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APPLICATION OF SURFACED CUTTERS FOR MACHINING OF WOOD-BASED MATERIALS

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ABSTRACT

The present paper describes results of recent research aimed to make high wear resistance cutter for machining of wood-based materials. Medium density fibreboard (MDF) was chosen for wear test because it is quite abrasive, ease blunts edges of cutters, is inhomogeneous material: contains glue and different mineral particles. It is well known that cutting particleboard results wearing out of cutter faster than machining of natural wood. Because of this, experimental cutters made by surfacing using submerged arc welding (SAW) technique and prepared material powder mixture spread on the surface of cutters blank, were introduced in this research. Suggested material powder mixture ensured obtaining the high alloyed and wear resistant surface layer on the cutting edge of cutter. The wear performance of experimental and commercial cutter was accomplished on the typical industrial thickness planer with a face milling cutterhead using MDF as workpiece. Wear of experimental cutters showed very similar performance as commercial cutter made of high speed steel HSS18.

KEYWORDS: Medium density fibreboard, wear resistance, submerged arc welding, powder mixture.

INTRODUCTION

Wood is probably the best known natural composite material in which cellulose fibres are arranged in bunches and are bonded with lignin. The dramatic decrease of natural wood resources in the World related with the need to use wastes from natural wood manufacturing, have made further improvements of wood-based composite materials highly essential. Combining wood with other materials allowed to developed composites with specific properties, which are often better than the properties of natural wood. To achieve the highest properties, special techniques and machining tools are required. Evolution of wood cutting tool materials, as well as new implementation of new techniques, helped to process wood-based composite materials efficiently ensuring a high quality product. Although new tools and techniques have been developed and are in use, there is a need for a better understanding of the properties of wood-based materials and of the factors influencing the machining process.

Medium density fibreboard (MDF) is an engineering wood-base material used for variety of furnishing, industrial, and for interior/exterior construction applications, because of its applicable properties such as surface appearance, dimensional stability and excellent machinability. The last strongly depends on the cutting parameters, cutting forces, material and geometry of cutting tool. Drilling is one of the processes in furniture industry due to the necessity of component assembly; however it is largely affected by the delamination of these materials under the cutting forces during machining (Davim et al. 2008).

On the other hand delamination reduces appearance characteristics of final product therefore it is essential to choose the best combination of cutting tool and drilling parameters in order to minimize this negative effect. Presented results revealed that the delamination can be reduced effectively with higher cutting speed and lower feed rate values (Gaitonde et al. 2008). MDF used for furniture is coated with a wood veneer or different sorts of laminate to get appearance of natural wood, so in that cases machining process is highly affected by tool wear and chip formation.

Particleboards are cheaper and more homogeneous than bulk wood, nevertheless, it is abrasive enough to abrade the conventional tungsten carbide tools employed during its machining. On machining, high friction forces are generated at the tool/MDF interface. As a result, the WC grains detach from the edge, and it causes the wear of the cutting tool. That‘s why it is necessary to improve the wear resistance of these tools; the best solution is to protect them with a hard coating (Benlatreche et al. 2009, Warcholinski et al. 2011, Kusiak et al. 2005). CrAlN-coated carbide tools with different Al content were tested in standard MDF machining. The lowest wear of tool was achieved with 5 % of Al in the coating. Comparing the standard, waterproof and fireproof particleboards, the last one showed highest wear performance, caused by highest degree of impurities.

Tools made of sub-µm-grain Al_2O_3 ceramics have good technological characteristics not only for machining of hardened steels, but also for the machining of wood-based materials. Results obtained by other authors with the various cutting materials indicates that by using nano-ceramic cutting edges it is possible to achieve longer cutting paths than those possible to achieve with sintered carbide or hard metal (Gogolewski et al. 2009). Sommer et al. 2013 declare that oxide ceramics are promising materials for cutting of wood-based materials as they exhibit high hardness, high wear and chemical resistance.

The study of Nouveau et al. 2007 deals with application of chromium aluminium nitride hard coatings in machining of MDF. Such coatings are commonly used in metal machining practise, but not so much research is done for application of coatings as wear and corrosion protection of wood-base cutting tools. The best results were achieved with tool coated with 10 % of N2 which allowed to machine 2.5 times more than the standard tool with equal wear conditions.

Cutters such as circular saws, band saws and routers are typically used to machine MDF to the required size and profile. Tipped cutters should ensure qualitative cutting and prolong the life of the tool. Polycrystalline diamond (PCD) tips are widely used in wood industry due to extended tool life resulting from their superior properties over traditional tool materials (Philbin and Gordon 2005). The exceptional hardness, thermal conductivity and low friction coefficient of diamond, make it an excellent tool material for the machining of particleboard.

In spite of the usage of stellites, cemented carbides, and polycrystalline diamond as the main cutting tool materials in this work four types of wear resistance coatings were realised using submerged arc welding and prepared powder mixture spread on the surface of plain carbon steel, afterwards tested on machining of MDF.

MATERIAL AND METHODS

Wear resistant coatings were surfaced on skived surface of cutter blank made of cheap plain carbon steel (C 0.14-0.22 %; Si 0.12-0.13 %, Mn 0.4-0.65 %, S≤ 0.05 %, P ≤ 0.04 %). The surfacing process (Bendikiene et al. 2015) was performed in a single pass using submerged arc welding (SAW) technique with alloying materials mixture (~ 6 g) spread on the surface under the flux. Before surfacing each sample was mechanically polished. The chemical composition of powder mixture is presented in Tab. 1.

Each presented coating using powder mixture was replicated three times, and average results were analysed and discussed. Selection of flux powder mixture should meet the expectations of high wear resistance and possible enhance of other exploitation properties. Chromium (Cr) (Nouveau et al. 2005) and tungsten (W) was used seeking to obtain high wear resistance layers. Typically chromium carbide particles nucleates from the melt, while tungsten carbides able to withstand thermal cycle of welding and does not form during crystallization. Last mentioned have high hardness and extremely high toughness. Fine particles of tungsten carbides completely dissolve in the melt, while comparatively big and partially fused remain in the solution increasing resistance to wear.

Tab. 1: Chemical composition of powder mixture.

No.	Powder content, wt. (%)								Liquid glass	Flux
	SiC	HSS	WC-8% Co	Cr	W	Glass	Fe-70%Mn	Case hardened stainless steel		
1	20	80								AMS1
2	36		27	28			9			AMS1
3	40			10	40		10			AMS1
4	18	26	9			9		26	12	

Presence of chromium effects formation of retained austenite which slows a decomposition of austenite, herewith chromium provide some corrosion resistance. Presence of cobalt stabilized ferrite – decreasing the temperature range, in which austenite exists, at the same time increasing critical cooling rate and heat resistance of the coatings. The silicon carbide (SiC) naturally are used as deoxidizer in the welding flux. The deoxidizers react with oxygen at the welding temperature, and significantly decrease the quantity of oxides in the bead increasing quality of the weld. Adding silicon into the flux improve the metal mass transfer coefficient, form and modify slag. Fe-70 % Mn was used for enrichment of coating by manganese and for deoxidation purpose. On the other hand, manganese stabilized austenite increasing strength of ferrite.

A single 1.2 mm diameter electrode low carbon wire (C < 0.1 ; Si < 0.03 , Mn 0.35-0.6, Cr < 0.15 , Ni < 0.3 %) was used for the surfacing. The SAW was carried out with an automatic welding device (torch MIG/MAG EN 500 78), with welding parameters: Welding current 180 – 200 A, voltage 22 – 24 V, travel speed – 14.4 $m.h^{-1}$, and the wire feed rate – 25.2 $m.h^{-1}$. Blended powder of materials was spread on the surface of the base metal and fused by metal arc. Standard flux AMS1 (GOST 9087-81; SiO2 38-44 , MnO 38-44, CaF_2 6-9, CaO < 6.5, MgO < 2.5, Al_2O_3 < 5, Fe_2O_3 < 2 , S < 0.15, P < 0.15 %) was used to shield and to prevent the welding area.

Coatings of each suggested composition were heated at the temperature of 1100°C afterwards hammered in order to examine influence of plastic deformation on the wear properties of tool. During hot hammering face of coatings was plastically deformed and flattened to the level of base metal, as a result time of cutter machining was reduced (no additional machining needed). Second positive cause of blacksmith process was self-hardening of high alloyed coatings in the air, consequently just tempering followed hot plastic deformation.

Mechanical behaviour of cutters coated using suggested technology was assessed in the terms of hardness and wear properties. Hardness measurements of the coatings were accomplished on the wrought and heat treated (tempered) inserts using Rockwell tester TK – 2 at the load of 1470 N with diamond indenter.

Wear resistance tests were performed and results of all the obtained surfaces were compared with conventional standard steel grade HSS18 by weight loss of samples (with an accuracy of ± 0.1 mg).

The wear performance of experimental and commercial cutter was accomplished on the typical industrial thickness planer (SR3-6) with a face milling cutterhead using MDF as workpiece. The milling was conducted according longitudinal milling, with contrary acting vectors of cutting speed v_c and feeding speed v_f. Milling conditions were the same for each tested cutter. The cutterhead was designed to have two cutting edges, to avoid misbalance which can appear having only one insert, two experimental inserts were mounted, but only one tested.

RESULTS AND DISCUSSION

Both hammered and as surfaced experimental cutters were produced with dimensions of 60 x 30 x 3.55 mm. Experimental cutters were strait sharpened and its edges were converged according general grinding procedures of cutters; main characteristics of experimental tools: Rake angle β – 40º, weight of cutter – 45.5 g. The main geometrical parameters of experimental cutter are presented in Fig. 1.

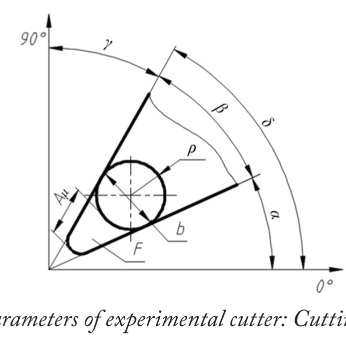

Fig. 1: The main geometrical parameters of experimental cutter: Cutting angle β, sharpness angle δ, rake angle γ, and clearance angle α.

Hereafter accurate dimensions of inserts were ensured measuring inserts using electronic calliper with the accuracy of ± 0.001 mm. The surface roughness tester – profilotemer Mahr MarSurf PS 1 was used to evalute roughness of rake face and clearance face: Roughness of rake face R_a – 0.14 µm, roughness of clearance face R_a, – 0.07 µm.

Hardness of coatings inserts reached values of 61 HRC; after following tempering at 500°C values of hardness were increased, showing effect of secondary hardening (Tab. 2).

Tab. 2: Hardness of coating.

Post weld treatment	**Hardness, HRC**						
	1	**2**		**3**		**4**	
	As weld	As weld	T*	As weld	T**	As weld	T**
As weld	61	50	59	60	57	60	63
Hammered	61	49	50	50	55	60	61
* Tempered at 550°C.							
** Tempered at 500°C.							

Medium density fibreboard are more homogeneous materials than solid natural wood, but wood is an anisotropic material, while wood-based materials (MDF) can be assumed as a stock of several isotropic layers (Boucher et al. 2007), consequently density distribution on the board thickness almost follows a parabolic curve (Fig. 2). On the other hand, MDF is more abrasive than natural wood (Labidi et al. 2005). Other general mechanical and physical properties of tested MDF are as follows: tensile strength > 0.35, flexural strength ≥ 13, elasticity modulus ≥ 1600 N.mm^{-2}, humidity 5 – 13 %, average density 650 – 700 kg.m^{-3}. MDF used in industry is available in various thicknesses; for testing of wear resistance of experimental cutters 18 mm thick board was used.

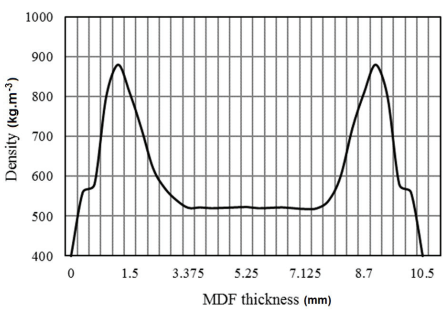

Fig. 2: Profile of MDF density.

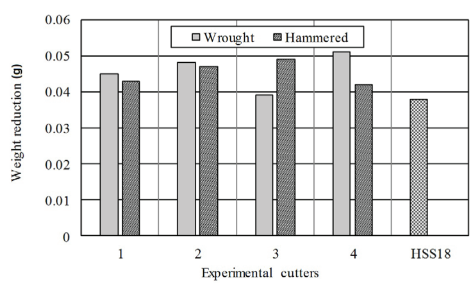

Fig. 3: Wear of experimental and commercial cutter made of HSS18.

The wear measurement of cutters was based on the determination of weight reduction after 1200 m of cutting length, with cutting conditions: Cutting speed v_c – 31 m.s^{-1}, feed speed v_f, – 6 m.min^{-1}, depth of milling h – 2 mm, milling width b – 45 mm, diameter of cutterhead d – 103 mm. Sample cutters were weighted on electronic scales (accuracy ± 0.01 g) for determination of wear behaviour.

The best wear performance was observed testing experimental wrought cutter No. 3 (Fig. 3). Working edge of this sample cutter was rich in chromium and tungsten, maximum hardness (60 HRC) was achieved after surfacing procedure, while additional plastic deformation reduced hardness till 50 HRC. After tempering at the temperature of 500°C hardness remained the same, showing high thermal stability of surfaced coating. Wear behaviour of commercial cutter showed very similar results.

When using glass, SiC and Fe – 70 % Mn for preparation of surfacing materials powder mixture, it is not necessary to use conventional flux, because such a combination of materials gave us sufficient fair metallurgical processes. Hammered cutter No. 4 obtained using above mentioned chemical composition was surfaced using liquid glass. Powder mixture was agitated with liquid glass in order to obtain smooth compound, which was sealed on the skived surface of cutter blank and dried for 3 h at the temperature of 250°C.

Cutting tool temperature-another important factor affecting the cutter wear in machining, because hardness, toughness, and chemical properties of tool material degrade when tool's temperature increases. Continuous plastic deformation and shear at chip formation generated thermal energy and friction which appeared on the rake and clearance face of tool, at the same time the friction between sample and back face of tool. Outcome heat was transferred to the cutting tool and work sample. This heat had a negative influence to quality and accuracy of machined products and for the main parameters of cutting: cutting speed, depth of cut, blunting and cutting power. Consequently cutting power of all presented cutters was tested in the whole cutting length (Fig. 4).

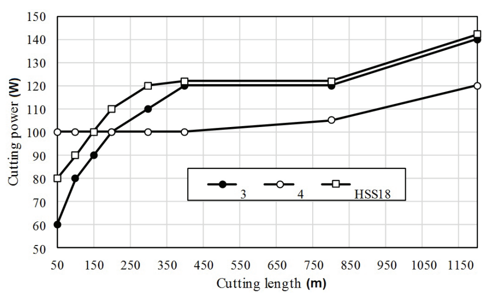

Fig. 4: Cutting power of cutters for the feed 0.5 mm.

Values of cutting power of cutter No. 3 and HSS18 showed similar tendency, until 400 m of cutting length cutting power was increased, because of crumbling of the top of blade's cutting edge. At this stage of machining the cutting edge radius grew rapidly as well. Linear or stable cutting power intensity was observed for all cutters in the cutting length from 400 to 1200 m. Wear by crumbling of inserts blades was displaced by plastic wear phase. Surfaced cutters can be used for machining of wood.

CONCLUSIONS

The results showed that application of surfacing using submerged arc welding technique and materials powder mixture spread on the surface of substrate under the flux, increased wear resistance of experimental cutters for machining of wood-base materials. Shank of experimental cutter was made of plain carbon steel with alloyed high wear resistant working edge. So, using suggested technology it is possible to reduce expenses of machining of wood-based products, and to recycle industrial waste (metal machining waste was used for the preparation of powder mixture). Summarizing the achievements of presented study the following can be stated: relatively hard coatings (50-63 HRC) surfaced on a cutter blank made of soft plain carbon steel can replace some commercial cutters made of high speed tool steels for machining of wood-base materials.

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