

DESCRIPTION

METHOD OF MANUFACTURING COATED TOOL

Technical Field

[0001] The present invention relates to a method of manufacturing a coated tool such as a die for press working, a die for forging, a cutting tool such as a saw blade, or a cutting tool such as a drill, the coated tool being coated with a diamond-like carbon film (hereinafter also referred to as "DLC film").

Background Art

[0002] In the case of molding workpiece materials such as aluminum, copper, and resin in dies, part of the workpiece materials may be adhered to surfaces of the dies, whereby product abnormality such as galling or generation of flaws may occur. To solve this problem, coated dies, which are dies having DLC films on surfaces thereof have been in practical use. A DLC film which contains substantially no hydrogen (tetrahedral amorphous carbon film: ta-C film) has been widely applied to coated dies because of its high hardness and excellent wear resistance.

However, since the high-hardness DLC film which contains substantially no hydrogen is formed by an arc ion plating method using a graphite target, particles (graphite spheres) with sizes of several micrometers, called droplets, are inevitably mixed into the DLC film, whereby the surface roughness of the DLC film is deteriorated.

[0003] Against such a problem, Patent Literature 1 discloses that coating with a smooth, high-hardness DLC film which contains substantially no hydrogen is enabled by applying a filtered arc ion plating process, which uses a mechanism for collecting droplets.

Citation List

Patent Literature

[0004] Patent Literature 1: Japanese Patent Application Laid-Open (JP-A) No. 2008-297171

SUMMARY OF INVENTION

Technical Problem

[0005] A DLC film having high hardness and a smooth surface state can be achieved by forming using a filtered arc ion plating process such as that of Patent Document 1. There is, however, a tendency that a high-hardness DLC film has poor adhesion, and it tends to be

difficult to achieve satisfactory adhesion by simply applying a filtered arc ion plating process.

Moreover, there is a demand for thicker high-hardness DLC films in order to improve the durability of a coated tool in a harsh usage environment. However, if a film forming time to form a thick DLC film is made longer, arc discharge is liable to become unstable, and it is difficult to achieve thick high-hardness DLC films with securing excellent adhesion.

[0006] The invention is accomplished in view of such circumstances as described above, and relates to a method of manufacturing a coated tool capable of forming a thick high-hardness DLC film with securing excellent adhesion.

Solution to Problem

[0007] A method of manufacturing a coated tool of the invention is a method of manufacturing a coated tool by forming a diamond-like carbon film on a surface of a base by a filtered arc ion plating process, the method comprising:

a first process of subjecting the surface of the base to a gas bombardment treatment by applying a negative bias voltage of from -2500 V to -1500 V to the base and introducing a mixed gas containing hydrogen gas into a furnace; and

a second process of forming a diamond-like carbon film on the surface of the base by introducing nitrogen gas into the furnace, after the gas bombardment treatment has been performed, and feeding a current to a graphite target,

the second process comprising reducing a flow rate of the nitrogen gas and increasing the current fed to the graphite target.

[0008] It is preferable that the diamond-like carbon film has a thickness of 2.0 μm or more.

It is preferable that a total of an increase in the current fed to a graphite target in the increasing of the current fed to the graphite target is 40 A or more.

Effects of Invention

[0009] In accordance with the invention, a high-hardness DLC film having excellent adhesion can be formed as a thick film. Further, since the method enables to form a film stably, a coated tool having excellent durability can be stably manufactured.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] Fig. 1 is a photographic observation by a scanning electron microscope of a cross-section (at a magnification of 17340 $\times$) of a DLC film coated by Example 4.

Fig. 2 is a schematic diagram of a T-shaped filtered arc ion plating apparatus employed in EXAMPLES.

DESCRIPTION OF EMBODIMENTS

[0011] The inventor has investigated methods for forming thicker high-hardness DLC films having excellent adhesion. The inventor has found the importance, in a filtered arc ion plating process, of controlling gas bombardment treatment of a base prior to forming a DLC film, and controlling the atmosphere in a furnace and the current fed to a graphite target during forming of the DLC film, and arrived at the method of manufacturing a coated tool of the invention. Details of the invention are explained below.

[0012] A conventionally-known filtered arc ion plating apparatus may be employed in the invention. Employing a filtered arc ion plating process enables a high-hardness DLC film to be formed having a smooth surface state with fewer droplets contained in a coated film, containing substantially no hydrogen, and achieving a nanoindentation hardness of 50 GPa or greater. In particular, it is preferable to use a T-shaped filtered arc ion plating apparatus as a smoother DLC film having higher hardness can be formed thereby.

[0013] In order to improve durability of the coated tool, the DLC film in the invention preferably has a nanoindentation hardness of 50 GPa or greater. 55 GPa or greater is more preferable, and 60 GPa or greater is even more preferable. Moreover, 70 GPa is still more preferable. However, if the hardness of the DLC film is too high, residual compressive stress may become too high, and adhesion thereof to the base may be reduced. Accordingly, the nanoindentation hardness is preferably 100 GPa or less, and is more preferably 95 GPa or less.

[0014] Nanoindentation hardness is plastic hardness of a sample (DLC film) exhibited when the sample is plastically deformed by indenting a probe into the sample. A load-displacement curve based on an indentation load and an indentation depth (displacement) is determined and the hardness is calculated therefrom. Specifically, the hardnesses of ten points in a film surface are measured using a nanoindentation apparatus manufactured by ELIONIX INC. under the measurement conditions of an indentation load of 9.8 mN, a maximum load retention time of 1 sec, and a removal rate of 0.49 mN/sec after loading, and the hardness is determined as an average value of six points, which remain via exclusion of two points, one of which having the highest value and the other of which having the second highest value, and two points, one of which having the lowest value and the other of which having the second lowest value.

[0015] A DLC film having high hardness, such as one that has a nanoindentation hardness of 50 GPa or greater, tends to have extremely high internal stress and poor adhesion with a base. Therefore, a technique of improving adhesion of a DLC film to a base by disposing an intermediate film of which the hardness is lower than that of the DLC film has been

conventionally proposed. However, according to the investigation of the inventor, it was observed that an intermediate film of a metal, a carbide, a nitride, or the like existing between a base and a DLC film is insufficient for improving adhesion because the DLC film preferentially causes separation which starts from a surface defect in the intermediate film. Therefore, investigation in the invention was conducted on gas bombardment treatment performed before formation of a DLC film in view of avoiding impairing adhesion even when a DLC film is directly formed on a base.

[0016] As a first process in the invention, a mixed gas containing hydrogen gas is introduced into a furnace and the surface of the base is subjected to gas bombardment treatment.

Investigations by the inventor has found that there is a lot of oxygen present at an interface between a film and a base, and a reduction in adhesion, in cases in which conventional gas bombardment treatment using argon gas is performed. The oxygen present at an interface is mainly caused by oxidization of the film initially formed onto a surface of the base, and is a residual element that is not able to be completely removed by gas bombardment treatment with argon gas.

Thus, in the invention, a surface of a base is subjected to gas bombardment treatment, with introducing a mixed gas containing hydrogen gas into a furnace (vacuum chamber). Due to subjecting the surface of the base to gas bombardment treatment using a mixed gas containing hydrogen gas, an oxidized film on the surface of the base reacts with hydrogen ions and is reduced, and the oxidized film and surface contaminations are sufficiently removed, increasing the adhesion of the DLC film formed directly onto the base.

[0017] The mixed gas containing hydrogen gas is preferably a mixed gas containing hydrogen gas at 4% by mass with respect to a total mass of argon gas and the hydrogen gas. If a content of the hydrogen gas is less than 4% by mass, sometimes it is difficult to remove an oxidized film by gas bombardment treatment with the mixed gas. Moreover, a mixed gas containing hydrogen gas at 5% by mass or greater is more preferably employed, and a mixed gas containing hydrogen gas at 7% by mass or greater is still more preferably employed. A mixed gas containing hydrogen gas at 10% by mass or greater is yet more preferably employed. However, in a mixed gas in which the hydrogen gas exceeds 30% by mass, an effect of the gas bombardment treatment to remove the oxidized film and surface contamination tends to become constant (the effect is not raised even if the concentration of hydrogen gas is raised even more). Hence, a mixed gas containing hydrogen gas at 30% by mass or less is preferably employed. A mixed gas containing hydrogen gas at 25% by mass or less is more preferably employed. A mixed gas containing hydrogen gas at 15% by mass or less is still more preferably employed.

[0018] In the gas bombardment treatment employing a mixed gas described above, a negative bias voltage applied to the base is set to from -2500 V to -1500 V. If the negative bias voltage applied to the base is greater than -1500 V (further to the plus side than -1500 V), then due to low collision energy of gas ions, the effect of removing oxidized film and surface contamination tends to be smaller, and adhesion of the high-hardness DLC film to the base tends to be reduced. Moreover, if the negative bias voltage applied to the base is less than -2500 V (further to the minus side than -2500 V), then the plasma readily becomes unstable, and sometimes abnormal discharge occurs. If abnormal discharge occurs, abnormal discharge (arcing) marks are formed on a surface of the tool, which may cause irregularities on the tool surface. The negative bias voltage applied to the base is more preferably -2400 V or greater, and is still more preferably -2300 V or greater. The negative bias voltage applied to the base is preferably -1600 V or less, and is more preferably -1700 V or less.

The gas bombardment treatment with the mixed gas is preferably performed for 60 minutes or longer in order to sufficiently remove oxides on the surface of the base. Performing for 70 minutes or longer is more preferable. It is preferable to adjust an upper limit of the duration of gas bombardment treatment appropriately according to a shape and substance of the base. However, if the duration of gas bombardment treatment with the mixed gas is 180 minutes or longer, then the effect of the gas bombardment treatment to remove oxidized film and surface contamination tends to become constant (the effect is not further improved). Hence, gas bombardment treatment with the mixed gas is preferably performed for 180 minutes or shorter.

[0019] As a second process in the invention, nitrogen gas is introduced into the furnace after the gas bombardment treatment has been performed, and a current is fed to a graphite target so as to form a DLC film on the surface of the base that has been subjected to gas bombardment treatment.

By forming the DLC film containing nitrogen in a state in which the oxidized film on the surface of the base has been sufficiently removed by the gas bombardment treatment, a residual compressive stress of the DLC film on the surface of the base is decreased, and the adhesion of the DLC film to the base can be increased. In order to decrease the residual compressive stress of the DLC film on the base side and to further improve the adhesion of the DLC film to the base, the flow rate of nitrogen gas introduced to the furnace after the gas bombardment treatment is preferably 5 sccm or greater. There may be a case in which sufficient adhesion improvement cannot be obtained when the flow rate of the nitrogen gas is less than 5 sccm. 10 sccm or greater is more preferable.

On the other hand, if the flow rate of the nitrogen gas introduced to the furnace after

the gas bombardment treatment is too great, then a content of nitrogen contained in the DLC film increases and the film hardness decreases, as result of which wear resistance decreases and deposition of a welded material readily occurs when a non-ferrous material is machined. Accordingly, the flow rate of the nitrogen gas is preferably 60 sccm or less. 50 sccm or less is more preferable. 40 sccm is still more preferable.

If the flow rate of nitrogen gas introduced into the furnace is too small with respect to a volume of the furnace (vacuum chamber), then sometimes it is difficult to obtain sufficient effect of improvement in adhesion of the DLC film. Accordingly, [furnace volume (in m^3)] / [flow rate of nitrogen gas introduced to the furnace (in sccm)] is preferably 10×10^{-2} (m^3/sccm) or less. 5.0×10^{-2} (m^3/sccm) or less is more preferable. Moreover, if the flow rate of the nitrogen gas introduced to the furnace is too high with respect to the volume of the furnace, the excess nitrogen is readily contained in the DLC film. Therefore, [furnace volume (in m^3)] / [flow rate of nitrogen gas introduced to the furnace (in sccm)] is preferably 0.1×10^{-2} (m^3/sccm) or greater. 1.0×10^{-2} (m^3/sccm) or greater is more preferable.

[0020] In the second process in the invention, a process for forming the DLC film is provided in which the flow rate of the nitrogen gas is reduced and a current is fed to the graphite target.

Introducing nitrogen gas to form a DLC film is effective for increasing its adhesion to a base, however, hardness decreases if the DLC film as a whole contains too many nitrogen atoms. Deposition of a welded material also readily occurs when a non-ferrous material is machined. Thus in the invention, in view of preventing incorporation of too much nitrogen gas into the DLC film as a whole, the DLC film is formed by feeding the current to the graphite target with reducing the flow rate of the nitrogen gas. By providing a process of forming the DLC film during which the nitrogen gas flow rate is reduced, the DLC film on the base side contains a lot of nitrogen atoms, the residual compressive stress is reduced, and the adhesion to the base is increased, and the DLC film on the surface side contains less nitrogen atoms, increasing the wear resistance and weld deposit resistance.

In the second process, preferably the DLC film is formed while reducing the flow rate of nitrogen gas introduced into the furnace stepwise. Preferably the DLC film is formed by finally stopping the introduction of nitrogen gas and feeding current to the graphite target. It is preferable to form the DLC film with stopping the introduction of nitrogen gas, as it enables a surface of the DLC film, at which the film may come in contact with other members, to have a high hardness and a small liability to have thereon a weld deposit from workpieces. In order to achieve a DLC film having higher hardness and less liability to have thereon a weld deposit from workpieces, preferably the introduction of nitrogen gas is finally stopped,

and the DLC film is formed with a pressure inside the furnace of 5×10^{-3} Pa or less.

In the second process, a hydrocarbon gas such as acetylene may be introduced into the furnace so as to increase an amount of hydrogen content in the DLC film on the base side. Alternatively, a hydrocarbon gas such as acetylene may be introduced into the furnace after the first process, and then the second process executed.

[0021] In the second process in the invention, a process for forming the DLC film is provided in which current fed to the graphite target is increased.

The inventor has found that large irregularities develop on a surface of a graphite target as DLC film formation proceeds and arc discharge becomes unstable when forming a DLC film using a filtered arc ion plating process. It has been found that, even when large irregularities develop on a target surface, arc discharge tends to become stable by feeding a higher current to the graphite target. However, even if the current fed to the graphite target is set high, if the input power is constant, then arc discharge gradually becomes unstable as DLC film formation proceeds, and it becomes difficult to form a thick high-hardness DLC film having excellent adhesion. In particular, when current at a high value is fed at an initial stage of DLC film formation under a condition of the target surface is flat, discharge becomes unstable to generate droplets to a great extent, which cause development of large irregularities on the film surface, whereby problem arises in terms of smoothness of the film surface. The inventor has found that it is possible to stabilize arc discharge and continuously form a DLC film by feeding a constant current to a graphite target and forming the DLC film for a fixed duration, then increasing the current fed to the graphite target before the arc discharge becomes unstable. Accordingly, a process for forming a DLC film in which the current fed to the graphite target is increased during film formation is provided in the invention. A thicker, high-hardness DLC film can be thereby stably formed with small load on the apparatus.

The current fed to the graphite target may be increased stepwise, or may be increased continuously. In order to form a thicker DLC film, the current fed to the graphite target is preferably increased stepwise. The current fed to the graphite target is preferably increased in total by 40 A or more. A total of 55 A or more is more preferable, and a total of 60 A or more is still more preferable. Formation in this manner enables stable formation of a thick DLC film having high hardness.

It is preferable that the current value to be fed differs according to the surface state of the graphite target, and a small current value (from 30 A to 50 A) is initially employed at which the surface of the graphite target is in a flat state. It is desirable to increase the current value stepwise thereafter.

In the second process, the process of reducing the flow rate of nitrogen gas and the process of increasing current fed to the graphite target may be executed at the same time, or may be executed separately. For example, the timing for reducing the flow rate of nitrogen gas and the timing for increasing the current fed to the graphite target may be the same as each other, may be different to each other, or configuration may be made so as to alternate between a timing for reducing the flow rate of nitrogen gas and the timing for increasing the current fed to the graphite target. Moreover, DLC film formation is preferably performed by eventually stopping the introduction of nitrogen gas, and increasing the power fed to the graphite target. Formation in this manner enables an even thicker high-hardness DLC film to be obtained.

[0022] If the current fed to the graphite target becomes too great, then arc discharge is liable to be unstable. In the second process in the invention, the process of increasing the current fed to the graphite target is provided; however, in order to continue stable film formation, the current fed to the graphite target is preferably 150 A or less. 120 A or less is more preferable. However, if the current fed to the graphite target is too small, then sometimes it is not possible to perform sufficient DLC film formation. The current fed to the graphite target is accordingly preferably 20 A or more. 30 A or more is more preferable.

[0023] Even for a high-hardness DLC film, it is sometimes difficult to obtain excellent durability at a thin thickness. In order to impart a coated tool with excellent durability in ever harsher usage environments, the thickness of the DLC film is preferably 1.0 μm or more, and 1.5 μm or more is more preferable. The thickness of the DLC film is still more preferably 2.0 μm or more.

However, sometimes there is deterioration in the surface roughness of the film surface if the DLC film thickness is too thick. There is also a higher risk of local separation of the DLC film if the thickness of a high-hardness DLC film is too thick. The DLC film thickness is accordingly preferably 5.0 μm or less. The DLC film thickness is more preferably 4.0 μm or less.

[0024] The base temperature during DLC film formation is preferably 200°C or lower. If the base temperature is a higher temperature than 200°C, then the hardness tends to decrease due to graphitization of the DLC film. Moreover, the base is preferably applied with a negative bias voltage of from -300 V to -50 V during DLC film formation. If the negative bias voltage applied to the base is greater than -50 V (further to the plus side than -50 V), then the collision energy of the carbon ions is small, and defects, such as voids, are liable to develop in the DLC film. If the negative bias voltage applied to the base is lower than -300 V (further to the minus side than -300 V), then abnormal discharge tends to occur during film

formation. The negative bias voltage applied to the base during DLC film formation is more preferably from -200 V to -100 V.

[0025] A base on which the DLC film is formed and that is a base of a coated tool is not particularly limited in the invention, and can be appropriately selected depending on an application or a purpose. For example, cemented carbide alloys, cold tool steels, high-speed tool steels, plastic die steels, hot work tool steels, and the like are applicable. Of the bases, a high carbon steel or cemented carbide alloy having a carbon content of 1% by mass or more, which contains the large amount of carbide in a base material and on which film separation easily occurs, is preferable in view of the higher degree of adhesion improvement.

Examples of such high carbon steels include JIS-SKD11.

[0026] There may be cases in which a DLC film formed by a filtered arc ion plating process has a deteriorated surface roughness when a thickness of the film is large. In this case, it is preferable to smooth a surface of the DLC film by performing, after the DLC film is formed, a polishing treatment. The DLC film may be adjusted to have a further preferable smooth surface by polishing the surface.

EXAMPLES

[0027] <Film Formation Apparatus>

A T-shaped filtered arc ion plating apparatus was used as a film formation apparatus (volume of vacuum chamber in furnace: 0.49m³). The schematic view of the apparatus is illustrated in Figure 2. The apparatus includes a film formation chamber (6), arc discharge-type evaporation sources on each of which a carbon cathode (cathode) (1) provided with a graphite target is mounted, and a substrate holder (7) for carrying a base. A rolling mechanism (8) is present underneath the substrate holder, and the base rotates and revolves via the substrate holder. Reference numeral (2) denotes a carbon film formation beam, and reference numeral (3) denotes spherical graphite (droplet) neutral particles.

When arc discharge on a surface of the graphite target is generated, only carbon carrying an electric charge is curved by a magnetic coil (4) and arrives at the film formation chamber, whereby the base is coated with a film. Droplets carrying no electric charge are collected in a duct (5) without being made to curve by the magnetic coil.

[0028] <Base>

A base of a steel material that had a dimension of $\phi 20 \times 5$ mm, was tempered to have 60 HRC, and was equivalent to JIS-SKD11 was used for evaluating a manufactured DLC film with respect to a separation state and weld deposit resistance.

A base (dimension: 4 mm $\times$ 8 mm $\times$ 25 mm, average particle size: 0.8 μ m, hardness:

91.2 HRA) made of a cemented carbide alloy formed of tungsten carbide having a cobalt content of 10% by mass (WC-10% by mass Co) was used for evaluating a manufactured DLC film with respect to nanoindenter hardness, film analysis, and measurement of a film thickness with a fracture surface.

A base of a steel material that had a dimension of 21 mm × 17 mm × 2 mm and was equivalent to JIS-SKH51 was used for evaluating a manufactured DLC film with respect to a scratch test and adhesion measured by a Rockwell hardness tester.

All of the bases described above were polished to have an arithmetic mean roughness Ra (in conformity with JIS-B-0601-2001) of 0.01 μm or less and a maximum height roughness Rz (in conformity with JIS-B-0601-2001) of 0.07 μm or less, prior to be coated with DLC films. After the polishing, each base was degreased and washed, and fixed to the substrate holder in the chamber.

Each base was coated with a DLC film under the following conditions.

[0029] <Example 1>

Vacuum drawing of the film formation chamber was performed to 5×10^{-3} Pa in a furnace (vacuum chamber), and the base was heated to around 150°C by a heating heater, and held for 90 minutes. Then, a negative bias voltage applied to the base was set at -2000 V, and gas bombardment treatment with a mixed gas containing 5% by mass of hydrogen gas in argon gas was performed for 90 minutes. The flow rate of the mixed gas was set to from 50 sccm to 100 sccm.

After the gas bombardment treatment, nitrogen gas was introduced into the chamber, a bias voltage of -150 V was applied to the base, and the temperature of the base was set to 100°C or less. Then, the DLC film was formed in the following manner by increasing the current fed to the graphite target stepwise from 40 A to 90 A, and reducing the flow rate of nitrogen gas stepwise from 20 sccm to 0 sccm.

First, DLC film formation was performed for a duration of about 30 minutes with the flow rate of nitrogen gas introduced to the furnace of 20 sccm, and the current fed to the graphite target of 40 A.

DLC film formation was further performed for a duration of about 30 minutes with the flow rate of nitrogen gas reduced to 10 sccm, and the current fed to the graphite target increased to 50 A.

DLC film formation was further performed for a duration of about 40 minutes with the flow rate of nitrogen gas reduced to 5 sccm, and the current fed to the graphite target increased to 60 A.

DLC film formation was further performed for a duration of about 40 minutes with

the introduction of nitrogen gas stopped, the furnace internal pressure of 5×10^{-3} Pa or less, and the current fed to the graphite target increased to 70 A.

DLC film formation was further performed for durations of about 40 minutes with the current fed to the graphite target increased to 80 A.

DLC film formation was further performed for durations of about 60 minutes with the current fed to the graphite target increased to 90 A.

[0030] Example 2

Gas bombardment treatment was performed similarly to that in Example 1. After the gas bombardment treatment was performed, nitrogen gas was introduced into the furnace, a bias voltage of -150 V was applied to the base, and the temperature of the base was set to 100°C or lower. Then, the DLC film was formed in the following manner by increasing the current fed to the graphite target stepwise from 35 A to 95 A, and reducing the flow rate of nitrogen gas stepwise from 25 sccm to 0 sccm.

First, DLC film formation was performed for a duration of about 20 minutes with the flow rate of nitrogen gas introduced to the furnace of 25 sccm, and the current fed to the graphite target of 35 A.

DLC film formation was further performed for a duration of about 20 minutes with the flow rate of nitrogen gas reduced to 20 sccm, and the current fed to the graphite target increased to 40 A.

DLC film formation was further performed for a duration of about 20 minutes with the flow rate of nitrogen gas reduced to 15 sccm, and the current fed to the graphite target increased to 45 A.

DLC film formation was further performed for a duration of about 20 minutes with the flow rate of nitrogen gas reduced to 10 sccm, and the current fed to the graphite target increased to 50 A.

DLC film formation was further performed for a duration of about 20 minutes with the flow rate of nitrogen gas reduced to 7 sccm, and the current fed to the graphite target increased to 55 A.

DLC film formation was further performed for a duration of about 20 minutes with the flow rate of nitrogen gas reduced to 5 sccm, and the current fed to the graphite target increased to 60 A.

DLC film formation was further performed for a duration of about 20 minutes with the introduction of nitrogen gas stopped, the furnace internal pressure of 5×10^{-3} Pa or less, and the current fed to the graphite target increased to 65 A.

DLC film formation was further performed for durations of about 20 minutes at each

current value with the current fed to the graphite target increased stepwise to 70 A, 75 A, 80 A, 85 A, and 90 A.

[0031] Example 3

Gas bombardment treatment was performed similarly to that in Example 1. After the gas bombardment treatment was performed, nitrogen gas was introduced into the furnace, a bias voltage of -150 V was applied to the base, and the temperature of the base was set to 100°C or lower. Then, the DLC film was formed in the following manner by increasing the current fed to the graphite target stepwise from 30 A to 95 A, and reducing the flow rate of nitrogen gas stepwise from 20 sccm to 0 sccm.

First, DLC film formation was performed for a duration of about 20 minutes with the flow rate of nitrogen gas introduced to the furnace of 20 sccm, and the current fed to the graphite target of 30 A.

DLC film formation was further performed for a duration of about 20 minutes with the flow rate of nitrogen gas reduced to 15 sccm, and the current fed to the graphite target increased to 35 A.

DLC film formation was further performed for a duration of about 20 minutes with the flow rate of nitrogen gas reduced to 10 sccm, and the current fed to the graphite target increased to 40 A.

DLC film formation was further performed for a duration of about 20 minutes with the flow rate of nitrogen gas reduced to 5 sccm, and the current fed to the graphite target increased to 45 A.

DLC film formation was further performed for a duration of about 20 minutes with the introduction of nitrogen gas stopped, the furnace internal pressure of 5×10^{-3} Pa or less, and the current fed to the graphite target increased to 50 A.

DLC film formation was further performed for durations of about 20 minutes at each current value with the current fed to the graphite target increased stepwise to 55 A, 60 A, 65 A, 70 A, 75 A, 80 A, 85 A, and 90 A.

[0032] Example 4

Gas bombardment treatment was performed similarly to that in Example 1. After the gas bombardment treatment was performed, C₂H₂ gas and nitrogen gas are introduced into the furnace, a bias voltage of -150 V was applied to the base, and the temperature of the base was set to 100°C or lower. Then, the DLC film was formed in the following manner by increasing the current fed to the graphite target stepwise from 35 A to 95 A, and reducing the flow rate of nitrogen gas stepwise from 25 sccm to 0 sccm.

First, DLC film formation was performed for a duration of about 10 minutes with the

flow rate of nitrogen gas introduced to the furnace of 25 sccm, the flow rate of C_2H_2 gas introduced to the furnace of 25 sccm, and the current fed to the graphite target of 35 A.

DLC film formation was further performed for a duration of about 10 minutes with the flow rate of C_2H gas reduced to 20 sccm and the flow rate of nitrogen gas reduced to 20 sccm, and the current fed to the graphite target increased to 40 A.

DLC film formation was further performed for a duration of about 10 minutes with the flow rate of C_2H gas reduced to 15 sccm and the flow rate of nitrogen gas reduced to 15 sccm, and the current fed to the graphite target increased to 45 A.

DLC film formation was further performed for a duration of about 10 minutes with the flow rate of C_2H gas reduced to 10 sccm and the flow rate of nitrogen gas reduced to 10 sccm, and the current fed to the graphite target increased to 50 A.

DLC film formation was further performed for a duration of about 10 minutes with the flow rate of C_2H gas reduced to 7 sccm and the flow rate of nitrogen gas reduced to 7 sccm, and the current fed to the graphite target increased to 55 A.

DLC film formation was further performed for a duration of about 10 minutes with the flow rate of C_2H gas reduced to 5 sccm and the flow rate of nitrogen gas reduced to 5 sccm, and the current fed to the graphite target increased to 60 A.

DLC film formation was further performed for a duration of about 25 minutes with the introduction of C_2H gas and nitrogen gas stopped, the furnace internal pressure of 5×10^{-3} Pa or less, and the current fed to the graphite target increased to 65 A.

DLC film formation was further performed for durations of about 20 minutes at each current value with the current fed to the graphite target increased stepwise to 70 A, 75 A, and 80 A.

[0033] Example 5

Gas bombardment treatment was performed similarly to that in Example 1. After the gas bombardment treatment was performed, C_2H_2 gas and nitrogen gas are introduced into the furnace, a bias voltage of -150 V was applied to the base, and the temperature of the base was set to 100°C or lower. Then, the DLC film was formed in the following manner by increasing the current fed to the graphite target stepwise from 50 A to 80 A, and reducing the flow rate of nitrogen gas stepwise from 15 sccm to 0 sccm.

First, DLC film formation was performed for a duration of about 6 minutes with the flow rate of nitrogen gas introduced to the furnace of 15 sccm, the flow rate of C_2H_2 gas introduced to the furnace of 10 sccm, and the current fed to the graphite target of 50 A.

DLC film formation was further performed for a duration of about 45 minutes with the introduction of C_2H gas stopped, the flow rate of nitrogen gas set to 15 sccm, and the

current fed to the graphite target increased to 60 A.

DLC film formation was further performed for a duration of about 45 minutes with the flow rate of nitrogen gas reduced to 5 sccm, and the current fed to the graphite target increased to 70 A.

DLC film formation was further performed for a duration of about 100 minutes with the introduction of nitrogen gas stopped, the furnace internal pressure of 5×10^{-3} Pa or less, and the current fed to the graphite target increased to 80 A.

[0034] Example 6

Gas bombardment treatment was performed similarly to that in Example 1. After the gas bombardment treatment was performed, nitrogen gas was introduced into the furnace, a bias voltage of -150 V was applied to the base, and the temperature of the base was set to 100°C or lower. Then, the DLC film was formed in the following manner by increasing the current fed to the graphite target stepwise from 25 A to 95 A, and reducing the flow rate of nitrogen gas stepwise from 15 sccm to 0 sccm.

First, DLC film formation was performed for a duration of about 20 minutes with the flow rate of nitrogen gas introduced to the furnace of 15 sccm, and the current fed to the graphite target of 25 A.

DLC film formation was further performed for a duration of about 20 minutes with the flow rate of nitrogen gas reduced to 10 sccm, and the current fed to the graphite target increased to 30 A.

DLC film formation was further performed for a duration of about 20 minutes with the flow rate of nitrogen gas reduced to 5 sccm, and the current fed to the graphite target increased to 35 A.

DLC film formation was further performed for a duration of about 20 minutes with the introduction of nitrogen gas stopped, the furnace internal pressure of 5×10^{-3} Pa or less, and the current fed to the graphite target increased to 40 A.

DLC film formation was further performed for durations of about 20 minutes at each current value with the current fed to the graphite target increased stepwise to 45 A, 50 A, 55A, 60 A, 65 A, 70 A, 75 A, 80 A, 85 A, 90 A, and 95 A.

[0035] <Example 7>

Gas bombardment treatment was performed for 90 minutes with a negative bias voltage applied to the base set at -2000 V and a mixed gas containing 10% by mass of hydrogen gas in argon gas. After the gas bombardment treatment was performed, nitrogen gas was introduced into the chamber, a bias voltage of -150 V was applied to the base, and the temperature of the base was set to 100°C or less. Then, the DLC film was formed in the

following manner by increasing the current fed to the graphite target stepwise from 35 A to 95 A, and reducing the flow rate of nitrogen gas stepwise from 25 sccm to 0 sccm.

First, DLC film formation was performed for a duration of about 20 minutes with the flow rate of nitrogen gas introduced to the furnace of 25 sccm, and the current fed to the graphite target of 35 A.

DLC film formation was further performed for a duration of about 20 minutes with the flow rate of nitrogen gas reduced to 20 sccm, and the current fed to the graphite target increased to 40 A.

DLC film formation was further performed for a duration of about 20 minutes with the flow rate of nitrogen gas reduced to 15 sccm, and the current fed to the graphite target increased to 45 A.

DLC film formation was further performed for a duration of about 20 minutes with the flow rate of nitrogen gas reduced to 10 sccm, and the current fed to the graphite target increased to 50 A.

DLC film formation was further performed for a duration of about 20 minutes with the flow rate of nitrogen gas reduced to 5 sccm, and the current fed to the graphite target increased to 55 A.

DLC film formation was further performed for a duration of about 20 minutes with the introduction of nitrogen gas stopped, the furnace internal pressure of 5×10^{-3} Pa or less, and the current fed to the graphite target increased to 60 A.

DLC film formation was further performed for durations of about 20 minutes at each current value with the current fed to the graphite target increased stepwise to 65 A, 70 A, 75 A, 80 A, 85 A, 90 A, and 95 A.

[0036] <Example 8>

Gas bombardment treatment was performed for 90 minutes with a negative bias voltage applied to the base set at -2000 V and a mixed gas containing 20% by mass of hydrogen gas in argon gas. After the gas bombardment treatment was performed, nitrogen gas was introduced into the chamber, a bias voltage of -150 V was applied to the base, and the temperature of the base was set to 100°C or less. Then, the DLC film was formed in the following manner by increasing the current fed to the graphite target stepwise from 35 A to 95 A, and reducing the flow rate of nitrogen gas stepwise from 25 sccm to 0 sccm.

First, DLC film formation was performed for a duration of about 20 minutes with the flow rate of nitrogen gas introduced to the furnace of 25 sccm, and the current fed to the graphite target of 35 A.

DLC film formation was further performed for a duration of about 20 minutes with

the flow rate of nitrogen gas reduced to 20 sccm, and the current fed to the graphite target increased to 40 A.

DLC film formation was further performed for a duration of about 20 minutes with the flow rate of nitrogen gas reduced to 15 sccm, and the current fed to the graphite target increased to 45 A.

DLC film formation was further performed for a duration of about 20 minutes with the flow rate of nitrogen gas reduced to 10 sccm, and the current fed to the graphite target increased to 50 A.

DLC film formation was further performed for a duration of about 20 minutes with the flow rate of nitrogen gas reduced to 5 sccm, and the current fed to the graphite target increased to 55 A.

DLC film formation was further performed for a duration of about 20 minutes with the introduction of nitrogen gas stopped, the furnace internal pressure of 5×10^{-3} Pa or less, and the current fed to the graphite target increased to 60 A.

DLC film formation was further performed for durations of about 20 minutes at each current value with the current fed to the graphite target increased stepwise to 65 A, 70 A, 75 A, 80 A, 85 A, 90 A, and 95 A.

[0037] Example 9

Gas bombardment treatment was performed similarly to that in Example 1. After the gas bombardment treatment was performed, nitrogen gas was introduced into the furnace, a bias voltage of -150 V was applied to the base, and the temperature of the base was set to 100°C or lower. Then, the DLC film was formed in the following manner by increasing the current fed to the graphite target stepwise from 35 A to 95 A, and reducing the flow rate of nitrogen gas stepwise from 40 sccm to 0 sccm.

First, DLC film formation was performed for a duration of about 20 minutes with the flow rate of nitrogen gas introduced to the furnace of 40 sccm, and the current fed to the graphite target of 35 A.

DLC film formation was further performed for a duration of about 20 minutes with the flow rate of nitrogen gas reduced to 30 sccm, and the current fed to the graphite target increased to 40 A.

DLC film formation was further performed for a duration of about 20 minutes with the flow rate of nitrogen gas reduced to 20 sccm, and the current fed to the graphite target increased to 45 A.

DLC film formation was further performed for a duration of about 20 minutes with the flow rate of nitrogen gas reduced to 10 sccm, and the current fed to the graphite target

increased to 50 A.

DLC film formation was further performed for a duration of about 20 minutes with the flow rate of nitrogen gas reduced to 5 sccm, and the current fed to the graphite target increased to 55 A.

DLC film formation was further performed for a duration of about 20 minutes with the introduction of nitrogen gas stopped, the furnace internal pressure of 5×10^{-3} Pa or less, and the current fed to the graphite target increased to 60 A.

DLC film formation was further performed for durations of about 20 minutes at each current value with the current fed to the graphite target increased stepwise to 65A, 70 A, 75 A, 80 A, 85 A, 90 A, and 95A.

[0038] Example 10

Gas bombardment treatment was performed similarly to that in Example 1. After the gas bombardment treatment was performed, nitrogen gas was introduced into the furnace, a bias voltage of -350 V was applied to the base, and the temperature of the base was set to 100°C or lower. Then, the DLC film was formed in the following manner by increasing the current fed to the graphite target stepwise from 35 A to 95 A, and reducing the flow rate of nitrogen gas stepwise from 25 sccm to 0 sccm.

First, DLC film formation was performed for a duration of about 20 minutes with the flow rate of nitrogen gas introduced to the furnace of 25 sccm, and the current fed to the graphite target of 35 A.

DLC film formation was further performed for a duration of about 20 minutes with the bias voltage of -300 V applied to the base, the flow rate of nitrogen gas reduced to 20 sccm, and the current fed to the graphite target increased to 40 A.

DLC film formation was further performed for a duration of about 20 minutes with the bias voltage of -250 V applied to the base, the flow rate of nitrogen gas reduced to 15 sccm, and the current fed to the graphite target increased to 45 A.

DLC film formation was further performed for a duration of about 20 minutes with the bias voltage of -200 V applied to the base, the flow rate of nitrogen gas reduced to 10 sccm, and the current fed to the graphite target increased to 50 A.

DLC film formation was further performed for a duration of about 20 minutes with the bias voltage of -150 V applied to the base, the flow rate of nitrogen gas reduced to 7 sccm, and the current fed to the graphite target increased to 55 A.

DLC film formation was further performed for a duration of about 20 minutes with the flow rate of nitrogen gas reduced to 5 sccm, and the current fed to the graphite target increased to 60 A.

DLC film formation was further performed for a duration of about 20 minutes with the introduction of nitrogen gas stopped, the furnace internal pressure of 5×10^{-3} Pa or less, and the current fed to the graphite target increased to 65 A.

DLC film formation was further performed for durations of about 20 minutes at each current value with the current fed to the graphite target increased stepwise to 70 A, 75 A, 80 A, 85 A, 90 A, and 95A.

[0039] <Example 11>

Gas bombardment treatment was performed for 90 minutes with a negative bias voltage applied to the base set at -2500 V and a mixed gas containing 5% by mass of hydrogen gas in argon gas. After the gas bombardment treatment was performed, nitrogen gas was introduced into the chamber, a bias voltage of -150 V was applied to the base, and the temperature of the base was set to 100°C or less. Then, the DLC film was formed in the following manner by increasing the current fed to the graphite target stepwise from 35 A to 95 A, and reducing the flow rate of nitrogen gas stepwise from 25 sccm to 0 sccm.

First, DLC film formation was performed for a duration of about 20 minutes with the flow rate of nitrogen gas introduced to the furnace of 25 sccm, and the current fed to the graphite target of 35 A.

DLC film formation was further performed for a duration of about 20 minutes with the flow rate of nitrogen gas reduced to 20 sccm, and the current fed to the graphite target increased to 40 A.

DLC film formation was further performed for a duration of about 20 minutes with the flow rate of nitrogen gas reduced to 15 sccm, and the current fed to the graphite target increased to 45 A.

DLC film formation was further performed for a duration of about 20 minutes with the flow rate of nitrogen gas reduced to 10 sccm, and the current fed to the graphite target increased to 50 A.

DLC film formation was further performed for a duration of about 20 minutes with the flow rate of nitrogen gas reduced to 7 sccm, and the current fed to the graphite target increased to 55 A.

DLC film formation was further performed for a duration of about 20 minutes with the flow rate of nitrogen gas reduced to 5 sccm, and the current fed to the graphite target increased to 60 A.

DLC film formation was further performed for a duration of about 20 minutes with the introduction of nitrogen gas stopped, the furnace internal pressure of 5×10^{-3} Pa or less, and the current fed to the graphite target increased to 65 A.

DLC film formation was further performed for durations of about 20 minutes at each current value with the current fed to the graphite target increased stepwise to 70 A, 75 A, 80 A, 85 A, 90 A, and 95 A.

[0040] Comparative Example 1

Gas bombardment treatment was performed similarly to that in Example 1. After the gas bombardment treatment was performed, nitrogen gas was introduced into the furnace, a bias voltage of -150 V was applied to the base, and the temperature of the base was set to 100°C or lower. Then, the DLC film was formed in the following manner by setting the current fed to the graphite target to 50 A, and reducing the flow rate of nitrogen gas stepwise from 10 sccm to 0 sccm.

First, DLC film formation was performed for a duration of about 10 minutes with the flow rate of nitrogen gas introduced to the furnace of 10 sccm.

DLC film formation was further performed for a duration of about 10 minutes with the flow rate of nitrogen gas reduced to 5 sccm.

DLC film formation was further performed for a duration of about 30 minutes with the introduction of nitrogen gas stopped and the furnace internal pressure of 5×10^{-3} Pa or less.

[0041] Comparative Example 2

Gas bombardment treatment was performed similarly to that in Example 1. After the gas bombardment treatment was performed, a bias voltage of -150 V was applied to the base, and the temperature of the base was set to 100°C or lower, with no introduction of nitrogen gas into the furnace. DLC film formation was further performed for a duration of about 50 minutes with the furnace internal pressure of 5×10^{-3} Pa or less and the current fed to the graphite target of 50 A.

[0042] < Comparative Example 3 >

Gas bombardment treatment was performed for 90 minutes with a negative bias voltage applied to the base set at -2000 V and argon gas.

After the gas bombardment treatment was performed, nitrogen gas was introduced into the chamber, a bias voltage of -150 V was applied to the base, and the temperature of the base was set to 100°C or less. Then, the DLC film was formed in the following manner by setting the current fed to the graphite target to 50 A, and reducing the flow rate of nitrogen gas stepwise from 10 sccm to 0 sccm.

First, DLC film formation was performed for a duration of about 10 minutes with the flow rate of nitrogen gas introduced to the furnace of 10 sccm.

DLC film formation was further performed for a duration of about 10 minutes with

the flow rate of nitrogen gas reduced to 5 sccm.

DLC film formation was further performed for a duration of about 30 minutes with the introduction of nitrogen gas stopped and the furnace internal pressure of 5×10^{-3} Pa or less.

[0043] < Comparative Example 4>

Gas bombardment treatment was performed with a condition similar to that in Comparative Example 3. Thereafter, CrN was applied as an intermediate film. After the intermediate film formation, a bias voltage of -150 V was applied to the base and the temperature of the base was set to 100°C or lower, with no introduction of nitrogen gas into the furnace.

DLC film formation was further performed for a duration of about 50 minutes with the furnace internal pressure of 5×10^{-3} Pa or less and the current fed to the graphite target of a constant value of 50 A.

[0044] Comparative Example 5

Gas bombardment treatment was performed similarly to that in Example 1. After the gas bombardment treatment was performed, nitrogen gas was introduced into the furnace, a bias voltage of -150 V was applied to the base, and the temperature of the base was set to 100°C or lower. Then, the DLC film was formed in the following manner by setting the current fed to the graphite target to 80 A, and reducing the flow rate of nitrogen gas stepwise from 10 sccm to 0 sccm.

First, DLC film formation was performed for a duration of about 25 minutes with the flow rate of nitrogen gas introduced to the furnace of 10 sccm.

DLC film formation was further performed for a duration of about 25 minutes with the flow rate of nitrogen gas reduced to 5 sccm.

DLC film formation was further performed for a duration of about 70 minutes with the introduction of nitrogen gas stopped and the furnace internal pressure of 5×10^{-3} Pa or less.

[0045] < Comparative Example 6>

Gas bombardment treatment was performed for 90 minutes with a negative bias voltage applied to the base set at -1300 V and a mixed gas containing 5% by mass of hydrogen gas in argon gas. After the gas bombardment treatment, a bias voltage of -150 V was applied to the base, and the temperature of the base was set to 100°C or less. DLC film formation was further performed for a duration of about 50 minutes with the current fed to the graphite target of 50 A.

[0046] < Comparative Example 7>

Gas bombardment treatment was performed for 90 minutes with a negative bias voltage applied to the base set at -1000 V and a mixed gas containing 5% by mass of hydrogen gas in argon gas. After the gas bombardment treatment, a bias voltage of -150 V was applied to the base, and the temperature of the base was set to 100°C or less. DLC film formation was further performed for a duration of about 50 minutes with the current fed to the graphite target of 50 A.

[0047] Each of the samples was coated with the DLC film while the film formation and cooling were repeated so that the temperature of the base became 200°C or less.

Each sample coated with the DLC film was subjected to hardness measurement, surface roughness measurement, adhesion evaluation, and weld deposit resistance evaluation. The measurement conditions thereof are explained below.

[0048] <Measurement and Evaluation>

-Measurement of Nanoindentation Hardness-

The hardness of each film surface was measured using a nanoindentation apparatus manufactured by Elionix Inc. The hardnesses of ten points were measured under the measurement conditions of an indentation load of 9.8 mN, a maximum load retention time of 1 sec, and a removal rate of 0.49 mN/sec after loading, and the hardness was determined from an average value of six points, which remained via exclusion two points, one of which having the highest value and the other of which having the second highest value, and the two points, one of which having the lowest value and the other of which having the second lowest values. It was observed that fused quartz as a standard sample had a hardness of 15 GPa, and a CVD diamond film had a hardness of 100 GPa.

[0049] -Measurement of Surface Roughness-

Arithmetic mean roughness Ra and maximum height roughness Rz were measured from a roughness curve according to JIS-B-0601-2001 using a contact-type surface roughness measuring instrument SURFCOM 480A manufactured by Tokyo Seimitsu Co., Ltd. The measurement conditions thereof were an evaluation length of 4.0 mm, a measurement rate of 0.3 mm/sec, and a cutoff value of 0.8 mm.

[0050] -Evaluation of Adhesion-

The surface of the DLC film of each sample just after having been coated was observed using an optical microscope manufactured by Mitutoyo Corporation at a magnification of about 800 times, whereby the state of separation of the surface was evaluated. The evaluation criteria of the separation at the surface of the DLC film are as follows.

<Evaluation Criteria of Separation of Surface>

A: No separation was observed at the surface.

B: A minute separation was observed.

C: A separation was observed.

[0051] A separation load was measured using a scratch tester (REVETEST) manufactured by CSM. The measurement conditions thereof were measuring load: from 0 to 100 N, load speed: 99.25 N/min, scratch speed: 10 mm/min, scratch distance: 10 mm, AE sensitivity: 5, indenter: Rockwell, diamond, tip radius: 200 μm , hardware setting: F_n contact of 0.9 N, F_n speed: 5 N/sec, F_n removal speed: 10 N/sec, and approach speed: 2%/sec. A load at which a base of a scratch mark bottom was completely exposed was evaluated.

[0052] An indentation was made in the DLC film of each of the samples using a Rockwell hardness tester (AR-10, manufactured by Mitutoyo) with a C-scale diamond indenter. The condition of film separation at the periphery of the indentation was evaluated by observation at about 800 times magnification using an optical microscope manufactured by Mitutoyo Corporation. The following adhesion evaluation criteria were employed in the Rockwell hardness (HRC) indentation test.

< Evaluation Criteria of HRC Indentation Test (HRC adhesion)>

A: No separation, or separation with an equivalent circle diameter of less than 5 μm

B: Fine separation present (separation of an equivalent circle diameter of 5 μm or more but less than 10 μm)

C: Large separation present (separation of an equivalent circle diameter of 10 μm or larger)

[0053] -Weld Deposit Resistance Test-

To evaluate a weld deposit resistance, a ball-on-disk tester (Tribometer manufactured by CSM Instruments) was used. An aluminum A5052 sphere (6 mm in diameter) was pressed at a load of 5 N against a disc-shaped test piece of the base coated with the DLC film being rotated at a rate of 100 mm/sec. A test distance was set to 100 m.

[0054] Table 1

	Gas Bombardment Conditions	DLC Film Formation Conditions		DLC Film Characteristics			Adhesion Evaluation			Weld deposit resistance Evaluation
		Current Fed to TG (A)	N Gas Flow Rate (sccm)	Thickness (μm)	Hardness (Gpa) ^{*1}	Surface Roughness (μm)	Surface Separation	HRC Adhesion	Scratch Load (N)	
EXAMPLES	1	Ar +5% H Bombardment at -2000V	40→90	20→0	1.75	90	Ra0.03 Rz0.30	A	55	No Weld deposit
	2	Ar +5% H Bombardment at -2000V	35→95	25→0	2.00	93	Ra0.02 Rz0.04	A	50	No Weld deposit
	3	Ar +5% H Bombardment at -2000V	30→95	20→0	2.74	95	Ra0.02 Rz0.70	A	53	No Weld deposit
	4	Ar +5% H Bombardment at -2000V	35→95	25→0	3.20	95	Ra0.02 Rz0.81	A	55	No Weld deposit
	5	Ar +5% H Bombardment at -2000V	50→80	15→0	1.23	92	Ra0.03 Rz0.61	A	65	No Weld deposit
	6	Ar +5% H Bombardment at -2000V	25→95	15→0	2.15	75	Ra0.01 Rz0.55	A	57	No Weld deposit
	7	Ar +10% H Bombardment at -2000V	35→95	25→0	2.20	95	Ra0.02 Rz0.61	A	63	No Weld deposit
	8	Ar +20% H Bombardment at -2000V	35→95	25→0	1.93	85	Ra0.02 Rz0.73	A	57	No Weld deposit
	9	Ar +5% H Bombardment at -2000V	35→95	40→0	1.88	80	Ra0.01 Rz0.46	A	63	No Weld deposit
	10	Ar +5% H Bombardment at -2000V	35→95	25→0	2.08	81	Ra0.02 Rz0.73	A	62	No Weld deposit
	11	Ar +5% H Bombardment at -2500V	35→95	25→0	1.83	95	Ra0.02 Rz0.48	A	61	No Weld deposit
COMPARATIVE EXAMPLES	1	Ar +5% H Bombardment at -2000V	50	10→0	0.40	75	Ra0.01 Rz0.08	A	61	No Weld deposit
	2	Ar +5% H Bombardment at -2000V	50	0	0.43	75	Ra0.01 Rz0.06	B	52	Weld deposit Present
	3	Ar Bombardment at -2000V	50	10→0	0.30	53	Ra0.01 Rz0.06	B	59	Weld deposit Present
	4	Ar Bombardment + CrN at -2000V	50	0	0.40	60	Ra0.01 Rz0.27	C	28	Weld deposit Present
	5	Ar +5% H Bombardment at -2000V	80	10→0	1.30	90	Ra0.02 Rz0.65	A	49	No Weld deposit
	6	Ar +5% H Bombardment at -1300V	50	0	0.40	68	Ra0.01 Rz0.14	B	43	Weld deposit Present
	7	Ar +5% H Bombardment at -1000V	50	0	0.40	60	Ra0.01 Rz0.11	B	50	Weld deposit Present

*1 nano-indentation hardness

[0055] The manufacturing conditions and evaluation results of Table 1 are now summarized. Examples 1 to 11 are DLC films having high film hardness and a thickness of 1.0 μm or more, with almost no film separation in evaluation of surface separation and HRC indentation tests, and, moreover, with scratch loads of 50 N or more and excellent adhesion in all evaluations. It was also found that deposition of welded material and film separation did not occur in the weld deposit resistance test. Moreover, arc discharge during film formation was stable, and it was possible to conduct continuous, stable film formation with Examples 1 to 11.

A photographic observation of a cross-section of the coated DLC film of Example 4 is illustrated in Fig. 1, as a typical example of a photographic observation of a cross-section of a coated DLC film of Examples. In Fig. 1, it is found that a smooth DLC film not containing droplets is coated at approximately 3.0 μm . Thus application of the method of manufacturing of Examples enables a thick DLC film having excellent adhesion, high hardness, and few film defects to be coated, and enables stable manufacturing of a coated tool having excellent durability.

Comparative Example 1 is a DLC film having excellent adhesion property and weld deposit resistance, similar to in Examples. However, arc discharge became unstable due to the current fed to the graphite target being constant, and it was difficult to coat a DLC film of greater thickness.

In Comparative Example 2, there was a tendency that surface separation is more liable to occur than in Examples, due to the DLC film being coated without the introduction of nitrogen gas. Deposition of welded material in the weld deposit resistance evaluation and separation were observed.

In Comparative Example 3, there was a reduction in adhesion compared to Examples due to the gas bombardment treatment performed with argon gas alone. Deposition of welded material in the weld deposit resistance evaluation and separation were observed.

In Comparative Example 4, there was a reduction in adhesion compared to Examples due to the CrN intermediate film coated after gas bombardment treatment performed with argon gas alone. Deposition of welded material in the weld deposit resistance evaluation and separation were observed.

In Comparative Example 5, a DLC film was obtained having excellent adhesion and weld deposit resistance similar to Examples. However, film formation was not stabilized since arc discharge became unstable due to the constant current fed to the graphite target to cause misfiring of arc discharge during film formation. Further, the scratch load was more liable to be smaller than in Examples.

In Comparative Examples 6 and 7, removal of residual oxygen on the surface of the

base was insufficient since the negative bias voltages applied to the base during gas bombardment treatment were -1300 V or -1000 V, respectively. Accordingly, there was a reduction in adhesion compared to Examples. Deposition of welded material in the weld deposit resistance evaluation and separation were observed.

CLAIMS

1. A method of manufacturing a coated tool by forming a diamond-like carbon film on a surface of a base by a filtered arc ion plating process, the method comprising:
a first process of subjecting the surface of the base to a gas bombardment treatment by applying a negative bias voltage of from -2500 V to -1500 V to the base and introducing a mixed gas containing hydrogen gas into a furnace; and
a second process of forming a diamond-like carbon film on the surface of the base by introducing nitrogen gas into the furnace, after the gas bombardment treatment has been performed, and feeding a current to a graphite target,
the second process comprising reducing a flow rate of the nitrogen gas and increasing the current fed to the graphite target.
2. The method of manufacturing a coated tool according to claim 1, wherein the diamond-like carbon film has a thickness of 2.0 μm or more.
3. The method of manufacturing a coated tool according to claims 1 or 2, wherein a total of an increase in the current fed to a graphite target in the increasing of the current fed to the graphite target is 40 A or more.