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THE INFLUENCE OF THE TOOL GEOMETRY AND FEED RATE ON THE DRILLING QUALITY OF PRE-LAMINATED PARTICLEBOARD

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Abstract:

Pre-laminated particleboard is a wood based composite extensively used in the furniture industry. Drilling is the most common machining process which prepares the panels for joining. The tip angle of the drill bit and the feed speed during drilling play a major role in gaining a good surface quality and minimizing the delamination tendency of the pre-laminated particleboard. The objective of this study was to measure and analyze the influence of the two above-mentioned factors on the processing quality, evaluated by de size of delaminations, both, at the entrance side and the exit side of the drill bit. To assess the defect, two parameters were used: the delamination factor and the effective area of delamination. The results showed that, in general, the combination of small tip angle with low feed rate minimizes the delamination of pre-laminated particleboard panels at drilling.

Key words: *drilling; particleboard; delamination.*

INTRODUCTION

Drilling is one of the most usual and frequent type of processing in the wood industry with the most common application in the furniture industry. This has developed along years into a massive production of cases made of doweled joint panels, where the main raw material is particleboard and mainly pre-laminated (according to FAOSTAT, the worldwide particleboards production in 2011 was of app. 94.7mil.m^3).

The operation of free drilling, which is common for on-line processes, raises a surface defect noticed, at the pre-laminated particleboards, to occur around the drilled holes. 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).

Some long ago, Radu (1967), in his extensive study on drilling with twist drills, 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”.

More 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. 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, most of research on delamination of wood based materials focussed mainly on MDF and less to the drilling of pre-laminated particleboards. Therefore, this paper is aiming to study the delamination defect which occurs when drilling pre-laminated particleboards, but compared to other studies, this study employs tools and cutting parameters used in the woodworking industry.

Objectives

The objective of this study is to evaluate the influence of the tool geometry and feed speed on the drilling quality of the pre-laminated particleboard. The processing quality was evaluated by de size of delamination measured, both, at the entrance and exit sides of the drilled holes. In order to evaluate the delamination damage occurred during drilling, two parameters were involved: the delamination factor, which was used by previous researchers, but also, the effective delamination area measured with an image analysis method, called ImageJ.

METHOD, MATERIALS AND EQUIPMENT

For the experiments, four flat drills (rake angle γ = 0°) with the tip angle, $2\kappa_r$, of 30°, 60°, 90°, 120° and one spade drill, all having a cutting diameter of 10mm, were used (Fig.1). The clearance angle of all drills was the same α = 20°. The symbols used for those drills were tip angle related; T30, T60, T90, T120, respectively TS for the spade drill.

Forty square samples, 80mm side, were cut from a single pre-laminated particleboard, 18 mm thick. They were divided into four groups of ten specimens each. Each specimen was drilled with five different drills (T30, T60, T90, T120, respectively TS) (Fig. 2). 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 five types of drills, namely 3000rpm. This led to four feed speed values, v_f: 0.6, 1.8, 3.0 and 4.2m/min.

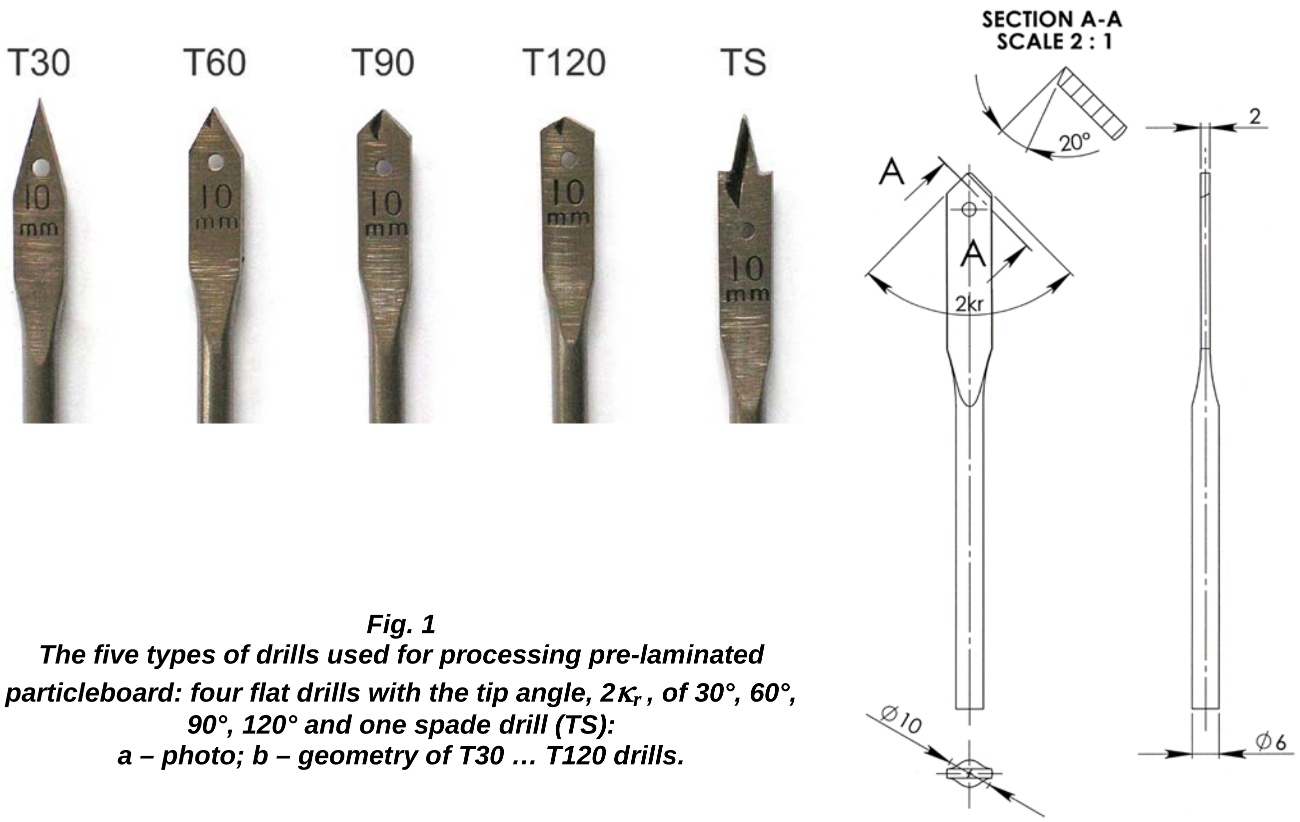
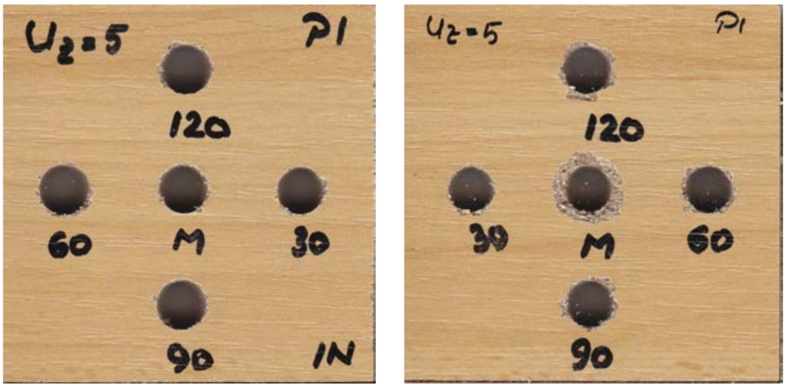


Fig. 1
The five types of drills used for processing pre-laminated particleboard: four flat drills with the tip angle, 2κ_r, of 30°, 60°, 90°, 120° and one spade drill (TS):
a – photo; b – geometry of T30 … T120 drills.

For drilling, a CNC type ISEL GFV/GFY was used, which allowed the exact set-up of the drills rotation speed and of their feed speeds.

After drilling, each hole diameter was measured with an electronic calliper, with a 0.01mm precision, on two perpendicular directions and a mean diameter was calculated for both hole sides (entrance and exit), as can be seen in Fig. 3a. All drilled specimens were then scanned on both sides and received codes, IN, for entrance side (Fig. 2a) respectively OUT, for exit side (Fig. 2b).



a

b

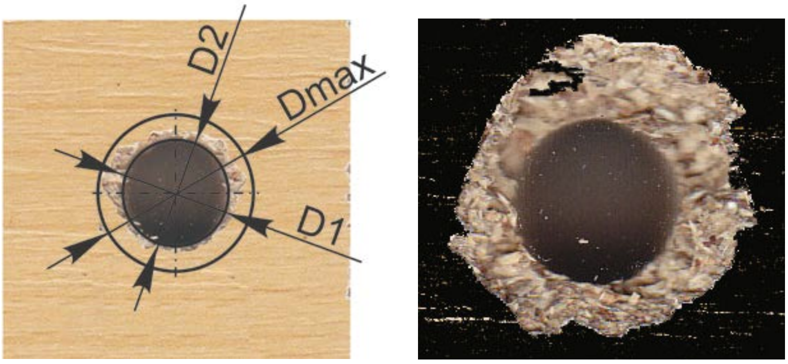
Fig. 2
Pre-laminated particleboard specimens drilled with the five types of drills (T30, T60, T90, T120, respectively TS in the middle) when the tooth bite was 0.5 mm:
a - the entrance side; b - the exit side.

The scanned images were used to evaluate the delaminations that occurred around each hole, on both sides. Two methods were used for this purpose and they are presented as follows:

- the delamination was evaluated by the delamination factor F_d , given in [1], where D_{max} is the diameter of the circle circumscribed to the defect, while D is the mean hole diameter given by caliper measurements (Fig. 3a)

$$F_d = \frac{D_{\max}}{D} \qquad [1]$$

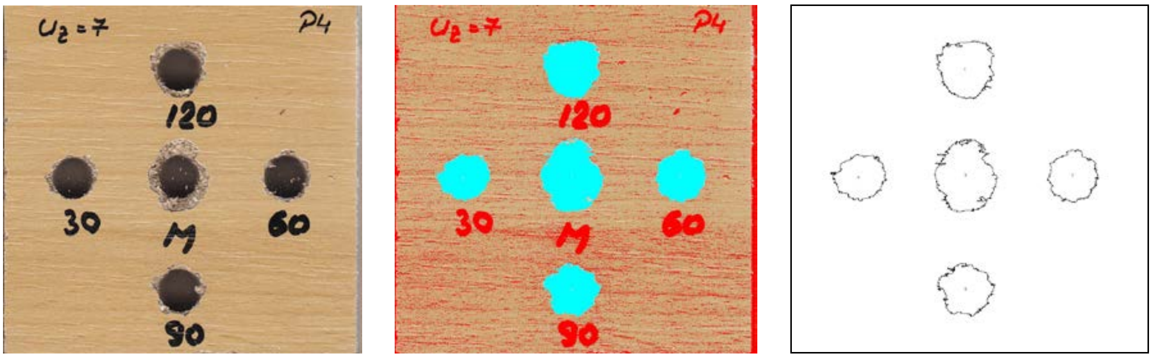
- the second method used an image processing software, ImageJ (http://en.wikipedia.org/wiki/ImageJ), to measure exactly the area with delamination, ***S*,** the white area in Fig. 3b.



a b

Fig. 3
Evaluation of the particleboard delamination caused by drilling:
a - by the delamination factor F_d.; b - by the ImageJ image processing software.

Compared to the delamination factor, 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. In this study, they were holes with delamination surrounding them (blue areas in Fig. 4b). Further, numerical data measuring their area was acquired in a spreadsheet.



a b c

Fig. 4
Exit side of a pre-laminated particleboard specimen drilled with five different tool geometries and 0.7 mm tooth bite: a - specimen scanned image; b - ImageJ detection of drilled areas including delaminations;
c - contour detection of drilled holes with delaminations.

The delaminated area was calculated for each hole as the difference between the hole area with defect measured with ImageJ and the processed hole area, calculated with the mean diameter obtained from two calliper measurements taken on perpendicular directions.

RESULTS AND DISCUSSION

The mean values, standard deviation and coefficients of variation were calculated for both defect assessment parameters: the delamination factor F_d (Table 1 and Table 2) and the delamination effective area (Table 3 and Table 4).

Table 1

The mean values, standard deviations and coefficients of variation for the delamination factor, at the entrance side of the specimens, for various feed rates and drill geometries

IN	f_z = 0.1mm			f_z = 0.3mm			f_z = 0.5mm			f_z = 0.7mm		
	mean	SD	cvar (%)	mean	SD	cvar (%)	mean	SD	cvar (%)	mean	SD	cvar (%)
T30	1.18	0.03	2.82	1.20	0.05	4.46	1.26	0.06	5.08	1.26	0.07	5.50
T60	1.10	0.07	6.26	1.20	0.03	2.60	1.29	0.09	6.83	1.30	0.05	3.61
T90	1.23	0.08	6.19	1.22	0.05	4.15	1.23	0.05	4.13	1.31	0.06	4.88
T120	1.25	0.05	3.73	1.24	0.04	3.38	1.27	0.06	4.38	1.31	0.05	3.67
TS	1.18	0.04	3.50	1.26	0.06	4.37	1.25	0.03	2.35	1.29	0.05	3.98

Table 2

The mean values, standard deviations and coefficients of variation for the delamination factor, at the exit side of the specimens, for various feed rates and drill geometries

OUT	f_z = 0.1mm			f_z = 0.3mm			f_z = 0.5mm			f_z = 0.7mm		
	mean	SD	cvar (%)	mean	SD	cvar (%)	mean	SD	cvar (%)	mean	SD	cvar (%)
T30	1.25	0.03	2.48	1.24	0.04	3.62	1.27	0.05	3.57	1.33	0.06	4.65
T60	1.24	0.06	5.14	1.30	0.06	4.27	1.41	0.14	9.99	1.40	0.09	6.75
T90	1.27	0.05	3.61	1.35	0.07	5.45	1.39	0.10	7.34	1.43	0.07	4.96
T120	1.39	0.09	6.67	1.39	0.11	7.66	1.54	0.17	11.07	1.66	0.26	15.51
TS	1.67	0.06	3.67	1.71	0.08	4.80	1.77	0.05	2.56	1.71	0.11	6.22

Table 3

The mean values, standard deviations and coefficients of variation for the effective delamination area, at the entrance side of the specimens, for various feed rates and drill geometries

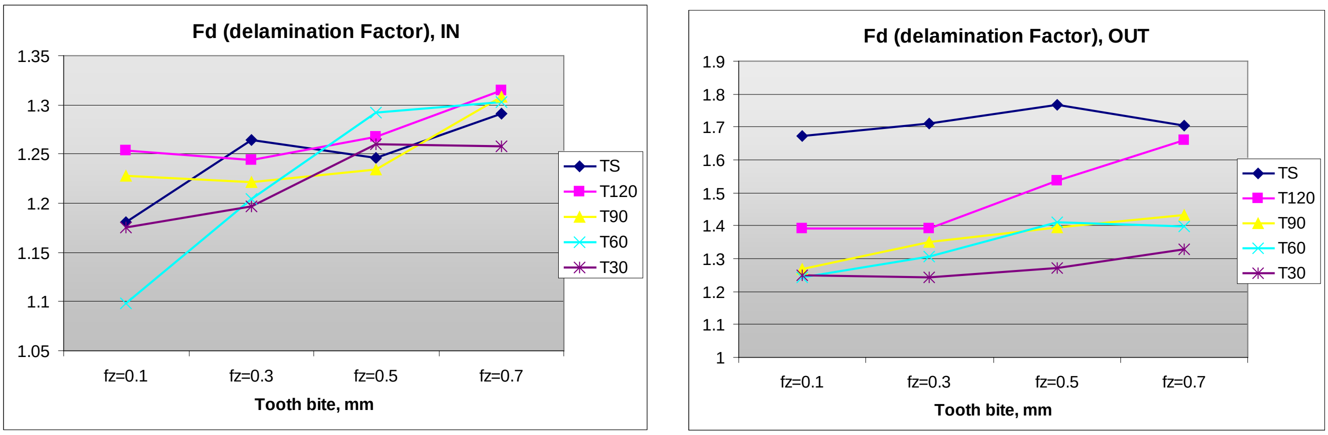
IN	f_z = 0.1mm			f_z = 0.3mm			f_z = 0.5mm			f_z = 0.7mm		
	mean	SD	cvar (%)	mean	SD	cvar (%)	mean	SD	cvar (%)	mean	SD	cvar (%)
T30	6.94	1.73	24.93	4.92	1.44	29.32	8.23	1.53	18.59	8.81	3.36	38.12
T60	4.67	1.14	24.39	7.36	0.96	12.98	14.88	2.65	17.83	15.12	1.64	10.84
T90	7.63	1.32	17.24	8.78	2.09	23.84	10.95	2.60	23.72	12.96	2.11	16.25
T120	11.52	2.33	20.20	11.33	2.97	26.20	13.18	2.06	15.64	15.78	3.10	19.62
TS	6.73	1.31	19.50	10.69	3.04	28.43	11.06	3.10	28.02	12.62	3.16	25.00

Table 4

The mean values, standard deviations and coefficients of variation for the effective delamination area, at the exit side of the specimens, for various feed rates and drill geometries

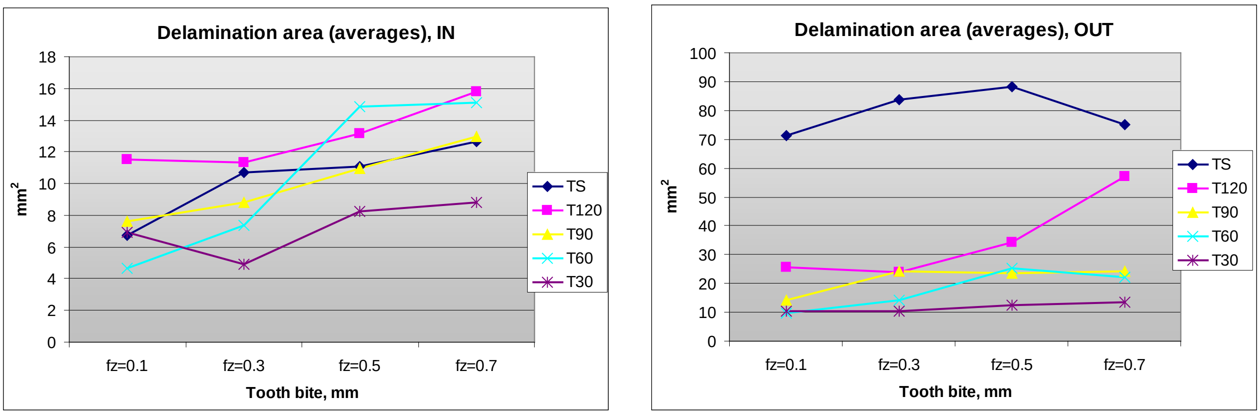
OUT	f_z = 0.1mm			f_z = 0.3mm			f_z = 0.5mm			f_z = 0.7mm		
	mean	SD	cvar (%)	mean	SD	cvar (%)	mean	SD	cvar (%)	mean	SD	cvar (%)
T30	10.25	2.75	26.79	10.43	2.82	27.02	12.47	2.33	18.67	13.43	2.90	21.58
T60	9.61	3.73	38.82	14.27	3.56	24.95	25.35	10.89	42.94	22.18	7.17	32.32
T90	14.31	4.89	34.17	24.34	11.89	48.87	23.61	5.64	23.87	24.22	8.91	36.80
T120	25.63	5.27	20.55	23.98	4.48	18.70	34.37	13.15	38.26	57.18	41.04	71.78
TS	71.16	10.10	14.19	83.82	10.36	12.35	88.16	13.74	15.58	75.16	17.73	23.59

The variation of both type of delamination parameters with the tool feed speed and geometry is depicted in Fig. 5 and Fig. 6.



a b

Fig. 5
The variation of the delamination factor with the tool feed speed and geometry (figures represent mean values): a - at the entrance side of the drilled specimens; b - at the exit side of the drilled specimens.



a b

Fig. 6
The variation of the effective delamination area with the tool feed speed and geometry (figures represent mean values): a - at the entrance side of the drilled specimens; b - at the exit side of the drilled specimens.

By comparing the delamination expressed by both parameters, delamination factor and effective delamination area, it can be observed a similar trend, especially for the exit side, which means that delamination factor is a close non-dimensional approximation of the defect and its evolution with processing parameters. However, if an exact measure of the delamination area is requested, then the effective delamination area is advantageous because it can give a dimensional quantification.

Whatever the specimen (hole) side, 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). The most sensitive to the variation of the feed rate was T60, where the delamination doubled at the exit side and tripled at the entrance side for a tooth bite of 0.7mm compared to 0.1mm.

The defect zone was larger at the exit side of the drill compared to the entrance side with the greatest amount for TS (6-10 times), followed by T120 (2-3 times) and then by the other tool geometries T90, T60 and T30 (1.5-2 times).

The influence of the drill geometry on the processing quality was different, depending on the drilling side. The exit side showed a clear increase in the delamination defect with the increase in the drill tip angle, where the worse surface was obtained with TS, followed by T120, T90, T60 and T30.

As far as the entrance side was concerned, the influence of the tool geometry did not have a clear trend. In general, T120 gave the worse quality, while T30 was in the range of best surfaces. However, because of its elongated tip geometry, processing with T30 in case of thin boards is limited to manufacturing through holes rather than with limited depth (Fig. 7).

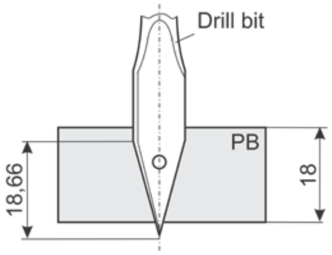


Fig. 7
Limitation of T30 drill bit and its elongated tip geometry when manufacturing thin boards.

Therefore, considering the delamination occurred at the entrance side as well as at the exit side, for small tooth bites of 0.1mm and 0.3mm, a drill type T60 seems the best option for getting the best quality and for having the flexibility of choice for holes with or without limited depth. At the opposite, the drills types TS and T120 seem to have worsened the drilling quality compared to drills with smaller tip geometry, with the exception of T60 for entrance side and large tooth bites (0.5mm and 0.7mm).

CONCLUSIONS

Free drilling is a common operation for pre-laminated particleboards in the furniture industry. The quality of this operation can be assessed by the delamination occurring around the hole. This paper examined this defect by means of two parameters: a non-dimensional one used also by other researchers, the delamination factor, and one measuring the effective area of defect with an image processing method. The influence of the feed rate (tooth bite) and tool geometry (tip angle) was assessed by the above quality parameters. Both parameters showed similar trend with the advantage of the latter for giving dimensional information about the defect area.

Generally, the delamination increased with the increase of the tooth bite (feed rate) for all drill geometries. The defect zone was larger at the exit side of the drill compared to the entrance side with the greatest amount for the spade drill, followed by the flat drills in a sequence of decreasing tip angle.

The exit side showed a clear increase in the delamination defect with the increase in the drill tip angle, but the influence wasn't as clear for the entrance side.

If delamination and flexibility of hole depth is considered, a flat drill with 60° tip angle gave the best quality for small feed rates. The spade drill and the flat drill with the greatest tip angle, 120°, do not seem appropriate for processing pre-laminated particleboards.

Further studies may complete these results for various rotation speeds and other types of drills to optimise the process quality at drilling pre-laminated particleboards.

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