Optimising deposition parameters of W-DLC coatings for tool materials of high speed steel and cemented carbide

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The paper presents the results of investigations on the selection of optimal deposition parameters for W-DLC coatings produced by pulsed reactive magnetron sputtering in order to obtain the coatings with high adhesion to the high speed steel (HSS) and cemented carbide (HM) substrates. To optimise the deposition parameters for W-DLC coatings Taguchi’s method was used. An acetylene flow rate, the substrate bias voltage, the thickness of W-DLC coatings and the thickness of chromium sublayer were selected as deposition parameters and for each of them three levels of values were determined. Adhesion, wear resistance and hardness of coatings were chosen as the criteria for selecting the optimum deposition parameters. The test results showed that all the selected parameters have a significant effect on the adhesion of coatings. The thickness of W-DLC coatings has a very significant effect on the adhesion to HSS substrates and in a case of HM substrates the same effect has the thickness of a chromium sublayer. The wear resistance of coatings increases with an increasing acetylene flow rate and decreases with the increasing substrate bias voltage. High correlation was found between the H/E ratio of coatings and their wear resistance as well as toughness. The W-DLC coating showing the best properties ($H = 90$ N, $k_V = 3.8 \times 10^{-7}$ mm$^3$/Nm) was marked by the nanocomposite structure containing about 40% of nanocrystalline tungsten carbide phase and 60% of amorphous carbon matrix.

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1. Introduction

Coatings including carbon, metal or non-metal and often hydrogen are determined in a various manner, e.g. Me-C:H, X-C:H, XC/a-C, XC/a-C:H, or X-DLC, where Me, X = W, Ti, Si, Cu, Ag and others and DLC = Diamond-like Carbon. Due to favourable tribological properties, these coatings are quite widely used for coating machine components, particularly in the automotive industry [1–3]. Their properties depend mainly on mutual share of carbide phase (XC) and an amorphous carbon matrix DLC (a-C or a-C:H). Coatings whose composition is close to stoichiometric one, i.e. without participation of amorphous carbon phase have nanocrystalline structure of specific metal or non-metal carbides and demonstrate high hardness [4–8], but at the same time low resistance to fractures and unfavourable tribological properties, especially in dry friction conditions [5,6]. Coatings containing excess of carbon in relation to stoichiometric composition demonstrate nanocomposite aggregate structure, i.e. they are composed of nanocrystalline carbide phase dispersed in DLC amorphous matrix [4–11]. Nanocomposite coatings, depending on mutual participation of carbide and amorphous phase demonstrate very different mechanical properties. If the volume contents of amorphous carbon phase are 15–20%, coatings may demonstrate significantly higher hardness than stoichiometric nanocrystalline coatings, in particular if titanium carbide constitutes nanocrystalline phase [7,10,12]. In line with increase in content of amorphous carbon phase, hardness of the coatings decreases, but their toughness increases [5,13]. If the content of amorphous carbon phase exceeds 80%, the coatings demonstrate favourable tribological properties, especially in dry friction conditions [5–11]. Taking the above into consideration, nanocomposite coatings based on carbon show a number of desired properties from the perspective of using them for coating of tools, especially for machining non-ferrous alloys or wood. Their nanocomposite structure demonstrates favourable combination of hardness and toughness. XC carbides (e.g. WC, TiC) demonstrate high hardness and wear resistance. DLC (a-C or a-C:H) matrix, which at elevated temperature and stress is subject to graphitisation and oxidation [14–18] may be a source of graphite-like substances of low shear strength, while occurring in the point of blade contacting with the worked material, may cause desired reduction of cutting forces. The aforesaid properties and positive results of cutting properties of