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Coating Method on Plastics Substrate and Coated Substrate

Field of the Invention

This invention relates to a coating method on a plastics substrate and relates particularly,
5 though not exclusively, to a deposition method for a hard coating on plastics substrate;
and to an electrically conductive substrate having such a hard coating deposited thereon.

Background to the Invention

Surface deterioration of a component of a mechanism happens when two
10 sliding surfaces come in contact for an extended duration. For example, a motor
assembly having a shaft that spins against a sleeve during operation.

Deterioration may be increased when the shaft is heavily loaded during rotation,
or when the operational environment is unclean.

15 Frequently, friction-related failures of components of mechanisms cause the
mechanism to break down due to inadequate maintenance and care. This
causes the contact surfaces to degrade, and thus affects the functionality of the
components.

20 Research on thin lubrication films is advancing to minimize the amount of wear,
and also to reduce friction in the contact region. A dry lubrication film is most
preferred for micro-mechanism, such as watches, motors or actuators where
dimensional spaces are limited.



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The demand for replacing metal mechanical components with plastics components is increasing. This is because plastic materials are easily processed by molding even though their shape may be complicated. In consequence, productivity is high. Also, due to the nature of the plastics material the weight of the component is reduced. However plastics materials are softer than metals, so they wear more easily. To reduce wear on metal surfaces, a hard material such as a diamond-like-carbon ("DLC") is coated on the metal surface. But it is very difficult to coat DLC films on plastics substrates due to the high internal stress in the DLC film. The high stress causes the DLC coating to peel from the plastics substrate if the adhesion between the coating and the substrate is poor. A DLC coating is a preferred material because of its properties such as high hardness, low friction coefficient, and chemical inertness. DLC coatings are used in many mechanical components such as, for example, bearing systems, and tools.

15 **Summary of the Invention**

According to a first preferred aspect there is provided a method for applying a coating to a substrate. The method includes applying a bias voltage to the substrate, the substrate being of an electrically conductive plastics material. A coating film of a coating material is deposited on at least one surface of the electrically conductive substrate. The bias voltage is controlled during the deposition process. The voltage may be applied using a substrate holder.

The coating material may be a diamond-like-carbon material. The deposition process may be one of: chemical vapour deposition, sputtering deposition, filtered-cathodic-

vacuum-arc deposition, and ion beam sputtering deposition. The electrically conductive plastics material may contain electrically conductive fibres. The controlling of the bias voltage may be for controlling the coating film hardness, stress and strength of adhesion to the electrically conductive plastics substrate.

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According to a second preferred aspect there is provided a component for a mechanism, the component comprising a substrate of an electrically conductive plastics material having embedded therein fibres of an electrically conductive material; the electrically conductive substrate having deposited thereon a
10 coating film of a diamond-like carbon.

The fibers may be of stainless steel. The electrically conductive plastics substrate may have a sheet resistance of no more than $1\Omega/\text{square metre}$.

15 **Brief Description of the Drawings**

In order that the present invention may be fully understood and readily put into practical effect there shall now be described by way of non-limitative example only a preferred embodiment of the present invention, the description being with reference to the accompanying illustrative drawings.

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In the drawings:

Figure 1 shows the schematic diagram of filtered-cathodic-vacuum-arc (FCVA) deposition system;

Figure 2 shows the tribology test setup; and

Figure 3 shows the results of the tribology test.

Detailed Description of the Preferred Embodiment

5 There are various preparation methods for applying a DLC coating or film to a substrate such as, for example:

- (a) chemical vapour deposition ("CVD");
- (b) sputtering deposition;
- (c) filtered-cathodic-vacuum-arc ("FCVA") deposition;
- 10 (d) ion beam sputtering deposition; and so forth.

In deposition processes, especially hard materials deposition, applying a bias voltage to the substrate assists in controlling the film properties, and adhesion between the film and the substrates. This is due to the hard material having a high film stress, which causes cracking or peeling. The bias voltage can control
15 the energy of ions that reach the substrate.

Among the methods given above, FCVA deposition has advantages when coating a film of high hardness and low friction coefficient because it can
20 precisely control the bias voltage.

The FCVA deposition system is shown in Figure 1, where the carbon plasma is produced through high current arcing of a graphite cathode 10, preferably a pure graphite cathode, in a high vacuum. This causes arcing 11 and the

production of C^+ ions 14 that move along a pathway 15. An electromagnetic field is created by electric magnets 12 to steer the carbon plasma in a curved path towards the desired surface of the substrate 17 in a deposition chamber 16. The electromagnetic field also filters out undesired macro-particles for a purer and denser film structure. A focusing electromagnetic field is produced by focusing electromagnets 13 adjacent the deposition chamber 16.

The energy of ions 14 is controlled by a bias voltage 18 that is applied directly to the substrate 17 or is applied to the substrate 17 using a metal substrate holder (not shown). This is possible as the substrate 17 is made of an electrically conductive plastics material. By controlling (i.e. adjusting and optimizing) the biasing voltage 18 applied to the electrically conductive substrate 17 during the deposition process, the film hardness, stress and strength of adhesion can be controlled.

By using electrically conductive plastics for the electrically conductive substrate 17 the bias voltage 18 is applied to the electrically conductive substrate 17. This may be by using a metal substrate holder (not shown). Conductive plastics contain stainless steel fibers. An example of a conductive plastics material is "SUSTEC" manufactured by JFE Techno-Research Corporation (Chiba, Japan). However, any other suitable conductive plastics material may be used. The fibers may be of any suitable electrically-conductive material. The dimensions of the stainless steel fibers in the conductive plastics used are about $10\mu m \times 80\mu m$. The stainless steel fibers make the plastic material electrically conductive. Its

conductivity is controlled by the number and size of the fibers. Even with fibers in the material, there is no problem in molding.

With prior systems, the bias voltage 18 was applied to a metal holder of an electrically non-conductive substrate 17 and not directly to the substrate 17. As the plastics material of the substrate was not conductive the bias voltage 18 could not be applied directly to the substrate. This caused poor adhesion of the DLC coating film to the non-conductive substrate.

Two types of plastics substrates were prepared and which had different electrical conductivity. A first substrate was of a non-conductive plastics material and had a sheet resistance of about $10^4 \Omega/\text{square metre}$. The second substrate was of a conductive plastics material as described above and having a sheet resistance of about $1 \Omega/\text{square metre}$. Preferably, the sheet resistance is no more than about $1 \Omega/\text{square metre}$. A DLC film was coated on the surfaces of the two substrates. The film was about $1 \mu\text{m}$ thick. The FCVA method was used with optimized biasing range of 0 to -100V. Even when the bias voltage is 0V, the substrate is conductive because the substrate has a charge due to ions in the substrate if the substrate is an insulator.

A tribology test was then conducted on the two substrates. As shown in Figure 2, the tribology test uses ball 20 loaded with a weight 22. The ball 20 is placed in contact with a test surface 23 on a planar plate 24 of a motorized turntable. During the test, the contact ball 20 slides across the test surface 23 in a circular

path when the plate 24 spins. The friction drag at the contact interface is detected by a linear force transducer 21 such as, for example, a strain gauge. The deflection of the cantilever arm 25 of the ball holder 26 is detected in a plane parallel to the test surface 23.

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The friction force is then evaluated as the resistance intensity of the drag between the ball 20 and the test surface 23. By recording the friction force over a period of time, the wear trend of the surface 23 can be identified to understand the durability of the surface 23. As the surface 23 starts to
 10 deteriorate due to prolonged abrasion, it can be observed as incremental change in the detected surface resistance.

For the tribology test, a 4mm diameter Si_3N_4 ball 20 was used and the applied load 21 on the ball 20 was 0.1N. The planar plate 24 was spun at 200rpm.
 15 Figure 3 shows the results of the tribology test. The horizontal axis indicates the number of cycles (revolutions of the test surface 23). This represents the number of times the ball 20 scratched the test surface, and the vertical axis is the coefficient of friction. The trend from the electrically conductive substrate is relatively smooth. That means no cracking or peeling occurred during the test.
 20 However, the trend from the non-conductive substrate shows a sudden change in the coefficient of friction at about 700cycles. This sudden change is due to the breakage of the coated DLC film. With a non-conductive substrate, the adhesion between the DLC film and the substrate is relatively poor because the bias voltage 18 could not be applied effectively.

This may allow the use of plastics materials for a wider range of components for mechanisms, the components having reduced wear characteristics.

- 5 Whilst there has been described in the foregoing description a preferred embodiment of the present invention it will be understood by those skilled in the technology concerned that many variations or modifications in details of design or construction may be made without departing from the present invention.

The Claims:

1. A method for applying a coating to a substrate, the method comprising:
applying a bias voltage to the substrate, the substrate being of an
electrically conductive plastics material;
5 depositing a coating film of a coating material on a surface of the
electrically conductive substrate; and
controlling the bias voltage during the deposition process.
2. A method as claimed in claim 1, wherein the voltage is applied using a substrate
holder of a metal.
- 10 3. A method as claimed in claim 1 or claim 2, wherein the coating material is a
diamond-like-carbon material.
4. A method as claimed in any one of claims 1 to 3, wherein the deposition
process is selected from the group consisting of: chemical vapour deposition,
sputtering deposition, filtered-cathodic-vacuum-arc deposition, and ion beam
15 sputtering deposition.
5. A method as claimed in any one of claims 1 to 4, wherein the electrically
conductive plastics material contains fibres of stainless steel.
6. A method as claimed in any one of claims 1 to 5, wherein the controlling of the
bias voltage is for controlling the coating film hardness, stress and strength of
20 adhesion to the electrically conductive plastics substrate.
7. A method as claimed in any one of claims 1 to 6, wherein the electrically
conductive plastics substrate has a sheet resistance of no more than $1\Omega/\text{square}$
metre.

8. A component for a mechanism, the component comprising a substrate of an electrically conductive plastics material having embedded therein fibres of an electrically conductive material; the electrically conductive substrate having deposited thereon a coating film of a diamond-like carbon.
- 5 9. A component as claimed in claim 8, wherein the fibres are of stainless steel.
10. A component as claimed in claim 8 or claim 9, wherein the electrically conductive plastics substrate has a sheet resistance of no more than $1\Omega/\text{square metre}$.