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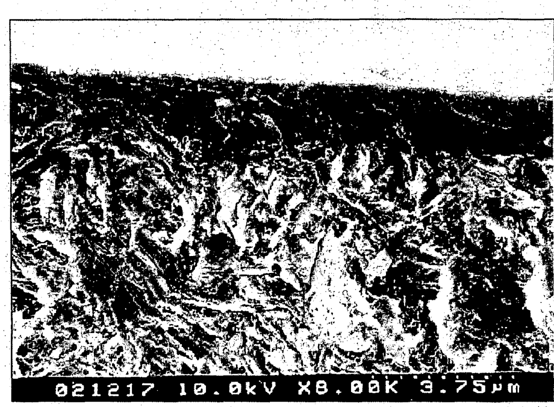
(54) NITRIDED VALVE LIFTER AND METHOD FOR MANUFACTURE THEREOF

(57) A sliding surface (2) of a valve lifter (1) or a shim (3) is subjected to a gaseous nitriding to have a surface hardness of Hv 660 or higher and a thickness of a compound layer (6) of 1 to 5 μm. The nitrided layer on the surface is a dense compound layer (6) with a porosity of 5 % or less.

FIG. 3



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Description

TECHNICAL FIELD

[0001] The present invention relates to a valve lifter which is a valve driving component, subjected to nitriding, of an internal combustion engine, and a producing method thereof, and further relates to a combination of the valve lifter and a cam.

BACKGROUND ART

[0002] Referring to Fig. 10, in a direct drive valve actuating system 10 of an internal combustion engine, a valve lifter 1 for converting a rotating motion of a cam 11 into a reciprocating motion of a valve 12 is subjected to a sliding contact in a reciprocating motion with a cylinder block 14 and a shim 3 or an upper surface 2 (cf. Fig. 1) of the valve lifter coming into contact with the cam 11 is subjected to a sliding contact under a high load and an impact load, so that an improvement in a wear resistance and an impact resistance is indispensable. On the other hand, the surface roughness of sliding surface of the cam 11 of which a material has a wear resistance and an impact resistance properties has to be improved to reduce an attacking nature against the valve lifter due to avoiding a boundary lubricating condition.

[0003] A nitriding process has been commonly employed as a simple method for improving the wear resistance of the valve lifter 1, but a compound layer (also called a white layer by those skilled in the art) formed on the outermost surface by nitriding, having a high hardness but being also very brittle, has been removed by grinding, polishing or the like, whereby a nitriding diffusion layer only is left for use.

[0004] However, the characteristics of the compound layer having a high hardness and a low friction coefficient are attracting attention as a measure for meeting recent requirements for a higher power or a lower fuel consumption of the internal combustion engine, and a sliding component specification, in which a compound layer is left even after a polishing for reducing friction on the upper surface 2 of the valve lifter 1 in sliding contact with the cam 11, and a producing method thereof is proposed and disclosed for example in JP-A No. 2002-97563.

[0005] However, in the sliding component and the producing method thereof as disclosed in JP-A No. 2002-97563 employs a prior nitriding process; whereby a compound layer having a brittle surface layer with deteriorated surface roughness is formed relatively thick (5 to 15 μm) in the nitriding process, and relatively large deformation is occurred in the processed articles. Consequently it is necessary to improve the surface roughness while leaving the compound layer in a subsequent step, and there is required a very difficult and unstable polishing process of making a thin compound layer further thinner.

[0006] An ordinarily employed process for forming the compound layer, such as a gaseous soft nitriding, is generally conducted for several hours at about 570°C aiming at a formation of compound layer of about 10 μm. However such process forms a porous layer and is associated with drawbacks not only of forming a brittle ε-phase ($Fe_{2-3}N$) but also of causing a large deformation in a processed article and a significant deterioration in a surface roughness. In the nitriding as before mentioned above, the compound layer is composed of a porous ε-phase ($Fe_{2-3}N$) of the outermost surface (porous layer), and a dense γ'-phase (Fe_4N) and/or a mixed phase of ε-phase and γ'-phase (ε+γ' phase) under the porous layer. These dense γ'-phase and/or mixed ε+γ' phase are relatively large columnar crystals oriented almost perpendicular to the surface.

[0007] In such nitriding process, as the surface roughness significantly influences the wear of a counterpart material, a polishing process after the nitriding is indispensable in order to reduce an attacking nature against the counterpart material, but a polishing margin has to be selected relatively large since the porous layer has an uneven thickness. Also since a uniform polishing is difficult to achieve for example because of an unevenness in the hardness, the porous layer may still remain after the polishing. In the upper surface of the valve lifter in a sliding contact under a high load and an impact load, the state, in which the porous layer is remained on the upper surface, results in a peeling or falling off of it, thus leading to a trouble.

[0008] JP-A No. 2002-97563 discloses polishing means such as buffing for eliminating the porous layer and for controlling a thickness and a surface roughness of the compound layer. However, since the compound layer is composed of an ε-phase ($Fe_{2-3}N$), a dense γ'-phase (Fe_4N), and a mixed ε+γ' phase, and it is difficult to do a uniform polishing because of a phase distribution and a hardness variation, there tend to be given a portion where the compound layer is completely removed and a portion where the compound layer still remains within a same polished surface, so that a compound layer with uniform thickness cannot be obtained. Consequently there are encountered such drawbacks that the wear resistance varies and an effect of reducing the frictional torque cannot be obtained.

[0009] Also even in case a uniform compound layer is obtained by a polishing in keeping with a surface undulation as disclosed in JP-A No. 2002-97563, an improvement in the surface roughness is still insufficient. Also the aforementioned polishing process is very costly.

[0010] Regarding the cam in sliding contact with the valve lifter, on the other hand, the ground surface roughness of the sliding surface (of the cam) is relatively rough so that it causes deterioration in a surface roughness of the brittle compound layer of the upper surface. Thus, expensive equipments for paper-lapping machine, etc. and long machining time resulting in the high cost are required in order to reduce the frictional torque from the beginning of the operation and to avoid an unstable boundary lubricating condition. These are drawbacks.

DISCLOSURE OF THE INVENTION

[0011] An object of the present invention is to solve the aforementioned drawbacks, i.e., it is to provide a valve lifter in which a uniform and dense nitriding compound layer of a high wear resistance is formed on a surface, and a producing method thereof bringing about little deterioration in the surface roughness and little deformation in the processed article by the nitriding process and not requiring a polishing process for improving a wear resistance, a surface roughness and a dimensional accuracy. Furthermore, the object of the present invention is to provide a valve lifter, which is used in combination with the cam of which the sliding surface is not polished by the paper-lapping machine, etc.

MEANS FOR SOLVING THE PROBLEMS

[0012] In a nitrided layer, there are generally formed, in layered manner, a diffusion layer of a relatively low nitrogen concentration and a compound layer of a high nitrogen concentration. A high nitriding temperature forms a thick compound layer with a brittle porous outermost surface. Although the brittle porous layer can be minimized by adopting a lower nitriding temperature, the diffusion layer also becomes thin in such case. As the diffusion layer in the valve lifter requires a thickness of 50 to 100 μm, it is desirable to obtain such diffusion layer of 50 to 100 μm as mentioned above and a compound layer of dense and a predetermined surface roughness showing high hardness and low frictional coefficient.

[0013] As a result of an intensive investigation, the present inventors have found that the valve lifter with improved surface roughness and good wear resistance of the upper surface after nitriding can be obtained by improving surface roughness of that before nitriding, and by suppressing growth of the compound layer in the nitriding process. The present inventors have further found that the combination of the valve lifter aforementioned and the cam improves the surface roughness of the cam in running-in without costly polishing of paper-lapping, etc. and totally improves wear resistance and reduces frictional torque, resulting in low cost process.

[0014] More specifically, the valve lifter according to the present invention, subjected to gaseous nitriding or gaseous soft nitriding on the upper surface thereof, is characterized in that a compound layer formed on the outermost surface has a thickness of 1 to 5 μm and an upper surface roughness Ra of the compound layer is 0.05 or less. The producing method of the valve lifter according to the present invention is characterized in that the surface roughness Ra of the upper surface before nitriding is finished in a range of 0.01 to 0.03 by a grinding or polishing process. Such polished valve lifter is subjected to a nitriding process under a nitriding condition so selected as to obtain a thickness of a surface compound layer of 1 to 5 μm, thereby obtaining a valve lifter having nitrided compound layer of a high hardness and a low frictional coefficient on an outermost surface of the upper surface and also having a surface roughness Ra of 0.05 or less.

[0015] A thickness of the compound layer after the nitriding or less than 1 μm cannot provide a wear resistance or an effect of reducing the frictional torque. Also a thickness larger than 5 μm results in a formation of a porous layer or a deterioration in the surface roughness and leads to a peeling problem of the compound layer in use because of a large thickness of the compound layer, so that an upper limit is selected as 5 μm. Also a surface roughness Ra of 0.05 or less can be utilized without difficulty for a sliding component. In the present invention, the surface roughness Ra of the upper surface is selected equal to or less than 0.05, since a surface roughness Ra higher than 0.05 results in increasing an attacking nature against a counterpart material and cannot obtain an effect of reducing the frictional torque. In the surface roughness Ra equal to or less than 0.045, its surface possesses a function of polishing the counterpart material of the cam, resulting in reducing the frictional torque. It is more desirable that the surface roughness Ra is equal to or less than 0.045.

[0016] In the valve lifter according to the invention, a porosity in the compound layer after nitriding is 5 % or less, and, in an observation of a cross section almost perpendicular to the surface portion at a magnification of 8,000 times by SEM, as shown in Fig. 3, for example, the surface portion does not show a porous layer but consists of a relatively dense compound layer. In the present invention, the porosity is selected equal to or less than 5 %, as a porosity of 5 % or less means a density sufficient for use in a sliding component such as a valve lifter. A porosity higher than 5 % influences the surface roughness and cannot provide an wear resistance or an effect of reducing the frictional torque.

[0017] Furthermore, as shown in Fig. 7, the present invention is characterized in that the surface has a lot of protrusions of 0.5 μm or less in average diameter, consisting of fine carbide, nitride, sulfide, oxide or a mixture of two or more thereof. These protrusions improve the surface roughness of the cam (to Ra of around 0.02) due to its polishing function in sliding contact therewith, and fall out the surface of the valve lifter leaving dimples on the surface without increasing its surface roughness. The surface roughness of the valve lifter itself remains as it is. Also, it is disclosed in JP-A Hei6-2511 that the surface roughness of the upper surface of silicon nitride valve lifter in sliding contact with the cam is between 0.2 of Rz and 0.7 of Rz. However, it is disclosed that an improvement of the surface roughness is not observed in the condition equal to or less than 0.2 of Rz. So the structure disclosed in JP-A Hei6-2511 is different from that according to the present invention.

[0018] The material generally used in camshaft, i.e., casting iron, casting steel, those subjected to treatments of chilling, carburizing, quenching, etc., and iron-based sintered materials and those subjected to quenching treatment, are used as the counterpart material of the cam in combination with the valve lifter according to the present invention.

[0019] Furthermore, in the producing method of the valve lifter according to the present invention, a porous layer harmful to the valve lifter is not formed in the nitriding process. A uniform and dense nitrogen compound layer of 1 to 5 μm, composed of a γ' -phase and/or a mixed phase of a γ' -phase and an ε-phase and comprises equiaxed crystals, is formed on the surface of the valve lifter, and the upper surface has a surface roughness Ra of 0.05 or less and shows little deformation. Consequently no polishing is necessary after the nitriding process, and there is not encountered an insufficient removal of the porous layer or an excessive removal of the nitrogen compound layer to be left in the case of removing the porous layer by polishing.

[0020] Also the valve lifter, owing to dense compound layer of uniform thickness formed by nitriding, is characterized in that the upper surface has a uniform surface hardness equal to or higher than Hv 660.

[0021] In addition to the foregoing, the producing method of the valve lifter according to the present invention is characterized in that the nitriding temperature is between 500 and 560°C. Nitriding at a temperature less than 500°C cannot form a sufficient nitrogen compound layer because of a low nitriding speed, while nitriding at a temperature exceeding 560°C causes a porous layer formation, thus requiring a polishing for removal of the porous layer after the nitriding. Another characteristic is that the nitriding atmosphere is suitably controlled to form a γ'-phase and/or a mixed phase of a γ'-phase and an ε-phase on the upper surface of the valve lifter. Another characteristic is that the nitrogen compound layer comprises equiaxed crystals.

[0022] In the present invention, a base material for the valve lifter can be a carbon steel for general structure, an alloy steel or a tool steel commonly used for the valve lifter.

[0023] Also as a nitriding process applicable to such material, in addition to a gaseous nitriding and a gaseous soft nitriding, there can also be employed an ion nitriding, a radical nitriding or a salt bath nitriding, but the ion nitriding and the radical nitriding do not provide an advantage in cost because of a very limited throughput, while the salt bath nitriding is associated with an environmental difficulty and is unable to secure the surface roughness, so that the gaseous nitriding and the gaseous soft nitriding are suitable in the present invention.

[0024] The gaseous nitriding or the gaseous soft nitriding generally uses NH_3, but it is also possible to use a substance, such as urea, capable of forming an effective nitriding atmosphere to the steel material. In the present invention, N_2 gas is used for controlling the atmosphere, however it is also possible to supply a decomposed gas of NH_3, a modified gas (RX gas), a N_2 gas etc. singly or in a mixture in a necessary amount. In the present invention, CO_2 gas is used as a gas for a soft nitriding, however there can also be employed a method using a CO-containing gas such as modified gas. In case the nitrogen compound layer formed in an oxi-nitriding or a nitro-sulphurizing which also belongs to the nitriding process contains a ternary element, the effect of the present invention can be obtained as long as the nitrogen compound layer formed on the surface is composed of a γ'-phase and/or a mixed phase of a γ'-phase and an ε-phase.

[0025] In the producing method of nitrided valve lifter according to the present invention, a gaseous nitriding method or a gaseous soft nitriding method is employed under a control of temperature, time and atmosphere to form a dense nitrided layer having a porosity of 5 % or less without a porous layer. In such valve lifter, there is little deterioration in surface roughness and little deformation by nitriding. In the producing method of the valve lifter according to the present invention, therefore, it is not necessary to control the thickness and the surface roughness of the compound layer. Thus it is not necessary to polish the upper surface for removing the porous layer. The compound layer has an uniform thickness and a superior wear resistance. Also, a high performance valve lifter can be obtained with a low cost, since a costly polishing process is not required. Furthermore, when the valve lifter according to the present invention slides in combination with the cam, it improves the surface roughness of the cam due to its polishing function without increasing its surface roughness. The surface roughness of the valve lifter itself remains as it is.

[0026] The valve lifter includes a configuration of a valve lifter with shim in which a shim is provided between an upper face of the main body of the valve lifter and the cam and comes into a sliding contact with the cam, and a shimless configuration of a valve lifter in which a shim is not provided but an upper surface of the valve lifter comes into direct contact with the cam, and the valve lifter and the producing method thereof according to the present invention are applicable to both configurations. The present invention is applicable to a valve lifter of which an upper surface or the like is provided with an oil hole, a hole for other objectives, a bevel portion or a groove. Furthermore, the nitriding compound layer which is provided by the present invention is applicable also to a boss part 4 of the valve lifter, coming into sliding contact with a stem end or the like of the valve.

BRIEF DESCRIPTION OF THE DRAWINGS

[0027]

Fig. 1 is a cross-sectional view of an example of a valve lifter (shimless) in which the present invention is applicable.
Fig. 2 is a cross-sectional view of another example of a valve lifter (with shim) in which the present invention is applicable.
Fig. 3 is a photomicrograph (x8,000) of a cross section of an upper surface of a valve lifter after nitriding according to the present invention.
Fig. 4 is a cross-sectional view showing a compound layer in Fig. 3.
Fig. 5 is a photomicrograph (×8,000) of a cross section of an upper surface of a valve lifter after nitriding according to a prior art.
Fig. 6 is a cross-sectional view showing a porous layer in Fig. 5.
Fig. 7 is a photomicrograph (×8,000) of an upper surface of a valve lifter after nitriding according to the present invention.
Fig. 8 is a photomicrograph (×8,000) of an upper surface of a valve lifter after nitriding according to a prior art.
Fig. 9 is a graph showing a relationship between a cam revolution and a frictional torque.
Fig. 10 is a cross-sectional view showing an example of use of a valve lifter.
Fig. 11 is a TEM micrograph (×30,000) of a cross section of an upper surface of a valve lifter after nitriding according to the present invention.
Fig. 12 is a TEM micrograph (×30,000) of a cross section of an upper surface of a valve lifter according to a prior art after removing a porous layer.
Fig. 13 is a photomicrograph (×8,000) of an upper surface of a valve lifter according to the present invention after sliding test.
Fig. 14 is a graph showing a comparison between the present invention and a prior art in which a variation of surface roughness of a valve lifter and a cam before and after running-in operation.
Fig. 15 is a graph showing a variation of surface roughness of a valve lifter according to the present invention and a cam of counterpart material before and after a sliding test.

BEST MODE FOR CARRYING OUT THE INVENTION

[0028] In the following, an embodiment of the present invention will be explained. A valve lifter 1 according to the present invention shown in Figs. 1 and 2 is a sliding component which, in a direct drive valve actuating system of an internal combustion engine as shown in Fig. 10, is provided between a cam 11 and a valve 12 for converting a rotating motion of the cam 11 into a reciprocating motion of the valve 12. For example, the producing method for the valve lifter 1 according to the present invention is applicable to an upper sliding surface 2 of the valve lifter 1, coming into sliding contact with a cam (not shown) as shown in Fig. 1. Also the present invention is applicable to a sliding surface 2 of a shim 3, coming into direct sliding contact with the cam, as shown in Fig. 2.

[0029] A specific example of the valve lifter 1 according to the present invention will be shown in the following. At first a forged SCM material was subjected to a carburization and to a quenching/tempering treatment so as to have a surface hardness of HRC 58 or higher and an effective hardened layer depth of about 1.0 mm, and a surface roughness of the upper surface, i.e., the sliding surface 2 is finished to Ra 0.01 to 0.03 using a grinding machine with a grinding wheel and abrasives, wherein the upper surface is preferably finished in such a manner that the sliding surface 2 has a surface roughness of Ra 0.02.

[0030] Then a gaseous soft nitriding process was conducted at a temperature of 520°C for 70 minutes in such a manner that the sliding surface 2 had a surface hardness of Hv 660 or higher and a compound layer 6 (cf. Fig. 4) had a thickness of 1 to 5 µm. The gaseous soft nitriding used a mixed gas of NH_3, N_2 and CO_2.

[0031] The gaseous soft nitriding was conducted, paying attention to homogeniety of temperature and atmospher, in order to form a compound layer uniformly within a range of 1 to 5 µm, to obtain a compound layer without a porous layer, and to obtain a surface roughness Ra of 0.05 or less with little deformation. It is also important to control the composition of the atmosphere gas and a decomposition rate of NH_3 in order to form a compound layer uniformly within a range of 1 to 5 µm and to obtain a compound layer without a porous layer. The valve lifter is subjected to the nitriding in an atmosphere arriving at a predetermined decomposition rate of NH_3. The decomposition rate of NH_3 can be controlled by a gas exchange rate (flow rate) or a composition ratio of a mixed gas. The nitriding process may be conducted using a gas regulated to a predetermined decomposition rate of NH_3 in another furnace. The decomposition rate of NH_3 in the example according to the present invention was 23 %.

[0032] In the present example, the gaseous soft nitriding was conducted under the aforementioned conditions, but compound layers without a porous layer of 3.5 and 2.5 µm were respectively obtained at conditions of a temperature of 560°C for 30 minutes, and a temperature of 500°C for 150 minutes. The decomposition rate of NH_3 in these cases, in comparison with the case of the condition at 520°C, had to be made larger in the case of the condition at 560°C, but was same in the case of the condition at 500°C. The decomposition rate of NH_3 was controlled within a range of 5 to 50 % according to the nitriding temperature of 500 to 560°C. Also valve lifters having a uniform compound layer and little deformation could be obtained by arranging the valve lifters in a row on a jig and by conducting the gaseous soft nitriding in such a manner that they were uniformly in contact with the atmospheric gas.

[0033] In a gaseous soft nitriding process of the condition at a temperature exceeding 560°C as conventionally conducted, the processing time was too short to obtain a required compound layer of 1 to 5 μm, and the atmosphere could not be controlled appropriately. As the decomposition of NH_3 effectively influences the nitriding only in case such decomposition takes place at the surface, the decomposition reaction of NH_3 on the surface of the processed article decreased in an atmosphere with a high decomposition rate of NH_3. In an atmosphere with a high decomposition rate of NH_3, a compound layer without a porous layer was obtained but its thickness was not uniform. In an atmosphere with a low decomposition rate of NH_3, on the other hand, the nitriding actively took place on the surface of the processed article, thereby forming a porous layer on the compound layer.

[0034] By the aforementioned gaseous soft nitriding process under the control of temperature, time and atmosphere, on the upper surface of the valve lifter, a nitrided layer composed of a diffusion layer 7 and a dense compound layer 6 having a porosity of 5% or less without a porous layer was formed on a base material as shown in Fig. 4.

[0035] Also on the surface of the compound layer, a lot of protrusions (white granular parts) as shown in Fig. 7 consist of fine carbide, nitride, sulfide, oxide or two or more of these compounds of an average diameter of 0.5 μm or less. This surface had a surface roughness of Ra 0.05 or less. Furthermore, the compound layer comprises equi-axed crystals in diameter less than 0.5 μm as shown in Fig. 11. The valve lifter according to the present invention obtained by this manner does not require polishing treatment for the improvement of wear resistance, surface roughness and dimensional accuracy.

[0036] Then, as comparative examples, valve lifters were prepared with same materials as in the aforementioned examples of the present invention, employing a method of a condition same as that of the nitriding process of the present invention, though the surface roughness values of the upper surfaces before the nitriding were different.

[0037] Table 1 shows examples of changes in the surface roughness values of the sliding surface 2 between before and after the nitriding process. It will be understood that, in the example of the present invention, the surface roughness Ra of the sliding surface after the nitriding can be maintained at 0.024 to 0.045 by polishing the sliding surface before the nitriding to a roughness Ra of 0.012 to 0.028. In contrast, in the comparative examples 1, 2 and 3, the surface roughness values after the nitriding exceeds Ra 0.05 in case the roughness values of the sliding surface before the nitriding exceeds Ra 0.03.

Table 1

		Surface roughness (Ra)		Finish condition before nitriding	Nitriding condition
		before nitriding	after nitriding		
Present Invention	Ex. 1	0.012	0.024	grinding machine, arbitrary grinding wheel and abrasive, oily coolant	gaseous soft nitriding, 520°C, 70 min., gas composition NH_3+N_2+CO_2
	Ex. 2	0.021	0.040		
	Ex.3	0.028	0.045		
Comp. Ex. 1		0.038	0.070	grinding machine, arbitrary grinding wheel and abrasive, oily coolant	gaseous soft nitriding, 520°C, 70 min., gas composition NH_3+N_2+CO_2
Comp. Ex. 2		0.055	0.100		
Comp. Ex. 3		0.080	0.170		

[0038] Figs. 5, 12 and 8 show micrographs of cross sections and a surface after nitriding on a valve lifter of comparative example 4 according to a prior art.

[0039] The valve lifter of the comparative example 4 is subjected to a gaseous soft nitriding at an ordinary temperature of 570°C and has a thick compound layer 6 compising columnar crystals and a large porous layer 8 on the surface (cf: Fig. 6). Also it shows a large deformation and a deterioration in the surface roughness, thus requiring a removal of the porous layer by a buff polishing in a subsequent step. Fig. 12 shows a TEM micrograph of a cross section of the valve lifter after removing the porous layer by buff polishing. The compound layer comprises relatively large columnar crystals oriented almost perpendicular to the surface.

[0040] Table 2 shows changes in the dimensional accuracy, and thickness values of the compound layer and the porous layer, before and after the nitriding, in the valve lifters of a present example 2 and a comparative example 4.

A deformation due to the nitriding is represented by a maximum displacement in an upper surface of the valve lifter as compared with an external periphery of the surface. The valve lifter according to the present invention shows little deterioration in the surface roughness and little deformation by the nitriding, and does not form a porous layer on the compound layer. Thus, because the polishing is not necessary as a subsequent machining, an unevenness in the thickness of the compound layer is not occurred.

Table 2

	Invention (Example 2)			Comp. Ex. 4		
	surface roughness (Ra)	deformation (μm)	compound layer (μm)	surface roughness (Ra)	deformation (μm)	compound layer
before nitriding	0.02	-	-	0.02	-	-
after nitriding	0.04	0.2	2.5 (no porous layer)	0.12	5-15	12.5 (porous layer 2.5-4.5)
polish after nitriding	polishing unnecessary			0.05 or less	-	0-9

[Experimental Example]

[0041] A valve lifter aforementioned example according to the present invention, and one of the comparative example 4 accoring to the prior art and the chilled cams were assembled in an engine and were subjected to a motoring test at revolutions of 1000 to 4000 rpm, and a frictional torque in sliding motion was measured. Fig. 14 is a graph showing changes in surface roughness values of the upper surface of the valve lifter according to the present invention and the cam (nose portion of the cam) of counterpart material before and after the running-in operation in comparison with that according to the prior art. In the valve lifter according to the present invention, sliding operation brings about deterioration in surface roughness of its upper surface and improvement in surface roughness of the cam due to its polishing function. In the valve lifter according to the prior art, on the other hand, the surface roughness of the upper surface of the valve lifter is greatly increased after the running-in operation.

[0042] Fig. 15 is a graph showing changes in surface roughness values of the upper surface of the valve lifter according to the present invention and the chilled cam (nose portion of the cam) of the counterpart material from before the running-in operation to after the durability evaluation. In the valve lifter according to the present invention, the change in surface roughness values of the upper surface is little. On the other hand, the surface roughness of the cam of the counterpart material is improved due to its polishing function (to Ra of around 0.02μm). Same improvement tendency is obtained in root mean square value of the surface roughness used as total sliding evaluation of the combination of valve lifter and the cam. Fig. 13 shows a sliding surface after the durability evaluation. Protrusions observed in surface before sliding improve the surface roughness of the cam (to Ra of around 0.02μm) due to its polishing function in sliding contact therewith, and fall out the surface of the valve lifter leaving dimples having an oil retaining effect on the surface without increasing its surface roughness. The surface roughness of the valve lifter itself remains as it is.

[0043] Fig. 9 is a graph showing a relationship between a revolution and a frictional torque. These results indicate that the valve lifter according to the present invention brings about little change in surface roughness values before and after the running-in operation and the durability evaluation, improves the surface roughness of the cam due to polishing function and provides lower frictional torque than that according to the prior art, i.e., superior sliding function.

[0044] As explained in the foregoing, the valve lifter according to the present invention is characterized in that a thickness of a compound layer is between 1 and 5 μm after the gaseous nitriding, and a surface roughness Ra of the upper surface is 0.05 or lower after the nitriding, and the compound layer does not have a porous layer on the surface, so that a buff polishing is basically not required. The producing method of the valve lifter 1 does not basically require a costly polishing treatment after the nitriding, and bring about superior wear resistance since a compound layer of a high hardness and a low friction coefficient can be uniformly formed on the sliding surface 2, thereby significantly reducing the manufacturing cost while maintaining high performances. Since the sliding in combination with the cam of the counterpart material brings about no deterioration in the surface roughness of the valve lifter itself but improvement in the surface roughness of the cam due to its polishing function, furthermore, there does not need any costly means which require expensive equipments such as paper-lapping machine, etc., and long machining time with regard to the cam of the counterpart material.

EFFECT OF THE INVENTION

[0045] As explained in the foregoing, in the valve lifter according to the present invention, the formation of a dense and hard nitrided compound layer of 1 to 5 μm without a porous layer and the gaseous nitriding treatment with little deterioration in the surface roughness and little deformation in the upper surface shape, does not require a polishing for controlling the compound layer after the nitriding such as for improving the surface roughness and removing the porous layer. Thus, there can be ensured a uniform surface property and a superior wear resistance.

[0046] Also by obtaining a uniform compound layer, it is possible to reduce the frictional torque in comparison with a valve lifter according to a prior art. Also a valve lifter of a low cost can be obtained, since a costly polishing process is not required. Since the sliding in combination with the cam of the counterpart material brings about no deterioration in the surface roughness of the valve lifter but improvement in the surface roughness of the cam due to its polishing function, furthermore, it is possible to realize a cost reduction of the cam in addition to the improvement of wear resistance and the reduction of frictional torque.

Claims

1. A valve lifter for an internal combustion engine which is subjected to gaseous nitriding or gaseous soft nitriding on at least an upper surface thereof, **characterized in that** a compound layer formed on outermost surface of the upper surface by the nitriding has a thickness of 1 to 5 μm and a surface roughness Ra thereof is 0.05 or less.

2. A valve lifter according to claim 1, wherein the compound layer is composed of aγ'-phase and/or a mixed phase of a γ'-phase and ε-phase.

3. A valve lifter according to claim 1 or 2, wherein the compound layer comprises equiaxed crystals.

4. A valve lifter according to any one of claims 1 to 3, wherein the compound layer has a porosity of 5% or less.

5. A valve lifter according to any one of claims 1 to 4, wherein a surface of the compound layer has a lot of protrusions of 0.5 μm or less in average diameter.

6. A valve lifter according to any one of claims 1 to 5, wherein the protrusions on the surface of the compound layer consist of a nitride, or a nitride including at least one of carbon, oxygen, sulfur and compounds thereof.

7. A valve lifter according to any one of claims 1 to 6, wherein the upper surface thereof has a surface hardness equal to or higher than Hv 660.

8. A combination of a valve lifter according to any one of claims 1 to 7 and a cam in sliding contact therewith, **characterized in that** a surface roughness of the cam is improved by a sliding contact between the upper surface of the valve lifter and the outer surface of the cam and the surface roughness of the valve lifter itself remains as it is.

9. A method of producing a valve lifter for an internal combustion engine which has gaseous nitriding layer or gaseous soft nitriding layer on an upper surface of the valve lifter, **characterized in that** a surface roughness Ra of the upper surface before nitriding is finished in a range of 0.01 to 0.03 by a grinding or a polishing process.

10. A method according to claim 9, wherein a temperature of nitriding is 500 - 560 °C.

FIG. 1

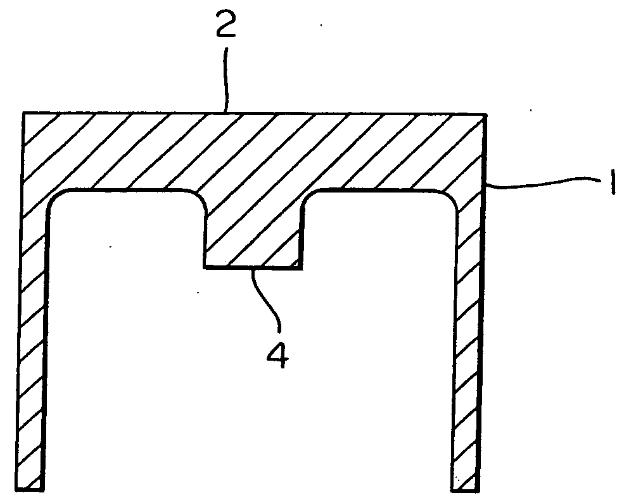


FIG. 2

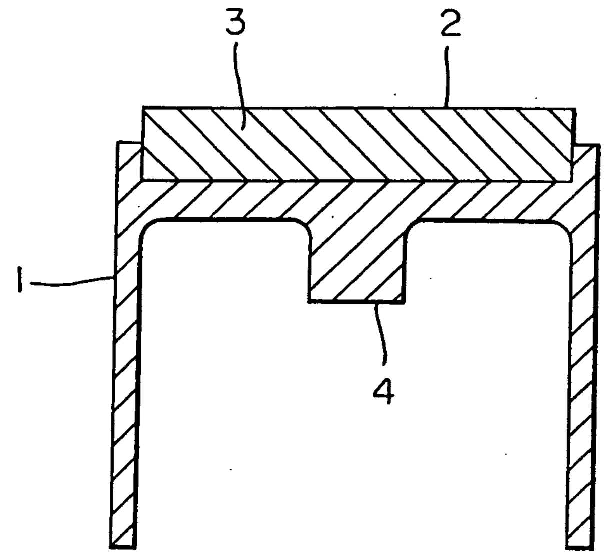


FIG. 3

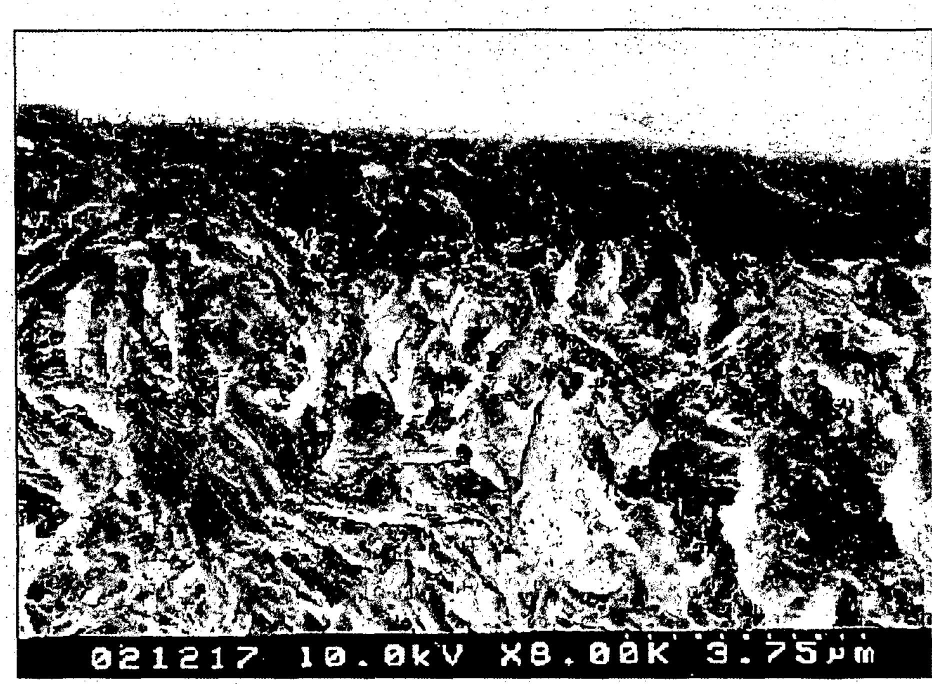


FIG. 4

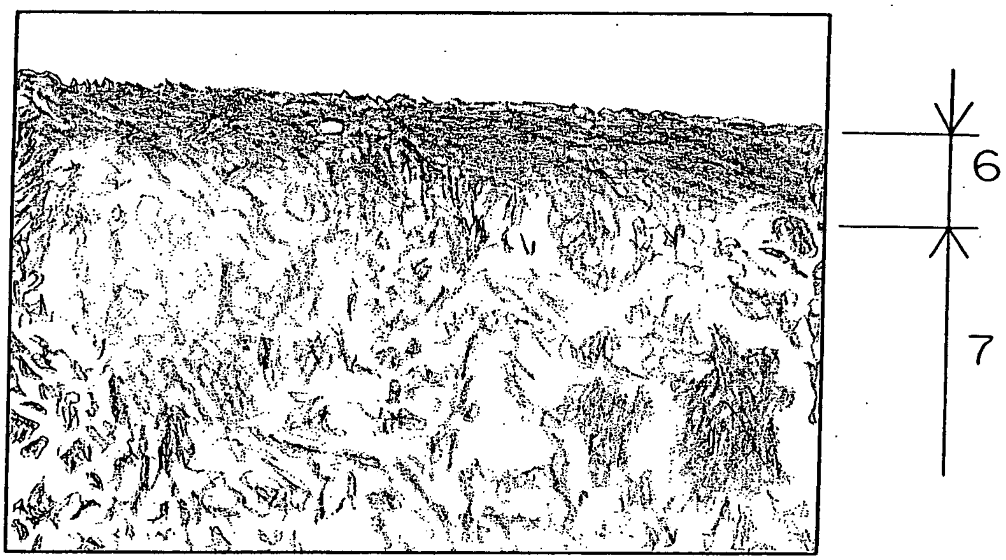


FIG. 5

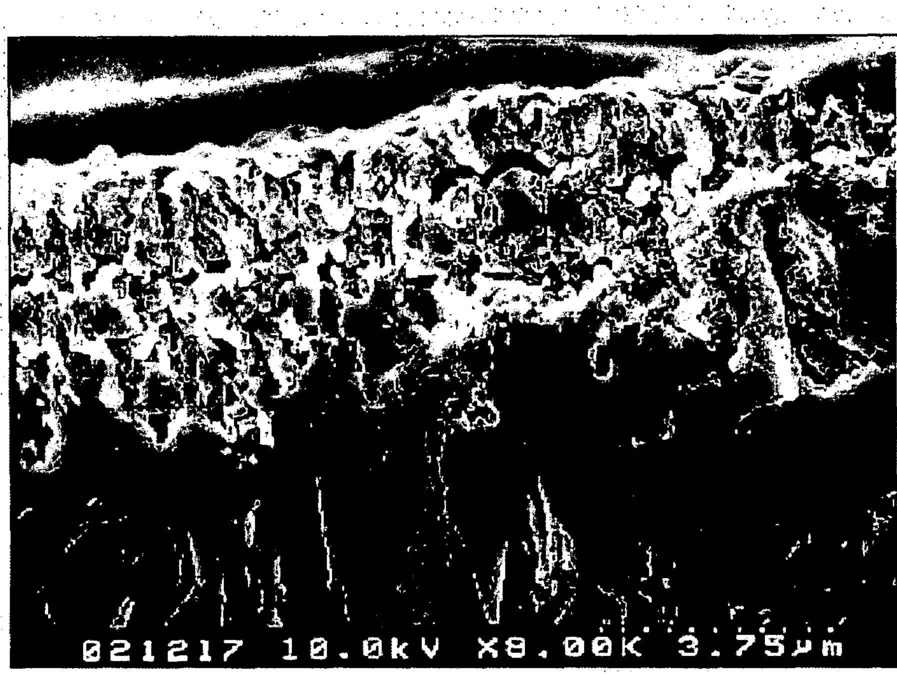


FIG. 6

FIG. 7

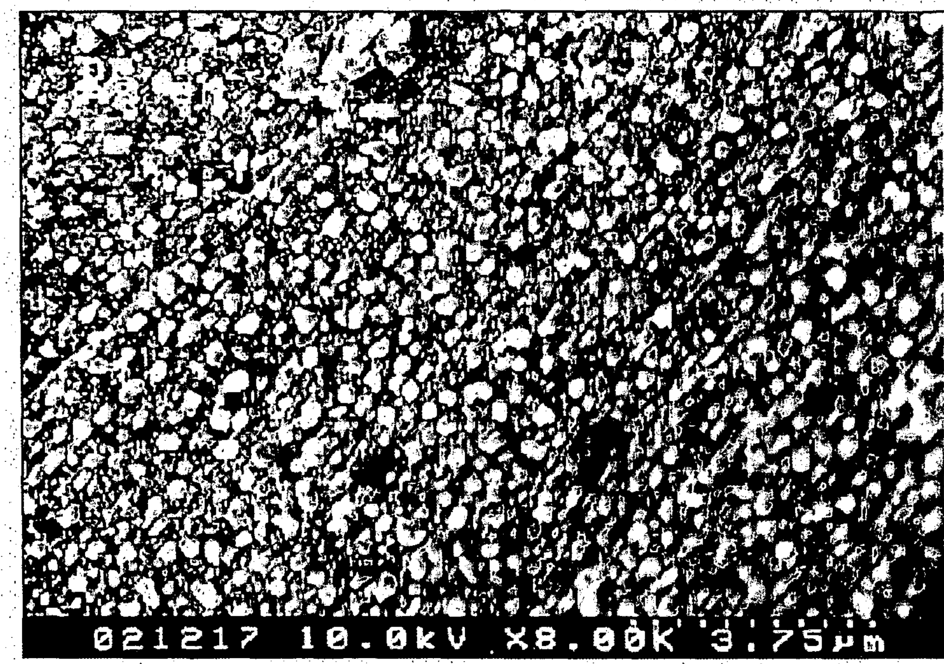


FIG. 8

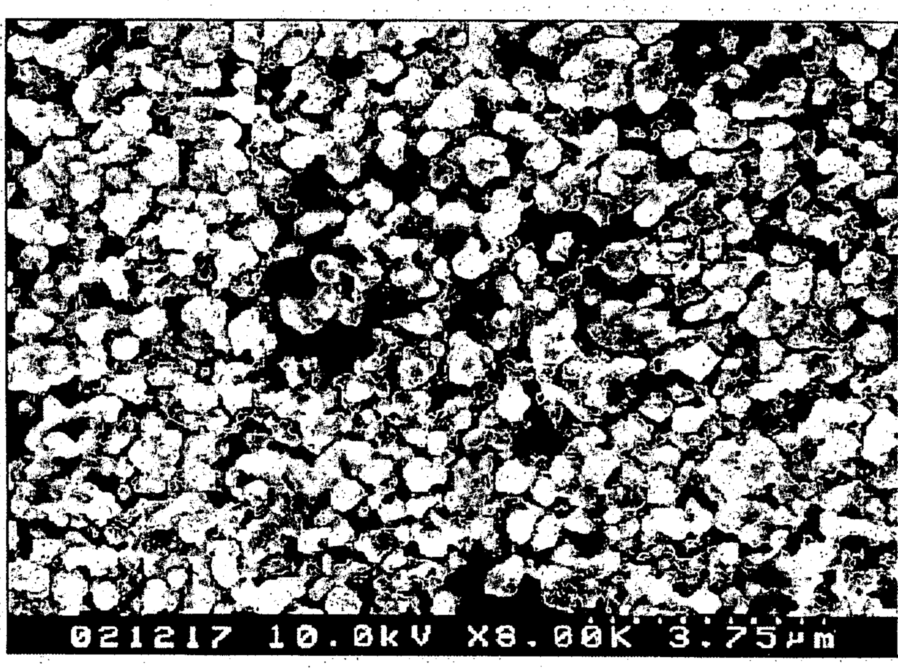


FIG. 9

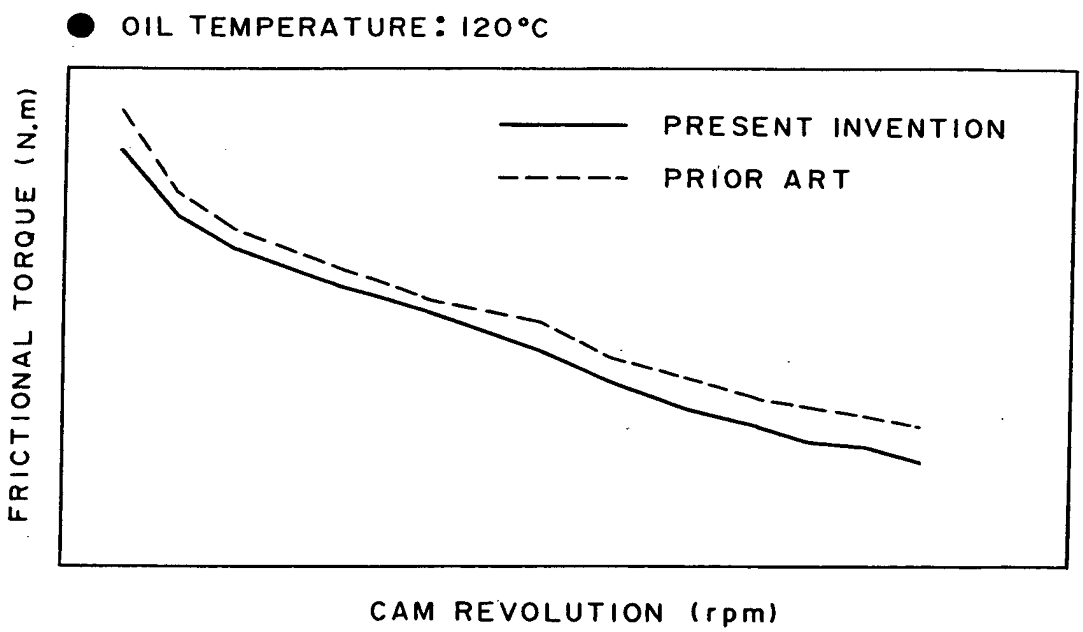

● OIL TEMPERATURE: 120°C
PRESENT INVENTION
PRIOR ART
FRICTIONAL TORQUE (N.m)
CAM REVOLUTION (rpm)

FIG. 10

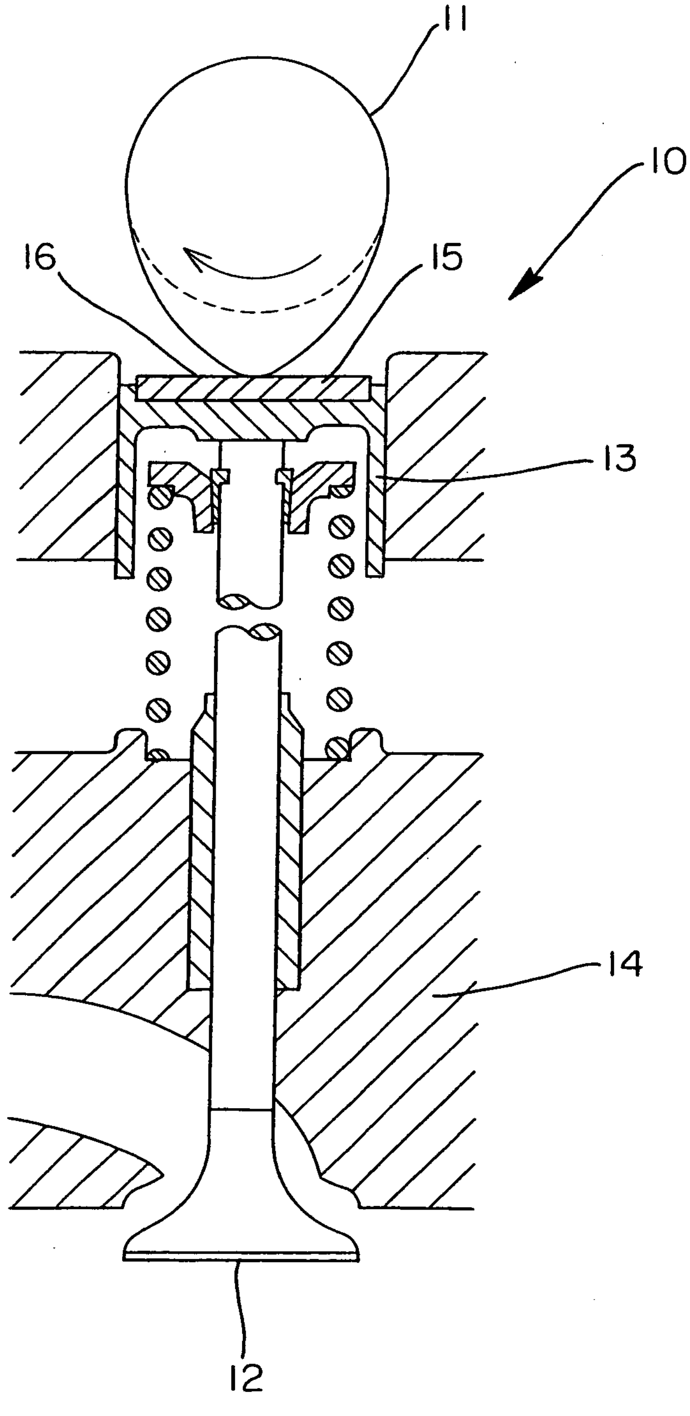


FIG. 11

FIG. 12

FIG. 13

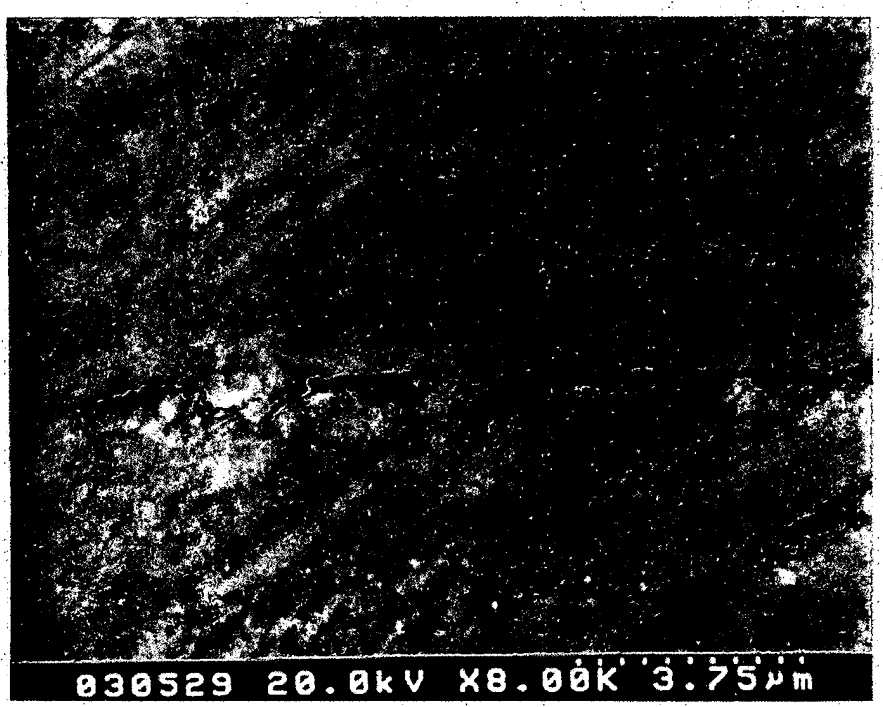


FIG. 14

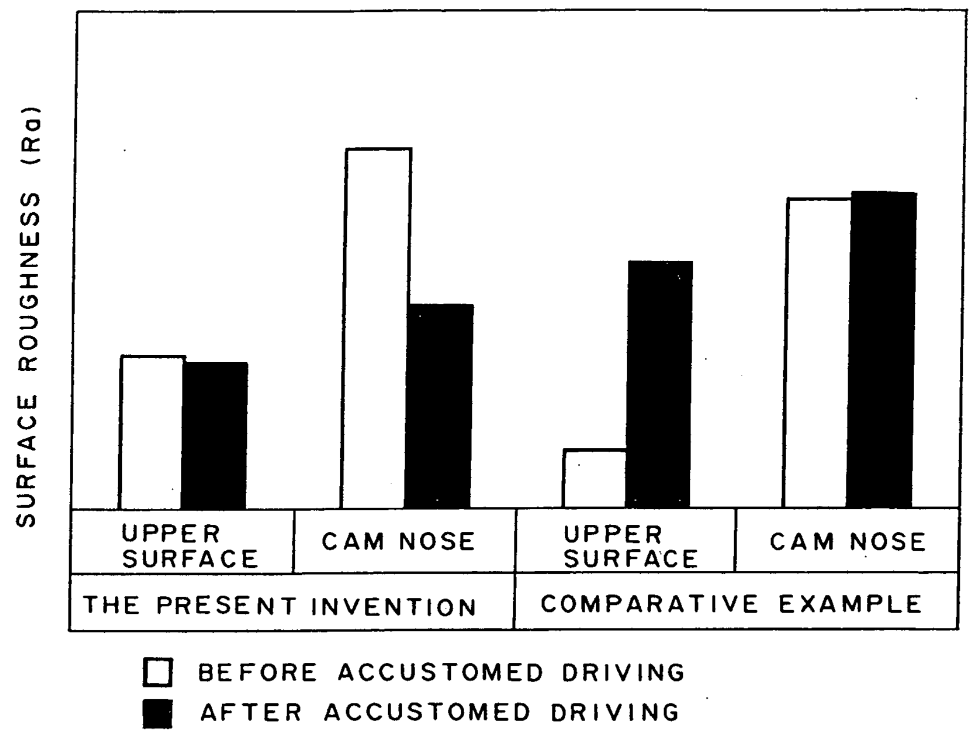
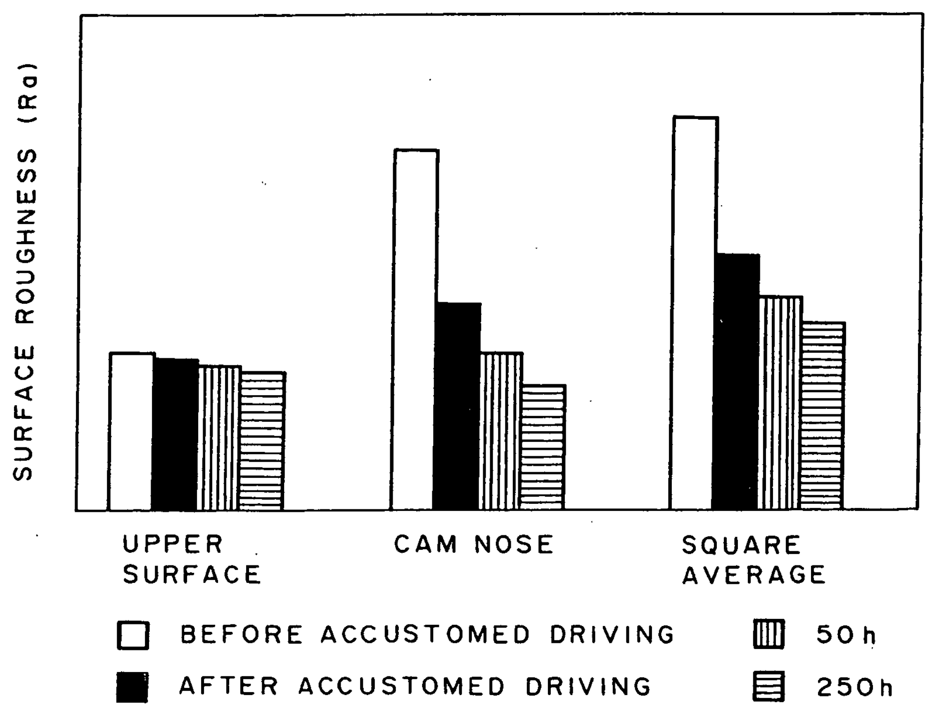

SURFACE ROUGHNESS (Ra)
UPPER SURFACE
CAM NOSE
UPPER SURFACE
CAM NOSE
THE PRESENT INVENTION
COMPARATIVE EXAMPLE
BEFORE ACCUSTOMED DRIVING
AFTER ACCUSTOMED DRIVING

FIG. 15


SURFACE ROUGHNESS (Ra)
UPPER SURFACE
CAM NOSE
SQUARE AVERAGE
BEFORE ACCUSTOMED DRIVING
AFTER ACCUSTOMED DRIVING
50h
250h

INTERNATIONAL SEARCH REPORT

International application No. PCT/JP2004/003022

A. CLASSIFICATION OF SUBJECT MATTER

Int.Cl[7] C23C8/32, C23C8/26, F01L1/14, C23C8/02

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] C23C8/32, C23C8/26, F01L1/14, C23C8/02

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	1994-2004
Kokai Jitsuyo Shinan Koho	1971-2004	Jitsuyo Shinan Toroku Koho	1996-2004

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 2002-212703 A (Toyota Motor Corp.), 31 July, 2002 (31.07.02), Full text (Family: none)	1-3,6,7 4,8
Y	JP 11-100655 A (Toyota Motor Corp.), 13 April, 1999 (13.04.99), Full text (Family: none)	4,10
X Y	JP 62-253908 A (Yamaha Motor Co., Ltd.), 05 November, 1987 (05.11.87), Full text (Family: none)	9 8,10

☒ 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

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search 08 June, 2004 (08.06.04)	Date of mailing of the international search report 22 June, 2004 (22.06.04)
Name and mailing address of the ISA/ Japanese Patent Office	Authorized officer
Facsimile No.	Telephone No.

Form PCT/ISA/210 (second sheet) (January 2004)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2004/003022

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 11-324858 A (Toyota Motor Corp.), 26 November, 1999 (26.11.99), (Family: none)	1-10
A	JP 2000-303161 A (Mazda Motor Corp.), 31 October, 2000 (31.10.00), & EP 1013779 A2 & US 6294029 B1	1-10
A	JP 10-245668 A (Daido Hoxan Inc.), 14 September, 1998 (14.09.98), (Family: none)	1-10
A	JP 5-340213 A (Toyota Motor Corp.), 21 December, 1993 (21.12.93), (Family: none)	1-10

Form PCT/ISA/210 (continuation of second sheet) (January 2004)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2004/003022

The numerical values of surface roughness described in the scope of claims and the specification of the present application have no units, and therefore, cannot specify the range thereof.

Form PCT/ISA/210 (extra sheet) (January 2004)