ASSESSMENT AND COMPARISON OF QUALITY OF LPBs

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ABSTRACT

Determination of quality of production of the same kind is performed in its predominant part by means of sampling test. This also applies to manufacture of particleboards (PBs). Statistical methods allow assessing and comparing the quality of products. To assess and compare the quality of individual manufacturers with respect to standard requirements, an interval estimate of the arithmetic mean value of indices has been used, and to compare the quality between different manufacturers, a test of hypothesis with respect to mean values of two samples has been used.

After performed tests of laminated particleboards (LPBs) of different manufacturers, statistically significant differences in the quality level between individual manufacturers have been established.

The aim of the investigation is approval of methods for application of statistical methods when selecting a manufacturer / supplier of PBs according to objective criteria related to production quality.

Key words: quality, statistical methods, laminated particleboards

INTRODUCTION

Quality, price and wide choice are main factors determining the corporate competitiveness. Production quality during manufacture of wood-based panels is mainly determined by means of sampling destructive testing. This necessitates the use of statistical methods for assessment and analysis of the results obtained. Main advantage of these methods is that one judges of the course of processes and assessment of quality of products on the basis of the data obtained from testing of samples.

The standards set minimum requirements to products according to their use, while the market imposes quite higher requirements. The minimum requirements to PBs are set in BDS EN 312:2010.

The aim of the investigation is approval of methods for application of statistical methods when selecting a manufacturer of PBs according to objective criteria related to production quality.

INVESTIGATION METHODS

For the investigation, LPBs type P2 (BDS EN 312:2010), manufactured by six different manufacturers, have been used. These boards are most used for furniture manufacture. Test pieces have been cut from them to determine each tested index pursuant to BDS EN 326-1:2001. For assessment and comparison, following indices have been chosen: bending strength established pursuant to BDS EN 310:1999, tensile strength perpendicular to the plane of the board, pursuant to BDS EN 319:2002 and swelling in thickness, pursuant to BDS EN 317:2002.

ASSESSMENT OF INDICES OF LPBs WITH RESPECT TO STANDARDISATION REQUIREMENTS

Pursuant to BDS EN 312:2010, minimum or maximum value for each index and for each type of board have been determined respectively, with the upper/lower limit of the confidence interval of the mean values obtained after testing the necessary sample of test pieces for the respective index having to be above/below the set minimum requirements, i.e. determination of an interval estimate of indices is necessary. To form an interval estimate of the arithmetic mean value in case of small sample, pursuant to BDS ISO 2602:2003 and BDS EN 326-2:2010, the Student's *t*-criterion is used under the assumption of normal distribution of the values of the random quantities (respective indices). The chosen significance level is α=5 %.

The lower limit of a one-tailed confidence interval of an index with normal distribution is determined by the following formula (BDS ISO 2602:2003):

$$L^{q}_{5\%} = \bar{x} - \frac{t_{0.05;n-1}}{\sqrt{n}} S_x \qquad \textbf{(1)}$$

and the upper limit of a one-tailed confidence interval, respectively by the formula:

$$U^{q}_{5\%} = \bar{x} + \frac{t_{0.05;n-1}}{\sqrt{n}} S_x \qquad \textbf{(2)}$$

where,

$L^{q}_{5\%}$ и $U^{q}_{5\%}$ are lower and upper limits of the confidence interval at significance level α=5%,

$\bar{x}$ – the arithmetic mean value of the index,

n – number of test pieces, n = 6

S_x – root-mean-square deviation,

$t_{0.05;n-1}$ – one-tailed critical value of the Student's *t*-criterion.

COMPARISON OF QUALITY INDICES BETWEEN DIFFERENT MANUFACTURERS

The type of manufacturer is a qualitative and not quantitative characteristic. On account of this, comparison between individual manufacturers (effect of type of manufacturer on quality of PBs) is possible to be made by means of test of hypothesis, i.e. comparison individually of the indices between manufacturers or by means of analysis of variance. The application of analysis of variance would only give us information whether the type of manufacturer matters or not, but not in which manufacturers the quality is higher. The individual comparison of the indices would allow us revealing the statistically significant difference between manufacturers. Exactly on account of this, for comparison of quality indices of LPBs in case of different manufacturers, test of hypothesis of two arithmetic mean values has been used. Depending on how the hypothesis has been defined, it may be determined whether there is statistically significant difference between compared indices (in case of two-tailed set hypothesis) or whether one of them has higher (respectively lower) value than the other (in case of one-tailed set hypothesis).

The test of hypothesis passes through several stages, viz.:

- Definition of null H_0 and alternative H_1 hypothesis;
- Determination of significance level (α=0,05);
- Choice of test method;
- Obtaining the information (data) necessary for the test;
- Calculation of the empirical characteristic of the criterion chosen;
- Determination of the theoretical value of the criterion, depending on the chosen significance level α and degrees of freedom ν;
- Comparison of the calculated and theoretical value of the criterion and taking a decision to accept or reject the null hypothesis.

The arithmetic mean values of the three indices given above are subjected to test for statistically significant difference.

For test of hypothesis about equality of mean values in case of small samples, the Student's *t*-criterion (Michev, D.V. 1984; Montgomery, D. 2001) is used. The null hypothesis is defined as:

H_0: $\bar{x}_1 = \bar{x}_2$,

i.e. there is no statistically significant difference between the arithmetic mean values of two samples $\bar{x}_1$ and $\bar{x}_2$.

The alternative hypothesis and the criterion to reject the null hypothesis depending on the method of setting the alternative hypothesis are given in Table 1.

Table 1: Alternative hypothesis and criterion to reject the null hypothesis

Alternative hypothesis	Condition to reject the null hypothesis
H_1: $\bar{x}_1 \neq \bar{x}$	$t_o > t_{\alpha/2;\nu}$ or $t_o < -t_{\alpha/2;\nu}$
H_1: $\bar{x}_1 < \bar{x}_2$	$t_o < -t_{\alpha;\nu}$
H_1: $\bar{x}_1 > \bar{x}_2$	$t_o > t_{\alpha;\nu}$

Taking into consideration that quality indices of boards of different manufacturers (manufactured on different production lines) are compared, the variances of the examined general populations are unknown. Also, it may not be expected that their variances are equal, i.e. $\sigma_1 \neq \sigma_2$. In this case, the calculated value t_o of the Student's *t*-criterion is determined by the following formula (Lambova, M. et al. 2008; Montgomery, D. 2001):

$$t_0 = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}} \qquad \textbf{(3)}$$

The degrees of freedom ν to determine the theoretical value of the same criterion are determined by the following formula:

$$\nu = \frac{\left(\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}\right)^2}{\frac{\left(\frac{S_1^2}{n_1}\right)^2}{n_1 - 1} + \frac{\left(\frac{S_2^2}{n_2}\right)^2}{n_2 - 1}} \qquad \textbf{(4)}$$

RESULTS AND DISCUSSION

BENDING STRENGTH

The arithmetic mean values (the bars) and the lower limit of the confidence interval (the tick) of the bending strength, obtained after the testing of test pieces of LPBs form individual manufacturers, are given on Fig. 1. The lower limit of the confidence interval of the arithmetic mean value in the case all manufacturers has higher values than the minimum requirements (11 N/mm^2) shown in BDS EN 312:2010 for boards type P2.

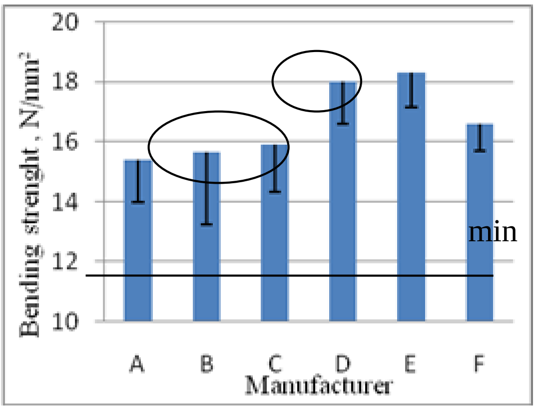

Figure 1: Bending strength and lower limit of the confidence interval

When comparing the bending strength, it has been established that there is no statistically significant difference between the mean values of this index (Table 2) between manufacturers A, B, C and F. These conclusions are warranted by the fact that the calculated values t_0 of the Student's *t*-criterion (Table 2) are lower than the theoretical values (Table 3), i.e. $t_0 < t$. This means that the null hypothesis may not be rejected and is accepted as true, i.e. H_0: $\bar{x}_1 = \bar{x}_2$. Comparing the mean values of manufacturer D or E with those of the remaining ones, however, statistically significant differences (t_0 in darker cells of Table 2) are obtained.

Depending on the method of setting the alternative hypothesis, it is possible that there is no statistically significant difference (in case of two-tailed set hypothesis), but one mean value is higher/lower than the other one (in case of one-tailed set hypothesis). An example of this is the mean value of the bending strength in manufacturer B, compared with that of manufacturer E and those in manufacturers C and D. Another specific case is that when comparing the mean values of manufacturers B and D where the result in manufacturer B is lower than that of manufacturer C, but it turns out that there is no significant difference from the mean value of manufacturer D. The reason for this fact is the higher dispersion of results in manufacturer B. This confirms the significance of the diespersion when assessing and analysing the results.

Table 2: Calculated values t_0 of the Student's *t*-criterion in case of bending strength and degrees of freedom (in parentheses) to determine the theoretical value of the same criterion

t_0	A	B	C	D	E	F
A						
B	0.19 (8)					
C	0.49 (10)	0.18 (9)				
D	2.62 (10)	1.70 (8)	1.97 (10)			
E	3.22 (10)	2.01 (7)	2.45 (9)	0.32 (10)		
F	1.46 (8)	0.75 (6)	0.76 (8)	1.68 (8)	2.36 (9)	

Table 3: Degrees of freedom and theoretical values of the Student's *t*-criterion in case of one-tailed and two-tailed set hypothesis

N	$\sigma_1 \neq \sigma_2$	*t*	$\sigma_1 \neq \sigma_2$	*t*
5	*two-tailed*	*2.57*	*one tailed*	*2.02*
6		*2.45*		*1.94*
7		*2.36*		*1.89*
8		*2.31*		*1.86*
9		*2.26*		*1.83*
10		*2.23*		*1.81*

TENSILE STRENGTH PERPENDICULAR TO THE PLANE OF THE BOARD

The values of the lower limit of the confidence interval in all manufacturers are higher than the minimum requirements for this index (0.35 N/mm²), given in BDS EN 312:2010 for this type of boards (Fig. 2).

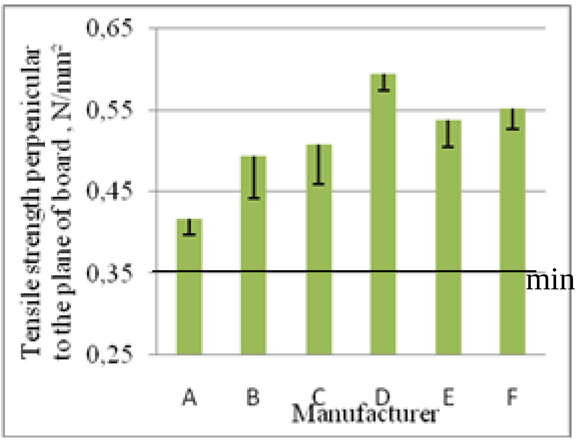

Figure 2: Tensile strength perpendicular to the plane of the board and lower limit of the confidence interval

The tensile strength perpendicular to the plane of the board is lowest in manufacturer A, and highest in manufacturer D, which is seen from Fig. 2 and is confirmed by the results presented in Table 4, i.e. in them $t_0 > t$. The tensile strength perpendicular to the plane of the board in manufacturer F is higher than that in B (2.02 > 1.89)

Table 4: Calculated values t_0 of the Student's *t*-criterion in case of tensile strength perpendicular to the plane of the board and degrees of freedom (in parentheses) to determine the theoretical value of the same criterion

t_0	A	B	C	D	E	F
A						
B	2.82 (6)					
C	3.51 (6)	0.41 (10)				
D	13.3 (10)	3.62 (6)	3.24 (7)			
E	6.46 (8)	1.44 (9)	1.01 (9)	2.89 (8)		
F	8.89 (9)	2.02 (7)	1.58 (7)	2.67 (10)	0.66 (9)	

SWELLING IN THICKNESS

For this type of boards (P2), there is no requirement with respect to swelling in thickness or water resistance. Big part of the manufacturers of LPBs, in view of the use of these materials for manufacture of kitchen furniture and furniture for wet rooms, aims at improving their properties exactly against such impacts.

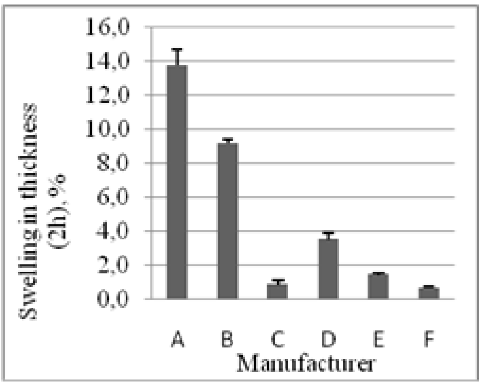

Figure 3: Swelling in thickness and upper limit of the confidence interval

From the data presented in Table 5 is seen that one may not claim that there is a statistically significant difference between the swelling in thickness of manufacturers C and F. In all remaining comparisons of the mean values for swelling, the differences are significant (Figure 3). The calculated Student's *t*-criterion reaches values scores of times higher than the theoretical ones (60.66; 64.81), which is an indicator of serious differences in the values for swelling in thickness. Low values of swelling have been established in the samples of manufacturers C, E and F.

Table 5: Calculated values t_0 of the Student's *t*-criterion in case of swelling in thickness and degrees of freedom (in parentheses) to determine the theoretical value of the same criterion

t_0	A	B	C	D	E	F
A						
B	9.86 (6)					
C	27.54 (6)	50.99 (10)				
D	20.68 (7)	24.42 (8)	11.23 (8)			
E	26.96 (5)	60.66 (8)	4.37 (7)	9.74 (6)		
F	28.6 (5)	64.81 (8)	1.53 (8)	13.29 (6)	8.75 (10)	

CONCLUSION

The methods experimented with for test of hypotheses when comparing some important characteristics of laminated particleboards offered on the market by different manufacturers.

After the performed tests and processing of obtained data with the use of an interval estimate of the results and test of hypothesis, it has been established that:

- The use of an interval estimate of the arithmetic mean values, also taking into account the dispersion of the values of the indices, gives more objective notion of quality level of LPBs;
- The interval estimate, in case of successfully chosen guarantee probability, may give sufficient security when the comparison is performed with respect to a company that is a standard of quality or with respect to requirements approved in standards;
- Comparison of quality indices of PBs by means of test of hypothesis allows revealing statistically significant differences between the compared indices in different manufacturers;
- The quality of the boards examined is higher than the standard requirements with respect to bending strength and tensile strength perpendicular to the plane of the board;
- The big dispersion exercises influence when calculating the Student's *t*-criterion, by decreasing its value. In this way, in case of seemingly different mean values of indices, their differences are statistically insignificant (Fig. 1);
- The mean value of the bending strength is highest in manufacturer E, but one may not claim that it differs statistically significantly from that of manufacturer D;
- The mean value of the tensile strength perpendicular to the plane of the board is highest in manufacturer D, and there are no statistically significant differences between the values of this index in manufacturers E, F, A and B;
- The mean values for swelling in thickness of manufacturers C and F are lowest, but one may not claim that they differs statistically significantly from each other.

The submitted methods and results contribute to obtaining an objective assessment of the quality of LPBs and in combination with other factors (mostly price) – in the choice of supplier

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