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# INFLUENCE OF CUTTING AND TOOL PARAMETERS ON THRUST FORCE IN DRILLING OF DIFFERENT FORMALDEHYDE EMISSION RATE PARTICLEBOARDS

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***Abstract:***
*Particleboard (PB) is used in furniture industry both for building flat-pack furniture and store fixtures. They are made from wood dried particles that are bonded using adhesives and pressed into sheets. Resins based on Urea Formaldehyde (UF) are mainly used to bonded wood particles because they provide low cost's strong, durable bonds even if they emitted formaldehyde (HCHO) that is involved of indoor air-pollution. Specific gravity varies along particleboard thickness from low specific gravity core of coarse particles in the middle of the panel to higher specific gravity layers of finer particles at the surface of the panel. An external layer consisting of resin-treated decor paper is often added for PB used for casework and millwork. The decor paper is displaying reproductions of wood, tiles or imaginative designs. Laminates have only tenth of a millimeter but acts as a formaldehyde diffusion barrier.*

*The thrust force is often measured as a parameter of the machining quality but also to avoid a premature wear of the tool and of the machine itself. Studies can be found in the literature concerning drilling of wood based panels with a more homogeneous specific gravity along thickness as Oriented Strand Board (OSB) or Medium Density Fiber (MDF) panels. Very few studies concern the drilling perpendicular to the thickness of the particle boards (PB). Our study is focused on influence of formaldehyde's rate of the particle board on thrust force when drilling with tools dedicated to particleboards.*

*The thrust force is obviously linked to specific gravity of the panel. The cutting and tool parameters have also a great influence on this force, mainly feed rate and tool diameter. In our study, a large set of cutting conditions are tested for tools dedicated to panel drilling with different diameters, spurs and materials of the body. Feed speed has the most relative important effect after drill diameter influence, while formaldehyde emission rate and spindle speed has no influence.*

***Key words****: drilling; low formaldehyde particleboards; specific drilling tools; thrust force.*

## INTRODUCTION

Particleboard (PB) is a wood panel product used widely in industries and households. They are manufactured from wood particles that are bonded using adhesives and press into panels. Most of wood particles historically come from fresh woods, as sawdust and chips from sawmill, chipped logs but also from recovery woods which constitutes now at least 35% of the total raw material. PB panel's process allows favourable properties such as surface characteristics and dimensional stability (Nemli *et al.* 2007, Salem *et al*. 2011). It creates also an inhomogeneous specific gravity along the thickness of the board from low specific gravity core of coarse particles in the middle of the panel to higher specific gravity layers of finer particles at the surface of the panel.

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Urea formaldehyde (UF) resins are mainly used to bonded wood particles because they provide low cost's strong, durable bonds even if they emitted formaldehyde (HCHO) that is one of the contaminants of indoor air-pollution. European Community have already imposed regulations limiting the emission of formaldehyde from building materials and from the materials used for the manufacture of furniture and fitments (Knoeppel *et al.* 1990). (Nemli *et al.* 2006) studied effect of core specific gravity, shelling ratio, wood species, and pressure on the formaldehyde content of PB. The most common methods to reduce formaldehyde emission from wood-based products are decreasing the F/U molar ratio (Que *et al.* 2007), incorporating other hardener type during synthesis (Aras *et al.* 2015), and adding formaldehyde scavengers to the particles before or after resin blending (Lum *et al.* 2013). (Barry and Corneau 2006) also shows that laminates which is an external PB layer consisting of resin-treated decor paper acts as formaldehyde diffusion barrier.

Drilling of wood based panels is a frequently practiced machining process in furniture manufacture owning to the need for component assembly. However, some works of various authors, when reporting about machining of wood based panels, have shown that the machinability is strongly dependent on the cutting parameters, cutting forces, cutting tools (material and geometry) and work piece material.

(Valarmathi *et al*. 2012, 2013) have planned drilling experiments on PB panels to predict influence of cutting and tool conditions on thrust force with carbide twist drills. They conclude that a 100° point angle of the drill with low feed rate and high spindle speed combination minimizes the thrust force with carbide twist drill. (Ispas *et al*. 2014, 2015) have shown that increase the tip angle decrease the drilling torque in contrary with thrust force for flat and helical twist drills. These results should be qualified because carbide tested drills are few used to drill PB panels.

Relationship between feed rate and cutting on the delamination factor at entry and exit of holes that are drilled in Medium Density Fibreboards was investigated (Davim *et al.* 2008). Their study shows that by employing the higher cutting speed and the lower feed rate, it is possible to reduce the delamination tendency that is supposed link to the thrust force. K10 cemented carbide drills that are used for the study are dedicated to drill thru-holes in wood based panel. They are closer to twist drills with their low point angle than to blind holes' drills which have no point angle but a centering point and two circumferential cutting edges called spur, as presented on Fig. 1. (Gaitonde 2008) and (Prakash 2009) have the same conclusions with similar tools.

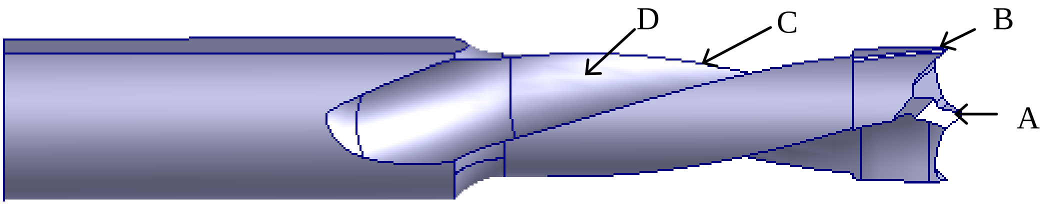


***Fig. 1.***
***Main geometry parameters of a blind hole's PB drill***
***Centering point (A), cutting spur (B), lip (C), flute (D).***

In the present study, influence of feed rate and spindle speed on thrust force in drilling of blind holes with tools dedicated to wood based panel drilling is evaluated. We used different diameters of drills with two specific spurs (round and point) and two cutting materials (steel and carbide).

## EXPERIMENTAL SETUP

### Particleboards specifications and specific gravity

Two rates of formaldehyde emission particle board panels are used for the study. The first corresponds to formaldehyde's emission with limit inferior to 0,124mg/m$^3$ and called E1-grade according to NF EN 312 standard. The second are Low Formaldehyde Emission Particle Board (LFEPB). Both PB used for our tests are produced by the same plant in order to reduce disturbances coming from process. Specifications of 19mm thickness PB are measured by the plant during production, gathered in Table 1 and compared to NF EN 312 standard.

*Table 1*

***Measured specifications of particle board panels used for drilling tests.***

| Specifications | E1 grade particle board | Low formaldehyde emission particle board | According to NF EN 312 |
|---|---|---|---|
| Average Specific gravity (kg / m$^3$) | 642 | 671 | |
| Static bending strength (N/mm$^2$) | 12,41 | 12,64 | ≥ 11 |
| MOE (N/mm²) | 2305 | 2330 | ≥ 1600 |
| Internal bond (N/mm²) | 0,49 | 0,49 | ≥ 0,35 |
| Moisture content (%) | 6,18 | 6,93 | 5% à 13% |
| Perforator value (mg/100g of dry panel) | 6,30 | 2,66 | ≤ 8 |

The perforator value represents formaldehyde content according to standard NF EN 120. We can notice that perforator value in our tests is three times lower for LFEPB than for E1 grade particle board.

We measure the specific gravity profile along thickness of each type of particle board using the laboratory specific gravity analyser DAX 6000 of Grecon. With this device, highly precise measurements can be carried out at a speed of up to 1 mm per second with the optimised measuring source, consisting of an x-ray combination. Typical measured specific gravity profiles of LFEPB and E1 grade PB are shown on Fig. 2.

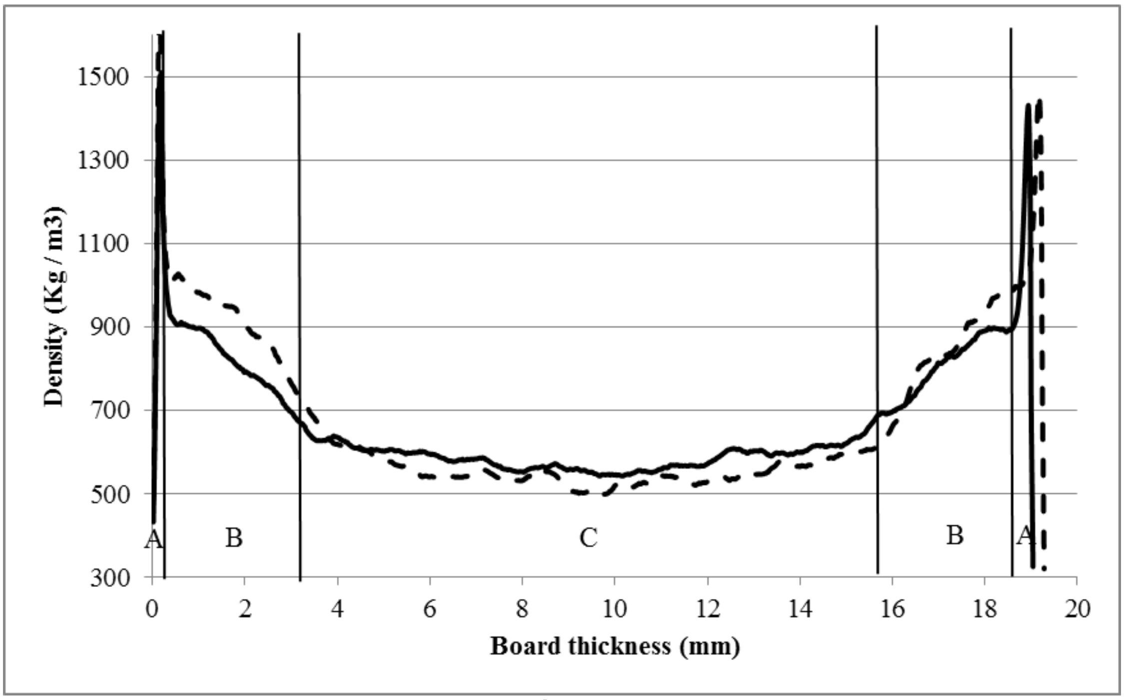


***Fig. 2.***
***Measured specific gravity profile of LFEPB (continuous line) and E1 grade PB (broken line) Melamine layer (A), external (B) and internal (C) core of coarse particles.***

Each of the three layers of the particleboard has its own specific gravity. The melamine layer has a thickness of 0.1mm and a specific gravity that reaches 1500kg/m$^3$.The external-layer particles specific gravity decrease from 900kg/m$^3$ to 600kg/m$^3$ along its 3mm of thickness. The internal-layer particles specific gravity is constant around of 575kg/m$^3$. There is no significant difference between specific gravity of LEFPB and E1 class in our tests.

**Specificity of drills dedicated to PB machining**

The drilling experiments are carried out using drills with a diameter of 6, 8, 10 and 12mm. Drills have round or point spurs and steel or carbide as material of the drill's body. In all cases, tip of the drill is in carbide and drills are brand new. Fig. 3 shows the four types of 8mm diameter drills available:

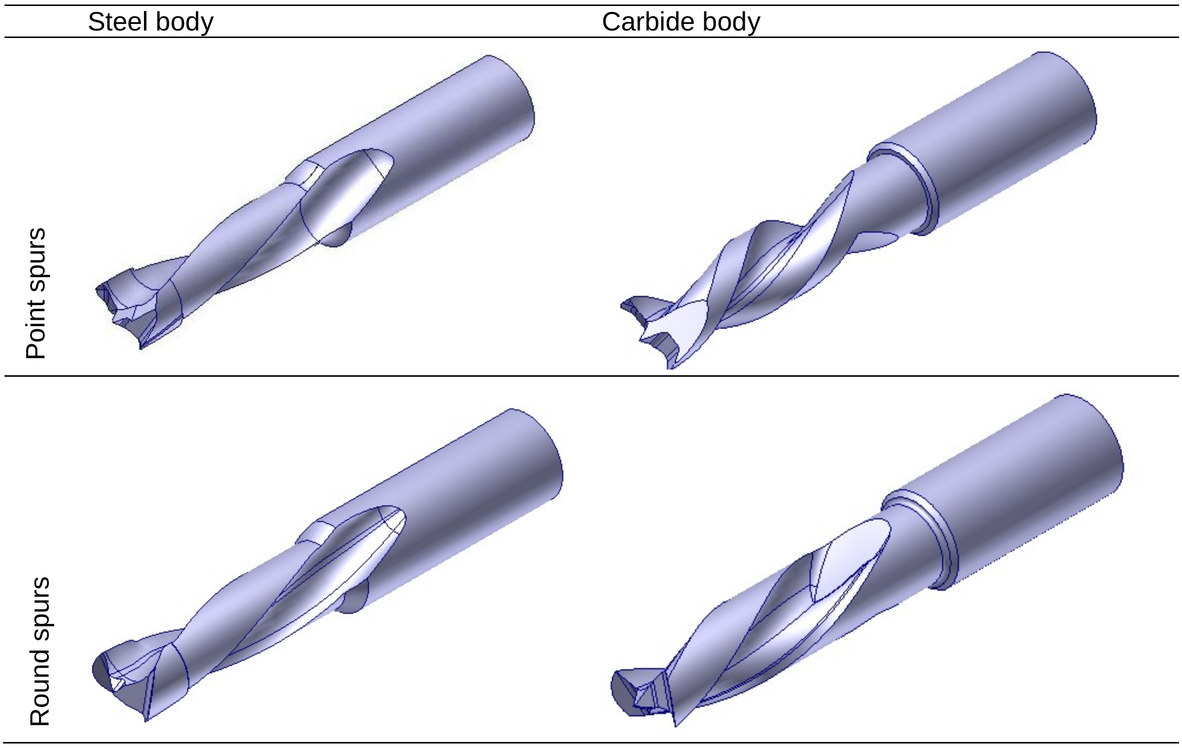


***Fig. 3.***
***Four types of drills dedicated to particle board machining used for this study.***

These four-faceted drills consist of separate cutting lip and secondary heel clearance facets at the end of the drill. Extending the secondary facets to the midway point of the chisel produces an apex at the center of the chisel's long axis and is called the self-centering point (Fig. 4A). It eliminates center punching and pilot holes. The junction between cutting lip and the secondary facet at the periphery of the tool is called the spur and its shape could be round or point (Fig. 4B).

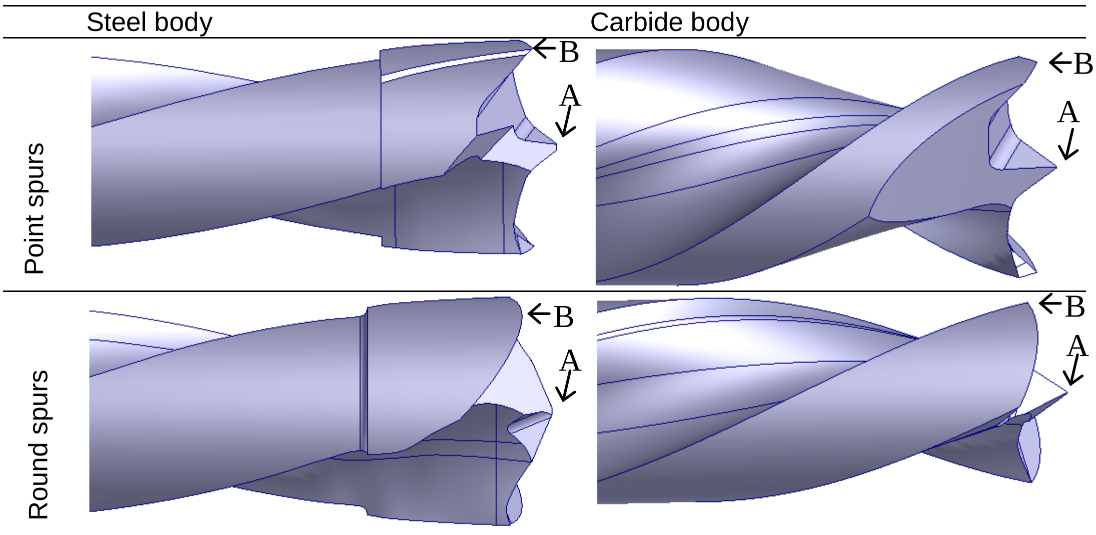


***Fig. 4.***
***Self-centering points (A) and spurs (B) of the four types of drills dedicated to particle board machining used for tests.***

Fig. 4 shows clearly that material used as the body of the drill has a great influence on shape of the drill, mainly on self-centering point and spur's geometry.

**Experimental setup of thrust force measurement**

The drilling machine (Cincinnati NT100VDA) is used to perform drilling tests. This laboratory machine tool customized from an industrial single spindle drilling machine is presented on Fig. 5. It has a rotation frequency from 200 to 8 000rpm and a feed speed from 0.01 to 2.7m/min.

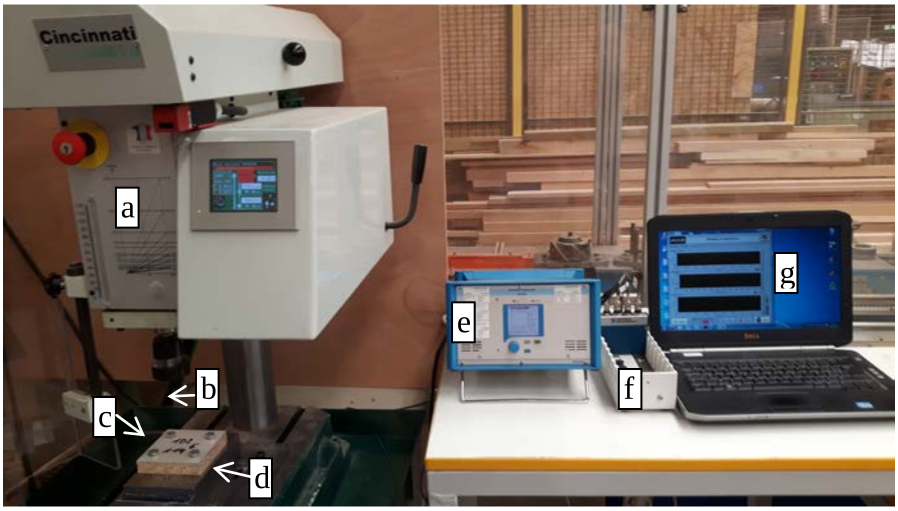


***Fig. 5.***
***Experimental setup: drilling machine (a), drill (b), PB sample (c), force dynamometer (d), charge amplifier (e) analog-to-digital converter device (f), personal computer (g).***

The thrust force is measured using three component piezoelectric Kistler dynamometer type 9257B (Fig. 5d). Its specifications are gathered in Table 2. Piezoelectric generates electric charge when deformed, and the multichannel amplifier type 5070 (Fig. 5e) converts electric charge into a proportional voltage easier to record.

*Table 2*

***Specification of Kistler dynamometer type 9257B***

| | |
|---|---|
| Weight (kg) | 7.3 |
| Transducer sensitivity | $F_x$, $F_y$ -7.5; $F_z$ -3.7 |
| Natural frequency (kHz) | $f_n(x,y) = 2.3$ ; $f_n(z) = 3.5$ |
| Protection class | IP 678 |

The data acquisition system CDaq 9172 (Fig. 5f) developed by National Instruments convert analog to digital signal that is stored in the PC (Fig. 5e). The sampling frequency is 2 KHz.

The design of experiments is based on Taguchi's method (Rao *et al.* 2013). The Taguchi technique is a methodology for finding the optimum setting of the selected factors (Athreya *et al.* 2012), which are drill diameter, spur and body's material of the drill, spindle and feed speed in or study. The Taguchi technique is based upon the technique of matrix experiments. The experimental matrices are special orthogonal arrays which reduce the number of tests. Conducted such orthogonal experiments allow to determine the optimum level for each factor and to establish the relative significance of the individual factors in terms of their main effects on the response. The depth of cut is fixed to 13mm which is a currently dimension found in manufacturers of PB furniture. Parameters and their levels are gathered in Table 3.

*Table 3*

***Drilling parameters and their level***

| Parameters | Levels | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| Spindle speed (rpm) | 2 000 | 4 000 | | |
| Spur geometry | Round | Point | | |
| Body's material | HSS | Carbide | | |
| Feed speed (m/min) | 0.5 | 1.5 | | |
| Drill diameter (mm) | 6 | 8 | 10 | 12 |

**RESULTS AND DISCUSSION**

It is obvious that an excessive thrust force is responsible for increasing drills wear. We have focused our study on parameters which can impact thrust force. Fig. 6 shows typical thrust force signal when PB is drilled.

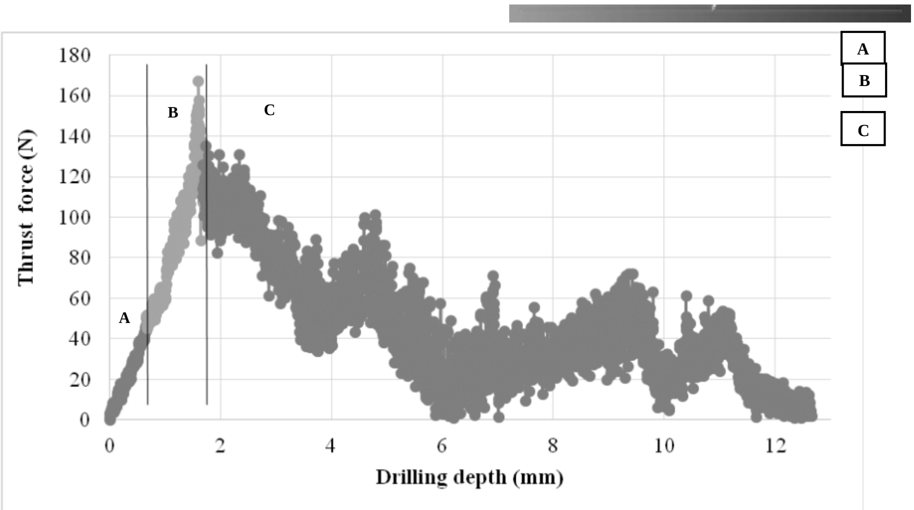


***Fig. 6.***
***Typical thrust force signal plot in respect with drilling edges: A) only the self-centering point, B) self-centering point and side edges, C) centering point and side and main edges.***

From Fig. 6, three different phases can be observed on the thrust force corresponding to drill geometry. During phase A, the self-centering point of the drill is the only part of the drill that penetrates the PB, but it produces an increase of the thrust force. It continues to increase at the same rate when side edges corresponding to the spur begin to work along the phase B until to reach its maximum value. At the beginning of the phase C, the secondary facet of the tool start to work and the thrust force decrease when de melamine layer of the panel is drilled. Spur geometry should be precisely design and choose because it creates maximum thrust force when it penetrates the panel.

In the present study, a large set of cutting conditions (Table 4) are tested for tools dedicated to PB drilling with different diameters, spurs and materials of the body and their influence on maximum value of thrust force is observed.

*Table 4*

***Taguchi L8 orthogonal array***

| N° | Spindle speed (rpm) | Spur Type | Body Material | Feed speed (m/min) | ∅ (mm) |
|---|---|---|---|---|---|
| 1 | 2000 | Round | Carbide | 0,5 | 6 |
| 2 | 2000 | Round | Steel | 1,5 | 8 |
| 3 | 2000 | Point | Carbide | 1,5 | 10 |
| 4 | 2000 | Point | Steel | 0,5 | 12 |
| 5 | 4000 | Point | Steel | 1,5 | 6 |
| 6 | 4000 | Point | Carbide | 0,5 | 8 |
| 7 | 4000 | Round | Steel | 0,5 | 10 |
| 8 | 4000 | Round | Carbide | 1,5 | 12 |

The experimental are repeated five times and the results are presented in Table 5. The average values and the signal-to-noise ratio of the maximum thrust force are used for analysis of parameters influence.

*Table 5*

***Taguchi L8 orthogonal array experimental data***

| | E1 grade PB | | | Low Formaldehyde Emission PB | | |
|---|---|---|---|---|---|---|
| Test N° | Thrust Force (Fz, N) | Thrust Force sd* (sFz, N) | S/N ratio of Fz (N) | Thrust Force (Fz, N) | Thrust Force sd* (sFz, N) | S/N ratio of Fz (N) |
| 1 | 178.2 | 13.77 | -45.04 | 159 | 12.21 | -44.04 |
| 2 | 337.4 | 21.04 | -50.58 | 297.4 | 28.05 | -49.5 |
| 3 | 378.6 | 28.76 | -51.59 | 362.6 | 41.31 | -51.24 |
| 4 | 261 | 23.71 | -48.37 | 235.8 | 14.92 | -47.47 |
| 5 | 173.2 | 31.84 | -44.92 | 178.8 | 23.39 | -45.12 |
| 6 | 169 | 13.49 | -44.59 | 172.6 | 12.09 | -44.76 |
| 7 | 222.2 | 19.54 | -46.97 | 214.1 | 19.38 | -46.65 |
| 8 | 593 | 62.08 | -55.51 | 567.6 | 47.94 | -55.11 |

* Standard deviation

Average and standard deviation of maximum thrust force are very close for LFEPB and E1 class PB. Effects of studied parameters on maximum thrust force are presented on Fig. 7.

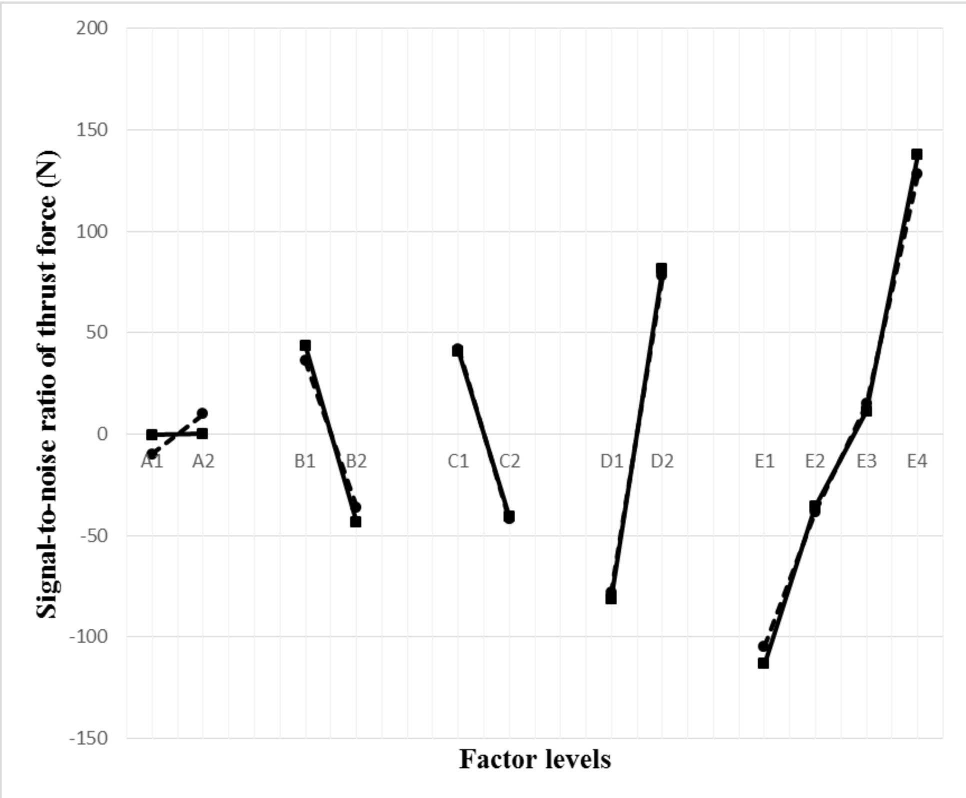


***Fig. 7.***
***Factor levels of parameters on maximum thrust force***
***A) Spindle speed B) Spur geometry C) Body material D) Feed speed E) Drill diameter of low formaldehyde emission PB (continuous line) and E1 grade PB (broken line).***

As expected, influence of parameters on LFEPB and E1 grade PB are similar according to measured thrust force experimental values. According to Taguchi's method, the best set of factors to minimize thrust force when drilling a particle board is by choosing a spindle speed of 2 000rpm and a feed speed of 0.5m/min using a 6mm diameter drill with a steel body and a point spur. The confirmation tests operated with

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this set of parameters show a fewer thrust force than Taguchi's tests of 125.52N with a standard deviation of 12.28N for E1 grade PB and 120.22N with a standard deviation of 13.43N for LFEPB.

All significant parameters seem to appear in our Taguchi's plan as the residual variance ε less than 15% (Fig. 8). Taguchi's analysis method highlights that spindle speed has no effect on thrust force at the chosen values. Spur geometry and material of the body have a low effect, of about 10% as shown on Fig. 8. Thrust force is lower with point spur and a drill constituted of a steel body and a carbide tip.

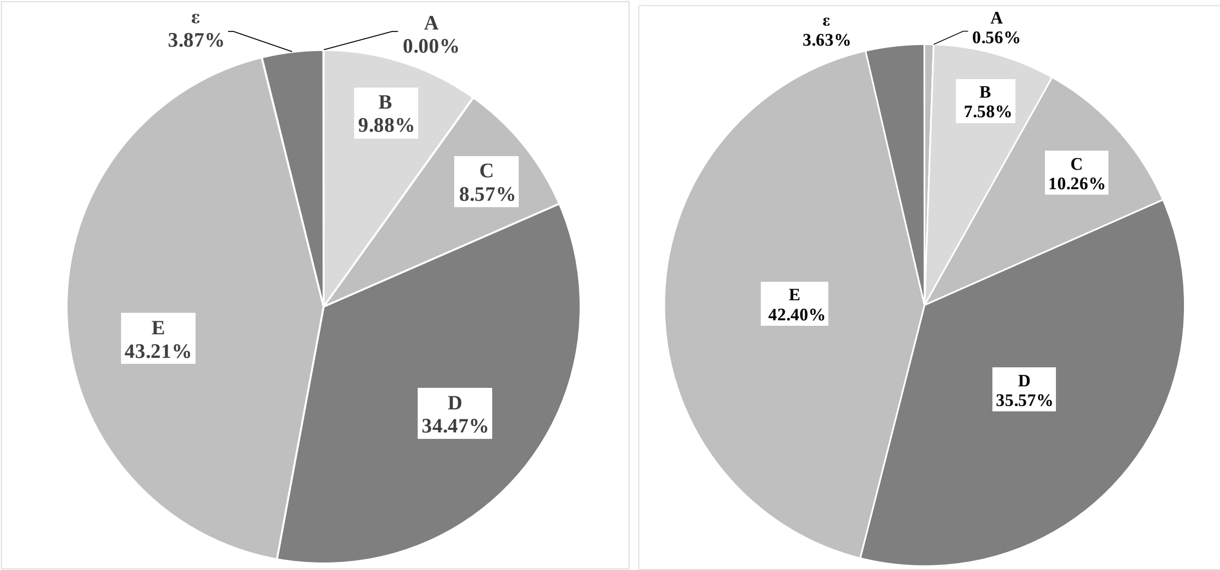
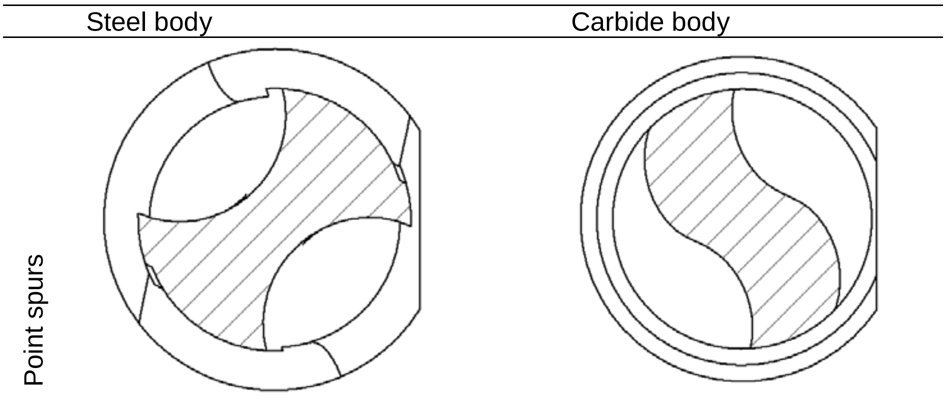



***Fig. 8.***
***Effects of parameters on thrust force. A) Spindle speed B) Spur geometry C) Body material D) Feed speed E) Drill diameter of low formaldehyde emission PB (right) and E1 grade PB (left).***

Feed speed has the most important effect on thrust force after drill diameter influence, which linearly varies. A compromise should be reached because decrease feed speed reduces thrust force and consequently avoid delamination while manufacturers wish to reduce drilling time by increase feed speed. We can suppose that the PB is compressed between the drill and the work piece holder when it is machined. For a same feed speed, the pressure on the panel is consistent regardless of spindle speed. Then, thrust force varies as the tool-PB contact area which depends on the drill diameter but not of spindle speed. Similarly, modifying feed speed conduce to vary thrust force for a same drill diameter, because tool displacement on a same area of PB is different.

Moreover, cross section of a drill depends of its material's body as shown on Fig. 9. The cross section corresponding to maximum thrust force, at two millimetres from the spur's plane, is 25±0.2mm$^2$ for a steel body and 32±0.6mm$^2$ for a carbide body for eight millimetres diameter's drill. For a same drill diameter, a lower cross section induces a lower thrust force.



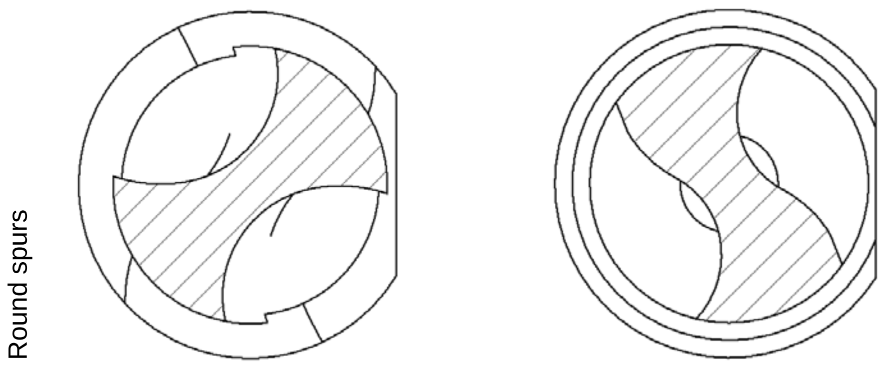



***Fig. 9.***
***Cross sections of 8 mm diameter drills at 2mm from spur's plane.***

Finally, as industrials that are machining LFEPB observe a faster drill's wear which is not due to increasing of thrust force, other causes as pollutants in particle boards should be investigated.

## CONCLUSIONS

The drilling experiments are planned and conducted according to Taguchi's method to predict the influence of cutting parameters on thrust force in drilling of particleboard panels. Various cutting conditions and tools' characteristics are tested and their effects are determined. The results indicated that spindle speed has no influence on thrust force. Moreover, spur type and material of the body have the same relative effect on thrust force, of about less than 10%. Thrust force is lower with point spur and a drill constituted of a steel body and a carbide tip. Feed speed has the most relative important effect of about 35% after drill diameter influence, which is about of 43% and varies linearly. The formaldehyde emission rate has absolutely no influence on thrust force in drilling of particle board.

In addition to this study, our future experiments will focus on tool wear. Indeed, as the formaldehyde emission rate has no influence on thrust force, we suppose that contaminants which are more present in LEFPB should increase tool wear. Moreover, even if point spurs minimise thrust force at the beginning of the tool life, they should wear faster than round ones. Finally, more defects appear on steel body drills during their lives as bending or twisting than on carbide body drills. They break if axial force or torque is too high. Steel body drills defects induce bad quality holes. A study on tool wear under industrial conditions is currently under way on the bases of the present study.

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