

Method of repairing DLC-coated components and DLC-coated aircraft component

The invention relates to a method of repairing components coated with diamond-like carbon (DLC), and to a DLC-coated aircraft component.

The prior art discloses the coating of highly stressed component surfaces with DLC. In automobiles, for example, camshafts, piston rings, bearing seats, valve guides and gears have been coated correspondingly for some time in order thus to reduce friction and hence wear.

DLC layers are applied to the desired component surface with the aid of the known methods of physical vapor deposition (PVD) or chemical vapor deposition (CVD). Under reduced pressure or in a low pressure atmosphere, the material to be applied as a layer is evaporated and condensed on the surface to be coated. If chemical reactions are still proceeding while the material to be applied is in the gas phase, this is referred to as CVD, or if not as PVD.

DLC coatings are currently considered solely for those components and applications where it is assumed that the DLC coating will surpass the whole lifetime of a component thus coated before the component is completely exchanged if appropriate. This is because of the current lack of any way of repairing a worn or damaged DLC coating in the prior art.

As a result, DLC coatings are only rarely used in aircraft construction. Those aircraft components where coating with DLC could be advantageous in principle are regularly under high stress. As a result, the component structure is frequently manufactured from highly durable and therefore costly material, which means that coating with DLC is regularly not

an option since, in the event of damage solely to the coating, the entire component would have to be disposed of owing to the lack of reparability.

It is an object of the present invention to provide a method
5 of repairing DLC-coated components by which a damaged DLC coating can be removed and/or replaced. It is a further object of the invention to provide an aircraft component matched to the repair method of the invention.

This object is achieved by a method according to the main
10 claim and an aircraft component according to further independent Claim 8. Advantageous developments are the subject of the dependent claims.

Accordingly, the invention relates to a method of repairing
DLC-coated components, especially a stator vane, comprising
15 the steps of:

- evaporating and/or converting the DLC layer by irradiation with a laser, wherein the properties of the laser radiation and the treatment duration are chosen such that the carrier material beneath the DLC layer is
20 not impaired; and
- cleaning the carrier material by blasting with a blasting agent that does not impair the carrier material.

The invention further relates to an aircraft component for use
25 in an aircraft engine, comprising an aerodynamically shaped vane region with the vane surface and an axis of rotation, wherein bearing journals for rotatable bearing in coaxially arranged bearing journal receivers are provided coaxially with the axis of rotation at each end of the vane region, wherein

the bearing journals are each formed so as to protrude from a stop surface for resting against an end face of the bearing journal receivers, wherein the outer faces of the bearing journals and stop surfaces have been provided with a DLC layer that can be repaired by the method according to the invention.

First of all, some terms used in association with the invention are elucidated:

"DLC" or "diamond-like carbon" in the context of the present invention, according to the definition by the International Union of Pure and Applied Chemistry (IUPAC): "Recommended terminology for the description of carbon as a solid", published as "IUPAC Recommendations 1995, Pure and Applied Chemistry 67 (3)", 1995 (doi:10.1351/pac199567030473), comprises predominantly sp³-hybridized and non-crystalline carbon, which is intended to encompass all sub-classes of DLC.

DLCs in industry are often divided into three generations according to the chronological sequence of synthesis, generally with a rising proportion of sp³-hybridized carbon with each generation, while the proportion of non-sp³-hybridized carbon and extraneous atoms falls. As the proportion of sp³-hybridized carbon increases, there is also an increase in material properties such as hardness and stiffness. Third-generation DLCs are "tetrahedral hydrogen free amorphous carbons" (ta-C). Expressed in terms of chemical structure, the following specific structures are among those encompassed: a-C, ta-C, a-C:ME, a-C:H, ta-C:H, a-C:H:Me, a-C:H:X and ta-C, where a-C represents amorphous carbon, Me represents metals (e.g. Ti, W), H represents hydrogen and X represents nonmetals (e.g. Si, O, N, F, B).

A material, surface or layer is "not impaired" in the course of a processing step when the material, surface or layer is

essentially altered neither mechanically nor chemically during the processing step. Thus, in principle, no material should be removed, nor should the chemical composition of the material be altered. But removal of material to a practically non-measurable degree may be tolerable.

The invention for the first time offers a method of damage-free removal of a DLC coating from a component. The substance of the component is not altered in this method, and so the component can regularly be recoated if required without further reprocessing.

In a first step, the DLC layer to be removed is either evaporated by irradiation with a laser or else converted to non-DLC carbon derivatives. The properties of the laser radiation (for example intensity) and the parameters of the irradiation (for example irradiation time or pulsation) are chosen here such that, on the one hand, the DLC layer is fundamentally evaporated and/or converted to non-DLC carbon materials, but, at the same time, the carrier material beneath the DLC layer to be removed is not impaired. More particularly, by means of suitable irradiation parameters, it is possible to achieve a rapid increase in temperature in the DLC layer that leads to the desired evaporation and/or conversion, while the material beneath does not undergo any significant increase in temperature that could trigger metallurgical processes. It is possible – for example by suitable test series – to ascertain suitable parameters without difficulty for any combinations of DLC layer and carrier material, which it is then possible to employ for DLC layers to be removed on components. Particularly suitable parameter ranges have been found to be pulse durations of less than 0.5 μs , preferably less than 50 ns, energy densities of 10 J/cm² to 100 J/cm², preferably 60 J/cm² to 80 J/cm², and/or pulse energy densities per unit layer thickness (volumetric

pulse energy) of 4 J/(cm²·μm) to 25 J/(cm²·μm), preferably of 10 J/(cm²·μm) to 20 J/(cm²·μm). If a relatively large region is processed successively with individual pulses, the individual pulses along a pulse path may overlap by 55% to 95%,
5 preferably by 65% to 85%, and/or two adjacent pulse paths may overlap by 5% to 35%, preferably by 7% to 27%.

Subsequently, the non-DLC carbon derivatives remaining on the carrier material that may be the result of the conversion and/or residues of the DLC layer after the evaporation are
10 removed by blasting with a blasting agent that does not impair the carrier material, and the carrier material is thus cleaned. The invention is based on the finding that the non-DLC carbon derivatives remaining on the carrier material have been converted by the preceding step of evaporating and/or
15 converting by laser irradiation to graphite or to other easily removable non-DLC carbon derivatives, for example soot. Graphite and other non-DLC carbon derivatives have distinctly lower hardness than DLC and, as a result, can be removed by blasting with a blasting agent that does not impair the
20 carrier material. The choice of a suitable blasting agent and the other parameters of blasting in order not to affect the carrier material can be ascertained without difficulty by tests for various carrier materials and then employed in the method of the invention.

25 Particularly advantageous and hence preferred blasting agents have been found to be nutshells, in which case the blasting is preferably performed at a pressure of 1 to 10 bar, preferably of 1 to 5 bar, at an angle of 20° to 160°, preferably of 40° to 120°, at a distance from the component of 10 mm to 250 mm.

30 After the carrier material has been cleaned, it is possible in principle to directly apply a new layer of DLC to the component or the cleaned carrier material again.

However, the carrier material is frequently a tie layer applied to a base material beneath and is regularly likewise damaged in the case of a damaged DLC layer to be removed.

It is therefore preferable – after cleaning of the carrier material and if the carrier material is a tie layer applied to a base material – to remove the tie layer in a chemical method that does not impair the base material. Thus, the DLC layer together with the tie layer provided for the purpose is removed, such that, if required for component recoating with DLC, the original layer construction comprising a tie layer applied beforehand can be reconstructed.

The tie layer may, for example, be a tie layer of chromium. A corresponding tie layer can be efficiently removed with sodium hydroxide solution under voltage. It has been found to be preferable to use a voltage of 1 to 10 V for the purpose, preferably of 4 to 6 V, and/or a solution with 20 to 200 g/l, preferably with 60 to 90 g/l, of sodium hydroxide as sodium hydroxide solution.

The method according to the invention makes it possible for the first time to provide coatings of DLC also on those surfaces where, owing to the stresses, even a DLC layer wears out within the lifetime that the component would otherwise have. This is because it is possible for the first time through the method according to the invention to remove and renew the DLC coating, such that the component can be repaired again during its lifetime in spite of spent or damaged DLC coating – possibly even repeatedly. This makes it possible to provide coatings of DLC even in particularly highly stressed surface regions of components that can be subjected to high stress and are thus costly.

In axial gas turbines, such as aircraft engines in particular, the use of variable stator vanes (VSVs) in the region of a compressor stage – generally in the region of the high-pressure compressor – is known for variably influencing the state of operation of a gas turbine. This is because it is possible by means of adjustable stator vanes to influence the rate at which air is conveyed through the gas turbine.

The variable stator vanes arranged in an annular manner about the shaft of the gas turbine are mounted so as to be rotatable about their longitudinal axis, in order to be adjustable with regard to their pitch with respect to the flow through the compressor stage. For this purpose, they have, at each of their two longitudinal ends, a bearing journal arranged coaxially with the longitudinal axis and protruding from a stop surface, by which they are rotatably mounted in corresponding receivers in the fixed turbine structure.

In the prior art, plastic bushings are provided in said receivers to form a slide bearing. However, the plastic bushings are subject to severe wear and have to be replaced regularly. If the plastic bushings are not exchanged in good time, the result is damage to the turbine structure that entails a possibly complex repair.

Coating of the bearing journals with DLC was omitted in the past since the corresponding coating is rubbed off owing to the high stresses during the lifetime that a variable stator vane would otherwise have, and there was no way of renewing it to date. Since the destruction of a variable stator vane with a DLC coating of the bearing journals that has rubbed off before the end of the actual lifetime bears no relation to the production costs for variable stator vanes, no such coating was ever seriously considered.

However, the method according to the invention now makes it possible to repair a DLC coating, and therefore a corresponding coating is for the first time economically possible even in the case of aircraft components such as variable stator vanes.

At least the outer faces of the bearing journals and the stop surfaces of a variable stator vane are provided here with a DLC layer, for which it is possible to make use of methods known from the prior art. All that has to be ensured is that the DLC layer is repairable by the method according to the invention. This too can be determined directly by suitable tests.

It is preferable when the DLC layer is composed of ta-C, which has already been described in detail above. This is true both of the method according to the invention and of the aircraft component according to the invention.

For further elucidation of the aircraft component according to the invention, reference is made to the remarks above.

The invention is now described by way of example by an advantageous embodiment with reference to the appended drawings. The figures show:

Figure 1: an aircraft component according to the invention;
and

Figure 2a-d: schematic diagram of the method according to the invention.

The aircraft component 1 according to the invention in Figure 1 is a variable stator vane, fundamental shape and function of which is known from the prior art. The stator vane is intended for incorporation into the stator of a high-

pressure compressor stage of an aircraft engine (not shown). It comprises an aerodynamically shaped vane region 2 with the vane surface 3 and an axis of rotation 4.

5 Provided coaxially with the axis of rotation 4 at each end of the vane region 2 are bearing journals 5 that can engage with corresponding bearing journal receivers in an aircraft engine. The bearing journals 5 protrude in each case from a stop surface 6, and these, in the assembled state of the stator vanes, rest on end faces of the bearing journal receivers. One
10 journal bearing 5 has an extension 7 for connection to an adjustment mechanism (not shown), by means of which the stator vanes in the assembled state can be adjusted with regard to their pitch.

The outer surfaces of the bearing journals 5 and the stop
15 surfaces 6 have been provided with a DLC layer 8. Even though corresponding DLC layers 8 may be known in other fields of industry, they have barely been used to date on bearing surfaces under high stress in the field of aircraft construction, since repair to the DLC layer which is required
20 in principle given the wear to be expected was not possible, and the single use of variable stator vanes is uneconomic owing to the costly base material of a titanium, stainless steel and/or nickel-base alloy.

By the method elucidated hereinafter with reference to Figure
25 2, however, it is possible to repair DLC layers 8, and therefore corresponding coating of the bearing regions of variable stator vanes is indeed economic and, furthermore, brings the further advantages of corresponding coatings, such as reduced friction.

30 Figure 2 elucidates, in schematic form, the removing of a DLC layer 8 from the surface of a bearing journal 5 of the

aircraft component 1 from Figure 1. There may be corresponding requirements if the DLC layer 8 has been worn and has too low a thickness or has some other defect.

5 The DLC layer 8 has been applied to the surface of a bearing journal 5 with the aid of a tie layer 9. Corresponding tie layers 9 are known in the prior art and are required depending on the material of the bearing journal 5 in order to assure sufficiently good adhesion of the DLC layer to the base material, in this case to the material of the bearing journal 10 5. The tie layer 9 is composed of chromium.

Beginning with the starting state shown in Figure 2a, in a first step, with the aid of laser irradiation, the majority of the DLC layer 8 is evaporated. The laser irradiation here is chosen with regard to its intensity and duration of treatment 15 such that the underlying material, the tie layer 9 here, is not impaired or damaged.

For this purpose, the treatment duration must regularly be as brief as possible, but this has the result that residues 10 of the DLC layer 8 may remain on the tie layer 9 (cf. Figure 2b). 20 It is also possible that the parameters of the laser treatment are chosen such that the DLC layer 8 does not evaporate, but is merely converted to non-DLC carbon derivatives. For reasons of clarity, however, reference is made hereinafter to the evaporation residues, even though the subsequent steps can 25 analogously also be performed on a DLC layer 8 that has merely been converted to non-DLC carbon derivatives.

However, the invention makes use of the finding that the preceding evaporation process converted the remaining residues 10 of the DLC layer 8 to graphite or other easily removable 30 non-DLC carbon derivatives. Since graphite or the other non-DLC carbon derivatives has a distinctly lower hardness than

DLC, the residues 10 can subsequently be removed by blasting with nutshells without any resultant damage to the layer beneath the residues 10, the tie layer 9 here (cf. Figure 2c).

In principle, it is possible to apply a new DLC layer 8
5 directly to the completely exposed and cleaned tie layer 9, for which it is possible to make use of the known methods of physical or chemical vapor phase deposition. In general, however, it is preferable also first to completely remove the tie layer 9 in order then to create a new layer construction
10 comprising a new tie layer 9 and a new DLC layer 8 directly atop the base material of the bearing journal 5.

In order to remove the tie layer 9, which is composed of chromium in the working example shown, without residue, the tie layer 9 is exposed to a sodium hydroxide solution having a
15 proportion of 60 to 90 g/l of sodium hydroxide in the solution, which is put under an electrical voltage of 4 to 6 V. This dissolves the tie layer 9 without residue without impairing the underlying material of the bearing journal 5.

After both the DLC layer 8 and the tie layer 9 have been
20 removed completely (cf. Figure 2d), a new layer construction can be effected. For this purpose, it is possible to make use of the processes and methods that are sufficiently well known to the person skilled in the art for application of a tie layer 9 and/or DLC layer 8, which do not require any further
25 elucidation at this point.

Claims

1. Method of repairing components (1) coated with a DLC layer (8), comprising the steps of:

5 - evaporating and/or converting the DLC layer (8) by irradiation with a laser, wherein the properties of the laser radiation and the irradiation parameters are chosen such that a carrier material beneath the DLC layer (8) is not impaired; and

10 - cleaning the carrier material by blasting with a blasting agent that does not impair the carrier material.

2. Method according to Claim 1, characterized in that the blasting agent is nutshells.

15 3. Method according to Claim 2, characterized in that the blasting with nutshells is performed at a pressure of 1 to 10 bar, preferably of 1 to 5 bar, at an angle of 20° to 160°, preferably of 40° to 120°, at a distance from the component of 10 mm to 250 mm.

25 4. Method according to any of the preceding claims, characterized in that the carrier material is a tie layer (9) which is applied to a base material and is removed after the carrier material has been cleaned in a chemical method that does not impair the base material.

5. Method according to Claim 4, characterized in that

the tie layer (9) is composed of chromium and is removed with sodium hydroxide solution under applied voltage.

6. Method according to Claim 5,
characterized in that

5 the voltage is 1 to 10 V, preferably 4 to 6 V, and/or the sodium hydroxide solution is a solution with 20 to 200 g/l, preferably 60 to 90 g/l, of sodium hydroxide.

7. Method according to any of the preceding claims,
characterized in that

10 cleaning of the carrier material or removal of the tie layer (9) is followed by application of a DLC layer (8) to the carrier material or a tie layer (9) applied to the base material beforehand.

8. Aircraft component (1) for use in an aircraft engine,

15 comprising an aerodynamically shaped vane region (2) with the vane surface (3) and an axis of rotation (4), wherein bearing journals (5) for rotatable bearing in coaxially arranged bearing journal receivers are provided coaxially with the axis of rotation (4) at each end of the vane
20 region, wherein the bearing journals (5) are each formed so as to protrude from a stop surface (6) for resting against an end face of the bearing journal receivers,
characterized in that

25 the outer faces of the bearing journals (5) and stop surfaces (6) have been provided with a DLC layer (8) that is repaired by a method according to any of the preceding claims.

9. Aircraft component (1) according to Claim 8,
characterized in that

30 a tie layer (9) of chromium is provided between outer faces

of the bearing journals (5) and/or stop surfaces (6) and DLC layer (8).

10. Aircraft component (1) according to either of Claims 8 and 9,

5 characterized in that
the DLC layer (8) is composed of ta-C.