In Fig. 2, arrow A indicates a direction of compressive load. Fig. 3 shows thrust ball bearing tester 2 to which inner race-shaped specimen 20 and outer race-shaped specimen 30 is set to undergo the rolling fatigue test. In Fig. 3, arrow B indicates a direction of supply of lubricating oil. In the rolling fatigue test using each of thrust rolling fatigue tester 1 and thrust ball bearing tester 2, it was found that slide occurred at an end portion of a rolling contact ellipse to some extent, and flaking caused by WEC and flaking caused by hydrogen embrittlement were distinguished from each other with high probability on the basis of the slide ratio. Specifically, in thrust rolling fatigue tester 1 shown in Fig. 2, the slide ratio at the end portion of the rolling contact ellipse was small so that the flaking due to WEC occurred. In contrast, in thrust ball bearing tester 2 shown in Fig. 3, the slide ratio at the end portion of the rolling contact ellipse was remarkably large so that the flaking due to hydrogen embrittlement occurred. Accordingly, the rolling fatigue test using thrust rolling fatigue tester 1 is hereinafter referred to as WEC rolling fatigue test, and the rolling fatigue test using thrust ball bearing tester 2 is hereinafter referred to as hydrogen-embrittlement rolling fatigue test.

[0043] After the WEC rolling fatigue test and the hydrogen-embrittlement rolling fatigue test, the specimens were subjected to measurements of surface carbon concentration (%), surface nitrogen concentration (%), mean carbide particle diameter (μm), carbide area ratio (%) and solid-solution carbon concentration (%) in a surface portion of each of the specimens. The surface carbon concentration and the surface nitrogen concentration were determined by a method of analyzing carbon concentration and nitrogen concentration. The mean carbide particle diameter and the carbide area ratio were determined by a method of calculating the mean carbide particle diameter and the carbide area ratio.

[0044] Referring to Fig. 4A, a flow of the method of analyzing carbon concentration and nitrogen concentration is explained. As illustrated in Fig. 4A, first, the specimen was cut. Subsequently, a surface of a cross section of the specimen cut was polished and then subjected to EPMA analysis. The EPMA analysis was conducted over a region extending from the cross sectional surface of the specimen to 0.1 mm in depth.

[0045] Referring to Fig. 4B, a flow of the method of calculating the mean carbide particle diameter and the carbide area ratio is explained. As illustrated in Fig. 4B, first, the specimen was cut vertically, and then a surface of the vertical cross section of the specimen was polished. Subsequently, the cross sectional surface of the specimen was subjected to etching with an etchant composed of 3% nitric acid alcohol solution. A region of the cross sectional surface was observed using a scanning electron microscope (SEM) at the magnification of 10,000. The region had a depth of 0.1 mm from the outer surface of the specimen. The observation was conducted over the depth at intervals of 0.01 mm. Eleven fields of view were photographed, and then the photograph was subjected to image analysis. Subsequently, a mean carbide particle size and a carbide area ratio of a carbide-precipitated portion to the whole region were calculated.

The calculation results were applied to the above-described formula (1) to determine solid-solution carbon concentration in the carburized surface portion of the specimen. The results of the calculations were shown in Table 2. In Table 2, for instance, the mathematical expression "7.00E+07" used in the columns of "WEC Life" and "Hydrogen Embrittlement Life", indicates "7.00 X 10^7".

[0046] As shown in Table 2, in Examples 1-11, the specimens were made of steel materials 1-8. Specifically, as shown in Table 1, the steel materials 1-8 contain 0.15 to 0.40% by mass of C, 0.50 to 1.50% by mass of Si, 0.20 to 1.50% by mass of Mn, 0.50 to 1.50% by mass of Cr, and 0.05 to 0.50% by mass of Mo, 0.010% by mass or less of P, at least one element selected from the group consisting of 0.50 to 3.50% by mass of Ni, 0.03 to 0.20% by mass of Ti, 0.03 to 0.15% by mass of Nb and 0.01 to 0.10% by mass of A1, and the balance of Fe and inevitable impurities. The specimens were subjected to the heat treatment pattern A or B. As a result, fine carbide particles having a mean particle diameter of 1.2 μm or less were precipitated and the carbide area ratio was 2 to 8%. Further, the solid-solution carbon concentration in the matrix was in the range of 0.6-0.95% by mass. Generation of a WEC-type structural change was considerably delayed. This was able to increase the rolling fatigue lives of the specimens. Further, in Examples 4-12, the rolling contact portions of the specimens had the Ni plating layer, whereby hydrogen infiltration into the matrix was suppressed and generation of the hydrogen embrittlement-type structural change was delayed. This was able to enhance the rolling fatigue lives of the specimens. Further, in Examples 4-12, the specimens were made of the steel materials 1-8 which contained a combination of Ti, Nb or V or the increased amount thereof. This caused increase in amount of fine carbide particles precipitated or nitride particles precipitated, thereby preventing crystal grains from coarsely growing during the heat treatment and enhancing the function of trapping hydrogen during the rolling fatigue test. This was able to increase the flaking lives of the specimens in both of the WEC rolling fatigue test and the hydrogen embrittlement rolling fatigue test.

[0047] In Example 12, the specimens were made of steel material 3 and subjected to the heat treatment pattern D. In this case, $M_{23}C_6$ carbide was not precipitated because of a small amounts of Cr and Mo contained in the steel material.

[0048] In contrast, in Comparative Examples 1-9, the specimens were subjected to the heat treatment pattern A. In this case, the specimens were held at the temperature ranging from the Ac_1 transformation point to less than the temperature of the Acm transformation point plus 150°C, where $M_{23}C_6$ carbide was precipitated, and then heated to the temperature ranging from 550°C to less than the Ar_1 transformation point and held at the temperature ranging from 550°C to less than the Ar_1 transformation point. As a result, M_3C carbide was coarsely precipitated at grain boundaries, and therefore, the flaking lives of the specimens were not remarkably improved in the WEC rolling fatigue test. Even when the specimens had the Ni plating layer in Comparative Examples 2-9, the flaking lives of the specimens were not greatly improved in the hydrogen embrittlement rolling fatigue test.

[0049] In Comparative Examples 1-2, the specimens were made of steel material 10 which had the Si content of less than 0.5% by mass as shown in Table 1. In these cases, the resistance to temper softening was reduced. Therefore, the flaking lives of the specimens were reduced in a relatively-high to high temperature condition in the WEC rolling fatigue test. In Comparative Example 3, the specimens were made of steel material 11 which had the Cr content of less than 0.5% by mass and the concentration ratio Cr/Si of less than 0.8% as shown in Table 1. The specimens had a small amount of carbide precipitated and a solid-solution carbon concentration of more than 0.95%. In this case, the flaking lives of the specimens were reduced in the WEC rolling fatigue test. In Comparative Example 4, the specimens were made of steel material 12 which had a concentration ratio (Mn+Ni)/Mo of more than 20 as shown in Table 1. Therefore, the amount of microsegregation of Mn and Ni became too large relative to Mo. Crack occurred from the segregation boundary of Mn and Ni upon high pressure being applied to the rolling contact portions of the specimens. As a result, the flaking lives of the specimens were reduced in both of the WEC rolling fatigue test and the hydrogen embrittlement rolling fatigue test.

[0050] In Comparative Examples 5-7, the specimens were made of steel materials 13-15 which had a Ti content, a Nb content or an Al content larger than the specified range of the present invention as shown in Table 1. In these cases, coarse particles of carbide or nitride were precipitated along grain boundaries. The solid-solution carbon concentration was less than 0.6%, and therefore, the flaking lives of the specimens were not greatly improved in both of the WEC rolling fatigue test and the hydrogen embrittlement rolling fatigue test. In Comparative Example 8, the specimens were made of steel material 16 which had a P content of more than 0.01% by mass as shown in Table 1. In this case, the amount of P segregated along grain boundaries was increased. Therefore, the flaking lives of the specimens were reduced in the hydrogen embrittlement rolling fatigue test.

[0051] In Comparative Example 9, the specimens were made of steel material 3 having the specified composition of the present invention, but the carbon concentration in the rolling contact portion thereof was more than 1.2%. In this case, coarse particles of carbide were precipitated along grain boundaries, and the solid-solution carbon concentration was reduced. As a result, the flaking lives of the specimens were reduced in both of the WEC rolling fatigue test and the hydrogen embrittlement rolling fatigue test.

[0052] In Comparative Examples 10-11, the specimens were made of steel material 11 which composition was out

of the range specified by the present invention as shown in Table 1, but the rolling contact portion thereof had a carbon concentration of 0.8-1.2% by using the heat treatment pattern C. As compared to the heat treatment pattern A, in the heat treatment pattern C, the step of holding at 970°C after carburizing, quenching and tempering was omitted. In this case, the M_3C carbide precipitated along grain boundaries during the primary carburizing and quenching step, made it difficult to form the solid solution in the matrix again. Therefore, the carbon concentration at and near grain boundaries became larger than that within the crystal grain, so that $M_{23}C_6$ carbide was able to be readily precipitated at and near the grain boundaries. This caused excessive trap of hydrogen infiltrating into the grain boundaries, so that the flaking lives of the specimens were relatively reduced in the hydrogen embrittlement rolling fatigue test. Further, in this case, the $M_{23}C_6$ carbide was not readily recrystallized, and therefore, the crystal grains were kept coarse. As a result, the flaking lives of the specimens were relatively reduced in the WEC rolling fatigue test.

[0053] This application is based on a prior Japanese Patent Application No. 2003-209275 filed on August 28, 2003, the entire contents of which are hereby incorporated by reference.

[0054] Although the invention has been described above by reference to certain examples of the invention, the invention is not limited to the examples described above. Modifications and variations of the examples described above will occur to those skilled in the art in light of the above teachings. The scope of the invention is defined with reference to the following claims.

Claims

1. A contact pressure-resistant member, comprising:

   a rolling contact portion having a carbon concentration ranging from 0.8 to 1.2%, the rolling contact portion being located on a surface of the contact pressure-resistant member and adapted to come into rolling contact with a counterpart,
   the contact pressure-resistant member being made of a steel material containing 0.15 to 0.40% by mass of C, 0.50 to 1.50% by mass of Si, 0.20 to 1.50% by mass of Mn, 0.50 to 1.50% by mass of Cr, and 0.05 to 0.50% by mass of Mo, 0.010% by mass or less of P, at least one element selected from the group consisting of 0.50 to 3.50% by mass of Ni, 0.03 to 0.20% by mass of Ti, 0.03 to 0.15% by mass of Nb and 0.01 to 0.10% by mass of Al, and the balance of Fe and inevitable impurities.

2. The contact pressure-resistant member as claimed in claim 1, wherein the steel material contains 0.16 to 0.40% by mass of C.

3. The contact pressure-resistant member as claimed in claim 1, wherein the steel material contains 0.50 to 1.25% by mass of Si.

4. The contact pressure-resistant member as claimed in claim 1, wherein the steel material contains 0.20 to 1.31% by mass of Mn.

5. The contact pressure-resistant member as claimed in claim 1, wherein the steel material contains 0.50 to 1.31% by mass of Cr.

6. The contact pressure-resistant member as claimed in claim 1, wherein the steel material contains 0.05 to 0.45% by mass of Mo.

7. The contact pressure-resistant member as claimed in claim 1, wherein the steel material contains 0.50 to 3.00% by mass of Ni.

8. The contact pressure-resistant member as claimed in any one of claims 1-7, wherein a concentration ratio Cr/Si between Cr and Si is in a range of 0.8 to 2.0% by mass, and a concentration ratio (Mn+Ni)/Mo of Mn and Ni to Mo is 20 or less.

9. The contact pressure-resistant member as claimed in any one of claims 1-8, wherein the steel material further comprises 0.05 to 0.5% by mass of V.

10. The contact pressure-resistant member as claimed in any one of claims 1-9, wherein the rolling contact portion has a concentration of carbon forming a solid solution of carbon and Fe, in a range of 0.60 to 0.95% by mass.

11. The contact pressure-resistant member as claimed in any one of claims 1-10, wherein the rolling contact portion has a total concentration of carbon plus nitrogen which ranges from 0.8 to 1.2%.

12. The contact pressure-resistant member as claimed in any one of claims 1-11, wherein the surface of the contact pressure-resistant member contains carbide particles having a mean particle diameter of 1.2 μm or less.

13. The contact pressure-resistant member as claimed in any one of claims 1-12, wherein the surface of the contact pressure-resistant member has a carbide area ratio of 2 to 8%.

14. The contact pressure-resistant member as claimed in any one of claims 1-13, wherein the rolling contact portion comprises a Ni plating layer formed on at least a part thereof.

15. The contact pressure-resistant member as claimed in claim 14, wherein the Ni plating layer has a thickness of 0.1 to 20 μm.

16. The contact pressure-resistant member as claimed in any one of claims 1-15, wherein the contact pressure-resistant member is adapted for use in a rolling contact for an automobile.

17. The contact pressure-resistant member as claimed in any one of claims 1-15, wherein the contact pressure-resistant member is adapted for use in a rolling element of a toroidal continuously variable transmission.

18. A method of making a contact pressure-resistant member having a rolling contact portion on a surface thereof, the rolling contact portion being adapted to come into rolling contact with a counterpart, the method comprising:

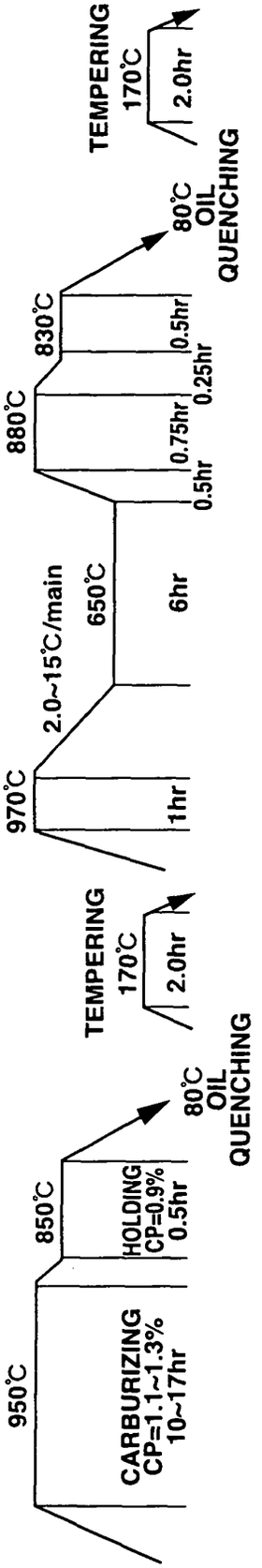
subjecting a workpiece made of a steel material containing 0.15 to 0.40% by mass of C, 0.50 to 1.50% by mass of Si, 0.20 to 1.50% by mass of Mn, 0.50 to 1.50% by mass of Cr, and 0.05 to 0.50% by mass of Mo, 0.010% by mass or less of P, at least one element selected from the group consisting of 0.50 to 3.50% by mass of Ni, 0.03 to 0.20% by mass of Ti, 0.03 to 0.15% by mass of Nb and 0.01 to 0.10% by mass of Al, and the balance of Fe and inevitable impurities, to either carburizing or carbonitriding to control a carbon concentration on a surface of the workpiece to a range of 0.8 to 1.2%; and
subjecting the workpiece to quenching and tempering.

19. The method as claimed in claim 18, further comprising:

holding at least the surface of the workpiece at a first temperature ranging from an Ac_1 transformation point to less than a temperature of an Acm transformation point plus 150°C, after the carburizing or carbonitriding;
heating the workpiece to a second temperature ranging from 550°C to less than an Ar_1 transformation point, after holding the at least the surface of the workpiece at the first temperature;
holding the workpiece at the second temperature;
holding the workpiece at a third temperature ranging from the Ac_1 transformation point to less than the Acm transformation point; and
subjecting the workpiece to rapid cooling.

20. The method as claimed in claim 18 or 19, further comprising forming a Ni plating layer on at least a part of the surface of the workpiece which is adapted to act as the rolling contact portion of the contact pressure-resistant member.

FIG.1A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10~17hr
850℃
HOLDING
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0.5hr
80℃
OIL
QUENCHING
TEMPERING
170℃
2.0hr
970℃
1hr
2.0~15℃/main
650℃
6hr
880℃
0.5hr
0.75hr
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OIL
QUENCHING
TEMPERING
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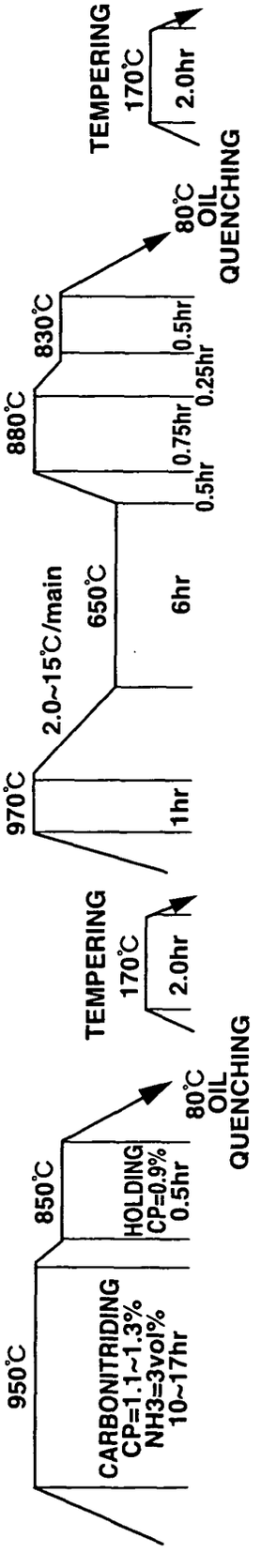
2.0hr

FIG.1B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10~17hr
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80℃
OIL
QUENCHING
TEMPERING
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2.0hr
970℃
1hr
2.0~15℃/main
650℃
6hr
880℃
0.5hr
0.75hr
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TEMPERING
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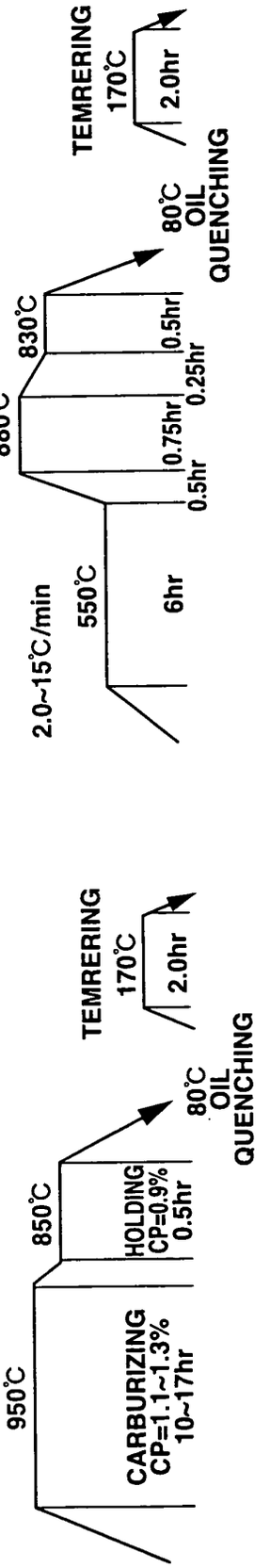
FIG.1C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CARBURIZING
CP=1.1~1.3%
10~17hr
850℃
HOLDING
CP=0.9%
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80℃
OIL
QUENCHING
TEMRERING
170℃
2.0hr
2.0~15℃/min
550℃
6hr
880℃
0.5hr
0.75hr
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TEMRERING
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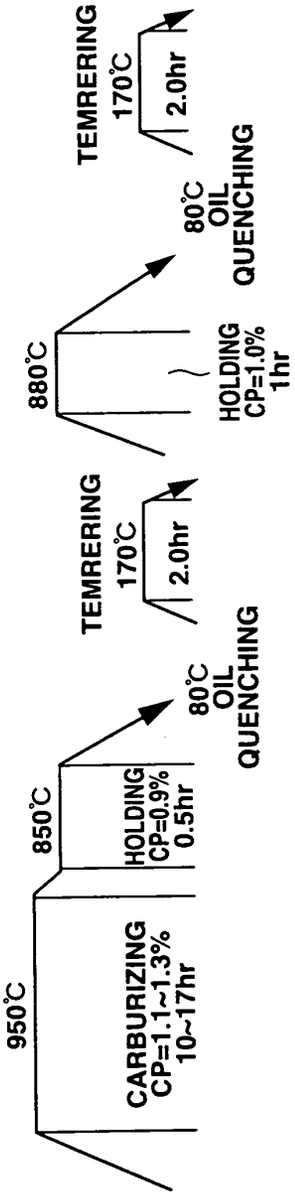
FIG.1D


950℃
CARBURIZING
CP=1.1~1.3%
10~17hr
850℃
HOLDING
CP=0.9%
0.5hr
80℃
OIL
QUENCHING
TEMRERING
170℃
2.0hr
880℃
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1hr
80℃
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QUENCHING
TEMRERING
170℃
2.0hr

FIG.2

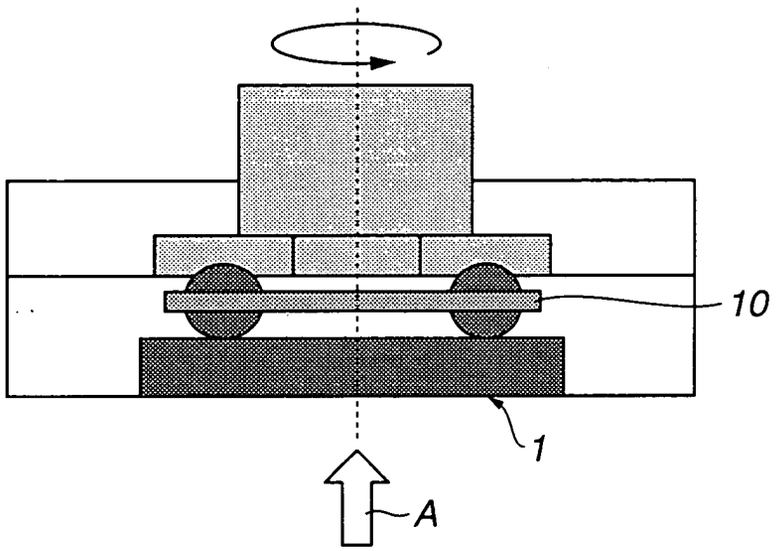


FIG.3

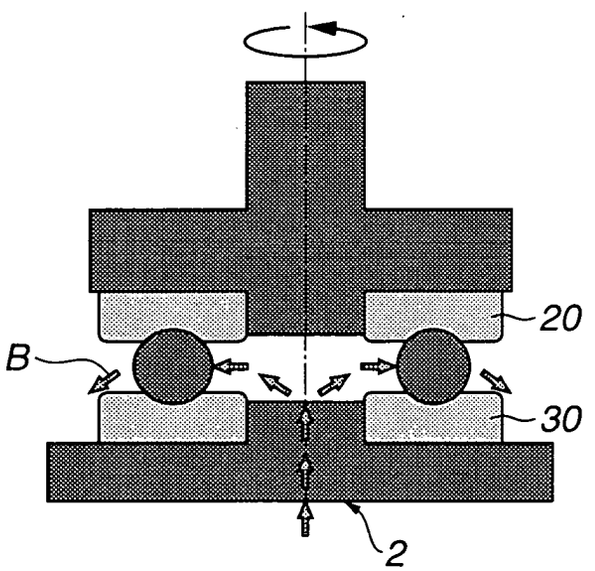


FIG.4A

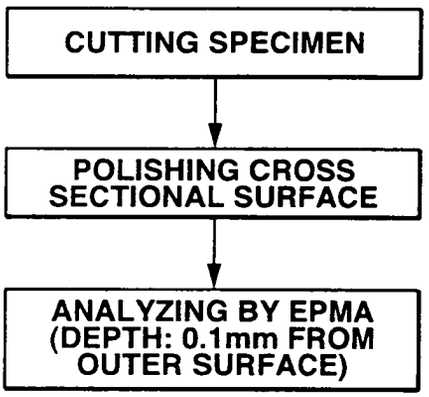
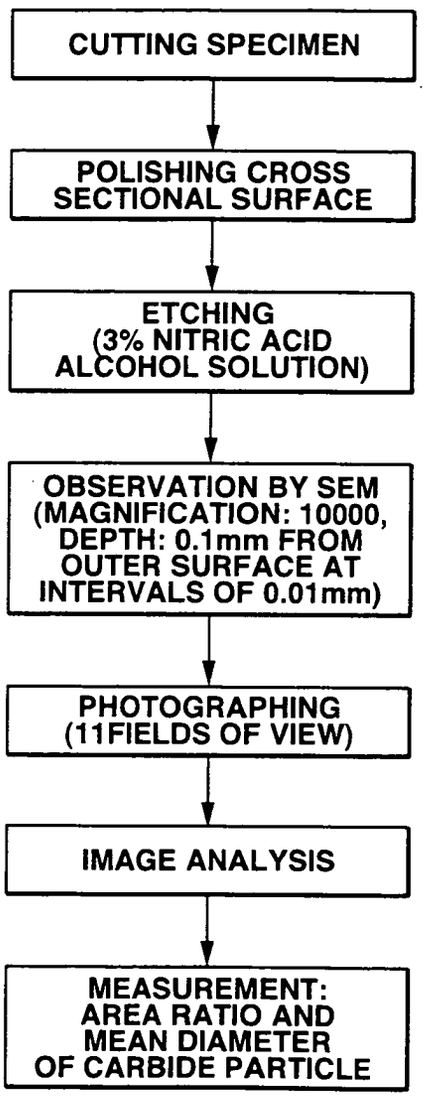

CUTTING SPECIMEN
POLISHING CROSS SECTIONAL SURFACE
ANALYZING BY EPMA (DEPTH: 0.1mm FROM OUTER SURFACE)

FIG.4B


CUTTING SPECIMEN
POLISHING CROSS SECTIONAL SURFACE
ETCHING (3% NITRIC ACID ALCOHOL SOLUTION)
OBSERVATION BY SEM (MAGNIFICATION: 10000, DEPTH: 0.1mm FROM OUTER SURFACE AT INTERVALS OF 0.01mm)
PHOTOGRAPHING (11FIELDS OF VIEW)
IMAGE ANALYSIS
MEASUREMENT: AREA RATIO AND MEAN DIAMETER OF CARBIDE PARTICLE

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 04 01 9630

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	25 November 2004	Gavriliu, A

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