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INFLUENCE OF TOOLS STAGE ON PARTICLEBOARDS MILLING

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ABSTRACT

The objective of the investigations presented in this paper was to determine forces value (feeding and normal forces) changes occurring during machining resulting from the change of the edge geometry (r = 2.5μm and 24μm) caused by blunting and which constitute an index of element quality after the processing. Values of these forces, referred to material properties (bending strength, modulus of elasticity, internal bond, density profile, densities of individual layers, specific fracture energy and coefficient of stress intensity) allow a fuller characterisation of the processed boards towards defining the sequence: material-process-quality.

The values of individual mechanical parameters, defining the level of forces occurring during machining, are characterising cutting properties of particleboards, that may allow predicting the characteristics of processing. Edge geometry changes to such an extent that they can be used to design an effective in-situ diagnostic system of the processing operation, that is based on normal force value.

KEY WORDS: fracture, cutting, properties, prediction, diagnostic, particleboard

INTRODUCTION

Wood-based materials continue to enjoy a steadily growing interest both as semi-finished and ready-to-use articles. Their sustained popularity can be attributed not only to economic advantages but also to the fact that, in many situations, wood-based materials do not only match but, in many cases, exceed the functional value of solid wood. Particle boards occupy a permanent and quite an important position among wood-based materials.

An essential condition for a good operation of an enterprise, i.e. of reaching a positive economic result, which applies not only to large factories with mass production but also to companies with short series or even single-article production, is the maintenance of high product quality. The application of modern, highly-efficient machine-tools, durable tools and the automation of manufacturing processes are some of the ways to obtain the required quality of the semi-finished products and, later on, of the final article. Wood as well as wood-based materials are characterised by considerable heterogeneity of their structure affecting the directionality of physical and mechanical properties. This emphasises the significant contribution of material properties in the process of quality assurance. Material properties of particle boards resulting from the poor quality of raw materials used for their production and the production technology itself (e.g. poorly glued laminate) lead to serious problems in assuring good quality of the processed elements. That is why the monitoring of the particle board processing, which consists in the measuring of forces and the assessment of the processing effects, aim at reaching the required quality as well as diagnosing the processing operations. Hence, the investigations on the impact of the condition of tools on the processing of laminated particle boards have not only scientific but also practical significance. A better insight into interrelationships between mechanical properties of particle boards and the distribution of the machining work in relation to the quality of the treated surface can be used to elaborate some practical conclusions and shed some new light on problems associated with designing, standardisation, realisation and diagnostics of the technological operations connected with the processing of laminated particle boards.

During the processing of laminated particle boards, the laminate near the processing area often gets damaged (Saljé and Drückhammer 1984) and near-surface parts of the board swell. This can be attributed, partly, to the properties of the processed material but, first and foremost, to the condition of the edge of the tool since, as the edge gets blunt, forces occurring during machine cutting and which determine processing conditions increase (Kowaluk et al. 2004). The significance of the increase of forces resulting from the progressing blunting was investigated during machining of MDF boards (McKenzie et al. 2001). It was emphasised that, on the basis of the force value parallel to the feed direction and taking into account the remaining processing parameters, it is possible to determine the turning moment. On the other hand, the normal force allows to determine, among others, the quality of the processed surface taking into account the tool rake angle. Also Palmqvist et al. (Palmqvist et al. 2003) carried out measurements of the machining forces during milling. The performed experiments involved the observation of force changes of the chip formation during the machining of solid wood, while maintaining the tool rotation rate close to that applied in industry. However, the impact of the edge condition on the value of machining forces was not analysed. Aguilera et al. (2000) determined optimal machining parameters of the MDF board with reference to the changing density profile of this material and appropriate roughness of the obtained surface. The measurement results they obtained during processing operations and in the course of simulations were similar. However, no mention was made about the edge condition of the tool as one of the factors affecting the value of forces during machining.

Another approach to determine the appropriate machining force of particle boards was adopted by Bouzakis and Koutoupas (2003). Particle boards used in the experiment were subjected to detailed material examinations. Thanks to the measurements taken of the machining forces during processing and in the result of the analysis of the designed FEM model, they managed to corroborate the thesis according to which the appropriate machining force is determined by the strength parameters of the processed material. On the basis of a strong correlation between the results of the FEM model analysis measurements of experimental investigations, the above-mentioned researchers indicated a possibility of the determination of the suitable machining force on the basis of information about the power consumption by the machine tool motor.

Wong and Schajer (2003) suggested that the machining conditions of particle boards are strongly influenced by the following three factors: shaving thickness, tool rake angle and the size of chips in the boards. If the process of shaving development is observed from the zero to maximum thickness, two basic traits become apparent. Firstly, the chip thickness usually differs from the theoretical one as a result of fractures occurring in the particle board below the line of machining. This phenomenon increases with the decrease of the tool rake angle. Secondly, the process of the shaving formation is characterised by three phases: friction, scraping off and the formation of a regular shaving. During the first two phases, force values parallel to the feed direction (F_Y) and normal (F_Z) are almost identical. It is only during the process of the regular shaving development that the force F_Y increases significantly, whereas the increase of the F_Z force is negligible.

In another publication, Palmqvist and Johansson (1999) reported a very significant influence of the normal force changes during rotational machining. It was found that it was this force that could lead to the development of machining defects and a significant improvement of processing effects could only be achieved by its minimisation. The investigations were carried out using MDF boards, beech and pine wood and plastic. While analysing machining processing of plastic, Palmqvist (2003) reported that processing defects could be minimised by decreasing the normal force value. This force changes both its direction and value. Hence, the author puts forward a number of possibilities of reducing the impact of this force, among others, by the appropriate selection of the mean shaving thickness, tool rake angle and the processing direction. However, he does not mention the impact of the edge condition on the value of the machining force and only assumes similar properties of the force distribution during machining of particle boards.

The objective of the investigations presented in this paper was to determine forces value changes occurring during machining resulting from the change of the edge geometry caused by blunting and which constitute an index of element quality after the processing. Values of these forces, referred to material properties, allow a fuller characterisation of the processed boards towards defining the sequence: material-process-quality.

MATERIAL AND METHODS

The tools used in the performed experiments comprised exchangeable blades made of sintered carbides of the following angle parameters: $\alpha = 15°$, $\beta = 55°$ and $\gamma = 20°$. The machining diameter was D=125 mm and the number of blades z = 1. An electron microscope was used to measure the tool-nose radius. The blade placed on the stub (Fig. 1a) was photographed along the bisector plane of the edge angle and next at the ± 1.9° angle to that plane (Fig. 1a). Special software, MeX from Alicona Imaging GmbH, was used for 3D image reconstruction and measurement of the blade (Fig. 1b). An edge nose radius of r = 2.5µm for the sharp tool and r = 24µm for the blunt tool was measured.

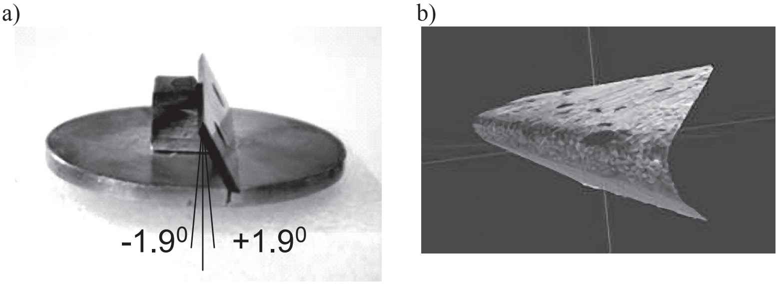

Fig. 1: Stub with exchangeable blade (a), and 3D reconstruction model of edge (b)

Two types of commercially available different three-layer particle boards designated as PB1 and PB2 were used in the experiments. The mechanical properties of the employed particle boards were determined in accordance with the appropriate standards for bending and tension experiments (PN-EN 310:1994, PN-EN 319:1993). In the course of the performed experiments, the following measurements were carried out: bending and tensile strength in directions perpendicular and parallel to the board planes and the elasticity modulus in bending were determined. In addition, the density profile of the processed particle boards was measured using an X-Ray densitometer, GreCon Density Analyser DA-X. The next characteristics of the examined material were the measurement of the fracture energy and fracture toughness using wedge splitting experiments (Stanzl-Tschegg et al. 1995). Critical stress intensity factor K_{Ic} was determined from the maximum splitting force, indicating the beginning of macro-crack growth. Fracture energy until the total breakage of the sample was calculated from the area under the load displacement curve (Fig. 2a, b) (Ehart et al. 1996a; Ehart et al. 1996b). The angle of the wedge used in the experiments was 18.4°, whereas the crosshead-speed during tests was 2 mm/min.

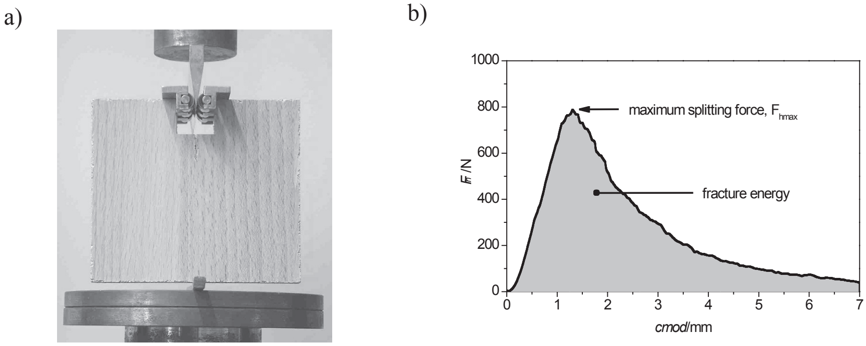

Fig. 2: Wedge splitting experiment (a) and exemplary result interpretation (b)

The measurement of forces occurring in processing was carried out during milling in cutting-against-feed (Fig. 3a). A typical industrial milling machine was equipped with a feeding device. Thanks the application of a computer assisted control of the feeding speed, it was possible to eliminate errors caused by differences between the set and obtained rates, which is the case when traditional feed devices are employed (slide of material).

Piezoelectric sensors were fixed below sample grip (Fig. 3) allowing measurement of forces from three directions of the Cartesian co-ordinate system.

Processing parameters were as follow: rotation speed n = 3700min^{-1}, feeding speed u = 3m/min and infeed ae = 2mm.

The measurement of forces was carried out in two perpendicular directions (Fig. 3). The signal from sensors superimposed with noises was analyzed and later filtered (Fig. 4a). The diagram of forces obtained in this way served to determine the maximum of the force, its increase with time (slope) and the area under the curve (Fig. 4b).

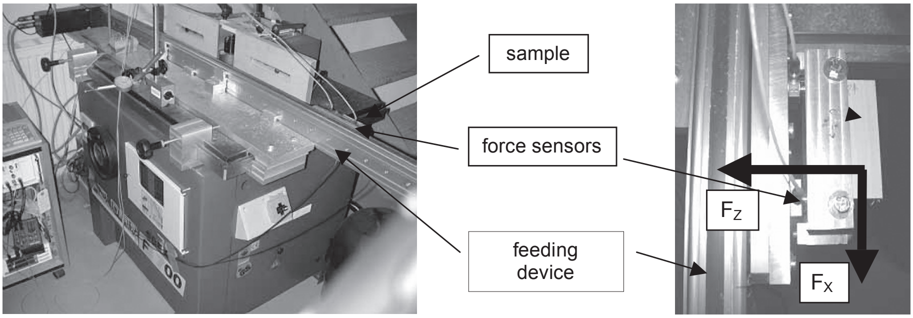

Fig. 3: View of the research assembly and details of sample holder with forces sensors

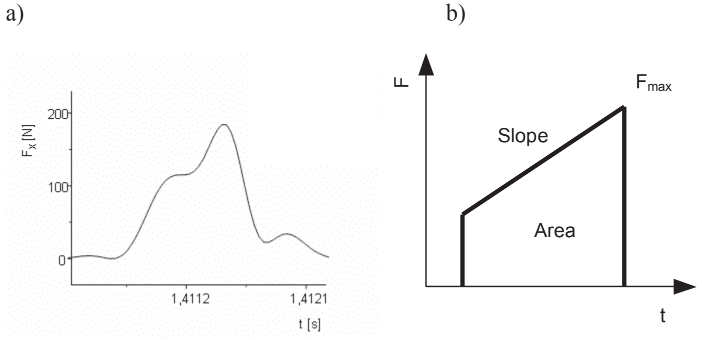

Fig. 4: Force signal received from sensors: low-pass-filtered signal (a) and calculated parameters (b)

RESULTS AND DISCUSSION

Materials properties

The results of measurements of the bending strength (Fig. 5) indicate very similar properties of the processed particle boards in this regard. The calculated standard deviation indicates very balanced properties of boards from the entire series of measurement replications. Naturally, similar results were obtained for the calculations of the elasticity modulus in bending (Fig. 6). The recorded difference in the value of modulus of elasticity in bending of about 4% does not exceed the measuring error. This means that the examined boards did not differ in this regard.

The internal bond strength IB was found to be about 8% greater in the PB1 particle board (Fig. 7) than for PB2. However, in the case of such non-homogeneous material and bearing in mind values of the standard deviation, it should be stated that the examined boards did not differ significantly with regard to their IB values.

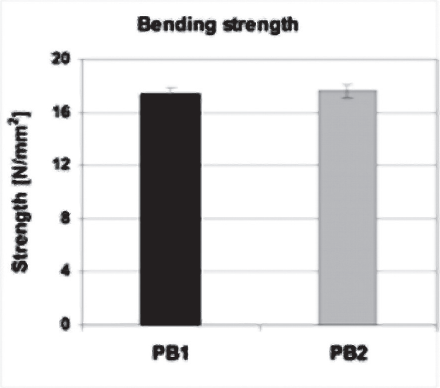

Fig. 5: Particleboard's bending strength

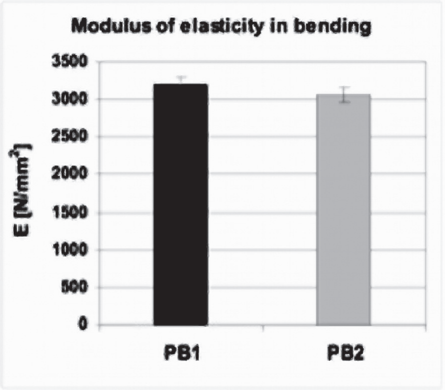

Fig. 6: Modulus of elasticity in bending

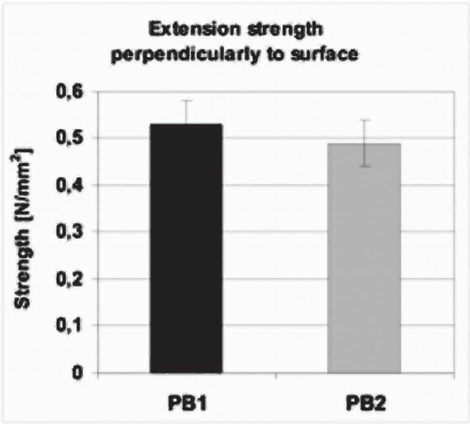

Fig.7: Internal bond strength

The density profile proved similar for both of the examined particle boards (Fig. 8). In the case of the PB2 board, an irregular density increase was observed of external layers about 2 mm from the surface. This fact emphasises the layered character of the particle board. As to numerical values, the higher density of the PB2 external layers was corroborated by the performed density analysis of individual layers (Fig. 9). It is evident that both boards are characterised by similar mean density for the entire cross-section, although the PB2 board was characterised by a lower density of middle layers. This property explains the lower tensile strength of this board in the direction perpendicular to the board planes (IB-strength) (Fig. 7). The performed statistical analysis of the research results failed to show any significant differences between the examined boards (probability value α = 5%).

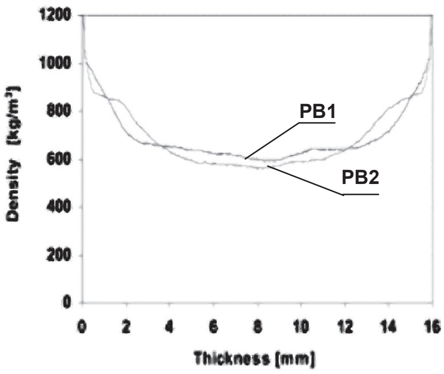

Fig. 8: Particleboard's density profile

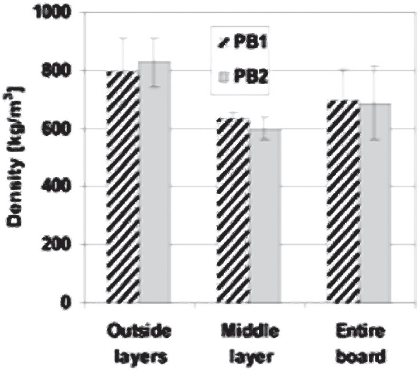

Fig. 9: Densities of individual layers and average density for entire boards

The specific fracture energy is the work necessary to create a unit area of cracked surface is greater in the case of the PB1 board (Fig. 10). Analysing the stress intensity coefficient, which is also higher in the case of PB1 (Fig. 11), it can be concluded that the PB1 material is less susceptible to fracture. Much more work is needed both to create a crack, i.e. greater critical stress intensity factor (Fig. 11), and for its propagation (Fig. 10). This can have an impact on the processing parameters.

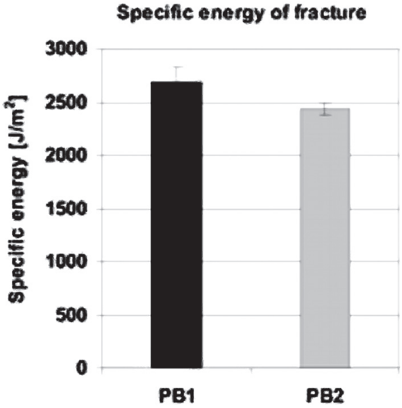

Fig. 10: Plot of specific energy of fracture for tested particleboards

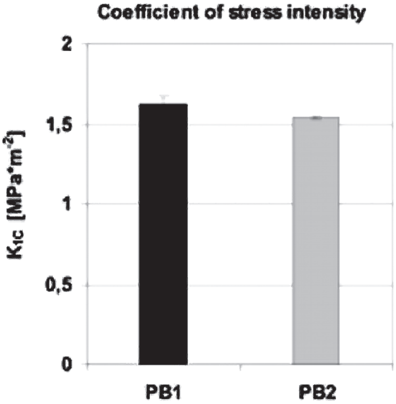

Fig. 11: Plot of coefficient of stress intensity for tested particleboards

Feeding force

The maximum force, parallel to the feed direction, is correlated with the condition of the machining blade edge (Fig. 12). The force reached its maximum, during machining with a sharp edge, at about 120 N. The application of a blunt edge increased this force by, respectively, over 60% for the PB1 and over 69% for the PB2.

A similar tendency is shown by the slope of the feeding force (Fig. 13). It is easy to see that, with the increase of the edge bluntness, also the applied force had to be increased. In addition, values of the variation of force per time increment are higher in the case of the PB2.

The above observations are confirmed by the measurement of the area under the curve – the force in the machining time function (Fig. 14) – which is proportional to the work of the chip removal. Also here, the values increase with the increase of bluntness. On the other hand, the comparison of the two boards lead to the conclusion that, regardless of the edge condition, the work required to remove the chip shows similar values.

It is evident from the above considerations that the PB1 board requires higher values of the work initiating the processing operation, i.e. maximum parallel force minus slope times cutting time. Consistently the values of the specific fracture energy and the stress intensity coefficient are higher for this board. A valuable correlation becomes apparent after the comparison of values of the physical and mechanical board properties with the parameter values of their processing. This means that even in the case of such non-homogeneous material as particleboard, it is possible to predict the effects of processing and, hence, the quality of the machining process.

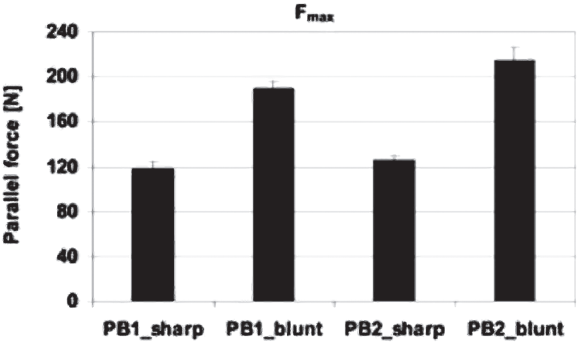

Fig. 12: Maximum parallel force for cutting with sharp and blunt tool

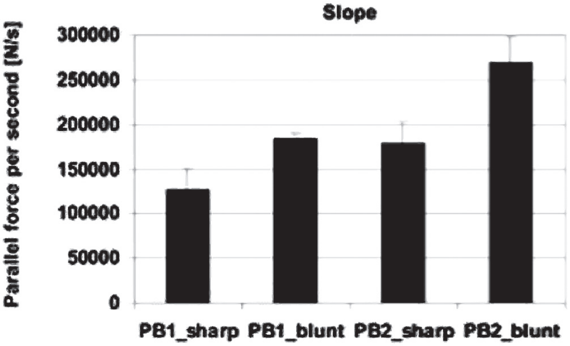

Fig. 13: Slope of feeding force

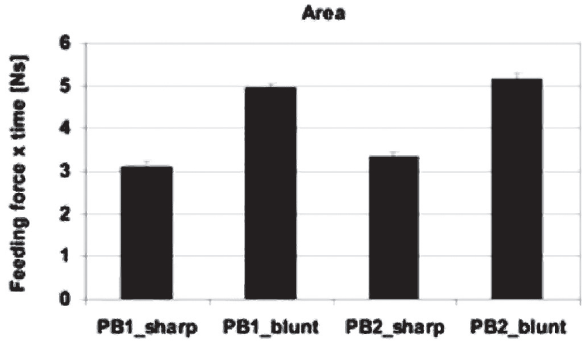

Fig. 14: Integration area (proportional to work of chip removal) for cutting sharp and blunt tool

Normal force

During the machining with a sharp edge, the maximum value of the normal force to the feed direction of the material reached its maximum at about 20N. When the machining was carried out using a blunt edge, the required force increased by more than four times (Fig. 15).

Even more spectacular change accompanying increased edge blunting occurs for the inclination of the normal force (Fig. 16). In the case of the machining of the PB1 board with a sharp and blunt edge this change is over 40 times, whereas for the PB2 board – over 35 times.

The area under the normal force curve reveals almost a six fold increase when the sharp tool is replaced by a blunt one, both in the case of the PB1 and PB2 boards (Fig. 17).

It is evident from the above considerations that the normal force is a very sensitive sensor of the edge geometric changes caused by blunting. This means that it is the best parameter of the processing operation which can be used to diagnose the process, also *in-situ*.

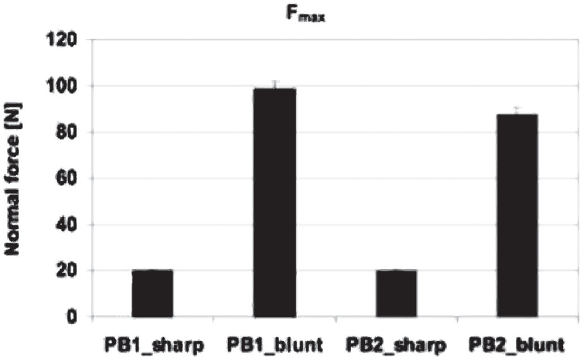

Fig. 15: Maximum normal force for cutting selected particleboards

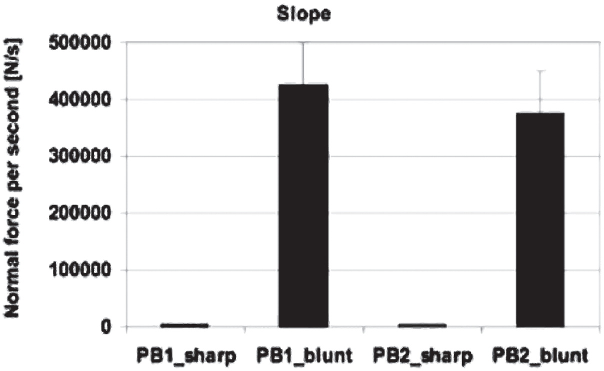

Fig. 16: Normal force increase

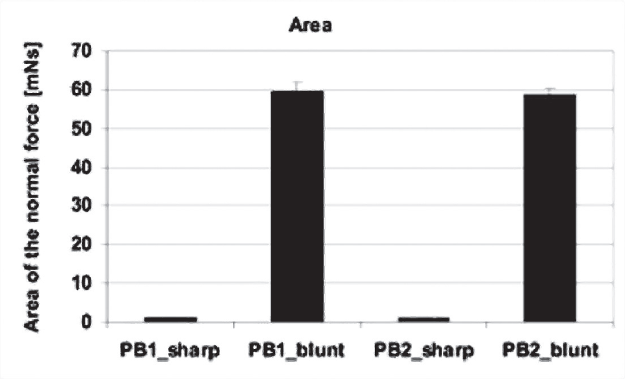

Fig. 17: Area of the normal force

CONCLUSIONS

The values of individual parameters defining the level of forces occurring during machining are characterised by a correlation with the individual mechanical properties of the machined particleboards. Therefore, the determination of the selected mechanical properties of the processed material may allow predicting the characteristics of its processing.

Edge geometry changes of the machining tool influence the mutual interrelationships of the pair: a tool – a processed material to such an extent that they can be used to design an effective *in-situ* diagnostic system of the processing operation. The basic parameter helping to achieve this target is the normal force to the feed direction which provides a very responsive sensor of the edge geometry changes resulting from its blunting.

An *in-situ* diagnostic system of the processing operation together with defined selected mechanical properties of the processed material may form a sound basis for a comprehensive control of the process intended to improve the processing quality even for such non-homogeneous material as particleboard.

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