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STUDY REGARDING THE VARIATION OF THE THRUST FORCE, DRILLING TORQUE AND SURFACE DELAMINATION WITH THE FEED PER TOOTH AND DRILL TIP ANGLE AT DRILLING PRE-LAMINATED PARTICLEBOARD

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Abstract:
Drilling of pre-laminated particleboards is a subject insufficiently covered by dedicated research. Therefore, the objective of this study was to examine the relationship of some key drilling parameters and analyze the variation of the thrust force, torque and surface delamination with the feed per tooth and drill tip angle at drilling pre-laminated particleboard. The surface quality was evaluated by the size of delaminations, at the exit side of the drill bit. To assess the defect, two non-dimensional parameters were used: the common delamination factor F_d *based on the measurement of diameters of the circle circumscribing the defect and of the processed hole, and a new delamination factor,* F_{dS}*, proposed by the authors and based on the effective measurements of the defect area with an image processing software. The experiments were performed on a range of feed per tooth rates from 0.1 to 0.7mm and four flat drill tip angles: 30°, 60°, 90°, 120°. The results showed that, a low feed rate generally minimizes both the drilling torque and the thrust force and also the delamination, while a small tip angle increases the drilling torque and generally minimizes the thrust force and delamination.*

The drill with T30 tip angle made exception from this trend, due to its geometry that caused the highest thrust force. The flat drill with 60° tip angle gave the best quality for small feed rates, while inducing the smallest thrust force, which makes it the preferable recommendation, amongst the tools tested, for drilling pre-laminated particleboards.

Key words: *drilling; particleboard; tool tip angle; feed per tooth; thrust force; torque; delamination.*

INTRODUCTION

Drilling is one of the most common and frequent mechanical processing operations not only in the wood industry, but also in the processing of metals, plastic materials, composites etc. In the furniture industry, its use has extended over the years, along with the massive development of case furniture production, obtained from panels joined by cylindrical dowels. This type of furniture uses mainly pre-laminated particleboard panels (PB), material whose worlwide production, according to FAOSTAT, registered a constant increase (http://faostat.fao.org).

Although the economical importance of the drilling operation has been constantly growing and will continue to grow, gaps in knowledge still persist, especially regarding the relationships between the geometrical parameters of the drill bits, the cinematic parameters of the working schedule (cutting speed and feed speed), the dynamic parameters (thrust force and torque) as well as the surface quality and energy consumption.

Research on wood drilling is not new. Ozenberg (1927) investigated the influence of the drill bit diameter and of the cutting edge geometry on the torque and feed speed (the thrust force being maintained constant) for different types of drill bits and for several wood species. The minimum torque and maximum feed speed were registered for a value of 20° of the clearance angle. However, the results are hard to be considered a reference for comparisons as the feed speed varied during cutting while the thrust force was the parameter maintained constant, contradicting the usual practice.

Similar research as of Ozenberg (1927) was conducted by Hetzel (1928), but focussed on drilling PB and plywood. The experimental set-up was the same, as well as the conclusions.

Serebrianîi (1954) experimentally determined the drilling dynamic parameters (thrust force and torque) on wood surfaces, when using three types of drills, each one having a specific geometry of the cutting edge. The tool diameters varied between 10-22mm, feed speeds were 0.6; 0.81; 1.57 and 2.09m/min and the drilling depth was up to 100mm. The results showed that the thrust force and torque increase with the drill diameter, depth of cut and feed speed and depend on the drill type and wood species.

Based on previous studies performed by Zhao (2000), Zhao and Ehmann (2002) developed an optimised geometry for a new class of spade drill bits for wood processing. The authors studied both theoretically and experimentally the influence of the proposed geometry on the performances of the new tools. The results showed that both the thrust force and torque increase with increasing feed speed (feed rate).

Valarmathi *et al*. (2012) found that the high spindle speed with low feed rate reduces the thrust force developed by the drilling of plain MDF panels.

Radu (1967) achieved an extensive study aiming at establishing the optimum drill characteristics for drills used for wood and PB, considering the torque, the thrust forces and the chip evacuation mode as function of the drill type, the wood material (oak, beech, spruce, PB), the feed speed and the drilling depth. The results showed that, as long as the point/tip angle increases, the torque and the specific resistance to cutting decrease, but the thrust force increases, regardless the feed direction. The study referred to the quality of drilling the particleboards in terms of visual qualifications of the surface in the neighbourhood of the processed holes. Parameters, as tool feed speed and tool geometry, were amongst the ones investigated, but the qualifications were limited to subjective qualitative assessments as: "good", "weak", "slight increase", "slight decrease". The author also noticed that the processing quality (expressed through fibre plucking and tearing at the inlet and outlet orifices) decreases when the thrust force and point/tip angle increase.

Delamination is a processing defect which consists of a local detachment of the coating layer engaging chips/particles pull-offs from the particleboard surface. This phenomenon can occur during drilling at the entrance side as well as at the exit side (for drilled through holes). Its magnitude depends on the processing parameters and can be used as an indicator of the drilling quality (Davim *et al*. 2008). Recently, the delamination caused by drilling the wood based panels, especially medium density fiberboards (MDF), was quantitatively assessed by using a parameter called delamination factor, F_d which is the ratio between the maximum diameter of the circle circumscribing the defect and the mean diameter of the processed hole. Hence, Davim *et al*. (2008) investigated the relationships and parametric interaction between the feed rate and the cutting speed on the F_d at entry and exit side of the holes in drilling the MDF. Two types of MDF panels, melamine coated and veneered, were tested using cemented carbide (K20) drills. The F_d decreased with the increase of the cutting speed and increased with the feed rate for both materials.

Palanikumar *et al*. (2009), Prakash *et al*. (2009) studied the performance characteristics given by F_d in drilling operations of MDF boards using carbide tools. The machining parameters considered were: the spindle speed, the feed rate and the drill diameter. They found that F_d decreases with the increase of the cutting speed and increases with the feed rate and drill diameter.

Prakash and Palanikumar (2011) investigated the influence, at MDF, of the spindle speed, feed rate and drill diameter on the surface roughness of the processed hole. The experimental result revealed that the most significant drilling parameter for the surface roughness was the feed rate followed by the cutting speed.

Regarding the drilling of particleboards, Valarmathi *et al*. (2013) advanced the idea that the thrust force developed during cutting play a major role in gaining a good surface quality and minimizing the delamination tendency. They studied the influence of the spindle speed, feed rate and point angle upon the thrust force. However, the drills they used had a geometry more specific to metals rather than for wood based materials (a tip angle $2\kappa_r \geq 100°$) and the same was true for the processing parameters (feed speeds v_f = 75 - 225mm/min). These experiments led to the same conclusions as with previous researchers concerning the trends for the delamination factor.

In conclusion, research on drilling wood based panels are few, and those that exist are made with drill bits with geometry features more characteristic for metal processing, while most of research on delamination of wood based materials focussed mainly on MDF and less on the drilling of pre-laminated particleboards.

Therefore, this paper is aiming to study the influence of the tool geometry (tip angle) and processing parameters (feed speed/feed per tooth) on the dynamic parameters (thrust force and torque) and the delamination defect at pre-laminated PB drilling, in typical woodworking conditions.

METHOD, MATERIALS AND EQUIPMENT

For the experiments, four flat drills (rake angle $\gamma = 0°$) with the tip angles, $2\kappa_r$, of 30°, 60°, 90°, 120° and having a cutting diameter of 10mm, were used (Fig. 1). The clearance angle of all drills was the same $\alpha = 20°$ (as recommended by Ozenberg, 1927). This selection was made as this type of drills are similar, as far as the cutting edge geometry is concerned, with the geometry of carbide tipped drills comonly used for

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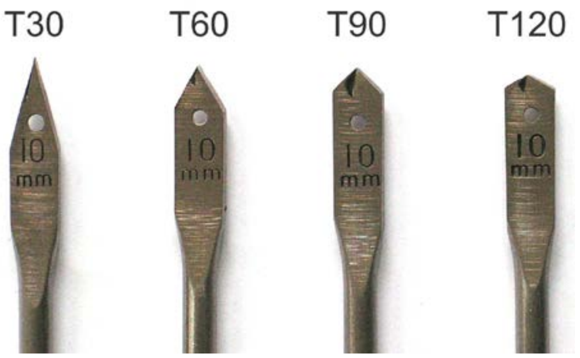
drilling particleboards (rake angle γ = 0º). The symbols adopted in this paper for those drills were tip angle related: T30, T60, T90, T120. T90 and T120 were selected because they and the range between these values, are amongst usual choices for drilling PB, but T60 and T30 were added to enlarge the analysis to the effect of smaller tip angles on surface quality as well as on the dynamic parameters: thrust force and torque.



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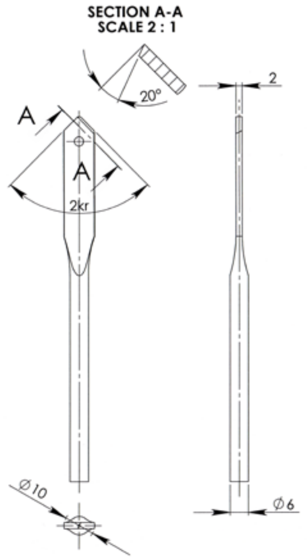
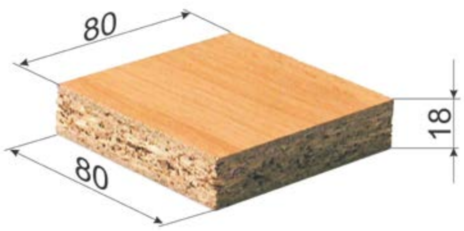


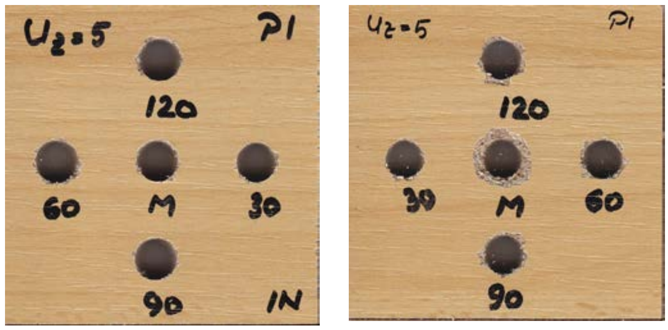
b.

Fig. 1.
Flat drills used for processing the pre-laminated particleboard. a - front images of the four flat drills with the tip angle, 2κ_r, of 30°, 60°, 90°, 120°
b – the geometry of T30 to T120 drills.

Forty square samples with the side of 80mm were cut from a single pre-laminated particleboard, 18mm thick (Fig. 2a). They were divided into four groups of ten specimens each. Each specimen was drilled with the four flat drills with different tip angles: T30, T60, T90, T120, (Fig. 2b). Each group was processed with a different feed speed so that the tooth bite, f_z, was different, having the following values: 0.1, 0.3, 0.5 and 0.7mm. The rotation speed, n, was kept the same for all four types of drills, namely 3000rpm. This led to four feed speed values, v_f: 0.6, 1.8, 3.0 and 4.2m/min.



a.



b.

Fig. 2.
Samples used for drilling. a - sample dimensions; b - sample displaying the drills entrance side, respectively the exit side with the consequent delamination defects around the holes.

Measuring and evaluation of the thrust force and torque

The machine used for drilling was a CNC processing centre type ISEL GFV/GFY, which allowed the exact set-up of the drills rotation speed and of the feed speeds (Fig. 3).

The thrust force at drilling was measured with a device consisting of three HBM force transducers type S2 (nominal force: 500N), placed at 120 °, at the same distance from the drilling axis (Fig. 3).

In order to amplify the signal from the force transducers to the data acquisition board, a Strain Masters signal amplifier was used. This electronic device is designed for static and dynamic strain measurements using quarter, half, and full bridge circuits, with 8 independent channels.

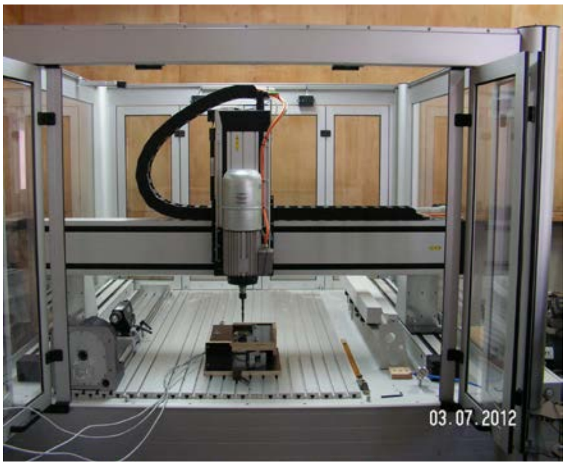


Fig. 3.
CNC processing centre type ISEL GFV/GFY endowed with a device for measuring the thrust force and consisting of three HBM force transducers.

The torque was evaluated by measuring the active power consumed by the spindle motor. This was measured by a Sineax P530/Q531 transducer for active and reactive power (Camille Bauer). Data was recorded with a multifunction DAQ Board Keithley Model KUSB-3108. The apparatus was connected to the electric circuit of the machine motor, according to the scheme presented in Fig. 4.

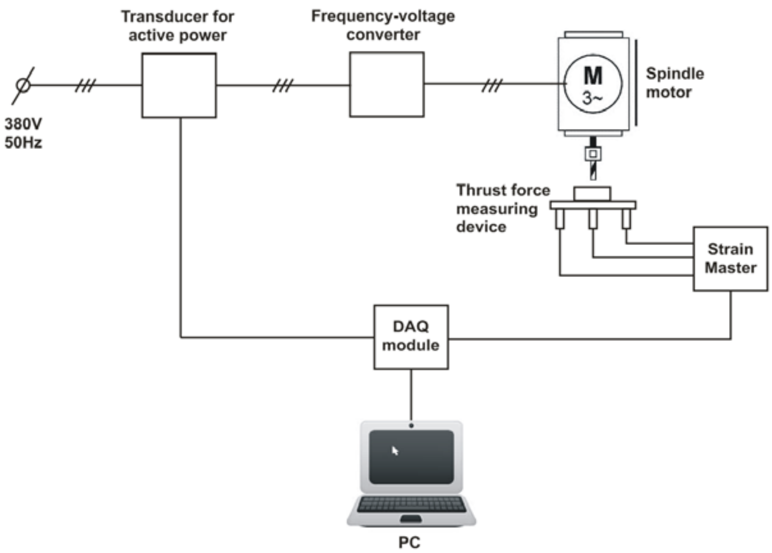


Fig. 4.
The connection scheme of the DAQ system used for measurements.

Data was further stored on a PC using a Keithley KUSB QuickDataAcq software, which measured on the first channel the values of the active power P_T consumed by the spindle motor during drilling. This included both the power consumed at idle running P_0 and the one consumed during drilling P_D. The software returns other three channels representing the force values recorded in the feed direction by each force transducer, their sum representing the thrust force F_T. For each drilling operation a data file was obtained, so that a total of 160 files were registered (4 feed speeds x 4 drill bits x 10 samples = 160 drilling operations).

The acquired data was exported in .xls format to an Excel file. In order to remove the noise and the dynamic components of the signals, these were filtered by a fourth-order, Butterworth digital filter.

After filtering, the data from the channels 2, 3 and 4 were summed 3 by 3 to get the variation of the thrust force. Next, the average values of the consumed active power and of the thrust force for each pair drill - feed speed were calculated.

Finally, the data representing the consumed active power P_T was processed in order to obtain the variations of the drilling torque T_D, according to the formula:

$$T_D = 9.55 \frac{P_D}{n} [N \cdot m] \qquad (1)$$

where: P_D is the power consumed only for drilling, $P_D = P_T - P_0$, in W;
n – spindle rotation, in rpm.

For each drill, three distinct phases of processing can be observed, as in the example in Fig. 5:

- phase 1, between moments T0 and T1 - the stage when the drill starts cutting and the entire cutting tip penetrates into the material (the initial penetration);
- phase 2, between moments T1 and T2 - when the drill cuts into the material, until the drill tip crosses the whole board thickness (the actual drilling);
- phase 3, between moments T2 and T3 - when the cutting tip begins to emerge from the material and achieves the complete breakthrough.

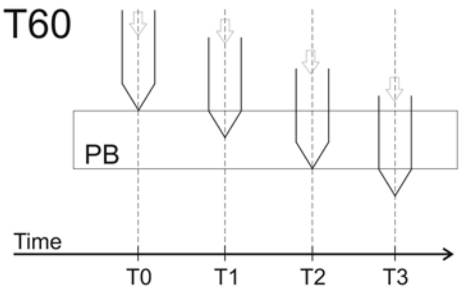


Fig. 5.
Example of drilling phases using T60.

The variation of the thrust force and torque with the feed rate (feed per tooth) was recorded for each drill tip angle. The variation of the thrust force and torque along the drilling phases was recorded and observed. Out of these observations, the maximum values were the ones kept for further analysis. These maximum values were means from ten measurements.

Measuring and evaluation of surface delamination at drilling

All drilled specimens were scanned on the exit side in order to assess the delamination defect occurring around each hole. This side was preferred because it showed the worse surface quality in comparison with the entrance side.

Two quality factors were used for this purpose and they are presented as follows:

- One delamination factor was the common F_d, used in the literature, which is the ratio between the maximum diameter of the circle circumscribing the defect and the mean diameter of the processed hole, according to Equation 2. For each hole, the diameter was measured with an electronic calliper, with a 0.01mm precision, on two perpendicular directions at the samples exit side. The measurement of the hole diameter as well as of the diameter of the circle surrounding the defect are shown in (Fig. 6a).

$$F_d = \frac{D_{max}}{D} \qquad (2)$$

where: D_{max} is the diameter of the circle circumscribing the defect;
D is the diameter of the processed hole measured as a mean of two perpendicular measurements.

- The second delamination factor F_{dS}, proposed by the authors, divides the extended area of hole including the surrounding defect, S_d, to the cross-sectional area S of the hole calculated with the mean diameter D obtained from the two calliper measurements taken on perpendicular directions:

$$F_{dS} = \frac{S_d}{S} \qquad (3)$$

where: S_d is the extended area of the hole including the surrounding defect (Fig.7 b);

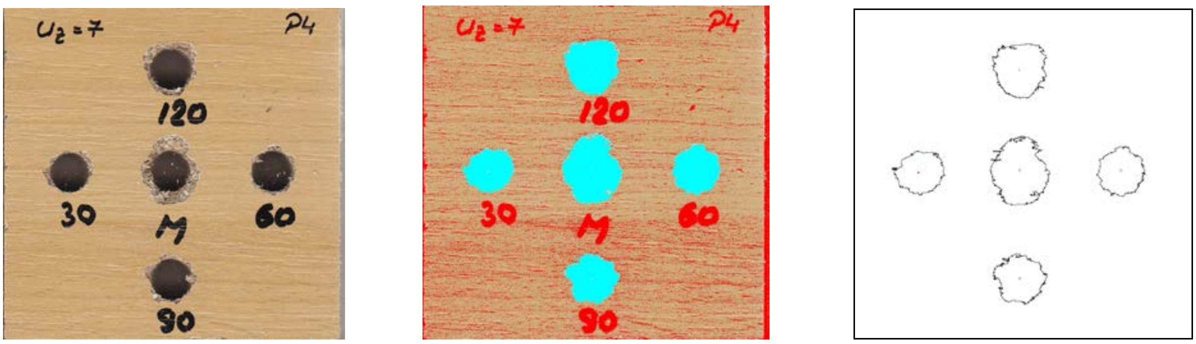
S is the cross-sectional area of the hole calculated with the mean diameter *D.*

For exactly measuring the area of hole with delamination, S_d, an image processing software, ImageJ (http://en.wikipedia.org/wiki/ImageJ), was used (Fig. 6b).

a. ***b.***

Fig. 6
Evaluation of the particleboard delamination caused by drilling:
a - measurement of diameters for calculation of the delamination factor F_d;
b - image of the hole with the defect surrounding it as given by ImageJ.

Compared to the first method, which approximates the zone with defect by taking into consideration the maximum diameter of a circle that circumscribes the defect, the second method is more precise, because it identifies exactly the damage around the holes. The method was previously used for wood species identification and the working principle was described in detail by Gurau *et al*. (2010). The software is able to detect image features, to select their contour and to return a mask image where only the items of interest are kept (Fig. 7). In this study, they were holes with delamination surrounding them (areas in Fig. 7b). Further, numerical data measuring their area was acquired in a spreadsheet.



a. ***b.*** ***c.***

Fig. 7.
Exit side of a pre-laminated particleboard specimen drilled with different tool tip angles and a 0.7mm tooth bite: a - specimen scanned image; b - ImageJ detection of drilled areas that included the delaminations (S_d); c - contour detection of drilled holes with delaminations.

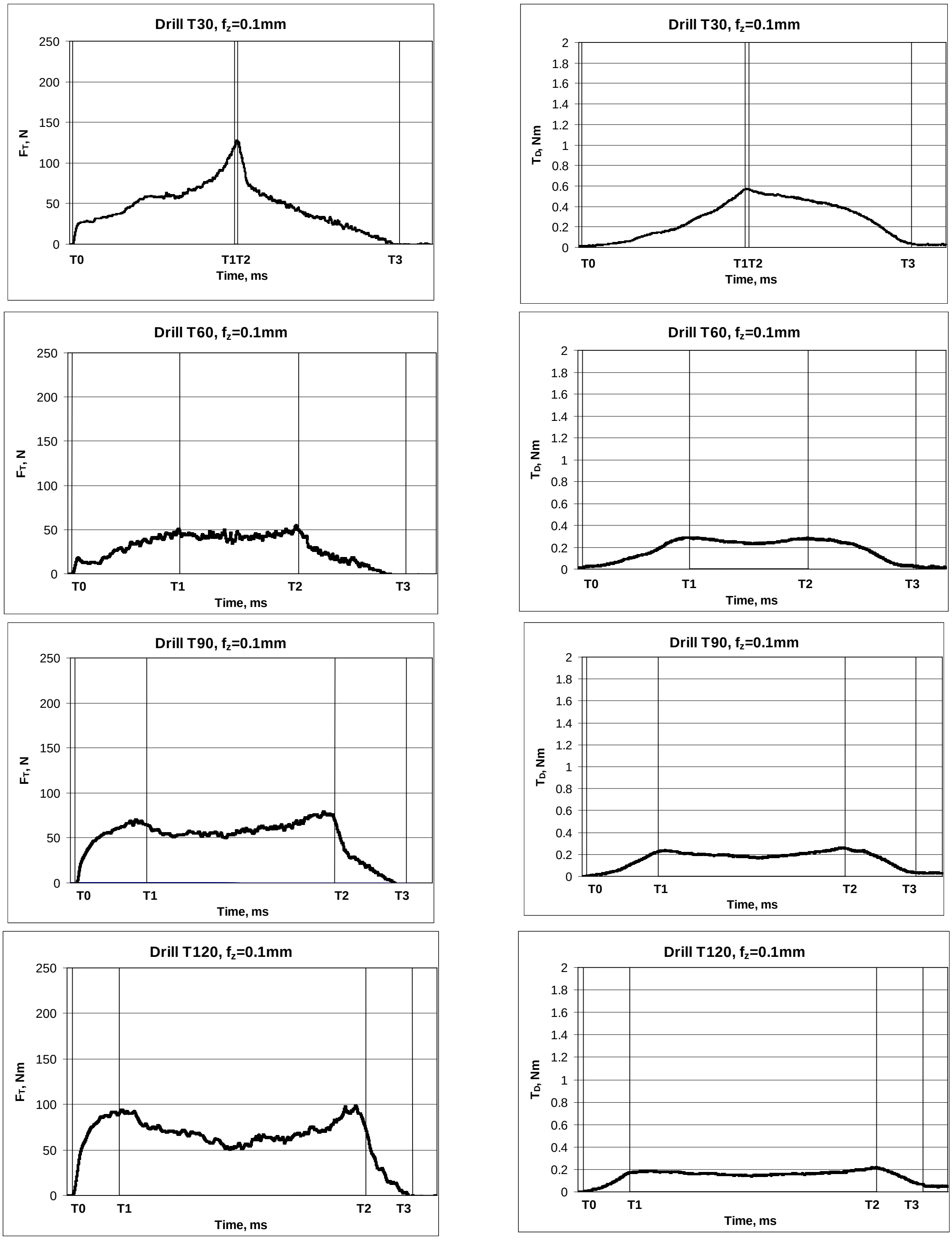
Both delamination factors were calculated for each feed per tooth combination and drill tip angle and the mean values out of 10 measurements were further considered in evaluations and comparisons.

RESULTS AND DISCUSSION

The influence of the feed per tooth and drill tip angle on the thrust force and torque

The variation of the thrust force and torque for all drill tip angles during the phases of processing from T_0 to T_3 is depicted in Fig. 8 (for a value of the feed per tooth f_z =0.1mm) and Fig. 9 (for a value of the feed per tooth f_z =0.7mm). It can be seen that, in the first phase, both, the thrust force and the torque increased until the cutting edges cut with their entire length (the moment T1). In the second phase (the moment T2) those dynamic parameters slightly decreased for drills T60, T90 and T120 due to the lower density of the PB core, while in the exit phase (the moment T3) they markedly decrease, as well as the power consumption. From Fig. 8 and Fig. 9 can be observed that both the drilling torque and the thrust force registered two peaks: one in the proximity of moment T1, at the end of the initial penetration and the second, in the proximity of the moment T2, at the end of the actual drilling phase.

It can be noticed that the highest values for both the drilling torque and feed force were recorded for processing with the drill bit T30, but only for a very short period (the moments T1 and T2 almost coincide), while the cutting edges cut through the entire thickness of the specimen (the T30 drill tip length was 18.66mm while the samples thickness was only 18mm). The lowest values of the thrust force were recorded with the drill bit T60 and the lowest values of the drilling torque occured for the T120 drill bit.



a. ***b.***

Fig. 8.

The variation of the dynamic parameters for drilling PB with a feed per tooth f_z=0.1mm: a - the thrust force; b - the torque. All values represent means from 10 measurements.

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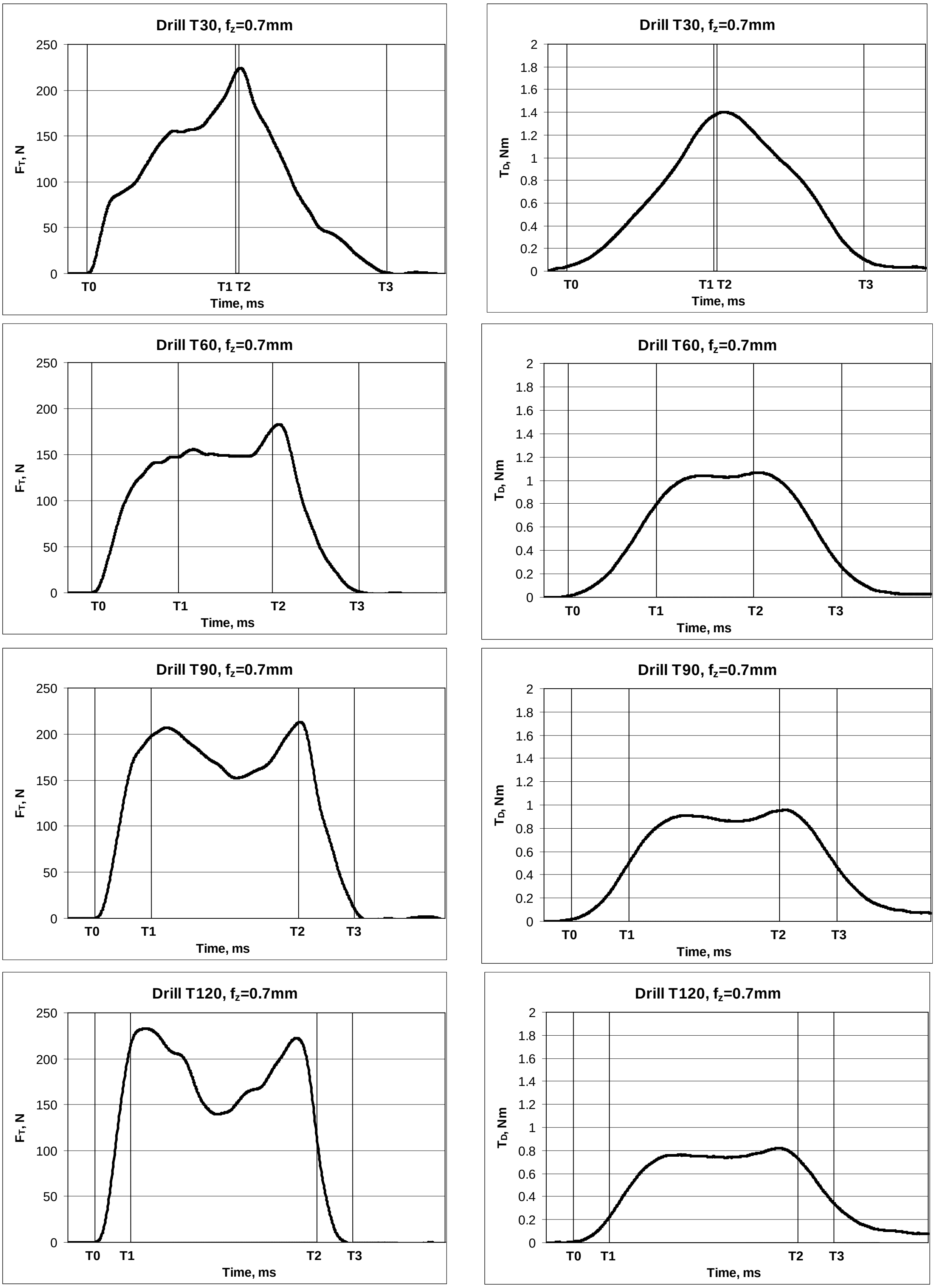
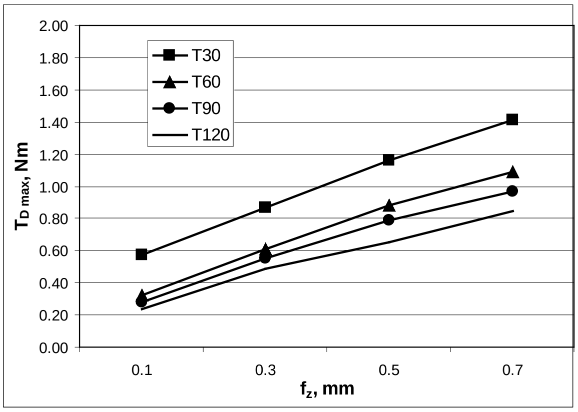


a. *b.*

Fig. 9.

The variation of the dynamic parameters for drilling PB with a feed per tooth f_z=0.7mm: a - the thrust force; b - the torque. All values represent means from 10 measurements.

The maximum values of the torque and the thrust force occurred at the moment T2 and their variation with the feed per tooth for all drill tip angles are presented in Fig. 10.



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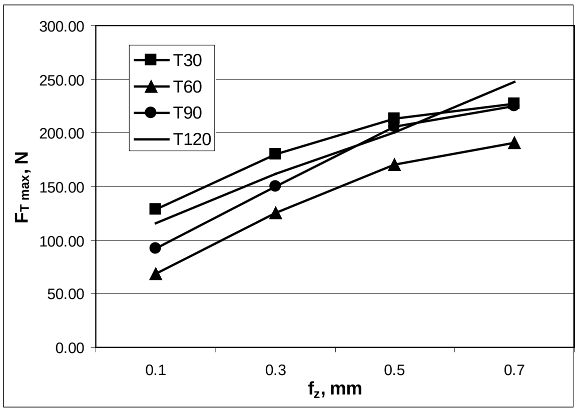

b.

Fig. 10.
The variation of the maximum values of the dynamic parameters with the feed per tooth and for all drill tip angles when drilling PB: a - the torque; b - the thrust force.
All values represent means from 10 measurements.

The actual maximum values of the torque and thrust force at drilling PB are included in Table 1 and Table 2.

Table 1
The maximum mean values of the torque T_D (in N.m) at drilling PB with a range of feeds per tooth and drill tip angles

	f_z=0.1mm	f_z=0.3mm	f_z=0.5mm	f_z=0.7mm
T30	0.575	0.870	1.158	1.410
T60	0.322	0.611	0.884	1.088
T90	0.283	0.552	0.786	0.968
T120	0.240	0.490	0.654	0.848

Table 2
The maximum mean values of the thrust force F_T (in N) at drilling PB with a range of feeds per tooth and drill tip angles

	f_z=0.1mm	f_z=0.3mm	f_z=0.5mm	f_z=0.7mm
T30	128.1	179.9	212.9	227.3
T60	68.1	125.1	170.6	191.0
T90	92.3	149.5	206.2	224.8
T120	115.4	162.3	199.9	247.7

From Table 1 and Fig. 10a, it can be seen that the drilling torque increased app. 2.5 times for T30, 3.4 times for T60 and T90, and 3.5 times for T120 for an increase of the feed per tooth from f_z=0.1mm to f_z=0.7mm. The highest values of the drilling torque were recorded with the T30 drill bit followed by T60, T90 and T120 in an increasing sequence of drill tip angle. The torque decreased from T30 to T120 app. 2.4 times for f_z=0.1mm and app. 1.8 times for the other feed rates tested. However the differences between T120, T90 and T60 drills were very small. The higher torques registered with the T30 drill are surely due to the longer length of the cutting edges compared with the other drills tested.

From Table 2 and Fig. 10b, it can be concluded that the thrust force also increased with an increase in the feed per tooth from f_z=0.1mm to f_z=0.7mm app. 1.8 times for T30, twice for T120, 2.4 times for T90 followed by T60, 2.8 times. For the T60, T90, T120 drills, the increase of the thrust force with the augmentation of the tip angle can be observed. The smallest values were registered by the T60 drill bit, which decreased compared to cutting with T120 drill app. 1.3 times (for f_z=0.7mm) to 1.7 times (for f_z=0.1mm).

However, the T30 drill bit does not comply with this rule (it should generate the lowest thrust force), probably due to the high inclination of the cutting edges which enlarged the contact length between the

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cutting edge and the wood based material. Another possible explanation could be given by the cutting edges length, which for the T30 drill was 19.3mm, much larger than the cutting edge length of the other drills tested: 10mm (T60), 7.1mm (T90) and 5.8mm (T120). This could lead to the generation of some very high cutting forces in the axial direction, higher than those generated by the processing with the other drills. Further investigations are needed to elucidate this phenomenon.

The influence of the feed per tooth and drill tip angle on the surface quality

The mean values and coefficients of variation calculated for both defect assessment parameters: the common delamination factor F_d and the area-based delamination factor F_{ds} can be seen in Table 3 and respectively in Table 4. The surface quality was assessed at the exit side of the specimen for a combination of feed per tooth rates from f_z=0.1mm to f_z=0.7mm and drill tip angles from T30 to T120.

Table 3

The mean values, standard deviations and coefficients of variation for the delamination factor F_d, at the exit side of the specimens, for various feed per tooth values and drill tip angles

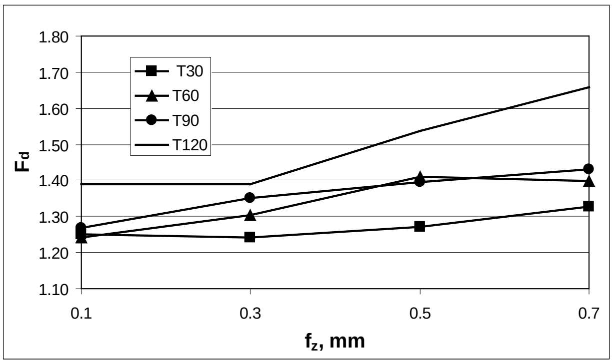
	f_z = 0.1mm		f_z = 0.3mm		f_z = 0.5mm		f_z = 0.7mm	
	mean	cvar (%)	mean	cvar (%)	mean	cvar (%)	mean	cvar (%)
T30	1.25	2.36	1.24	3.43	1.27	3.38	1.33	4.41
T60	1.24	4.87	1.30	4.05	1.41	9.47	1.40	6.40
T90	1.27	3.42	1.35	5.17	1.39	6.97	1.43	4.70
T120	1.39	6.33	1.39	7.27	1.54	10.51	1.66	14.71

Table 4

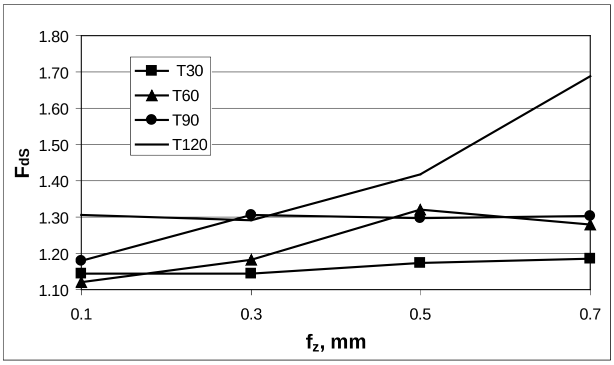
The mean values, standard deviations and coefficients of variation for the area-based delamination factor F_{dS}, at the exit side of the specimens, for various feed per tooth values and drill tip angles

	f_z = 0.1mm		f_z = 0.3mm		f_z = 0.5mm		f_z = 0.7mm	
	mean	cvar (%)	mean	cvar (%)	mean	cvar (%)	mean	cvar (%)
T30	1.14	3.19	1.15	3.28	1.17	2.66	1.19	3.24
T60	1.12	3.99	1.18	3.61	1.32	10.07	1.28	6.61
T90	1.18	4.93	1.31	10.84	1.30	5.12	1.30	8.17
T120	1.31	4.59	1.29	3.88	1.42	10.67	1.69	27.87

The variation of both type of delamination parameters with the tool feed speed and tip angle can be visualised in Fig. 11.



a



b

Fig. 11.

The variation of surface quality with the tool feed per tooth and tip angle at the exit side of the drilled specimens: a - assessed by the delamination factor F_d; b - assessed by the delamination factor F_{dS}. All values represent means from 10 measurements.

From Fig.11a and Fig.11b it can be seen that there was a general trend of delamination increase with the increase of the tooth bite (feed rate) observed by both defect parameters and all drill geometries. This result is in agreement with other results from literature (Valarmathi *et al.* 2013).

Similarly, it can be observed a clear increase in the delamination defect with the increase in the drill tip angle, where the worse surface was obtained with T120 followed by T90, T60 and T30.

By comparing the delamination expressed by both non-dimensional parameters, F_d and F_{dS}, it can be observed that they had a similar trend, which means that both delamination factors are close and represent a good approximation of the surface defect magnitude and of its variation with the processing parameters.

The correlation coefficients calculated for variations of F_d and F_{dS} with the feed per tooth rate at various drill tip angles in Table 5 show a very strong relationship between those quality parameters. Also, this result is an indication that F_{dS}, based on the calculation of areas, is, compared with the commonly used delamination factor F_d, an equally efficient quantification parameter of the processing defect at drilling.

Table 5

The linear correlation coefficients "r" between the variation with the feed per tooth of the delamination factors F_d and F_{dS} for each type of drill tip angle

	T30	T60	T90	T120	mean
F_d - F_{dS}	0.91	0.99	0.87	0.97	0.94

However, if an exact measure of the delamination area is requested, then, the method with ImageJ is advantageous because it can give a dimensional quantification of the effective delamination area, S_d - S. The values, in mm^2, of the delamination area produced for the range of feed per tooth rates and tool tip angles tested are contained in Table 6.

Table 6

The mean delamination area S_d - S, in mm^2, at drilling particleboards with various feed per tooth rates and tool tip angles

	f_z =0.1mm	f_z =0.3mm	f_z =0.5mm	f_z =0.7mm
T120	25.6	24.0	34.4	57.2
T90	14.3	24.3	23.6	24.2
T60	9.6	14.3	25.4	22.2
T30	10.3	10.4	12.5	13.4

From Table 6 it can be observed that an increase in f_z from f_z=0.1mm to f_z=0.7mm caused a consequent increase of delamination area more than double for T120 and T60 and 1.7 times for T90 and 1.3 times for T30.

Compared with T30 and for f_z=0.1mm, T60 induced a similar delamination area, which increased 1.4 times for T90 and 2.5 times for T120. The quality difference between processing with drills with tip angles from T30 to T120 increased with an increase in f_z.

The correlation between the torque and the thrust force with the surface quality

Table 7 contains the correlation coefficients between the variation with the feed per tooth for torque and the thrust force and the delamination factors F_d and F_{dS} at different drill tip angles. An increase of torque and of the thrust force with an increase in the feed per tooth rate correlated strongly with an increase of surface defect quantified by both delamination factors for all drill tip angles.

Table 7

The linear correlation coefficients "r" between the variation with the feed per tooth for the dynamic parameters and the delamination factors F_d and F_{dS}, for the exit side of the specimens and for each type of drill tip angle

	T30	T60	T90	T120
T_{Dmax} - F_d	0.86	0.95	0.99	0.92
T_{Dmax} - F_{dS}	0.95	0.90	0.80	0.86
F_{tmax} - F_d	0.75	0.97	0.99	0.94
F_{tmax} - F_{dS}	0.90	0.93	0.82	0.89

With regard to the drill tip geometry, it can be mentioned that the processing with T30, because of its elongated cutting edge, and in case of thin boards, is limited to manufacturing through holes rather than with limited depth (Fig. 12).

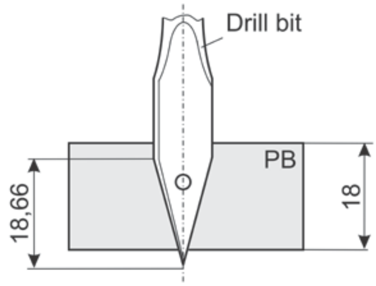


Fig. 12.
Limitation of T30 drill bit and its elongated tip geometry when manufacturing thin boards.

Therefore, considering the delamination occurred at the exit side of the specimen and the smallest thrust force at processing, a drill type T60 seems the best option for getting the best quality, especially for small tooth bites of 0.1mm and 0.3mm. Also, compared with T30, a drill with T60 tip angle gives the flexibility of choice for holes with or without limited depth. At the opposite, the drill type T120 seem to have worsened the drilling quality compared to drills with smaller tip geometry, while the thrust force had the highest magnitude if T30 is ignored.

CONCLUSIONS

The objective of this study was to evaluate the relationship between the tool tip angle, the feed per tooth with the thrust force and torque developed during drilling of coated PB and the drilling defect occurring as a delamination around the hole, at the exit side of the drilled specimen, where the size of the defect had the highest magnitude. To assess this processing defect, two non-dimensional parameters were used: the delamination factor commonly used in the literature, F_d, and a new delamination factor proposed by the authors, F_{dS}, based on the effective delaminated area measured with an image processing software, ImageJ. F_d is the ratio between the maximum diameter of the circle circumscribing the defect and the mean diameter of the processed hole, while similarly, F_{ds} divides the extended area of hole including the surrounding defect to the effective hole area.

Both parameters correlated well and indicated a similar quality trend for various tool tip angles and feed rates used, but the method with ImageJ had the advantage of quantifying the exact area of delamination if this is required.

The results showed that the thrust force, the torque and the surface delamination increased with an increase in the feed rate and this trend occurred for all tool tip angles tested. This result confirms similar findings from literature, although they were conducted for other materials and type of tools.

An increase in the drill tip angle caused, as expected, a decrease of torque, trend which correlated well with a decrease in surface quality, quantified by F_d and F_{dS}, from T30 to T120.

As far as the thrust force was concerned, a decrease in the drill tip angle from T120, to T90 and T60 caused a decrease in the thrust force, which was beneficial and correlated well with the surface quality around the hole. Exception from this trend made the T30 drill bit, where, perhaps the very long cutting edge caused the highest thrust force, while the defect size was at the minimum. In spite of producing the best quality, the drill with T30 tip angle has limitations to producing only through type of holes, due to its elongated cutting edge, in case of drilling thin boards of 18mm or below. Following, the flat drill with 60° tip angle gave the best quality for small feed rates, while inducing the smallest thrust force, which makes it the preferable recommendation for drilling coated particleboards.

This study has not exhausted the multitude of situations encountered in practice. Further work can be extended, for example, to other wood based materials, drill types or rotation speeds.

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