METHOD FOR AUGMENTATION THE INVOLUTE GEARS PERFORMANCE, USED IN THE MILITARY TECHNICAL SYSTEMS

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Abstract: *The involute gears, components of the mechanical transmissions of anti-aircraft guns, are stressed during the process because of strong wear, thus resulting in decreasing the reliability service. This paper presents a method to increase the reliability for these mechanisms by coatings consisting of thin layers of mechanically resistant based on nitrides.*

Keywords: *involute gears, physical vapor deposition, hard coatings, abrasion-resistant coatings, coating thicknesses, high-energy vapor particles.*

1. INTRODUCTION

Wear shortness the life time of machine parts and tools. Coatings consisting of thin layers of mechanically resistant material (hard coatings) have proved very successful in the past few years. For a long time it has been known that materials used for this purpose, nitrides and carbides, are very hard, exhibits good sliding behavior and are extremely resistant to wear.

On the other hand their brittleness and fracture susceptibility-not to mention the cost-prevent them from being used in solid form. However, when applied as thin coatings to components manufactured from steel and other materials, they loose their brittleness and basically conform to the toughness of the base material.

The advantages offered by these coatings are quite clear [1]:

- Extremely hard surfaces, while retaining the toughness of the component;
- Abrasion-resistant coatings with excellent adhesion;
- Low friction coefficient and good sliding behavior;
- Coating thicknesses of less than 1/100 mm.

The dimensional stability of the coated part is retained (no tolerance problems) and reworking after coating is only necessary in exceptional cases.

Last but not least, the attractive appearance of the golden titanium nitride (TiN) coatings is an additional advantage.

These hard coatings cannot be deposited by electroplating. Such thin coatings can only be deposited by evaporation using a vacuum process.

A common feature to all techniques is that the actual materials are produced during the coating application from metal fractions and gases. The gases e.g. nitrogen are introduced into a vacuum chamber from outside.

In order to produce hard coatings directly on to the substrates using this method two different process techniques are available namely:

– *C.V.D. (Chemical Vapor Deposition):* In this coating technique hard coatings are produced chemically starting from gaseous components at high temperatures by catalytic influence of the substrate surface.

– *P.V.D. (Physical Vapor Deposition):* The metal vapor is produced directly and reacts on the component with a reactive gas to form the hard coating.

To bring about the chemical reaction the C.V.D. technique requires high substrate temperatures in the range of 800˚C to 1100˚C with the associated disadvantages of loss of hardness and distortion. Furthermore, special precautions have to be taken to prevent environmental pollution by aggressive reaction by-products.

Low-temperature C.V.D. techniques for wear protection are still being developed on laboratory scale at present.

In contrast, P.V.D. techniques allow mechanically resistant materials to be deposited at temperatures as low as 200˚C. Consequently, coatings can also be applied to already quenched and drawn steels without loss of hardness and distortion. The P.V.D. coating process does not cause any environmental pollution.

2. P.V.D. TECHNIQUES FOR WEAR PROTECTION: ION PLATING

Normal deposition by evaporation in a vacuum is not adequate for wear-resistant coatings. The metal vapor which builds up the hard coating must consist of high-energy vapor particles. High-energy means particles with a high velocity. This is achieved by charging the vapor particles with a positive potential (ionization) and accelerating the negative voltage.

This negative voltage which is applied to the substrate and accelerates the ions is called the bias voltage. Coating with partly ionized metal vapor at bias voltage is termed ion plating. An evaluation of ion plating processes is primarily based on the following points:

1. Only the ionized fraction of the metal vapor can be clearly influenced with respect to its energy content.

2. Good adhesion at low coating temperatures is only possible if the ion energy and ion current density at the substrate are adequately high. Therefore, a high ion fraction, high ion energy and adequate ion current densities are necessary at the substrate.

Three vapor generation processes are suitable for ion plating:

a. Evaporation from a crucible using an electron beam in a triode arrangement or as a low arc evaporator. In the triode arrangement the plasma over the crucible is generated by an electron beam and the vapor is ionized in a second working stage.

The additional ionization step is not necessary in the low voltage evaporator. Since in both cases the material to be evaporated is present in a molten condition the evaporators must be installed at the bottom of the vacuum chamber.

b. Sputtering in a glow discharge. In this case a solid metal cathode is bombarded with high-energy gas ions causing attachment of the atoms at the cathode surface. A carrier gas such as Argon is required for these bombarding ions, and ionization takes place when the vapor particles pass through the glow discharge plasma.

c. Evaporation using a so-called vacuum arc. In this process the metal is simultaneously evaporated at microscopically small areas and the vapor particles are ionized and accelerated all in one single work stage. This so-called „arc P.V.D. process" [2] offers the highest degree of ionization, the highest average ion energy and for every application case more than adequate ion current density at the substrate.

Normal arcs in a gas atmosphere between a negative cathode and a positive anode with low voltage (order of magnitude 20V) and high amperage (order of magnitude 100V) are generally well known. However, in a low-pressure atmosphere or a vacuum, an arc with the same electrical characteristics changes its physical appearance at the cathode.

The arc no longer attacks the entire cathode, it moves around attacking only small spots of some micro-millimeters in diameter; the so-called cathode spots. Such a cathode spot exists only for some 5-40 ns and is then replaced by one or more new cathode spots in the immediate vicinity. It is possible to trace the path of the arc moving very quickly over the cathode.

The total electrical power of the arc concentrated in one such microscopic crater of a cathode spot causes momentary power density in the order of 10^9W/cm^2. As a result the solid cathode material is suddenly evaporated; the vapor particles are ionized several times and accelerated tremendously in a heated ion cloud in front of the cathode spot-the so-called plasma.

The principle of cathode erosion is shown diagrammatically. Mostly ionized vapor is emitted although there are individual emissions of molten droplets some of that are incorporated in the coatings.

Since the vapor particles are produced from the solid cathode material the physical arrangement of cathodes in a vacuum chamber can be varied.

The vast acceleration of the ions is particularly striking. The energy content of the emitted vapor cloud is more than 100 times higher than for conventional evaporation from a crucible even before the ions have been additionally accelerated by the bias voltage.

This clearly indicates that the arc process attains very good coating results even at low bias voltages. A distinctive feature is that coatings deposited at coating temperatures of 200°C are characterized by good adhesion. This means that a number of steels (cold worked steels) can be coated without loss of hardness or distortion.

In P.V.D. equipment the cathode is a solid piece of titanium with a simple circular or rectangular shape. The vacuum chamber walls act as the anode. The arc is ignited with an ignition trigger as a result of brief contact with the cathode.

Static magnetic fields behind the cathode assure uniform cathode erosion over the entire surface in the case of an uncontrolled arc-the so-called “random” arc. Locally variable magnetic fields are used if one wishes to control the arc’s erosion at the cathode surface.

This technique, the so-called “steered” arc, has been technically developed to such an extent in recent years that the path of erosion of the cathode spot over the cathode surface can be controlled in a reproducible manner. Another feature of the steered arc is that reduces the surface roughness of produced coatings and offers promising application possibilities for cathodes made up from segments of different materials. Figures 1 and 2 show the path of the arc on the cathode for uncontrolled and controlled movement.

Erosion of the cathode by a vacuum arc causes a flow of material in three forms: ions, uncharged metal vapor and molten metal micro particles (droplets). In the case of titanium the contribution of the mass flow in the form of ions to the total erosion rate is approximately 80%. Multi-charged ions are predominant in the generated metal plasma.

Ion with five or six unit charges can even be detected in a material with a high melting point (e.g. tungsten and molybdenum).

Another feature of the arc evaporation is the emission of droplets which decreases as the melting point of the material to be evaporated increases. However, methods are now available for influencing droplet size and frequency. The influence of the droplets (which primarily form in the ion bombardment phase before the actual coating process) on the performance of the coated tool depends on the respective application case.

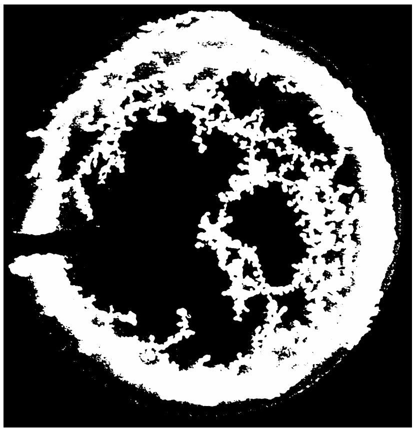

Fig. 1 Uncontrolled movement of the cathode spot over the cathode „random arc”

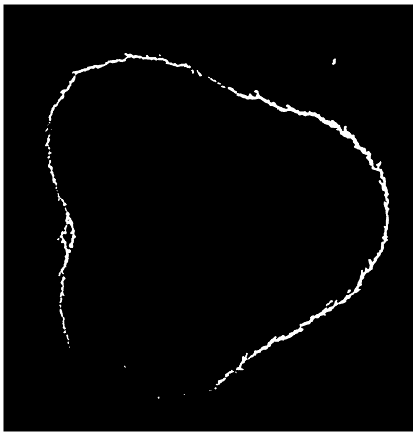

Fig. 2 Controlled movement of the cathode spot over the cathode „steered arc”

The role of droplets should not be overrated in the case of machining and cutting tools since arc coated tools attain a very long life even if droplets are present. Adhesion, stoichiometry, coating thickness, coating thickness distribution and stress condition are more important coating features which govern the performance of coated tools. However, the surface quality attained after a subsequent polishing step, which is normal practice for forming tools, permits the successful use of tools also for this application.

Prior to actual hard coating any microscopically thin oxide films and impurities adhering to the substrate are removed by intensive ion bombardment at high bias voltage.

During subsequent coating the high ion current density of the Arc P.V.D. Process ensures that loosely adhering coating particles are removed and that the hard coating is compressed. The effect of the ions can be compared to the coating being carefully hammered on to the surface of the component.

However, the most significant advantage of the Arc Process is that adhesive layers can be deposited at substrate temperatures at around 200° C.

This again is due to uniform high-energy ion bombardment; the substrate surface is changed microscopically – to a depth of a few nanometers – to create ideal growth conditions for the hard material which actually alloys with the surface.

Uniform ion bombardment during coating leads to a favorable stress pattern in the hard coating so that flaking and microcraks are avoided.

The excellent adhesion of the arc coatings is demonstrated clearly when compared to other ion-plated coatings.

Figure 3 [2] shows the different critic loads, as a measure of the adhesion, of an ion-plated TiN coating (a.) and a TiN coating deposited using the arc process (b.).

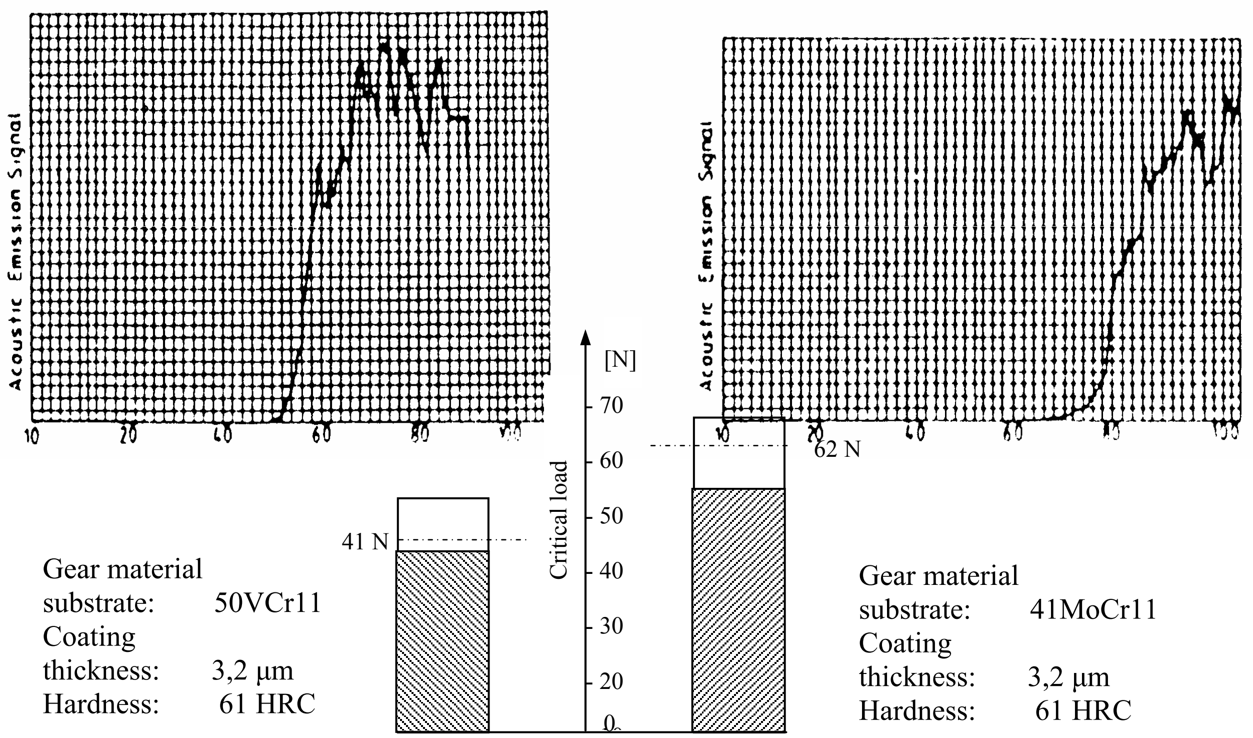

Fig. 3 Scratch test with ion-plated Ti coatings

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