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Preparation and wear behaviour of steel turning tools surfaced using the submerged arc welding technique

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Abstract. Nowadays metal machining industry has to meet economically the challenges of the surface quality and efficiency of the machined parts during turning and other metal removing processes. Turning is the process of machining ferrous metals with a hardness value more than 45 HRC in order to obtain the final product or billet. In the present work, an attempt has been made to prepare a turning tool by surfacing a shank billet made of plain carbon steel using the submerged arc welding technique, with spreading WC-8%Co powder on the surface of the base metal or inserting different amounts of graphite into the flux and afterwards fusing by a metal arc. The flux AMS1 (more than 50% SiO_2 and MnO) has a multifunctional purpose in welding. It serves not only to prevent the molten metal from the surrounding air but also to transmit additional elements to the weld during welding. The presumable chemical composition of surfaced tools was ensured by adding chemical elements which form hard carbides, and are high-temperature resistant. The focus was on graphite, tungsten (W), and cobalt (Co) systems in order to obtain layers of high wear resistance. The prepared and blended metal powder was used in two different ways: (1) spread on the surface of the plain carbon steel shank under the flux and (2) inserted into the flux. The obtained results were compared with a commercial turning tool made of high-speed tool steel. The wear resistance of surfaced experimental turning tools showed better wear performance than the standard tool. The wear crater area of the experimental tool measured after the wear test was 0.38 mm^2, while the wear of the standard tool exceeded 0.45 mm^2; the wear resistance of the experimental turning tool was about 15% higher.

Key words: turning tool, submerged arc welding, wear resistance, coating.

1. INTRODUCTION

Huge numbers of turning tools are available in today's industry. These are made from many different materials, ranging from plain carbon steel to advanced diamond tools. Some of the modern industrial materials have already found their niche in the manufacturing industry, however, in small enterprises using a light lathe practically all turnings are done either with carbon steel, high-speed tool steels, or tungsten carbide tipped tooling. This can be explained by the fact that the usage of advanced materials, such as ceramic and diamond, require higher cutting speed, stationary industrial machinery to operate accurately, and high production efficiency; it mainly associates with the optimization of production and extension of tool life, but not with improving surface finish (new tooling materials can ensure surface finish as well).

The plain turning tool has no changeable insert – the cutting edge and the shank form one solid unit made of the same material. These materials should possess high temperature resistance and strength, comparatively high toughness, and high wear resistance. By saving alloyed steels and decreasing expenses of manufacturing it is possible to make the cutting tool shank from other material than the tool head [1].

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For this reason iron-base surfacing has been widely used to protect cutting tools exposed either to pure abrasion or to a combination of abrasion and impact [2,3], and on severe worn, corroded or oxidized surfaces, to regain their functionality [4]. On the other hand, it is possible to use metal-to-metal sliding applications. The materials usually selected are steels with carbon contents between 0.1% and 0.7% and up to 20% alloying elements. The wear performance of a surfaced layer under these conditions primarily depends on its chemical composition, the resultant microstructure obtained after welding, and finally the welding technology used.

Recently, many hardfacing alloys have been suggested for surfacing in order to simultaneously increase both the toughness and abrasion or adhesive wear resistance. The high content of alloying elements such as chromium, tungsten, niobium, and molybdenum has enabled a significant refinement of the composed carbide phase [5,6]. Carbide-based cutting tools are used for the machining of carbon or stainless steel, and in all cases where tools made of other materials would wear away. Sharp cutting edges of carbide tools ensure better surface finish of final products, while higher heat resistance allows faster dry machining. Common materials of cutting tools are cemented carbide, hardmetal, or tungsten carbide with cobalt. The high content of fine and uniformly arranged tungsten carbide particles in a base gives the maximum wear resistance [7–9].

For dry machining different systems are used: iron-, nickel-, or cobalt-based alloys. The maximum limit temperature for iron-based alloys is 550 °C. For temperatures above this limit the usage of nickel or cobalt alloys becomes necessary [10,11]. The application of these materials helps to avoid overheating, but some actions should be taken to increase their machinability.

In the present work WC-8%Co powder was used to shape the working part of the turning tool. We used the submerged arc welding technique and two methods of adding the alloying matter to the weld: spreading it on the surface of the base metal (WC-8%Co) and fused by a metal arc, or inserting it (graphite) into the flux. This powder was chosen because of its typical reinforcement effect due to its high hardness, high thermal conductivity, significant plasticity, and good wettability. The use of cobalt as a binder in this powder ensured strong adhesion between phases.

2. EXPERIMENTAL

The experiments were performed on shank billets made of plain carbon steel (C 0.14–0.22%, Si 0.12–0.3%, Mn 0.4–0.65%, S ≤ 0.05%, P ≤ 0.04%) with dimensions of 135 mm × 15 mm × 15 mm. Four turning tools were surfaced in three passes using the submerged arc welding technique with an automatic welding device (torch MIG/MAG EN 500 78). The welding parameters were as follows: welding current 180–200 A, voltage 22–24 V, travel speed 14.4 m/h, and the wire feed rate 25.2 m/h. In each case a single 1.2 mm diameter electrode of low-carbon wire was used for welding (C < 0.1%, Si < 0.03%, Mn 0.35–0.6%, Cr < 0.15%, Ni < 0.3%).

The prepared and blended WC-8%Co powder was spread on the surface of the shank, while graphite powder was inserted into the commercial flux AMS1 (more than 50% SiO_2 and MnO) and fused by a metal arc. The optimal height of the spread mixture of 4 mm was chosen according to the results of previous experiments [12], which showed the influence of powder height on phase composition, especially on the quantity of retained austenite, and on the hardness of the surfaced layer after welding and after further tempering. The chemical composition of the materials mixture can be seen in Table 1. Each presented case using the materials mixture was replicated three times, and average results were analysed and discussed. Confirmatory experiments were performed on a commercial turning tool made of high-speed tool steel P6M5 GOST 19265-73 (C 0.80–0.88%, Cr 3.80–4.40%, W 5.50–6.50%, V 1.70–2.10%, Mo 5.00–5.50%) equivalent to HS 6-5-2 (LST EN ISO 4957:2003).

Phase evolution and the quantity of austenite retained in the surfaced layer (Table 1) were determined by X-ray diffraction (XRD) analysis conducted on the diffractometer DRON-6 using Cu-K_α (monochrome graphite, diffraction plane $d_{(002)} = 0.3352$ nm) radiation, at given voltage of 30 kV, and current – 20 mA. The chemical composition of surfaced layers was analysed using spectrometer vacuum analyser BELEC Lab 2000, which was adopted for the examination of steel. The main geometrical parameters of experimental tools were chosen according to general recommendations for turning tools geometry: the nominal rake angle of 8°–10° and the clearance angle of 7°–9°, required for the machining of midst carbon steel products. Four turning tools were produced and sharpened in a positive rake angle manner with the clearance angle $\alpha = 8°$, rake angle $\gamma = 8°$, primary entry angle $\varphi = 45°$, secondary entry angle $\varphi_1 = 45°$, tool cutting edge inclination angle $\chi = 5°$ (Fig. 1).

Table 1. Composition of the materials mixture for surfacing; 4 mm of WC-8%Co powder was spread on the surface of each coating

Tool No.	Flux, wt%		Quantity of retained austenite, %	Hardness, HRC after	
	Graphite	AMS1		Surfacing	Tempering at 570 °C
1	–	100	81.8	47	63
2	5	95	79.9	53	63
3	9	91	66.7	56	63
4	13	87	64.7	60	62

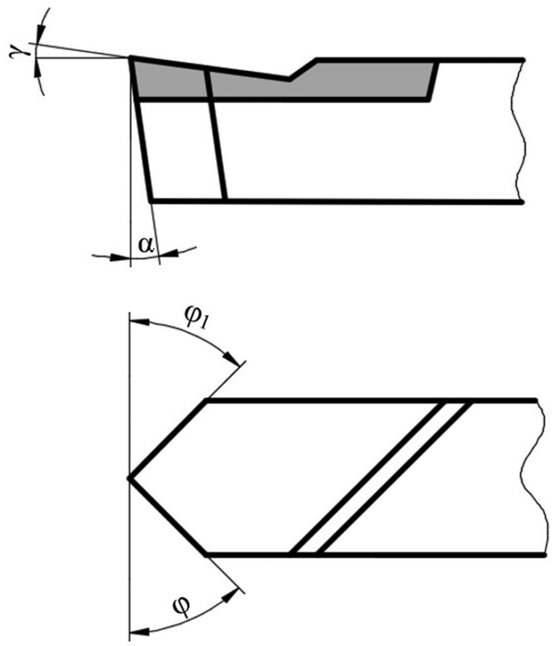


Fig. 1. The main geometrical parameters of the experimental turning tool.

The cutting speed was constant for each experimental turning tool tested on wear $v_c = 51.9\ \mathrm{min}^{-1}$, cutting depth 0.2 mm, feed rate 0.074 mm/rev.

The mechanical behaviour of surfaced layers was assessed in terms of the hardness and estimation of wear behaviour. Hardness measurements of the layers were accomplished on the wrought (after welding) and heat-treated (tempered) surfaces using the Rockwell tester TK-2 at the load of 1470 N with a diamond indenter.

The wear resistance and durability of surfaced turning tools were tested after 2100 m cutting length by a general turning operation, working on cylindrical (56 mm in diameter and 750 mm in length) shaft samples prepared of midst carbon steel with 0.45% C by the worn area on the rake face of the tool. The worn area was evaluated using the Lasico L-30 Mechanical Polar Planimeter with Adjustable Arms.

3. RESULTS AND DISCUSSION

The chemical composition of surfaced layers on experimental turning tools revealed after spectrum analysis showed the concentration of alloying elements in the layers (see Table 2). The highest concentration of alloying elements presented in Table 2 was found in the superficial layer or working area of the tool edge; this concentration decreased towards the weld. Spectrum analysis of superficial layers has shown that it is possible to compose high tungsten and cobalt concentration using the powder of WC-8%Co for surfacing. The obtained concentration of these elements (from 13.82% to 20.5%) exceeded their concentration in high-speed tool steel. Some of the tungsten was found to be in the form of tungsten carbide, which naturally is an extremely hard phase: Vickers hardness 1800–2450 HV. Herewith tungsten carbide has very high wear resistance and heat resistance (extremely high melting point 2870 °C); these unique properties of tungsten enable its use for the alloying of cutting tools.

Table 2. The chemical composition of the surfaced working area of experimental turning tools

Tool No.	Chemical composition, wt%								
	C	Si	Mn	Cr	Mo	V	W	Co	Rest
1	1.05	0.8	1.65	0.06	0.05	0.03	20.5	2.50	Fe
2	1.08	0.8	1.67	0.06	0.05	0.03	19.13	2.34	Fe
3	1.2	0.82	1.70	0.08	0.06	0.03	16.5	2.25	Fe
4	1.22	0.83	1.72	0.09	0.07	0.04	13.82	2.03	Fe

The presence of retained austenite in the experimental turning tool structures can induce both positive and negative or even dramatic changes in mechanical properties such as fatigue strength, toughness, hardness, yield strength, and machinability. For instance, a high level of retained austenite can result in lower elastic limits, moderate hardness, lower high cycle fatigue life, and volume instability, while a low level of retained austenite can initiate poor fracture toughness and weaken low cycle fatigue.

On the other hand, retained austenite can transform during exploitation as a result of increased temperature or plastic deformation. This causes volume increase of the final tool of approximately 4% and decrease in the accuracy of the turning tool.

Therefore analysis of retained austenite is essential in the determination of heat treatment processes and regimes. The hardness of surfaced tools after surfacing was influenced by the content of retained austenite.

X-ray diffraction analysis is a very fast and the most accurate method for the quantification of retained austenite in the microstructure of the tool, performed either after tempering or after the working operation. The results of XRD analysis confirmed the presence of retained austenite in the patterns before tempering and different amounts of the Fe_3W_3C phase in four experimental turning tools (Fig. 2).

During surfacing the melted WC-8%Co powder mixture was distributed among iron, and as a result on solidification iron tungsten carbide was formed. The highest peaks in each XRD pattern showed the presence of Fe_3W_3C. These coatings are expected to be of high wear resistance while testing them on turning.

High hardness of surfaced layers made these coatings very difficult to machine or sharpen according to cutting tool geometry [11,13]. Experimental turning

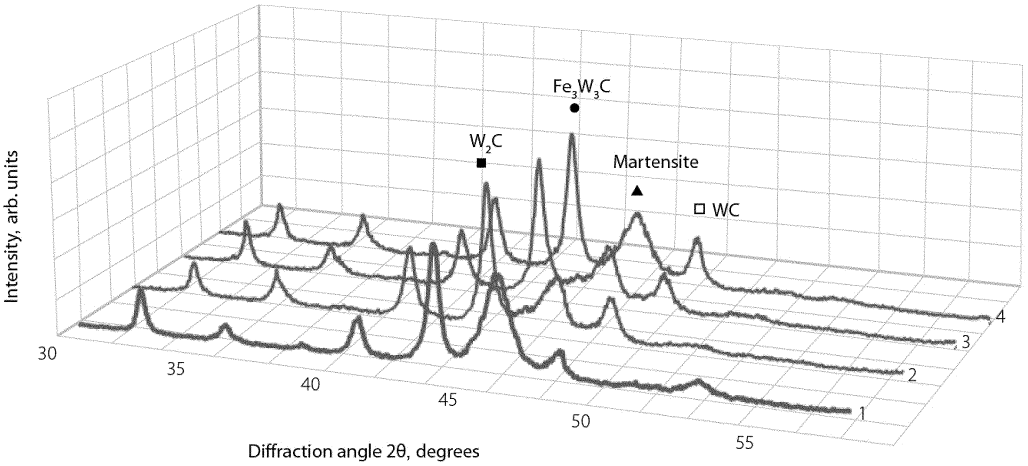
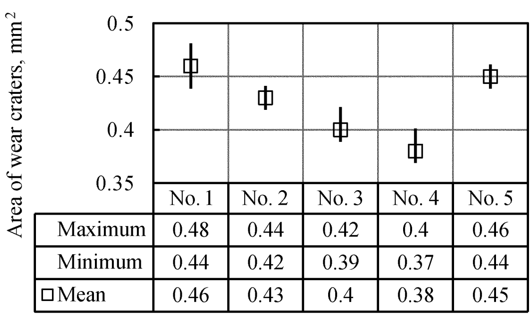


Fig. 2. X-ray diffractometry of experimental turning tools after tempering.

tools were subjected to high-temperature tempering at 570 °C with the purpose of minimizing internal stresses and reaching maximum values of secondary hardness.

The Rockwell numbers indicated in Table 1 showed signally increased hardness values especially of coating with the highest content of retained austenite after surfacing. The hardness of the turning tool No. 1 (content of retained austenite 81.8%) after surfacing was 47 HRC. During high-temperature tempering austenite transformed to martensite, and the hardness number increased to 63 HRC. This tool was surfaced using welding flux without any graphite additives. Very similar results were observed with other turning tools, but a more remarkable effect was achieved with a higher content of retained austenite. The higher amount of graphite was inserted into the flux, the lower content of retained austenite was composed after surfacing.

The results of wear resistance indicated wear craters on the rake faces of experimental tools. For comparison a commercial turning tool made of high-speed tool steel was tested under the same conditions (Fig. 3).



	No. 1	No. 2	No. 3	No. 4	No. 5
Maximum	0.48	0.44	0.42	0.4	0.46
Minimum	0.44	0.42	0.39	0.37	0.44
□ Mean	0.46	0.43	0.4	0.38	0.45

Fig. 3. The areas of wear craters of experimental turning tools Nos 1–4 and wear performance of the commercial turning tool No. 5.

It is obvious that the area of wear craters in the experimental turning tool No. 4 (Fig. 4b), which showed the lowest wear after the test was less than the wear

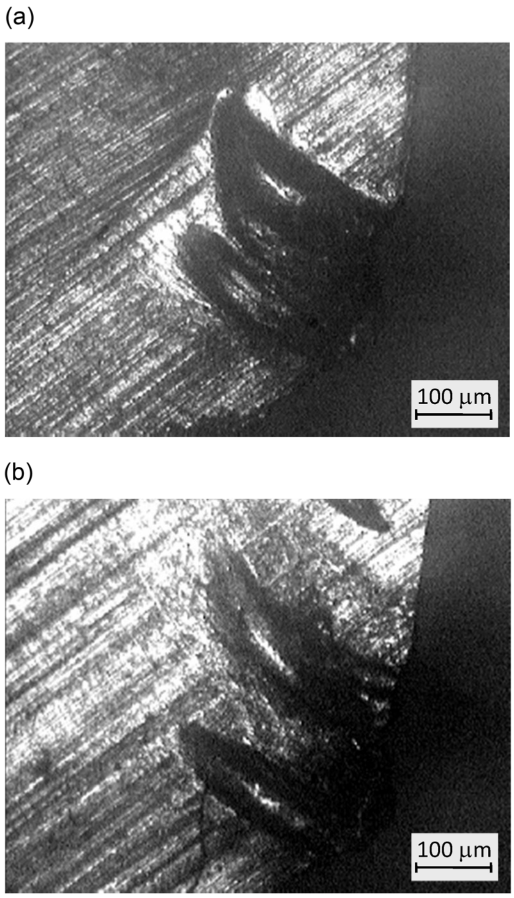


Fig. 4. Wear craters of (a) the commercial turning tool and (b) the experimental turning tool No. 4.

craters of the commercial turning tool (Fig. 4a). The presented results show that with increasing the graphite content inserted into the flux from 0% to 13% (experimental turning tools 1–4) the wear evolution becomes lower. The wear crater area of the turning tool No. 1 was 0.46 mm^2. In this case no addition of graphite was used for surfacing. However, the wear area of the turning tool No. 4, with 13% graphite inserted into the flux, indicated higher wear resistance of 0.38 mm^2.

The rest of the tools (No. 3 and No. 4) proved this tendency of wear. The wear behaviour of the commercial turning tool (No. 5 in Fig. 3) made of high-speed tool steel demonstrated a bit higher wear compared to turning tools with graphite additions in the flux for surfacing.

4. CONCLUSIONS

1. The wear resistance and durability of experimental turning tools primarily depend on the composition of the material powder mixture used for surfacing and on the content of graphite inserted into the flux.
2. The WC-8%Co powder mixture serves as an alloying agent when shaping the working surfaces of turning tools using the submerged arc welding technique. The typical reinforcement particles of tungsten carbide were observed after XRD analysis and were confirmed by hardness measurements. The maximum reached tungsten content in the experimental turning tool was 20.5 wt% (minimum 13.82 wt%), while cobalt had a narrower range from 2.03 to 2.50 wt%.
3. The wear resistance of experimental turning tools made according to the suggested technology can replace commercial turning tools. This technology enables saving resources of high-speed tool steels and other steels used for cutting tools.

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Räbustikaarkeevispinnatud teraslõikeriistade saamine ja kulumine

Regita Bendikiene, Antanas Ciuplys ja Lina Kavaliauskiene

Tänapäeval on metallitööstuses lõiketöödeldud detailide pinnakvaliteedile ja töötlemise hinnale esitatavad nõuded väga olulised. Detailide või toorikute saamisel on treimine rauasulamite kõvadusega üle 45 HRC üks lõiketöötlemise põhilisi protsesse.

Käesolevas töös on tehtud katse valmistada treitera süsinikterasest toorikute WC-Co kõvasulampulbri räbustikaarkeevituse teel, varieerides erinevate grafiidikoguste lisamisega räbustisse. Räbustina kasutati keevituses tarbitavat multifunktsionaalset räbustit AMS1 (üle 50% SiO_2 ja MnO), mis peale kaitsekeskkonna tagamise soosib ka lisaelementide sisestamist keevisesse.

Keevispinnatud tööriistade eeldatav keemiline koostis tagati karbiide moodustavate legeerivate elementidega, mis on samal ajal ka kõrge kuumuspüsivusega.

Põhitähelepanu oli pühendatud grafiit-volfram-koobalt-süsteemidele, saamaks kulumiskindlaid keevispindeid. Kasutati ettevalmistatud ja segatud metallipulbri kaht pealekandmise viisi: 1) süsinikterasest toorikupinnale kantud räbustialuse kihina, 2) segatuna räbustisse.

Saadud tulemusi võrreldi tööstuslikest kiirlõiketerastest valmistatud treiteradega. Eksperimentaalsed keevispinnatud treiterad näitasid paremat püsivust kui kiirlõiketerasest standardlõiketerad. Kui eksperimentaalterade kulumisjälje pindala oli 0,38 mm^2, siis standardtreiteradel oli see 0,45 mm^2 ja kulumiskindlus oli umbes 15% suurem.