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TAGUCHI ANALYSIS OF WC-CO TOOLS LIFE IN MILLING OF WOOD-BASED MATERIALS

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Abstract

This work presented results of researches concerning influence of chosen material factors (WC grain size) and cutting parameters (spindle speed and feed per tooth) on edges durability made of WC-Co during chipboards milling. Experiment was conducted and analysed according to Taguchi method. Machining was carried out with working centre equipped with one edges milling head. Researches proved statistically relevant and useful in industrial conditions influence of feed per tooth. Regards to maximal tool life, optimal conditions were obtained for following levels of factors: WC grain size - 0,5-0,8 μm, spindle speed - 10000 rpm, feed per tooth - 0,15 mm.

Key words: *WC-Co tool material, particleboard, CNC milling, tool life, Taguchi method*

INTRODUCTION

In industry conditions Taguchi method is applied in order to estimate a significance of input factors influence on final parameters of given process such as products quality. This method is relatively common due to lower level of tests efforts in comparison to classic ways of experiments programming. Mentioned above method was used for experiment optimization by many authors (Basavarajappa et al. 2008, Davim and Reis 2003, Tsao and Hocheng 2004, 2007), during machining of wood based materials (Gaitonde et al. 2008, Wilkowski et al. 2011, 2012, 2014), too.

In stage of input factors configuration the main consideration was their significant and predictable influence on cutting edges durability during machining of wooden materials. WC grain size among numerous material factors was chosen as basic factor determining physical-mechanical properties of tungsten carbides. WC grain size and contribution of binder (cobalt) decides as well about density, hardness, fracture strength, MOR, MOE as about other parameters connected with WC-Co tool machinability (Cha et al. 2001, Rosiński et al. 2014, Schubert et al. 1998).

Plan of experimental researches takes into account fact, that edge durability depends on structure and properties of tool material and also on cutting parameters. Therefore, crucial parameter in this range is cutting speed but to some lower extent - feed per tooth, too.

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MATERIAL AND METHODS

Durability tests were carried out in technological room of Faculty of Wood Technology SGGW in Warsaw. Raw, three layers chipboard manufactured by Pfleiderer with 18 mm thickness was subjected to machining. This is typical material used in mass production in furniture industry. Basic properties of mentioned above material was presented in Tab.1. Material for milling was divided into workpieces with dimensions 1000x400x18 mm. Machining process was conducted on working centre CNC Busellato Jet 130 with usage of one edge milling head (left rotations) Faba FTS.07L4043.01 with diameter 40 mm (Fig.1). WC-Co knifes produced by Ceratizit with dimensions 29,5x12x1,5 mm were used. Chosen properties of used for experiments tool materials were presented in Tab.2.

Tab.1. Selected mechanical and physical properties of using particleboard

Material	Density [kg/m^3]	Tensile strength [MPa]	Swelling after 24h [%]	Flexural strength MOR [MPa]	Modulus of elasticity MOE [MPa]
Particleboard 18mm thickness	648	0,41	20,5	8,68	2212

Fig.1. Milling head Faba FTS.07L4043.01

Tab.2. Properties of WC-Co materials used in experiments (according to producer)

Material symbol	Density [g/cm^3]	Hardness HV30	MOR [MPa]	WC grain size [μm]	Binder content Co [%]
UMG04	15,30	2450	3200	<0,2	2,0
SMG02	15,25	2200	3500	0,2 - 0,5	2,4
KCR08	15,20	1885	2300	0,5 - 0,8	3,2

Taguchi method is based on value of the signal-to-noise S/N (ETA) ratio as basic criterion in assessment of input factors influence on output values. As optimal values are

assumed these ones that distinguishes by maximal S/N ratio (Gaitonde et al. 2008). The S/N ratio characteristic for the bigger the better in Taguchi method can be expressed as follows:

$$\eta = -10 \log [1/n \, \Sigma(1/y^2)]$$

where η is the observe value (dB), y the experimental data, n is the number of observations (Tsao and Hocheng 2007). Three factors (WC grain size, spindle speed and feed per tooth), each on three level were showed in Tab.3. A L_9 orthogonal array was employed (Tab.4).

Tab.3. Factors and levels

Code	Factor	Levels		
		1	2	3
A	WC grain size	< 0,2 μm	0,2 - 0,5 μm	0,5 - 0,8 μm
B	Spindle speed	10 000 rpm	14 000 rpm	18 000 rpm
C	Feed per tooth	0,15 mm	0,30 mm	0,45 mm

Assumed levels of cutting factors are as high as possible (extreme values are allowable for this kind of machining with usage of analyzed machine).

Tab.4. L_9 orthogonal array

Trial	Levels of input factors		
	A	B	C
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Machining was carried out according to predicted earlier scheme showed in Tab.4. Milling of grooves (width of tool diameter - 40 mm) took place in workpieces made of particleboard on depth 6 mm. In each panel was made 10 passages of tool. After each transition (feed distance - 1 m) measurement of tool wear with usage of workshop microscope was carried out. Measurement concerned clearance surface of edge. Maximal width of wear was estimated (direct indicator VB_{max}). The machining with given edge was stopped when maximal wear width was equal or bigger than 0,2 mm. Thus this value was assumed as tool wear criterion. However, feed distance up to wear criterion (VB_{max} = 0,2 mm) was noticed as its durability indicator.

RESULTS AND DISCUSSION

Statistical results analysis was carried out in software Statistica 13.1. The result of ANOM is represented in the response diagram as shown in Fig.2. Optimal values of factor levels due to maximal edge durability are following: WC grain size - 0,5-0,8 μm, spindle speed - 10000 rpm, feed per tooth - 0,15 mm..

Only in case of factor - feed per tooth, S/N ratio exceeded beyond range ±2*standard error, that proved about its huge influence and simultaneously usefulness in industry conditions. The rest two factors (WC grain size and spindle speed) influenced not so much on S/N ratio. Thus, theirs usefulness in industry conditions is limited.

In order to assess percentage value of indicator referred to influence of given factor (*P* - percentage of contribution) ANOVA analysis (Tab.5) was done. Relevant influence of feed per tooth proved indicator *P* on level 93,1%. Overall influence of the rest of factors was lower than 5% (Tab.5).

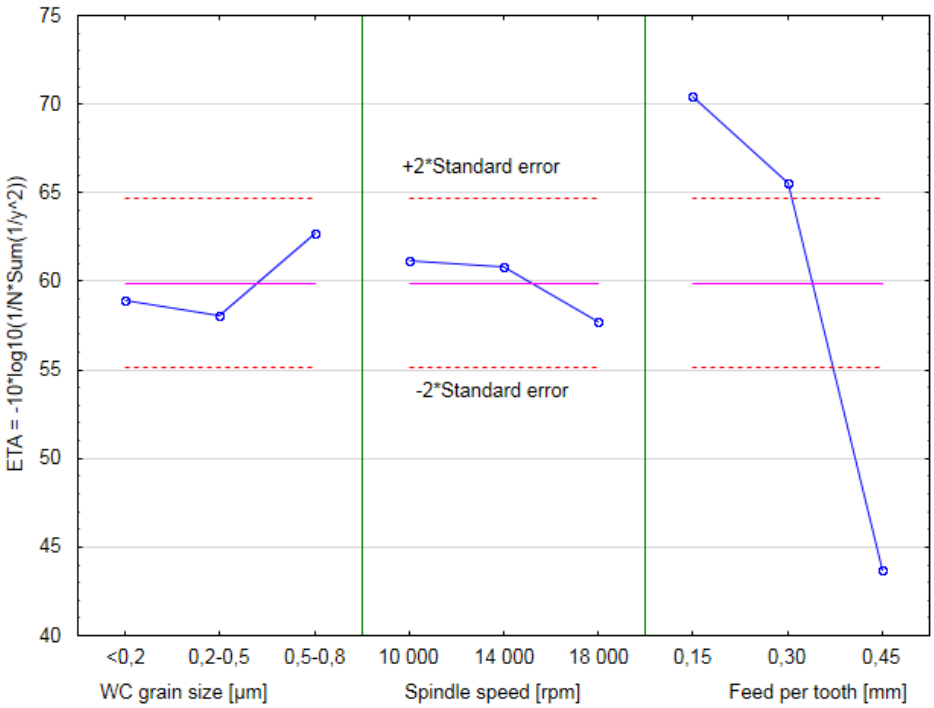

Fig.2. Response diagram of S/N (ETA) ratio for the tool life

Tab.5. ANOVA for the tool life of cutting factor

Factor	SS	d.f.	MS	F=5%	p	*P (%)*
A	35,99	2	18,00	1,053	0,4870	2,7
B	21,05	2	10,52	0,616	0,6189	1,6
C	1220,82	2	610,41	35,716	0,0272	93,1
Error	34,18	2	17,09			2,6
Total	1312,04	8				100,00

SS-sum of squares, d.f.-degrees of freedom, MS-mean square, *P*-percentage of contribution

Influence of spindle speed (*P*=1,6%) on edge durability seems to surprisingly low. This statement is in contrast to commonly assumed opinion that durability of edge in case of wood based materials machining depends mainly on cutting speed. Obtained in this researches results didn't confirmed this relationships. Maybe, it can follow from distinctive mechanism of WC-Co tool wearing in comparison for e.g. with high speed steel (HSS). In case of HSS dominant role in wearing process is friction. Thus, influence of cutting speed

and spindle speed is significant. In case of hard materials such as WC-Co besides abrasive mechanism of wearing, crucial contribution has fracture strength. Microscope observations revealed clear chippings of cutting edge (Fig.3). Thus, exceeding of given chip thickness and simultaneously cutting forces can decreases edge durability as result of chipping phenomena. This regularity should concern mainly the hardest WC-Co materials. This mechanism could justify optimal levels of factors keeping in mind edges durability. namely: big WC grain size – higher fracture strength, small spindle speed - higher resistance to abrasive wear and low value of feed per tooth – higher fracture strength.

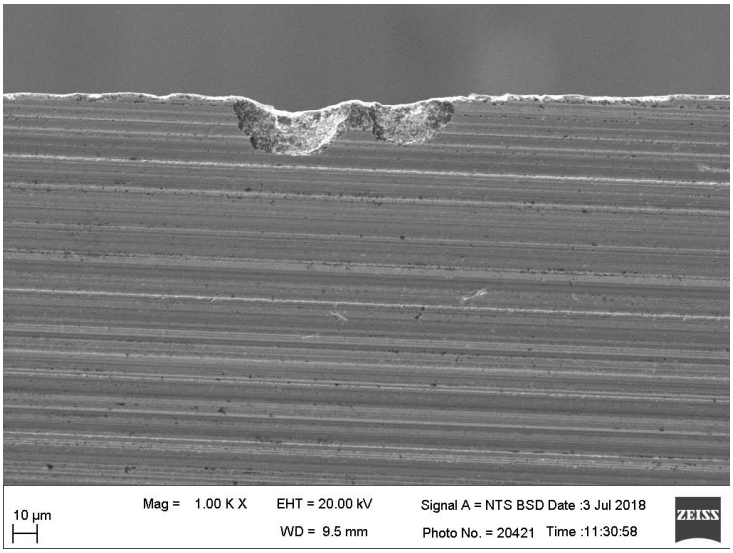

Fig.3. Chipping of WC-Co tool material (SEM image)

CONCLUSION

According to obtained results can be formulated following conclusions:

- Feed per tooth as well from statistical point of view as performance during milling of chipboards has the most important influence on tool well durability. The rest two factors (WC grain size and spindle speed) were in analysed range statistically irrelevant regards to tool durability.
- Optimal levels of factors according to edges durability were following: WC grain size - 0,5-0,8 µm, spindle speed - 10 000 rpm, feed per tooth - 0,15 mm..

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