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THE WEAR PROCESS OF ROUTER BIT DURING THE MACHINING DOVETAIL JOINTS

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ABSTRACT

The aim of the study was to explore the process of router bit tool wear during the processing of a through dovetail joint by means of a 3-axis CNC router. The dovetail joint was processed in birch plywood. The tools which were used for the examination of tool wear during the proposed production process were two two-fluted helical router bits made from sintered carbide. The parameters analysed were the radius of the wear of the cutting edges of tools in relation to the machined distance, material and also to the accuracy (surface quality) of the machined areas (joints). The cutting edge wear was measured by two methods: a contact method and a non-contact method. As a result, the study examines and describes the process of tool wear of the monitored tools for the mentioned method of processing. The study evaluates the measured parameters of processing in relation to the newly designed production procedure.

KEYWORDS: Tool wear, router bit, dovetail joint, plywood, CNC technology.

INTRODUCTION

The through dovetail joint is a classical furniture joint with outstanding strength properties. The joint consists of tails and pins, see Fig. 1b. The specific construction of the joint, which ensures its self-locking character and consequently considerable strength, requires a demanding technology. This joint is usually made manually (individual production) or by special machines and devices (batch production). The technology of current 3-axis CNC machines makes the manufacture of dovetail joints fast and accurate. However, it also bears some specifics. One of them is the inability of the technology to make sharp inner edges of the routed profile from angle 0° to 180° because of the rotating movement of the cutting tools and their shape. This limitation can be removed by boring a hole in place of the demanded edge which results in what is called "the Mickey Mouse ears", see Fig. 1a. CNC manufacturing technologies have a big potential in the fields of furniture production and wood processing, for example in competition with cheap labour. The manufacturing technologies of CNC machines and new composite materials are prerequisites for successful usage of this joint in the current environment of wood and furniture industry (Susnjara 2006).

The main goal of this study was to explore the process of router bit tool wear during the processing of a through dovetail joint, processed from birch plywood, by means of a 3-axis CNC router. The idea of such machining came from CNC rapid prototyping and new styles of furniture inspired by puzzle joints where wood based panels are often used.

Tool wear of materials during the processing of wooden materials has been dealt with by many authors. Generally, but quite extensively, this issue was described by Javorek (2006), Lisičan (1996) and Prokeš (1965). Specific measuring of cutting edge wear in coated router bits during high-speed processing by means of both contact and non-contact methods was performed by Kopecký et al. (2006). By comparing the methods, he reached the conclusion that the contact test is more accurate (and at the same time quite demanding concerning final evaluation). By analysing a number of specific problems of high-speed wood processing, Rousek (2004) established, among others, also the minimum feed rate in dependence on the degree of tool wear. The feed rate was established based on the basic assumption that the minimum width of a chip during a cutting process should be larger than the tool edge radius. I.e. the minimum feed per tooth is the rate which is still accompanied by a cutting process under the specified conditions. The mentioned study is in an obvious relation to Aguilera et al. (1999, 2000), who examined the tool wear of tools during routing in dependence on chip width and the quality of the processed surface. He found out that the smaller width of chip of the processed material, the higher quality is its surface, but at the same time the degree of the tool wear increases.

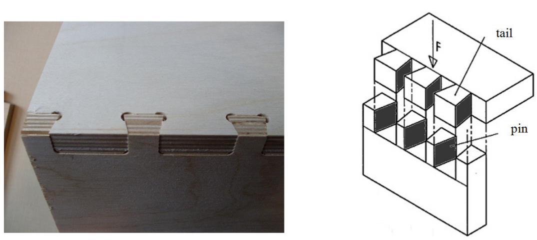


Fig. 1a (left) and 1b (right): The produced dovetail joint (left) and the description of the joint parts – the tails and the pins (right).

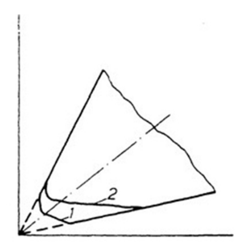


Fig. 2: Typical progress of the shape of router bit edge wear.

Theory of tool wear

Tool wear is a gradual change in edge microgeometry during processing due to which the tool loses the ability to splinter chips. This is caused by the fact that particles of metal get divided from the cutting wedge. The tool is worn out when the wedge reaches a specific critical point accompanied by an unacceptable low quality of the workpiece surface, undesired increase in the cutting force, burning and dimensional inaccuracies of the workpiece (Kopecký 2007).

The edge microgeometry during tool wear varies in dependence on the type of processing, chip width, cutting angles, the kind and the properties of the workpiece. The variety of the edge profiles after tool wear is so large that we cannot expect the same profile even in constant conditions for processing. A typical profile of a cutting wedge of a router bit is displayed in Fig. 2. The progress of wear *1* is typical of softwoods. Progress *2* represents routing of hardwoods and mainly abrasive materials, e.g. agglomerated or plywood as is the case of our study (Kopecký 2007).

MATERIAL AND METHODS

CNC machining of a through dovetail joint is untraditional, especially for the sloping of pins. In relation to potential use of the method for the furniture industry it is highly purposeful to find out in what way the selected router bits are worn.

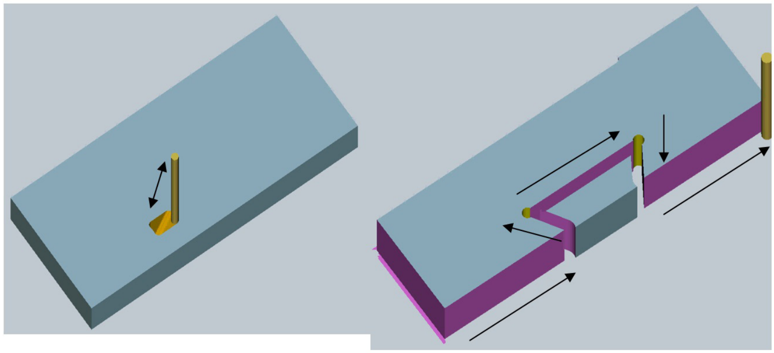
The actual analysis of the wear of tools was preceded by a study into the joint construction and its feasibility in CAM software. In dependence on the data ascertained from the review of the current state of the issue, the analysis of the constructional parameters and possible dovetail joint production procedures using CNC machines was performed. As a result, the optimum parameters and the optimum solution for the production by means of 3-axis, or 2.5-axis CNC routers were chosen.

The production method for a through dovetail joint by means of a 3-axis CNC router is based on the processing of the shape using two helical cylindrical bits. Both router bits are dextrorotary, positive with helical shape of the edge (helix angle about 70 degrees) and they are made of sintered carbides (HW-carbides of wolfram). The first bit, 5 mm in diameter (tool length 17 mm) makes the pin slope with an angle of 12 degrees by ramping method, see Fig. 3a. The second bit, 8 mm in diameter (tool length 22 mm) processes the tail of the joint and the entire shape of both counterparts, see Fig. 3b. The advantages of this process of dovetail joint production is the usage of available tools and the fact that even more complicated elements can be processed. However, as this is a specific procedure, the production presents a risk of premature damage to the tool.

The above described production of a through dovetail joint was performed in the 3-axis CNC router SCM Tech 90. The processing parameters, presented in Tab. 1., were chosen in relation to the quality of the processed surface (workpiece), further to be economical, and also in relation to the tool durability. The cutting speed and feed per tooth were established according to formulas (1) and (2).

Tab. 1: Parameters of processing through dovetail joints by helical router bits.

parameter / Bit diameter	Machined length l (m)	α	Cutting angles (°) β	γ	Cutting speed v_c (m.s^{-1})	Feed rate v_f (m.min^{-1})	Feed per tooth f_z (mm)	Revolutions n (per min)	Medium thickness of the chip h_m (mm)	Number of edges z (-)
5 mm	70	18	60	12	4.71	4	0.11	18.000	0.07 (70μm)	2
8 mm	60	8	76	6	7.54					



Figs. 3a (left) and 3b (right): Processing of pin slope by ramping method, 5 mm bit (left); and processing of tail slope, 8 mm bit (right).

$$v_c = \frac{\pi \cdot D \cdot n}{60} \tag{1}$$

where: n - revolutions,
D - tool diameter.

$$f_z = \frac{v_f}{n \cdot z} \tag{2}$$

where: v_f - feed rate,
n - revolutions,
z - number of edges.

The material used for the production of the joints is birch plywood, 12 mm (also cutting depth) in thickness (9 layers), in two versions: a typical plywood glued with non-waterproof glue (urea-formaldehyde; with 685 $kg.m^{-3}$ mid density of the board); and a "multiplex" plywood glued with waterproof glue (fenolformaldehyde; with 700 $kg.m^{-3}$ mid density of the board). The reason for the choice of the two versions of the machined material was the different abrasive ability of glues towards the tools as well as the usability of the material for furniture types (interior vs. exterior). The main geometric parameters of the processed joint are the angle of sloping of 12 degrees and the tail/pin ratio 2:1. The other dimensions depend on the thickness of the joined material (Joyce 1987, Noll 2002). The moisture content of the processed material ranged within 9±1 %.

Measurement methodology

The router bits used for the production of the dovetail joints were worn out in dependence on the selected trajectory of processing, see Figs. 3a and 3b. With respect to the character of the tool wear, corresponding methods of tool wear radius measuring were chosen:

- a contact method – measuring of the cutting edge - R, specifically the edge of 8 mm bit helix;
- a non-contact (photometric) method – measuring of the cutting edge - ρ, specifically the tip of 5 mm bit edge.

To analyse the radius of helix edge wear, a profilometer with inductive sensor Form Talysurf CLI 1000 was used (the contact method). An arm with a diamond tip of a 60° angle was moved along the bit edge surface, see Fig. 4. To capture the profile of helix edge tool wear, a metal prism was used, where the tool was laid with the fixing chuck. The edge tool wear was measured 1 mm from the tool tip, see Fig. 5. The TalyMap application served for control, checking and analysing the information from the inductive sensor.

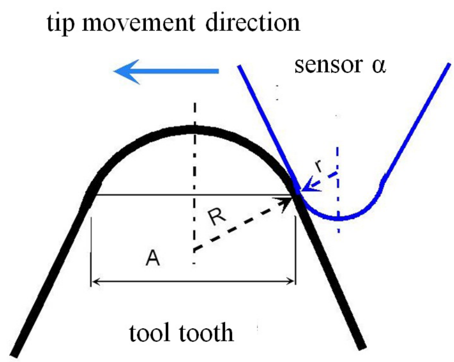


Fig. 4: The contact capturing of the edge wear radius by the diamond tip.

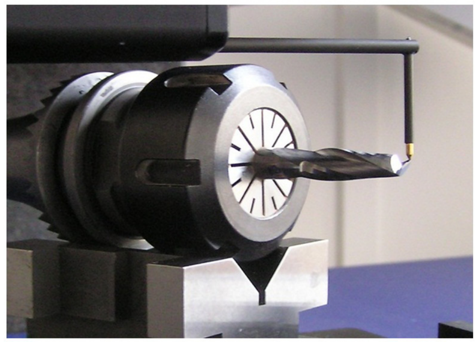


Fig. 5: Measuring of the helix edge wear radius by sensor of Form Talysurf.

After the edge profile is captured with the wear, it is necessary to perform correction, i.e. to analyse the radius of tool wear in width A, when the edge surface is in touch with sensor with its radius r. According to Fig. 4, the width of measuring of edge wear radius A depends on the radius of edge wear R and the tip angle of sensor α. The radius of sensor r = 0.002 mm is so small that it cannot affect the results. It follows from Fig. 4 that the width of measuring A depends on the measured radius R and the tip angle of the sensor tip α and it can be calculated based on formula

$$A = 2 \cdot R \cdot \cos \alpha \tag{3}$$

where: R – the measured radius,
α – the tip angle of sensor (60°).

Because a sensor with a tip angle of 60° was used, the relation (3) can be modified to this simplified formula (4):

$$A = 1.732 \cdot R \approx 1.7 \cdot R \tag{4}$$

In relation to preliminary measuring of radius R the widths corresponding to width A were chosen in the tip areas for these widths out of the measured profiles of tool edge and in these profiles the radiuses of edge wear R (ρ) were measured. The radiuses measured in this way have a minimum deviation from the real value (the difference in comparison to reality ranges at the level of sensor radius r = 0.002 mm). Each time the measuring of tool edges was performed eight times (four times measuring per an edge), the arithmetic mean was calculated and used in the graph, see results. An example of measured results of helix edge wear is displayed in Fig. 6.

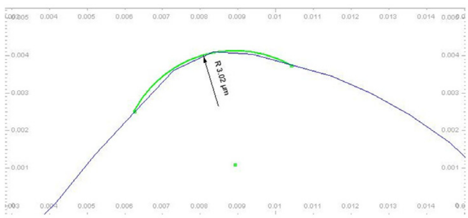


Fig. 6: An example of measuring of helix (8 mm) edge wear by contact method (axis values are in µm).

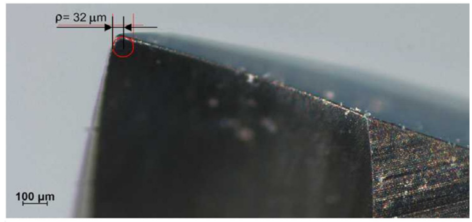


Fig. 7: An example of measuring of bit (5 mm) tip wear by non-contact method.

The radius of edge tip wear was captured by means of a system for image analysis and processing (photometrically). The monitoring of the degree of tool wear was conducted by means of a system for image analysis and processing NIS – Elements AR, ver. 2.3, which consisted of a digital 5 Mpix camera Nikon DS – Fi 1 with macrolens Navitar, fixed on a stand with lighting device KAISER RB 5000 DL, light source Schott KL 1500. The image resolution was set to 7.81 µm/pixel. Images of both tips of edges were captured, see results. The arithmetic mean from two measuring procedures was then used for the graph. An example of measured results of edge tip wear are presented in Fig. 7.

RESULTS AND DISCUSSION

The results of measurement of radiuses of edge tip wear ρ by the non-contact method and the helix edge wear R by the contact method, including the resulting regression curves (second degree polynomials) are presented in Figs. 8 and 9. On comparing both graphs it is obvious that the 5 mm bit edge tip gets worn out significantly faster (about 10 times faster) than the 8 mm bit helix edge. We assume that the reason why the edge tip is worn much faster is the higher stress laid on it because when the pin slope surface is being routed both the front edge and the helix edge are used. A solution for the stressed tool could be coating its edges, which would considerably enhance its durability. Further, it is obvious that common plywood has lower abrasive properties affecting the used tools in the given processing conditions than water-proof plywood of Multiplex type. In our opinion, this fact can be explained by a different composition of the glues or fillers which are added to water-proof plywood of Multiplex type. Because of the faster wear of the edge tip it was important to gain results concerning the comparison of the quality of the machined material – the pin slope surface. This was conducted by comparing the images of surface quality at the beginning and the end of processing. Fig. 10a shows the quality of the machined pin slope surface at the beginning of measuring (wear of about 20 µm). Fig. 10b shows the final quality of pin slope surface at the end of measuring - wear of about 70 µm = the limit of the medium thickness of chip as stated by Rousek (2004). At this limit quality of pin slope the completion (connecting) of the joint was a bit difficult, however still within tolerance for the joint.

According to Javorek (2006), higher number of revolutions per minute or smaller feed per tooth would give us better surface quality of the joint. Nevertheless, after machining first joint samples on available CNC machine and in accordance to Aguilera et al. (1999, 2000) we have decided to choose above mentioned parameters, including chip thickness of 70 µm, which corresponds to rough chipping by Ettelt and Gittel (2004). All these parameters were adequate enough to necessary joint quality and to appropriate tool wear. Furthermore, the reached tool wear is well comparable to progress *2* in Fig. 2. This tool wear curve confirms above mentioned statement from Kopecký (2007). Finally, by using two different methods of tool wear measuring we have to agree with Kopecký et al. (2006), who found the contact procedure more accurate and time demanding than the non-contact procedure.

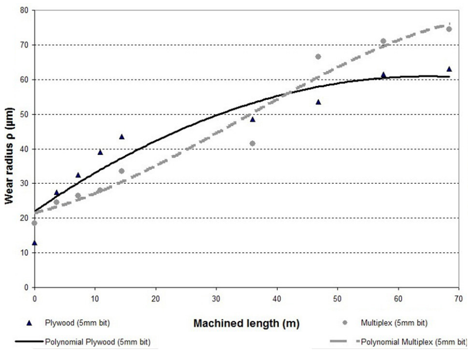


Fig. 8: Graph with results of measuring radius of 5 mm bit edge tip wear ρ*, including regression curves (polynomial).*

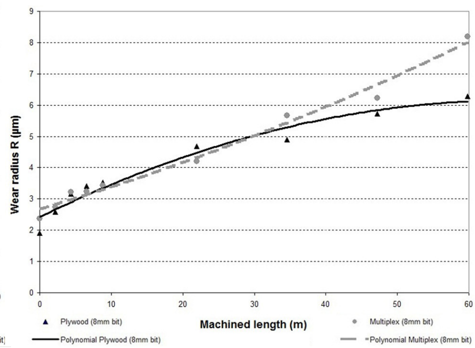


Fig. 9: Graph with results of measuring radius of 8 mm bit helix edge wear R, including regression curves (polynomial).

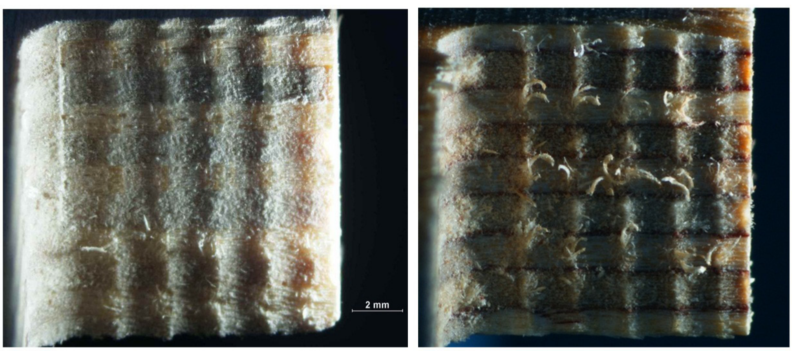


Fig. 10a (left) and 10b (right): The quality of machined surface of pin slope at the beginning (left) and at the end (right) of measuring.

Furniture joint research that have been done in the past, e.g. by Eckelman and Haviarová (2011) or Smardzewski (2002) quite extensively describes joint's properties in relation to different testing methods. The results of this specific research will be subsequently also completed by joint's mechanical properties in order to discover relations among other factors of joint creation. Such interdisciplinary approach already showed Prekrat and Španić (2009).

CONCLUSIONS

The study deals with the process of wear of router bits in relation to a newly proposed production procedure for through dovetail joints by means of 3-axis CNC processing centre. The mentioned procedure enables the joint to be used again for plywood in furniture industry and subsequently enhance of quality of furniture constructions. The main significance of the study lies in the description of the tool wear process expressed by differences between different tools, machined materials and in relation to the quality of machined surfaces. Thus:

- 5 mm bit edge tip wears significantly faster (about 10 times faster) on the machined length than the 8 mm bit helix edge
- common plywood has lower abrasive properties than water-proof plywood of Multiplex type.

The methods of wear measuring we used are currently considered to be among the most up-to-date ones; however, with respect to the complicated shape of chosen tools we cannot say that they are the most suitable ones. For our measuring, for example a combination of the methods would be more suitable, but this would be highly time-demanding. Our study therefore shows that it is appropriate to develop new measurement methodology for the measuring of similar processing tools and technologies.

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