FORCES AND WORK OF CUTTING VERSUS CUTTING SPEED IN LAMINATED PARTICLEBOARDS MILLING

Grzegorz Kowaluk - Waldemar Szymanski - Bartosz Palubicki - Piotr Beer

Abstract

The aim of the investigation was to characterize the influence of the cutting speed in milling of laminated particleboards on the cutting forces and specific work of cutting and its components: specific work of new surface creation and specific work of chip deformation. Presented investigation is the first literature-known try to study the distribution of specific work of cutting using a research stand equipped with industrial milling machine. The investigation confirms that with an increase in cutting speed, the forces decrease. Following that, the specific work of cutting and one of its components, the specific work of chip deformation, decrease with the cutting speed growth. However, the specific work of new surface creation increases as the cutting speed grows. That is a result of a higher fracture toughness under the "real life" cutting conditions and higher friction.

Key words: *particleboard, milling, force, work of cutting, speed, machining*

INTRODUCTION

According to **Pahlitzsch (1966)** for beech and pine the cutting force is decreasing with cutting speed increasing up to a minimum around 40m/s and increases afterwards. **McKenzie (1968)** affirms that the decreasing of the cutting force with the cutting speed increase can be explained by the friction: when the cutting speed grows, the friction is going down. But, **Kivimaa (1952)** says that there is no influence of the cutting speed for the cutting force for birch cut within 0-50m/s measurement range. These results are confirmed for solid wood. Except that of **Sinn et al. (2005)**, where the influence of the cutting velocity at a constant feed per tooth for the cutting forces was investigated, there are no similar research results for wood-based material such as particleboard. The glue content, more homogenous structure (than solid wood) and different type of chips can give new information about cutting characteristic of this material.

There is comprehensive investigation on the influence of the chosen factors on the work of cutting of particleboards. The influence of the tool's bluntness and particleboard's production parameters on the work of fracture (work of new surface creation) and work of chip deformation were studied [**Beer et al. 2002, Beer et al. 2005, Kowaluk et al. 2004 a, Kowaluk et al. 2004 c**]. Nevertheless there is still no information about the work of cutting distribution (on the work of new surface creation and work of chip deformation) in particleboard milling with varying cutting speed.

The aim of the presented work was to characterize the influence of the cutting speed in milling of laminated particleboards on the cutting forces and specific work of cutting and its components: specific work of new surface creation and specific work of chip deformation.

MATERIALS AND METHODS

Particleboards
In the investigation typical commercially-available three-layer laminated particleboards were used. The thickness of the boards was 16mm.

Tools
Carbide replaceable inserts were used in this investigation. Cutting diameter was 125mm and tool angles: α=15°, β=55° and γ=20°. Because of the short cutting path (less then 7m for each blade), the stage of the cutting edge was recognized always as sharp. The radius of the edge was about 5μm, and it was measured using the electron microscopy [**Kowaluk et al. 2004 c**]. Additionally, the pictures of the edges from the microscopy were analyzed with the MeX™ software by Alicona Imaging GmbH.

Research stand
The processing was conducted on a typical industrial wood milling machine equipped with control devices in the Christian Doppler- Laboratory for Fundamentals of Wood Machining at the BOKU in Vienna. Cutting direction was cutting-against-feed. Additionally a numeric control feeding device was used to eliminate errors caused by differences between the set and the obtained rates, which is the case when traditional feed devices are employed (slide of material). The constant feed speed in the investigation was 7m/min. The height of cutting layer was 1mm. During the machining the tool rotation speed was changed between 11 levels, in the range: from 1458min^{-1} to 4757min^{-1} (tab. 1). The following cutting speeds and mean chip thicknesses were achieved:

Tab. 1 Changed rotation speed and achieved cutting speed and mean chip thickness

Rotation speed, min^{-1}	1458	1840	2173	2506	2822	3128	3458	3793	4137	4523	4757
Cutting speed, m/s	9.5	12.0	14.2	16.4	18.5	20.5	22.6	24.8	27.1	29.6	31.1
Mean chip thickness a, μm	429	340	288	250	222	200	181	165	151	138	131

To measure the forces in cutting two piezoelectric sensors were used (
fig. 1) [**Kowaluk et al. 2004 a, Kowaluk et al. 2004 b**].

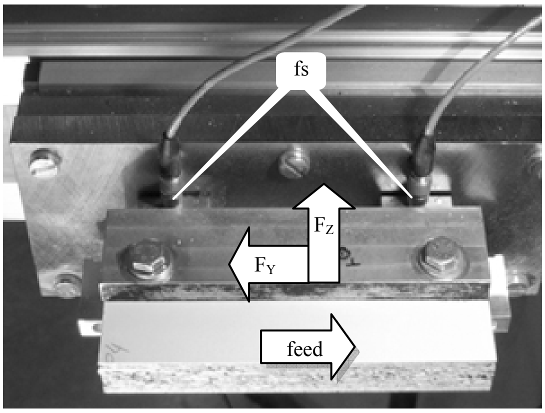

Fig. 1 Sample holder with two built-in force sensors (fs);
F_Y, F_Z-directions of the measured forces

Calculating of specific work of cutting and its components
Basically for the measured forces F_Y and F_Z for the mean chip thickness the followed parameters were calculated [**Beer et al. 2002, Huang et al. 2000**]:

- specific work of cutting E_A, kJ/m^2,
- specific work of new surface creation E_S, kJ/m^2,
- specific work of chip deformation E_D, kJ/(m^2*μm).

There is a followed dependence between the above mentioned works:

$$E_A = E_D \cdot a + E_S \quad (1)$$

where "a" is the mean chip thickness.

RESULTS AND DISCUSSION

In fig. 2 mean values of the measured forces in Y and Z direction at the mean chip thickness for all boards are showed. With the increase in cutting speed, the forces decrease. This trend corresponds with results of **Pahlitzsch (1966)** research. Most intensive decrease in the forces is observed in the range of the cutting speed of about 9.5-14.2m/s. When the cutting speed is higher than 14.2m/s, the forces change less spectacularly, especially the Z-force.

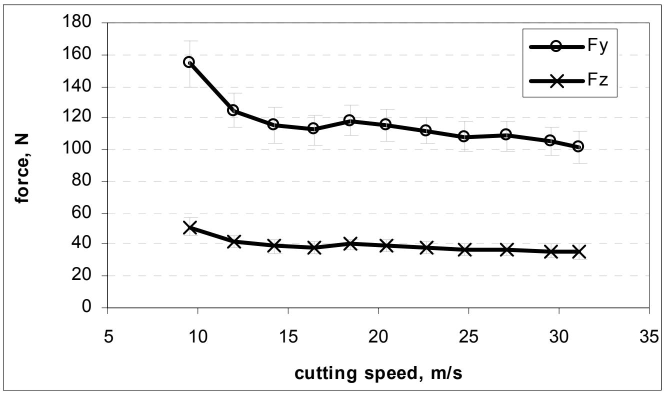

Fig. 2 Mean values of measured forces for all boards at cutting speeds

The dependence of the specific work of cutting E_A on the cutting speed is showed in fig. 3. With the cutting speed increasing, the specific work of cutting decreases. The shape of the curve in the figure is, of course, similar to the shape of the dependence of the F_Y-force on the cutting speed. A difference shown dispersion of the achieved results.

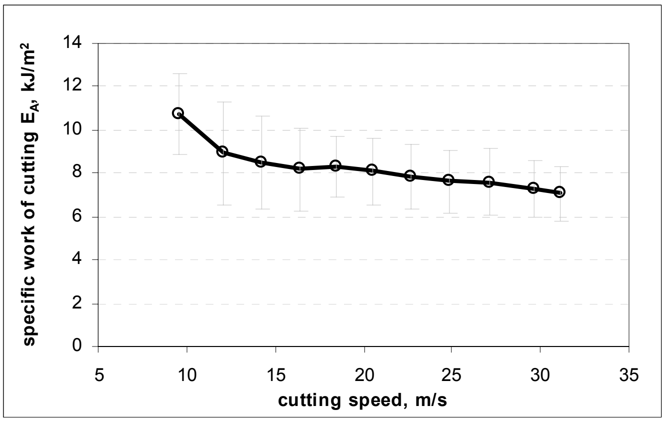

Fig. 3 Mean value of the specific work of cutting E_A for all boards

In fig. 4 the dependence of the specific work of new surface creation E_S on the cutting speed is showed. With the increase in the cutting speed ranging from 9.5 to 12m/s the specific work of new surface creation decreases. When the value of speed of cutting is over 12m/s the specific work of new surface creation increases.

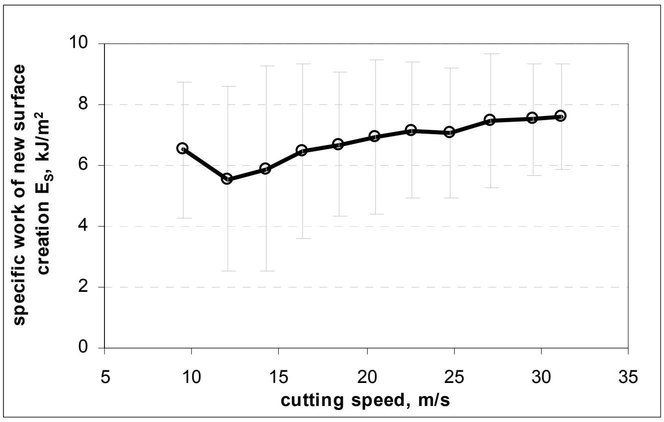

Fig. 4 Mean value of the specific work of new surface creation E_S for all boards

The dependence of the specific work of chip deformation E_D on the cutting speed is showed in fig. 5. With the cutting speed growing from 9.5 to 12m/s the specific work of chip deformation grows as well. Generally, for cutting speed higher than 12m/s the specific work of chip deformation decreases as the cutting speed grows.

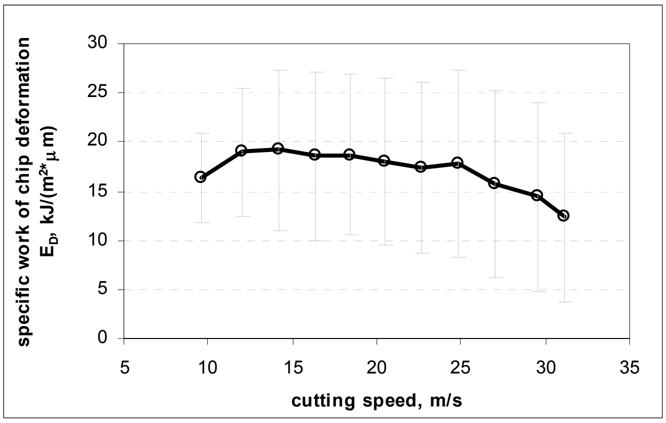

Fig. 5 Mean value of the specific work of chip deformation E_D for all boards

The above mentioned figures (fig. 3-fig. 5)show that the specific work of cutting and its components, specific work of new surface creation and specific work of chip deformation, are correlated with the cutting speed – even for a sharp tool. Bluntness of a tool would multiply the differences. With the increase of the cutting speed, the specific work of new surface creation grows as well. The reason for this situation can be the fact, that the cutting process is much more dynamical at a higher cutting speed, so the machined material is more resistant to creating a new surface. It is correlated with values of the specific work of chip deformation: as the cutting speed increases, specific work of chip deformation decreases. As the cutting speed grows, and when the feed speed is constant, the mean chip thickness goes down (**tab. 1**). It is easier to deform the chip of lower thickness but it is harder to fracture the material (create a new surface). Generally, even if the specific work of cutting increases as the cutting speed grows, the specific work of cutting – a general factor - decreases. It seems that decrease of the cutting force is caused by removal of a smaller amount of material, but not by a smaller value of friction. The specific work of new surface creation increases with cutting speed when the feeding speed is constant, as it was reported for the constant feed per tooth [**Sinn et al. 2005**]. In this case, on the one hand, fracture toughness under the *real life* cutting conditions grows with speed too. On the other hand, for a constantly smaller feed per tooth, as it was applied in this study, the increase in the specific work of new surface creation can be cased by a higher friction. Friction grows with sliding speed for dry solid wood [**Beer et al. 1998**] and that can be the case.

CONCLUSIONS

Results of conducted investigation led to the following conclusions:

- Cutting forces: parallel and normal to feed direction, are correlated with the cutting speed; they decrease with an increase in the cutting speed.
- With an increase in the cutting speed the specific work of cutting decreases.
- Specific work of new surface creation increases as the cutting speed grows. That is a result of a higher fracture toughness under the "real life" cutting conditions and higher friction.
- Specific work of chip deformation decreases when the cutting speed increases.

Acknowledgments
This study was carried out in cooperation with the Department of Woodworking and Basis of Machine Construction and the Christian-Doppler-Laboratory for Fundamentals of Wood Machining – BOKU Vienna, and with financial support of ÖAD-Austria and MNiI-Poland.

REFERENCES

Beer P., Ede Ch., Gindl M., Stanzl-Tschegg S., 2002: Cutting tests of laminated particle board regarding work of fracture and chips plastic deformation. Wood Science and Engineering in the Third Millennium Proc., "Transilvania", University Brasov, Romania

Beer P., Kowaluk G., Sinn G., Dziurka D. (2005): Mechanical properties of particleboards induce cutting quality. Proc of the 17th Int. Wood Machining Seminar, Rosenheim, Germany

Beer, P., Miklaszewski S., Sokolowska A. (1998): Tribological properties of wood. Proc. of the 10th Jubilee International Summer School - Mielno'98, Koszalin, *(in polish)*

Huang X., Jeronimidis G., Vincent J. F. V., 2000: The instrumented microtome cutting tests on wood from transgenic tobacco plants with modified lignification. Proc. of the 3rd Plant Biomechanics Conf. Freiburg – Badenweiler

Kivimaa E. (1952): Die Schnittkraft in der Holzbearbeitung, Holz als Roh- und Werkstoff, vol. 10

Kowaluk G., Dziurka D., Beer P., Sinn G., Tschegg S. (2004 c): Analysis of work of chip formation during cutting of blades with growing blunt, Proc. of the 4th Int. Conference Chip and Chipless Woodworking, Stary Smokovec – Tatry, Slovakia

Kowaluk G., Dziurka D., Beer P., Sinn G., Stanzl-Tschegg S. (2004 b): Influence of ammonia addition on particleboard properties, Proc. of the 2nd Int. Symposium on Wood Machining, Vienna, Austria

Kowaluk G., Dziurka D., Beer P., Sinn G., Stanzl-Tschegg S. (2004 a): Influence of particleboards production parameters on work of fracture and work of chips formation during cutting, Electronic Journal of Polish Agricultural Universities, Wood Technology, Volume 7, Issue 1.

McKenzie W. (1968): The frictional behaviour of wood, Wood Sci. Technol., vol. 2, no. 2

McKenzie W. M., Ko P., Cvitkovic R., Ringler M. (2001): Towards a model to predict cutting forces and surface quality in routing layered boards, Wood Sci. Technol. 35

Pahlitzsch G. (1966): Internationaler Stand der Forschung auf dem Gebiet des Hobelns und Fräsens von Holz und Holzwerkstoffen, Holz als Roh- und Werkstoff, vol. 24, no. 12

Sinn G., Beer P., Stanzl-Tschegg S. (2005): Analysis of cutting forces in circumferential flat milling of MDF and particleboard, Proc. of the Int. Conference on Integrated Approach to Wood Structure, Behaviour And Applications, Florence, Italy