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Glow discharge assisted low - temperature nitriding of knives used in wood processing

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ABSTRACT

Purpose: The plasma assisted surface treatment processes may be conducted at lowered temperatures thanks to shallow ion implantation influencing the driving force of diffusion. The low-temperature d.c. glow discharge assisted nitriding (LTN) method allows the process to be applied to steel grades irrespective of their tempering temperature but does not promote the formation of thick nitrided layers. The LTN process seems to be most suitable for improving the mechanical properties of cutting tools. The aim of this study was to elaborate the optimised LTN method of steel cutting tools treatment and its application for production ecological and cheap knives for wood processing industry.

Design/methodology/approach: The nitriding of low-alloy steel knives was conducted at temperatures of 320°C-350°C under a pressure of 4hPa. The microstructure and chemical composition of the nitrided layer was determined using XRD and XPS methods and the cutting properties of nitrided knives were investigated in wood processing industry.

Findings: The LTN process enables to control very precisely the microhardness distribution profile which decides on the cutting properties of a knife. The optimal process parameters were determined, they depended on the kind of tools application.

Practical implications: The LTN treated knives have been used in industry as planar knives and cutting heads for processing wet and dry, hard and soft wood. They appear to be competitive to traditional tools, ecological and cheap.

Originality/value: The elaborated low-temperature nitriding of low-alloy steel knives is an original process. The nitrided knives are a new sort of tools for wood processing.

Keywords: Surface treatment; Ion nitriding; Wood processing knives; Low-alloy steel

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1. Introduction

The term ‘low temperature process’ is used here to describe a physicochemical process that proceeds under thermodynamic conditions with the participation of non-mechanical work such as e.g. electric work, and hence differs from conventional processes by e.g. the rate at which it runs. The plasma-assisted processes may be conducted at low temperatures thanks to the ions that participate in them[1-11]. The possibility of carrying out d.c. glow-discharge plasma assisted nitriding at temperatures of 320°C and 275°C was demonstrated in refs. [1,2,3,6,9-14]. In such a process, most of the energy transferred to the cathode is the energy (100-500eV) acquired by the N_2^+ ions in the cathode potential fall. It is supposed that the ions bombarding the metal surface during plasma-assisted nitriding affect advantageously the process since, as a result of their shallow implantation, they enhance diffusion phenomena [6]. Systematic studies of the nitriding process realized via low-energy ions implantation compared with a triode glow discharge-assisted nitriding process [3]and comparison of the rate at which a d.c. glow discharge assisted nitriding of iron proceeds with the Lehrer diagram and with the results of simulation of ion implantation of a polychromatic N_2^+ ion beam with an energy up to 100eV [6] have proved that the fundamental mechanism that operates during low temperature plasma nitriding is the non-equilibrium increase of the diffusion driving force ($\Delta\varsigma$) associated with the increased nitrogen concentration on the surface of the metal due to the shallow implantation of the ions.

The substantial reduction of the nitriding temperature permits plasma nitriding to be applied to all steel grades irrespective of their tempering temperature. On the other hand, the low temperature of the process does not promote the formation of deep (thick) nitrided layers. Therefore, the low-temperature nitriding seems to be most suitable for improving the mechanical properties of cutting tools especially of knives made of low-alloy steel. The aim of the present study was to find whether the low temperature ion nitriding could be used for this purpose on the industrial scale.

2. Experimental

The nitriding was conducted in a d.c.glow discharge assisted prozess under a pressure of 4hPa. The temperature was measured with a thermocouple placed within a dummy product at a distance of 0.1mm from the treated surface.

The treated tools were cutting knives with an edge angle of 40-45°C used for processing wood at a speed of 49m/s. The operating conditions of these tools are especially severe because of wood heterogeneity, vibrations during the process, hydrogen brittleness etc. The cutting tools examined were made of HSS steel and low-alloy steel 75Cr1 and 80Cr1. The microstructure of the nitrided layer was analyzed by XRD (Philips) in a standard Bragg-Brentano configuration using $CuK\alpha_1$ and $CuK\alpha_2$ radiations which differ in their penetration depths and, thus, permit examining various zones of the layer.

The chemical composition of the nitrided layer was determined using the XPS methods (Escalab 210).

3. Results

3.1. Structure of the nitrided layer

Figure 1a,b shows an example of the structure of an optimized nitrided layer produced on a knife made of HSS18 steel (C-0.8, Si-04, Mn-0.4, P0.03, S-0.03, Cr-4.5, V-1.2, W-18.0 at.%) at a temperature of 350°C. The surface hardness increased from HV0.1 900 prior to the nitriding to HV0,1 1800 after the nitriding. The specific features of the structure of low-temperature nitrided steel is an increased concentration of free N atoms (about 1.1 at.%) at a distance of 240Å from the surface, and the presence of the non-equilibrium Fe_3N phase on the surface. At a depth of up to 20µm we have Fe_4N structures with an average grain diameter of 1000nm (the same as that of an Fe grain). The Fe_4 N precipitates have an average diameter of 54.29nm. The micro-stresses active in the layer do not exceed ε=2.5x10^{-3} (acc. to Williamson-Hall).

3.2. Hardness distribution profile

Examinations of the hardness distribution profile along the direction perpendicular to the cutting tool surface have demonstrated that the low temperature ion nitriding enables to control precisely this distribution. By way of example, Fig.2 shows various micro-hardness profiles obtained for various grades of steel, various temperatures and various process durations. Optimization of the hardness distribution is a very important factor in selecting the optimum process parameters for a given cutting tool.

3.3. Wear of the tool through edge chipping

Sharp cutting tools undergo wear due to abrasion, chipping and fatigue. Abrasive wear is most desirable since it is uniform. Chipping wear, on the other hand, is most disadvantageous. There is an optimum hardness at which the tool is not yet brittle, whereas its resistance to frictional wear is enough high. This optimum hardness and its respective distribution profile are determined experimentally based on the possibility of controlling precisely the material structure offered by low-temperature plasma nitriding. Figs.3a,b,c show examples of various cutting tools, such that are very brittle, optimally brittle and such that undergo wear through abrasion. It appears that, irrespective of the steel grade, the surface hardness of the cutting tools should not exceed HV0.05 1100. The optimum hardness was found to be HV0.05 900-1000.

Hydrogen brittleness, to which the tools are especially exposed when cutting wet wood, is very unfavorable. For this reason the nitride layer should be coherent and protect the tool against the infiltration of hydrogen[15].

3.4. Employment of low-temperature ion nitrided cutting tools in industry

The GASS manufactory in co-operation with the Warsaw University of Technology have applied the d.c.glow discharge assisted low-temperature nitriding to improvement cutting properties of knifes made of low alloy steel for wood processing purposes. The nitrieded knives have been used in industry as planar knives for processing soft and hard wood both wet and dry, and cutter heads fo modern production lines of high efficiency intended for processing wet soft wood. These tools appear to be competitive to traditional tools with knives made of alloyed martensitic (high-speed) steel. These tools are more-over ecological and cheap for they contain minimal amount of alloying additions, in particular of Cr.

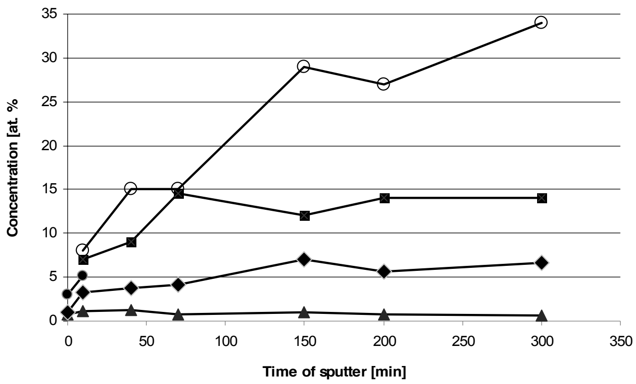

Fig. 1a. Structure of nitrided layer produced on a knife made of HSS18 steel at a temperature of 350°C

1) ▲- distribution of N and Fe perpendicular to the surface free N atoms, 2) ♦- free Fe atoms, 3) ○- chemically bounded N atoms, 4) ■-ions Fe+3 in compound, 5) ●- ions Fe+2 in compounds

Distance

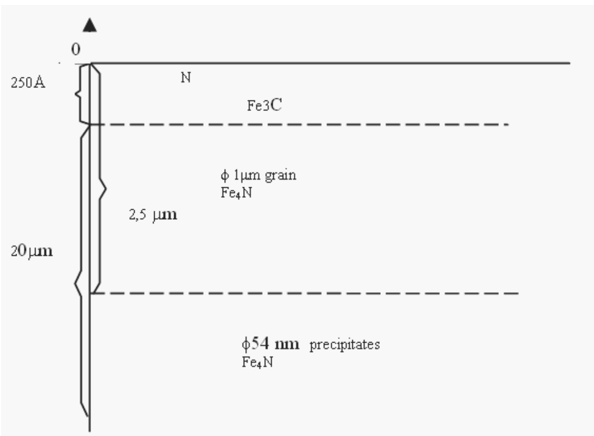

Fig. 1b. Structure of nitrided layer produced on a knife made of HSS18 steel at a temperature of 350°C -model

4. Conclusions

Based on the hypothesis that shallow ion implantation plays an advantageous role in plasma assisted processes conducted at low temperatures where the diffusion coefficient is relatively small, we have developed a method of low temperature nitriding (LTN) of metals with the participation of the ions present in diode glow discharge plasma. The LTN method permits controlling precisely the distribution of hardness in the direction perpendicular to the surface subjected to nitriding, which is of particular importance in the case of relatively thin diffusion layers such as those produced on cutting tools in order to improve their wear behavior. Thanks to the low process temperature, the LTN method can be used for treating steel irrespective of its tempering temperature. These properties of the LTN method permitted its application for production ecological and cheap knifes for wood processing industry.

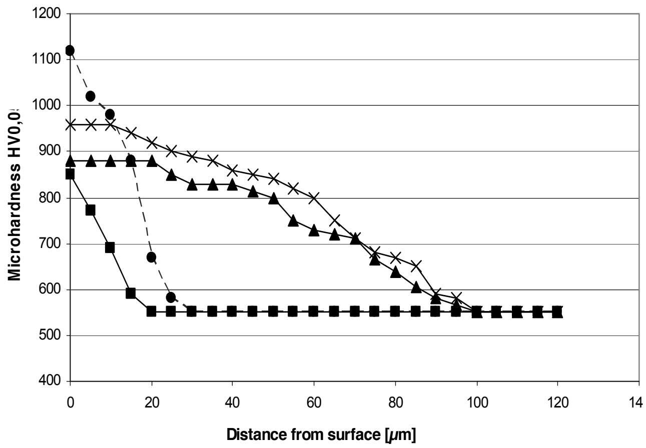

Fig. 2. Hardness distribution profiles perpendicular to the knife surface

● - T=350C t=12h steel75Cr1, x - T=400C t=6h steel 75Cr1,
■ - T=350C t=6h steel75Cr1, ▲- T=400C t=6h steel 80CrV2

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