THE STUDY OF SURFACE MODIFICATION OF THE PM HIGH SPEED STEEL

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Abstract
Steel produced by powder metallurgy (PM), Vanadis 30 (8% Co), was surface treated (plasma nitriding with thermal and temporal variations and PVD - coating within films) and subjected to mechanical testing. Investigations were carried out to determine optimum parameters of plasma nitriding intended for reaching high hardness, resistance to oxidation, low thermal conductivity and high resistance to wear. The thickness of the layer produced by nitriding was identified by measuring the cross-section microhardness. Test bars were used to evaluate the surface properties, microstructure, surface hardness, microhardness after cutting, phase composition, strength and cutting properties. By application of PVD - layers TiN and TiAlN, the strength of the material Vanadis 30 increased by 20-30% and the cutting properties improved by almost 60% in comparison with the conventional material produced by melt metallurgy (MM).
Keywords: powder metallurgy, surface treatment. plasma nitriding, PVD - coating, surface hardness, cutting life test

INTRODUCTION

The lifespan of tools is directly related to their surface wear, occurrence of fatigue cracks and corrosion. These effects manifest themselves first on the surface of tools, and because of that it is necessary to influence the mechanical and structural properties exactly in this zone. To resolve this problem it is necessary to study the complex physical and chemical processes on the surface of tools. These processes improve material characteristics in extremely strained micro volumes of tools during the operation and support their adjustment to operational conditions [1,2]. High speed steels (HSS) produced by powder metallurgy (PM) are characterised by homogeneous microstructure with uniformly distributed carbide phases resulting from suitable chemical composition and optimum thermal processing. This is the way to improve the surface stability during exposure to thermal stress and to achieve better mechanical properties compared to the conventional ones [3]. Tools produced from PM steels have to be heat treated before their use. Quenching and tempering are generally used to reach suitable hardness for direct use. If it is necessary to improve some properties of tools even further, particularly the surface characteristics, various forms of post-heat treatment have been used, such as plasma nitriding, coating by various PVD - methods or their combination, termed duplex coating [4], or the so-called hybrid process. Application of these procedures, either individually or in combination, can lead to fairly big changes from the point of view of surface properties, and also mechanical properties of the materials and the tool as a whole. One very important factor which should be considered before the realisation of processes of surface engineering

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is the fact that the newly developed PM steels differ considerably by their chemical composition and [5,6]. The aim of the paper was to point to some processes that take during plasma nitriding and coating of PM steel - type Vanadis 30.

The properties of the layers produced by plasma nitriding fulfil all expectations, for example increased cutting life of tools made from high speed steels, increased surface hardness and decreased coefficient of friction. However, with increasing hardness the brittleness of materials also increases due to the development of the so-called white nitride layer. However, nitriding can be carried out in a way which prevents development of the white layer on the surface of cutting tools [7,8]. PVD-coating – application of thin, hard, abrasion resistant coatings to finished materials, ensures high hardness, decreases the friction coefficient, secures high resistance to adhesive and abrasive wear and imparts high chemical stability [8,9]. The tools produced from PM steel, Vanadis 30, were subjected to pulse plasma nitriding at selected temperatures and time parameters, and the optimum nitriding parameters were determined by means of evaluation of microhardness of the layer produced by nitriding after cutting the samples. Within the subsequent surface treatment, the material Vanadis 30 was PVD coated by the ARC evaporation method (cathodic arc), producing TiN and TiAlN layers. The specimens obtained were evaluated for the surface hardness, microstructure after cutting, strength and the cutting properties.

EXPERIMENTAL PROCEDURE

PM materials were produced under the conditions of rapid solidification (RS), compacted by hot isostatic pressing (HIP). The HIP-process was realised at the temperature 1150°C under a pressure of argon of 200 MPa for 2 h. The as-compacted materials were heat treated (HT): soft annealed, austenitised at 1150°C/2 min oil quenched and tempered at 550°C/3 x 1 h quenched with water - in order to obtain the required hardness of the tool. Chemical composition of the powder produced by Böhler - Uddeholm (Sweden) was as follows: 1.28% C, 6.4% W, 4.2% Cr, 3.1% V, 5.0% Mo, 8.5% Co. The surface treatment included plasma nitriding at 500 and 530°C and holding times 60 and 120 min using the Rübig - PLASNIT and coating by the PVD - method by TiN and TiAlN layers at 530°C for 20 min. With regard to the diffusion strengthening of the surface, a dominant role is played by the chemical composition of the material, particularly sufficient content of alloying elements capable of producing nitrides. If the material lacks sufficient quantity of these elements dissolved in the solid solution, the surface strengthening is, as a rule, insignificant. The references describing other effects on the quality of layers produced by nitriding, kinetics of their growth and their properties are relatively scarce. Moreover, some of the papers are controversial and frequently neither corresponds to the theoretical knowledge nor to logically expected results. The method most frequently used in technical practice is the ionic saturation of steel surface with nitrogen that has spread all over the world [10], and because of the rapid growth of nitride layer and high variability of the process, plasma nitriding is also advantageous [11]. The basic parameters of surface nitriding are hardness and thickness of the layer. These parameters are as a rule the only controlling parameters required and therefore should be defined accurately. The depth of the layer was determined by the German standard DIN 190-3, according to which the nitrided layer ends at its vertical distance from the surface (HV0.3), or the microhardness is equal to the hardness of the base material´s HV0.5 increased by 50 HV units [12].

RESULTS AND DISCUSSION

The microstructure of the polished and etched samples (Fig.1) was observed on cross-sections using light microscopy and the phase analysis was carried out by an X-ray analyser. The matrix consisted of fine, uniformly distributed carbide phases and tempered martensite.

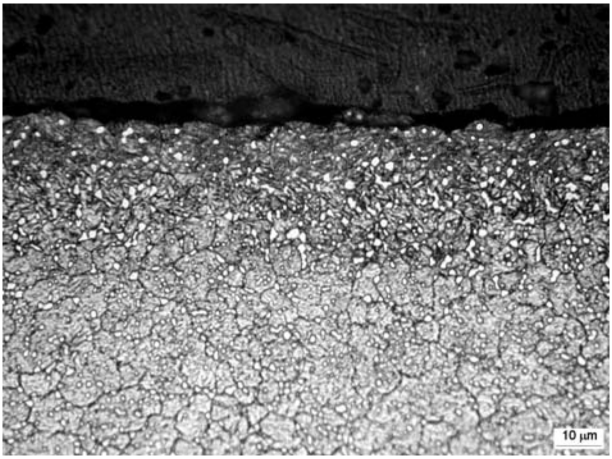

Fig.1. Microstructure of specimen Vanadis30 nitrided at 530°C/120 min (light microscopy).

The X-ray analysis identified carbide phases of the following types: MC (V), M_6C (Fe,W), M_7C_3 (Fe,Cr). After etching, the nitrided layer differs from the matrix by darker colour caused by more intensive etching of the nitrides produced. Important is the proportion of alloying additions in the region of the nitrided layer, which affect the diffusion of nitrogen according to the concentration limit and affinity which can lead to local differences in the formation of nitrides close to the surface [13]. In the zone of nitrided layers we identified phases of the type of Fe_4N, VN and various non-stoichiometric nitrides of V, Mo and Cr. Saturation of the surface with nitrogen and redistribution of carbon is reflected in microhardness and measurements of surface hardness values.

Figure 2 shows the profile of microhardness across the nitrided surface towards the matrix for the processes with variable temperature and time parameters.

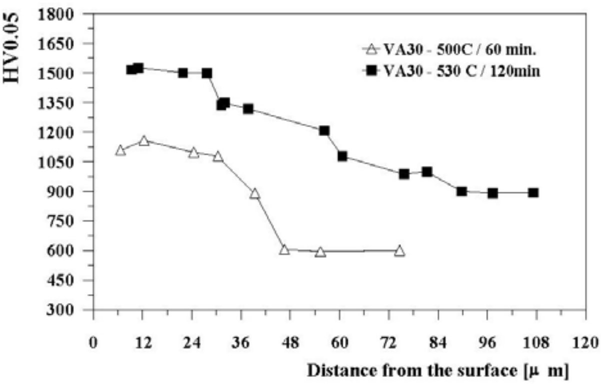

Fig.2. Microhardness depth profiles in nitrided surfaces.

In the nitrided layer of the material Vanadis 30 the microhardness reached 1163 to 1516 HV 0.05 and the surface hardness was 1196 HV 10. The hardness decreased towards the core and at the depth of about 50 μm reached the values typical of the basic material.

The test rods prepared from the material Vanadis 30 were coated by the PVD - method, employing ARC evaporation (cathodic arc) producing TiN and TiAlN layers of thickness 2 μm. Process conditions were at 530°C, time 20 min, (Fig.3).

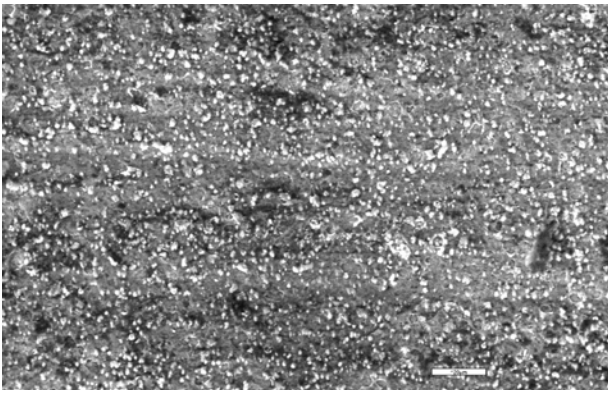

Fig.3. The morphology of surface deponed TiAlN - layer.

In order to select optimum materials and suitable coats one must know the relationships between chemical composition, microstructure and mechanical properties of the substrate/coat system, and to set certain criteria for individual specific conditions [8]: surface interaction with the work piece, hardness, fracture strength and internal stress, fracture toughness, adhesion, interaction substrate/layer, and differences in substrate/layer thermal expansions. Test rods were used to carry out the three-point bending strength test. This parameter is one of the mechanical properties used to compare the quality of cutting steels because it reflects the differences in modules of elasticity in tension and compression.

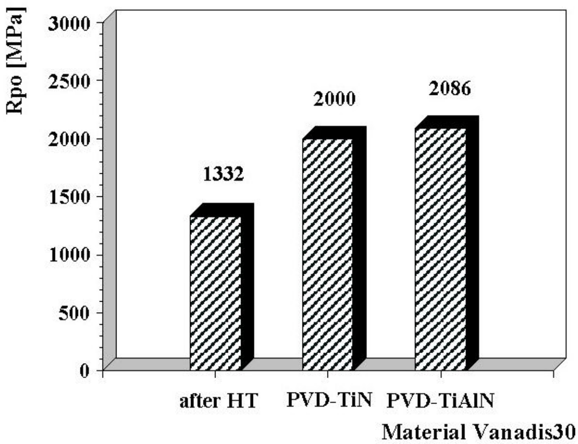

Fig.4. Bending strength (R_{po}) values of the test specimens after heat treatment and PVD-coating by TiN and TiAlN.

Figure 4, which shows the bending strength values for individual specimens, indicates a 50-56% increase for the material after coating with TiN and TiAlN in comparison with the materials after heat treatment as is explained in detail in [14]. The surface hardness for the TiN-layer reached the value of 1380 HV 0.5 and for TiAlN the value of 1392 HV 0.5.

Figure 5 shows the fracture of TiAlN-coated rod. In order to ensure suitable adhesion of the coat it is necessary to produce conditions for partial diffusion of the coating elements below the substrate.

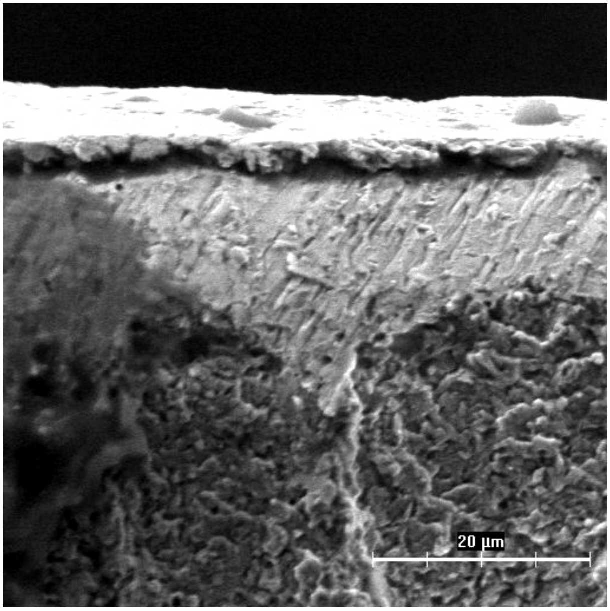

Fig.5. Surface fracture of TiAlN-coated rod after the bending strength test.

The roughness of surface is a factor affecting the quality of layer, and the assumption is that the unevenness of the substrate surface (R_m) is lower than the layer thickness (h_p), i.e. $R_m < h_p$. With the growing thickness of the PVD-layer, the differences in unevenness between the substrate and the layer increase. This fact confirms the assumption that the coat on the substrate surface fails to grow uniformly or to copy its surface [8,15]. The fracture acquires mostly a quasi-cleavage shape with regions of plastic fracture. The proportion of plastic fracture is related to more homogeneous distribution of primary carbides [16]. Phase analysis of coated materials allowed us to identify, besides above mentioned TiN, and Ti_2N phases, also various non-stoichiometric nitrides TiN_x and various systems of solid solutions $\alpha + \varepsilon$ or $\varepsilon + \delta$, as described also in [8]. In the case of the TiAlN-layer, a thin surface layer of Al_2O_3 was also detected which prevented degradation of the surface [8].

Tools, the so-called cutting tips from the material Vanadis 30 were subjected to a short-term cutting test, i.e. cutting edge wear according to ISO 3685-1977 using steel (ISO 683/1-87 or SN 41 2050) as the machined material. Decrease in the cutting depth by more than 20% or complete loss of cutting ability was used as a criterion of wear [17].

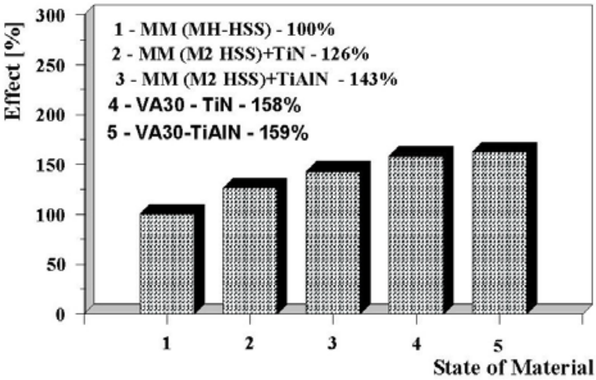

Fig.6. Cutting properties of PM and MM (HSS) materials (critical wear of the cutting tip).

Evaluation of cutting properties of coated tools from the point of view of reaching the highest cutting speeds and comparison with the material produced by conventional melt metallurgy (MM; the type M2 HSS) showed an almost 60% increase in the critical wear of the cutting tip in favour of the PM material Vanadis 30, Fig.6.

CONCLUSION

From the study it was concluded:

- Application of plasma nitriding to the material Vanadis 30 produced nitrided layers differing from the base material by increased intensity of etching caused by the occurrence of fine nitridic particles.
- Nitrided layers showed a marked increase in hardness in comparison with the basic material - the matrix. In the zone of the nitrided layer materials Vanadis 30 reached hardness to 1516 HV 0.05 and surface hardness to 1196 HV 10 with the nitriding process 530°C/120 min. In the direction to the core the hardness decreased, and at the depth of about 50 μm reached the values typical of the matrix.
- It was proved that surface strength was increased by the application of plasma nitriding due to the influence of the nitrides.
- PVD-coating with layers TiN and TiAlN at 530°C for 20 min of thickness approx. 2 μm resulted in a hardness of TiN layer equal to 1380 HV 0.5 and TiAlN a layer equal to 1392 HV 0.5.
- The bending strength (R_{po}) of coated tools increased by 50 to 56% compared to only heat treatment materials.
- Evaluation of cutting properties of coated PM tools using the highest cutting speeds showed an almost 60% increase in critical wear of the cutting tip in comparison with conventional materials produced by melt metallurgy (MM).

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