

Relative Machinability of Wood-Based Boards in the Case of Drilling – Experimental Study

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Machinability issues during drilling of wood-based materials were evaluated. Three types of standard wood-based materials of substantially different internal structures, *i.e.*, fibreboards, particle boards, and veneer boards, were selected as test samples. The experiment consisted of drilling holes through samples made of 14 different materials. The purpose of the experiment was to determine the quality of the edges of the holes and to evaluate values of the cutting force and torque. The obtained results were used to determine the relative machinability indexes based on the machining quality and cutting forces. These indexes were defined by referencing the obtained data of each tested material to one selected reference material: medium density fibreboard. The experimental data showed that the machinability index based on the quality criterion was not correlated with the index based on the cutting force criterion. The quality index was not correlated with the basic, routine parameters of wood-based boards. However, the cutting forces index sometimes showed a significant correlation of this type. The quality index showed the influence of the internal structure and homogeneity of the different types of materials.

Keywords: Machinability; Quality; Cutting forces; Wood-based materials; Drilling

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INTRODUCTION

Mass-produced wood-based materials are commonly used in a wide variety of industries such as furniture manufacturing, housing construction, or finishing interior. In all of these cases, the materials are intensively processed using saws, drills, cutters, *etc.* So their machinability becomes increasingly important. However, there is scant literature on the machinability of wood-based boards in comparison to, for example, the machinability of metals, to which thousands of articles and papers has been devoted. Moreover, there are no standard (or even generally accepted) criteria or test methods to quantify/compare the machinability parameters (Górski *et al.* 2010). The only official technical standard that directly relates to machinability of wood and wood-based materials is the ASTM D-1666 (2004) standard. Even though other criteria are mentioned as well, the quality of machining is the basic criterion for machinability used in this paper. In wood machinability studies this standard is sometimes ignored (Lhate 2011) or even criticized (Goli and Sandak 2016), but usually it is used without any major objections (Bustos *et al.* 2008; Farrokhpayam *et al.* 2010; Sandak *et al.* 2017). For cutting tests of wood-based boards, however, the situation is different. This is due to the fact that the ASTM D-1666 standard (2004) concentrates mainly on the planing of solid wood. In this case the experimental research is intended to determine the optimal (due to the

quality of machining) cutting conditions. Wood-based boards are not usually planed this way, due to the fact that their machinability is routinely determined without any reference to ASTM D-1666 (2004).

In general, machinability tests of wood-based boards are not numerous, yet they are not particularly rare either (Lin *et al.* 2006; Philbin and Gordon 2006; Somsakova *et al.* 2012; Wilkowski *et al.* 2013; Podziewski *et al.* 2014; Szymanowski *et al.* 2015). However, intensifying research in this area seems to be a necessity. Researchers often focus on different cutting criteria, such as the quality of machined surface or the cutting forces. They also use different cutting parameters and machinability indexes, which generally excludes the possibility of unambiguous comparison of the obtained results. Furthermore, the research conducted so far has been conducted randomly, in a very narrow group of materials. Therefore, it is not possible to compare the machinability of even the most popular standard wood-based materials in a direct, quantitative way. Of course their producers and distributors often declare that they are "easy to process" without validated evidence for this assertion. In the same way, they could claim that their product is "highly mechanically stable" and do not provide any numerical data on the subject.

Machinability evaluation in the case of drilling can be particularly useful. One of the standard properties listed in the product characteristics of wood-based boards refers to their ability to maintain the screw; this parameter is determined in accordance with the standard EN 320 (2011) after drilling the corresponding hole. Moreover, after consultation with scientists dealing with cutting theory and woodworking engineers, it was assumed that in case of drilling in wood-based materials only two machinability criteria are essential (technically speaking): the machining quality and the cutting force. The problem of the quality of the edges of drilled holes may in practice directly determine the suitability (or lack thereof) of a particular material for a particular construction application. Moreover, the size of the cutting forces, especially during making holes with small diameters, can considerably limit the machining capacity; reduced feed rates are used due to the risk of mechanical overloading of the drill. In addition, taking into account the work safety problem, such as dust creation in Computer Numerical Control (CNC) drilling of wood composites could also be important. This issue has been discussed in detail (Rogozinski *et al.* 2015).

The scope of this article is limited to machinability with a strictly technical character, so only the two main criteria as discussed above are used. In this way the machinability of several popular, mass-produced wood-based materials were quantitatively compared. This required the adoption of well-defined indexes, procedures, and the implementation of extensive experimental research. The main objectives of the study were:

- to suggest and try out special experimental procedures which should be considered a standard that can be applied to all types of wood-based boards (including innovative ones that are being developed in scientific units or that will be invented in the future);
- to determine the relative machinability of wood-based boards (that are currently produced on a mass scale) in form of explicit, quantitative indexes.

EXPERIMENTAL

Materials

This study used samples from three types of standard wood-based materials of substantially different internal structures, *i.e.*, fibreboards, particle boards, and veneer boards (with the possible use of solid wood). The first type (fibreboards) was represented by five materials: raw and melamine faced medium-density fibreboards (MDF), raw and lacquered high-density fibreboard (HDF), and raw hard fibreboard. The second type was represented by four materials: raw three-layer particleboards P4 and P5 (according to standard EN 312(2010)), melamine faced particleboard P3 (also according to EN 312(2010)), and raw oriented strand board (OSB). The third type was represented by five materials: raw compreg, raw transformer plywood, raw plywood, melamine faced plywood, and veneer faced blockboard. All samples came from wood-based boards produced on a mass scale and targeted on the European union market.

Table 1. Detailed Information about the Tested Wood-Based Boards

	Surface Density [kg/m ³]	Modulus of rupture (MOR) [N/mm ²]	Modulus of elasticity (MOE) [N/mm ²]	Brinell hardness HB	Main Application
Raw MDF	746 (836)	33.9	4180.0	4.0	Furniture components: frames, doors
Melamine faced MDF	756 (958)	33.5	4231.8	5.0	
Raw HDF	855 (869)	50.0	5495.9	5.6	Furniture components: backs, partitions
Lacquered HDF	801 (773)	40.5	4386.1	5.4	
Hard fibreboard	948 (969)	40.5	4128.4	10.1	Furniture components: backs, drawer bottoms
Particleboards P4	649 (861)	13.1	3204.4	2.6	Furniture components: upholstered furniture frames
Melamine faced particleboard P3	666 (838)	15.4	2948.4	2.1	Furniture components: frames, doors
Particleboards P5	725 (841)	21.1	3802.9	4.7	Furniture industry, construction
OSB	595 (648)	30.9	5490.1	4.2	Building construction, flooring
Compreg	1344 (1300)	137.9	12402.6	23.4	Machine parts, aircraft industry
Transformer plywood	986 (870)	149.8	15162.2	11.4	Power transformers

Raw plywood	661 (639)	77.0	8292.5	2.9	Construction, packaging
Melamine faced plywood	728 (721)	42.9	5912.3	4.1	Concrete shuttering, flooring
Veneer faced blockboard	586,6 (662)	52.5	5790.4	3.1	Furniture industry: doors and shelving

More detailed information is provided in Table 1. The numerical data were determined experimentally according to appropriate standards, although density was determined in two different ways. The average density (hereinafter referred to as "density") was determined in accordance with EN 323(1999). In addition, a density profile was determined using a GreCon DAX device (Fagus-GreCon Greten GmbH & Co. KG, Alfeld, Germany); an exemplary profile of this type is shown in Fig. 1. Based on the density profile, the density of outer surface layers of 2 mm thickness ("surface density") was determined. The bending modulus and bending strength were determined according to EN 310(1994) with an Instron 3382 universal testing machine (Norwood, USA). Hardness was measured according to EN 1534(2002), using a digital Brinell CV-3000LDB tester (CV Instruments, Netherlands). Additionally, in the case of three raw particleboards, the actual range of chips forming the outer layer was determined.

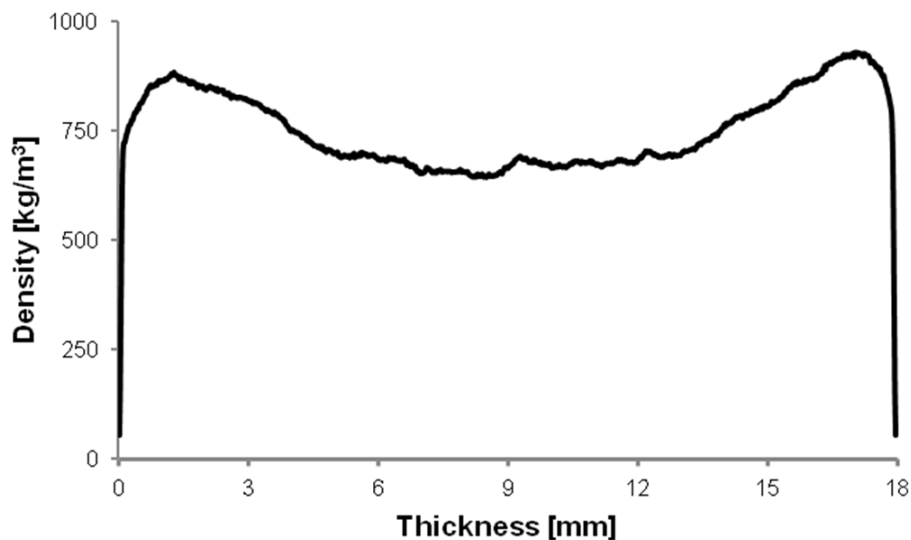


Fig. 1. Density profile for particleboards P4 determined using GreCon DAX

Methods

During the tests, a CNC machine (Busellato Jet 100, Thiene, Italy) and a Leitz single-blade drill with a polycrystalline diamond tip of 10 mm in diameter (catalog ID number 091193) were used. The experiment consisted of drilling through holes in samples made of all the wood-based materials (14 types, Table 1). The drills were used at a single cutting speed (6000 rpm) and at seven different feeds per revolution (ranging from 0.1 to 0.7 mm/rev). For each of these feeds, a series of 15 holes were performed (which implies over 100 holes in each material). This number was considered sufficient taking into account the actually observed scatter of the results and the fact that the all test panels were manufactured on a mass scale by reputable, global producers who guarantee

a high level of product repeatability. The purpose of the experiment was to determine the quality of the edges of the holes on both sides of the boards, *i.e.*, on the input side of the drill (“top” of the material) and on the output side (“bottom” of the material).

Moreover, the values of the cutting force and torque were measured. The obtained results were used to determine the relative machinability indexes based on the machining quality and on the cutting forces as criteria.

A digital camera (Canon 40D) with lens for macroscopic photos (Canon Macro Lens EF 100mm 1: 2.8 USM) was used to evaluate the quality of the edges of the holes. The photographs obtained were analyzed using CorelDRAW Graphics Suite X6 (v16.4.0.1280) graphical software. The same camera and software were used to evaluate the real range of chips forming the outer of three raw particleboards. On this basis, two characteristic diameters were defined, including the external damage area (Fig. 2).

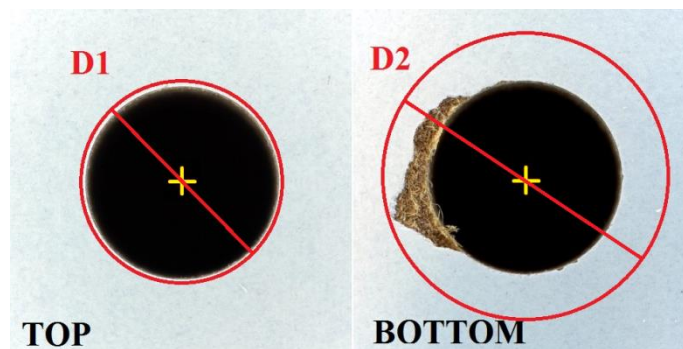


Fig. 2. The characteristic diameters determined on both sides of the boards during the machining quality testing

One of these diameters ($D1$) was determined from the insertion side of the drill in the material and the second from the output side ($D2$). The diameter values $D1$ and $D2$ were averaged for all feed rates. A relative index called the quality problem index (QPI) was calculated for each material according to Eq. 1,

$$QPI_X = 0.5[(D1_X - D)/(D1_{MDF} - D) + (D2_X - D)/(D2_{MDF} - D)] * 100\% \quad (1)$$

where QPI_X index defines the relative difficulty in machining of X material due to problems with the quality of the machining (the lower the index the better machinability of the X material); $D1_X$ and $D2_X$ describe the characteristic diameters concerning X material; and $D1_{MDF}$ and $D2_{MDF}$ denote the characteristic diameters of the reference material for which the raw MDF was taken; D is the nominal diameter of the drill (in this case: $D=10\text{mm}$).

The measuring track for cutting forces determination consisted of a special platform based on the piezoelectric dynamometer using a 2-component sensor (Kistler 9345, Winterthur, Switzerland). This sensor was able to measure the feed force (F) and the cutting torque (T). Moreover, the measuring track included a signal amplifier (Kistler ICAM 5073A, Winterthur, Switzerland), connector block (NI BNC-2110, Austin, USA), and a data acquisition device (NI PCI-6034E, Austin, TX, USA). The signal analysis was conducted in NI LabVIEW environment. A measuring platform with a fixed sample and typical measurement signals are shown in Fig. 3.

A relative index called the cutting force problem index (CFPI) was calculated for each material according to Eq 2,

$$CFPI_X = 0.5(F_X/F_{MDF} + T_X/T_{MDF}) * 100\% \quad (2)$$

where $CFPI_X$ index defines the relative difficulty in machining of X material with regard to size of the cutting forces (the lower the index the better machinability of the X material); F_X and T_X denote the feeding force and torque for the X material; and F_{MDF} and T_{MDF} describe the feeding force and torque of the reference material for which the raw MDF was taken.

When interpreting the above indexes, two facts must be taken into account, which are apparent from Eqs. 1 and 2. Both indexes for raw MDF are 100%; in this way the reference level was defined. At greater values of any of the indexes, the machinability is proportionally poorer.

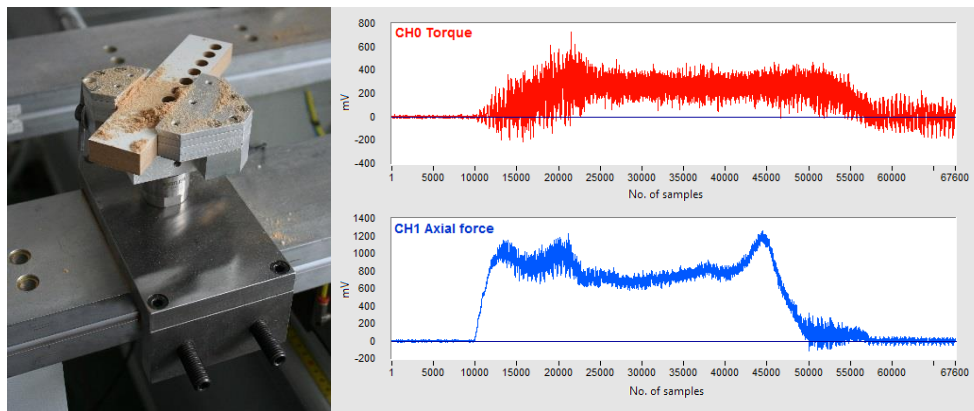


Fig. 3. The platform used to measure feed force and cutting torque and typical signal waveform

RESULTS AND DISCUSSION

A general comparison of the tested materials' machinability is shown in Fig. 4. This two-dimensional machinability chart includes all indexes based on the QPI and CFPI values determined during the study. These indexes were not correlated (Fig. 4).

Four groups of materials (Groups 1 through 4 in Fig. 4) were distinguished. Group 1 included a few boards that were the most easily machinable, as their QPI and CFPI values were below 200%. Among them, the best was melamine faced MDF, which produced half as many problems with machining quality than raw MDF; the cutting forces of both materials were at the same level. Moreover, group 1 included raw P4 particleboard and P3 melamine faced particleboard. Precisely due to good machinability, all of the above materials deserve to be very popular in furniture manufacturing. Group 2 contained six materials characterized by a quite low CFPI value (100% to 200%), but much worse QPI value (200% to 400%). Group 3 included raw light plywood and compreg, which possessed moderate QPI index (200% to 300%), but a relatively high CFPI value (300% to 500%). In contrast, group 4 included two raw materials (OSB and raw plywood) producing dramatic quality problems (QPI above 600%), but at the same time they indicated a relatively low CFPI value (100% to 200%).

Notably, none of the standard wood-based materials simultaneously exhibited a QPI of more than 300% and a CFPI of over 200%. The quality criterion differentiated the tested materials considerably more than the cutting force criterion. The QPI varied from

60% to almost 800%, and the CFPI varied from 100% to 500%.

In case of the QPI, the effects of internal structure of tested materials were clearly visible. With greater the homogeneity in the structure, better indexes were obtained (Figs. 5 and 6). The presence or absence of decorative coatings was also important. The use of melamine coatings was very favorable from this point of view. This was particularly evident in the case of plywood and MDF (Fig. 7). In contrast, HDF varnishing was extremely unfavorable (Fig. 8).

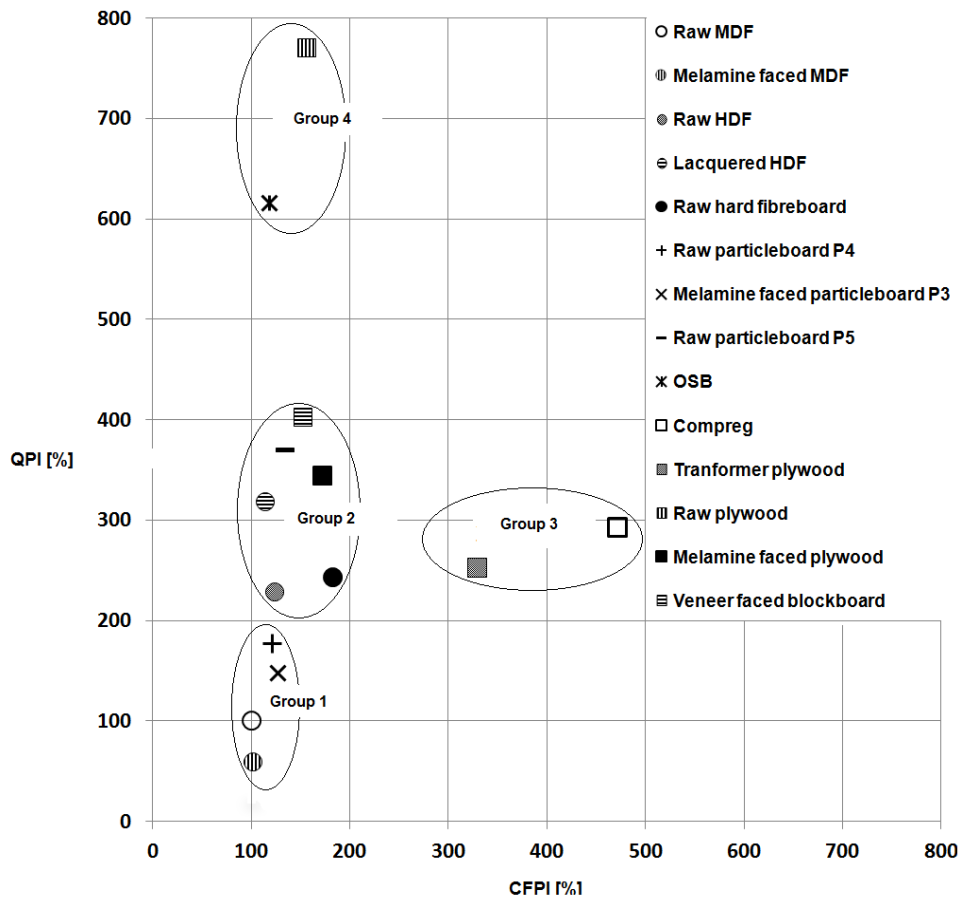


Fig. 4. Differentiation of wood-based boards in terms of difficulty in machining determined by two independent indexes (QPI and CFPI) which were defined in the case of drilling

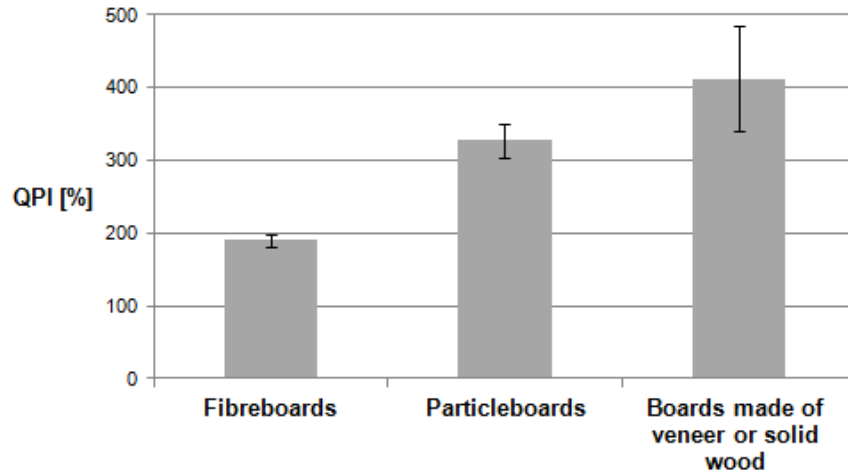


Fig. 5. Effect of the structure of wood-based boards on the quality problem observed during drilling (averaged results for three types of wood-based materials of substantially different internal structure)

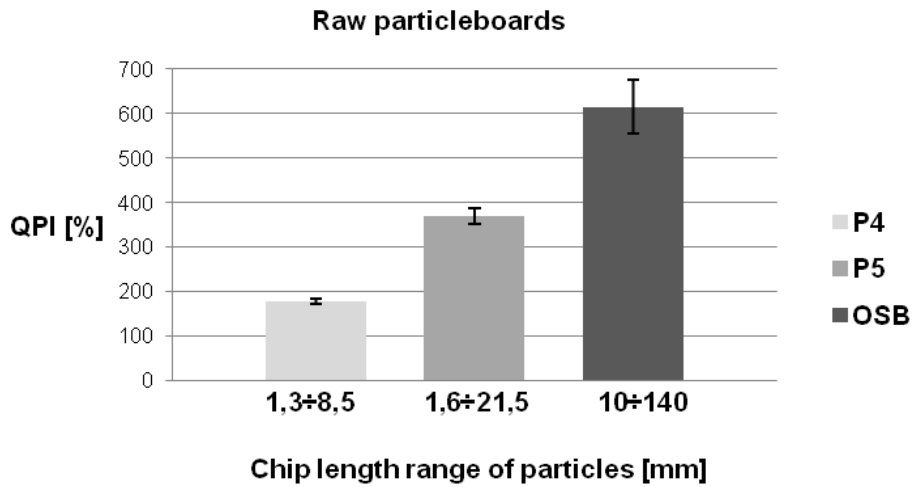


Fig. 6. Effect of the range of chip lengths constituting the outer layer of particleboard on the quality problem observed during drilling

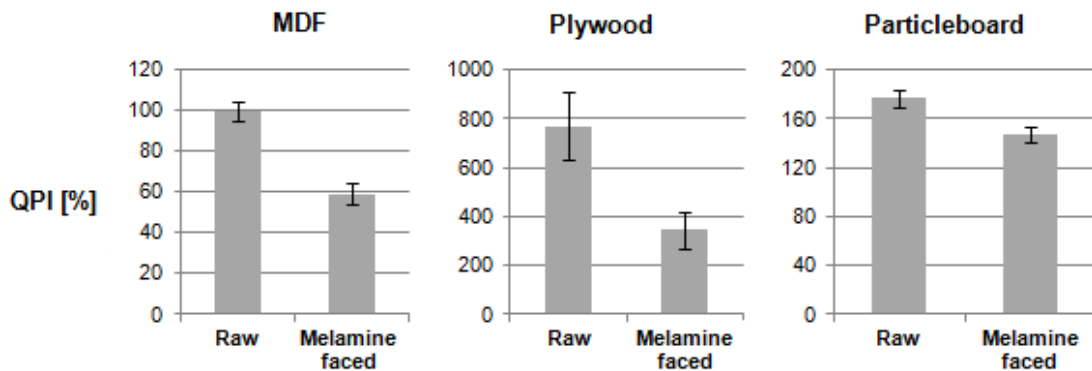


Fig. 7. Effect of melamine coating on the quality problem observed during drilling in MDF, plywood, and particleboard

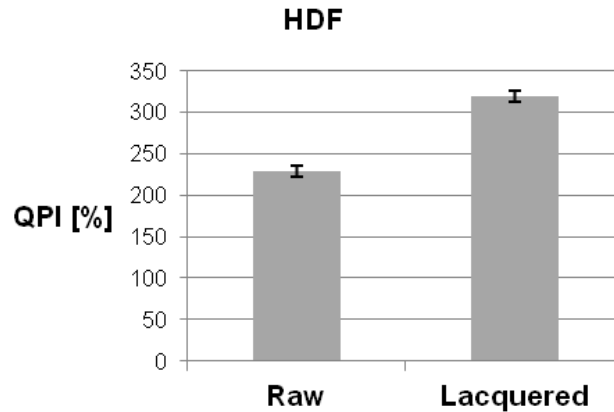


Fig. 8. Effect of the lacquer coating on the quality problem observed during drilling in HDF

The QPI had practically no correlation with the basic, routine parameters of wood-based panels such as density, hardness, modulus of elasticity, or bending strength.

The machinability index based on the cutting force criterion (CFPI value) indicated a very strong correlation coefficient ($R^2 > 0.9$ and $p < 0.005$) with density and hardness measurements. This was evident during a separate analysis of fibreboard and veneer panels (Figs. 9 and 10). Equally important correlations were not observed for particleboard (barely: $R^2 < 0.3$ and $p > 0.4$). This may have been due to the relatively low diversity of these boards in terms of density and hardness.

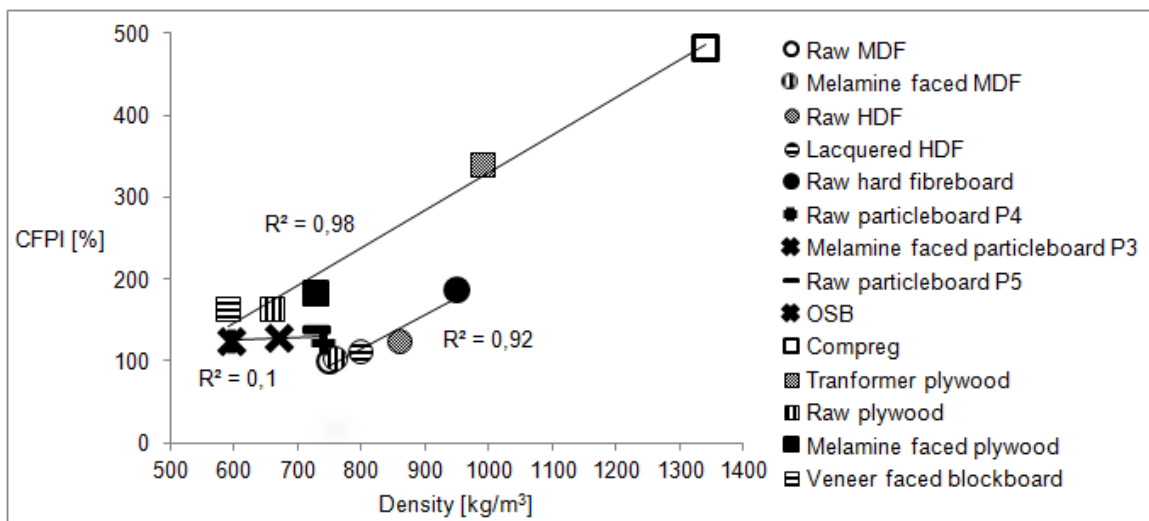


Fig. 9. Effect of density of boards on cutting forces problem observed during drilling

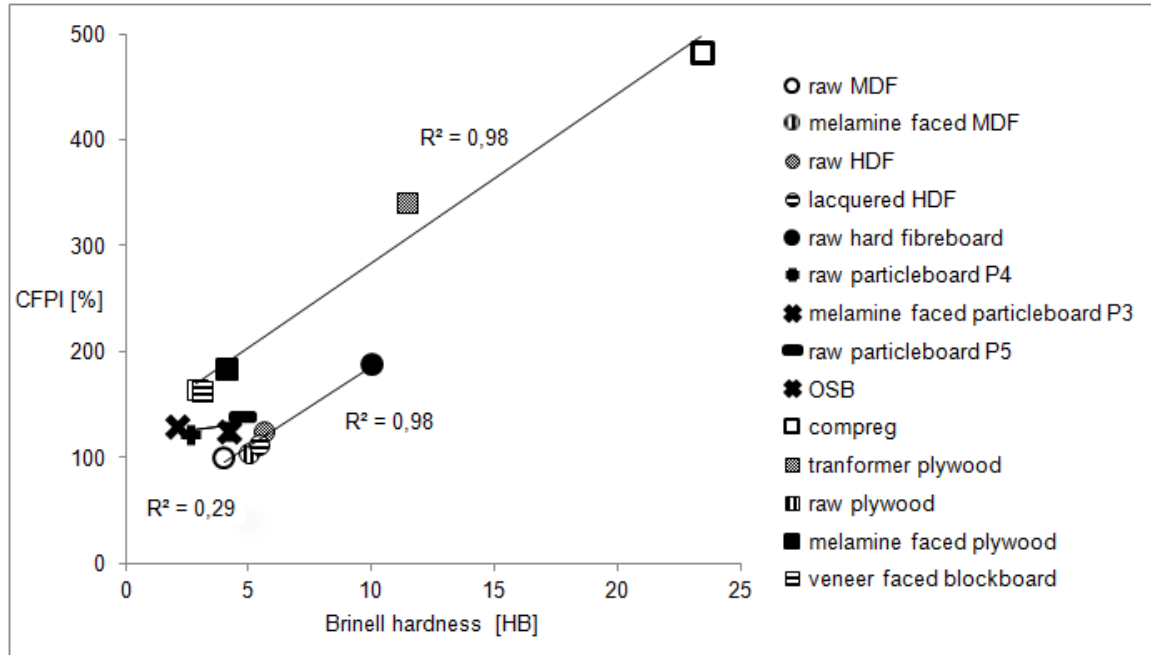


Fig. 10. Effect of hardness of boards on cutting forces problem observed during drilling

CONCLUSIONS

1. The machinability index based on the quality criterion was not correlated with the index based on the cutting force criterion. The quality problem index (QPI) value differentiated the wood-based boards to a greater extent than cutting force problem index (CFPI). However, none of the standard wood-based materials had a QPI greater than 300% and CFPI greater than 200%.
2. The QPI was not correlated with the basic, routine parameters of wood-based boards. The CFPI index sometimes showed a significant correlation (*e.g.*, density or hardness), but not for particleboards.
3. In the case of the QPI, the influence of the internal structure and homogeneity of the different types of materials was visible. The use or lack of decorative coatings was also important. The use of melamine coatings proved to be very favorable. This was particularly evident in the case of plywood and medium density fiberboard (MDF). In contrast, high density fiberboard (HDF) varnishing has proved to be unfavorable from this point of view.
4. Among tested materials MDF and P3/P4 particleboards were the easiest to machine, so their popularity in furniture manufacturing is well founded and seems to be worthy of promotion in other industries.
5. Experimental procedures developed in the study can be applied to unconventional wood-based materials (*i.e.*, innovative ones that are being developed in scientific units) to compare their machinability with boards currently produced on a mass scale. It is a quite promising and very desirable direction for future research.

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