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METHODS FOR ASSESSMENT OF SUPPLIERS OF RAW MATERIALS AND MATERIALS (UREA-FORMALDEHYDE RESIN)

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ABSTRACT

Raw materials and materials form a big part of the cost price of the end product. At the same time, the deviations from the requirements put forward to them impede the manufacturing processes, lead to additional expenditure for elimination and compensation of the discrepancies of the raw materials delivered, serious losses and lost profit for the manufacturer.

The provision of raw materials and materials of constant quality is not always achievable and that is why it is necessary to assess the deviations from the optimum requirements and to determine what it costs to us to eliminate / compensate them and at minimum expenditure at that.

In the report, methods for assessment of suppliers of urea-formaldehyde resin are presented. They reflect the relationship between manufacturing and financial indices (price, expenditure, lost profit) when assessing the losses from deviation in the raw materials quality.

Key words: methods, assessment, quality, supplier.

INTRODUCTION

Raw materials and materials form a big part of the cost price of the end product. At the same time, the deviations from the requirements put forward to them impede the manufacturing processes, lead to additional expenditure for elimination and compensation of the discrepancies of the raw materials delivered, serious losses and lost profit for the manufacturer.

The provision of raw materials and materials of constant quality is not always achievable. Loss is realised even within the determined tolerances of their parameters (it impedes the manufacturing processes, decreases the yield, increases the share of the discrepant production, etc.) That is why it is necessary to take steps to compensate these deviations from the quality of the raw materials and materials used. It is necessary to assess these deviations and to determine what it costs to us to eliminate / compensate them. For example, during the manufacture of particleboards (PBs), the smaller quantity of dry substance in the resin requires to increase the quantity of the resin put in, i.e. increased resin consumption.

The selection of a supplier is not only bound to the price of the raw materials, but also to a number of other indices and criteria most often related to the quality of the raw materials, the possibilities for delivery and maintenance, reputation of the companies, reliability, etc. (Chatterjee Pr., P. Mukherjee, Sh. Chakraborty 2011; Pi W.-N., C. Low 2006). Other authors propose to bind the assessment of the suppliers to the determination of all expenditures – direct and indirect, that has emerged with the use of a given raw material (Chen Ch.-Ch., Ch.-Ch. Yang 2002).

The selection of a supplier is based on different criteria for some of which maximum is expected, for others – minimum. These criteria often contradict one another or overlap to a certain degree (Chatterjee Pr., P. Mukherjee, Sh. Chakraborty 2011).

In literature, multicriteria methods based on a combination of methods for ranking of criteria and determination of weight coefficients and methods taking into account the deviations from the optimum solutions are used most often for selection of suppliers.

For ranking, the analytic hierarchy process (AHP) is among the most used ones (Chatterjee Pr., P. Mukherjee, Sh. Chakraborty 2011; Pi W.-N., C. Low 2006; Saaty, Th., L. 2008). According to Saaty, AHP is a theory for assessment through comparison by pairs of criteria by specialists. This comparison is according to a scale selected in advance, by criteria and subcriteria. Moreover, the comparison may be also performed depending on different viewpoints – benefit, possibilities, expenditures, risk, etc.

Chatterjee et al. (Chatterjee Pr., P. Mukherjee, Sh. Chakraborty. 2011) compare the two methods for assessment of suppliers with use of weight coefficients and a method for multicriteria compromise optimisation (VIKOR) and a method for elimination of the selection of variants, taking into account the reality (ELECTRE). After the VIKOR method, all possible variants for solutions are sought and ranked, whereas in the ELECTRE method the possible solutions are reduced consecutively through disclosure of “dominating” ones.

Chen and Yang (Chen Ch.-Ch., Ch.-Ch. Yang 2002) base the assessment of the suppliers on the determination of all expenditures, both direct expenditures for quality and indirect and hidden expenditures along the whole chain of quality from the design to the product realisation. The comparison between the suppliers is made by means of an index reflecting what is the percentage of the total expenditure compared to the expenditure for purchase of the raw materials. The additional expenditures related to additional activities because of discrepancies in the raw materials is also included in the total expenditures. The authors pay attention to the difficulties in the calculation of expenditures for inferior quality. The availability of procedures for disposing of products not equal to requirements in organisations with introduced quality management systems (QMSs) gives partial information about these expenditures.

Pi. and Low (Pi W.-N., C. Low 2006) propose to make the selection of a supplier by using a combination of two methods: an analytic hierarchy process (AHP) and a Taguchi loss function.

Feng et al. (Feng, C-X.; Wang, J.; Wang, J-S. 2001) use a probabilistic approach for selection of a supplier with the use of loss function and an index of possibilities of the process, which supposes to know the effect of the indices on the process stability.

The used methods and approaches for assessment and selection of a supplier are related to the use of methods for ranking, characterised by ease of execution and a possibility for inclusion of quantitative and qualitative indices, but also to a subjectivity of the result depending on the specialists who execute them. Together with the ELECTRE and VIKOR, as well as the Taguchi loss function, based on the deviations of the indices from the optimum values, allows making a general assessment and ranking the suppliers, but this assessment does not give quantitative and financial assessment of each supplier.

The use of the methods based on the total expenditure is impeded by the impossibility to determine the indirect and hidden expenditures related to the use of given raw materials.

The aim of this study is to propose and apply methods for assessment and selection of a supplier of a raw material (urea-formaldehyde resin) during manufacture of PBs.

METHODS

The investigation methods pass through several steps some of which are also characteristic of the methods presented above, viz.:

- Determination of criteria (requirements) and limitations to the raw materials (depending on their technical and manufacturing possibilities and financial limitations);
- Determination (sifting out) of the main criteria / indices;
- Determination of the effect of the raw materials quality on the manufacturing processes and the end product quality;
- Determination of the losses / lost profit with respect to each index for each supplier;
- Determination of the total losses for each supplier;
- Selection of supplier / suppliers.

In this work, assessment and selection of a supplier of urea-formaldehyde resin (UFR) for manufacture of PBs is made.

A number of requirements are put forward to the raw materials and materials and sometimes their number is such that the investigation and the determination of all is labour-consuming and useless because there is often interaction and/or overlapping between them and sifting out is necessary.

The assessment of the losses from deviation from the requirements to the raw materials used is preceded by a matrix diagram (Table 1). The use of these diagrams allows clear presentation of the relationships between the individual indices and enables reducing the number of controlled quality parameters (Dyukendzhiev, G., R. Yordanov 2008). The relationships between the indices is presented with assessment – weak, strong, very strong, with it being able to be positive or negative.

The assessment has been made for a laminated board 18 mm thick, at an average resin consumption of 9 % (dry content with respect to dry particles). Four UFR suppliers have been compared. The UFR price for the individual suppliers is as follows: supplier A – 255.6 lev/t; supplier B – 220.1 lev/t; supplier C – 198.8 lev/t and supplier D – 227,2 lev/t. The lost profit has been calculated at an average price of a laminated board of 13 lev/m².

The assessment of the losses from difference in the resin concentration is determined by the following formula:

$$L_r = \left(\frac{100}{C_n} - \frac{100}{C_a}\right).Q_r.P_r/1000, \text{ lev/m}^3 \quad \textbf{(1)}$$

where: L_r are the losses from the difference in the dry substance concentration, C_n – dry substance concentration pursuant to norm (66 %), C_a – the actual resin concentration (%), Q_r – dry resin consumption (kg/m³), P_r – price of resin with actual concentration (lev/t).

The lost profit as a result of deviation of viscosity from the optimum one is determined by the following expression:

$$LP_V = \frac{(V_A - V_{OP}).t_V}{t_P + (V_A - V_{OP}).t_V}.S_L P_L \quad \textbf{(2)}$$

where: LP_V is the lost profit because of deviations from the optimum viscosity, lev/m³; V_A – actual viscosity, *s*; V_{OP} – optimum viscosity (the least one), *s*; t_V – the time for increasing the pressing depending on the viscosity deviation (t_V = 0,5 s); t_P – pressing time (t_P = 180 s); S_L – LPB (laminated particleboard) area (at board thickness of 18 mm $S_L \approx 55.55$ m²/m³); P_L – LPB price, lev/m².

The losses from bonding strength are determined by the following expression:

$$L_{bo} = \frac{\left(-0,3\sigma_{bo} + 13.2 - P_{opt}\right)}{100} Q_r \frac{100}{K_a} . \frac{P_r}{1000}, \text{ lev/m}^3 \qquad \textbf{(3)}$$

where: L_{bo} are losses from deviations in the bonding strength; σ_{bo} - bonding strength determined pursuant to BDS EN 302-1:2013; P_{opt} – the optimum quantity of dry resin used (least, P_{opt} = 9%); C_a – the actual resin concentration (%), Q_r – dry resin consumption (kg/m^3), P_r – price of resin with actual concentration (lev/t).

To determine the effect of bonding strength on the resin quantity to achieve the minimum requirement for tensile strength perpendicular to the plane of the board, a single-factor passive experiment and regression analysis has been used to derive a mathematical equation of the relationship input/output index (Dyukendzhiev, G., R. Yordanov 2008).

The lost profit because of deviations from the optimum gel time are determined by the expression:

$$LP_G = \frac{\left(t_{G.A} - t_{G.opt}\right)}{t_P + \left(t_{G.A} - t_{G.opt}\right)} . S_L P_L \qquad \textbf{(4)}$$

where: LP_G is the lost profit because of deviations in the gel time, lev/m^3; $T_{G.A}$ – the actual gel time, s; $t_{G.opt}$ – optimum gel time (least), s.

RESULTS AND DISCUSSION

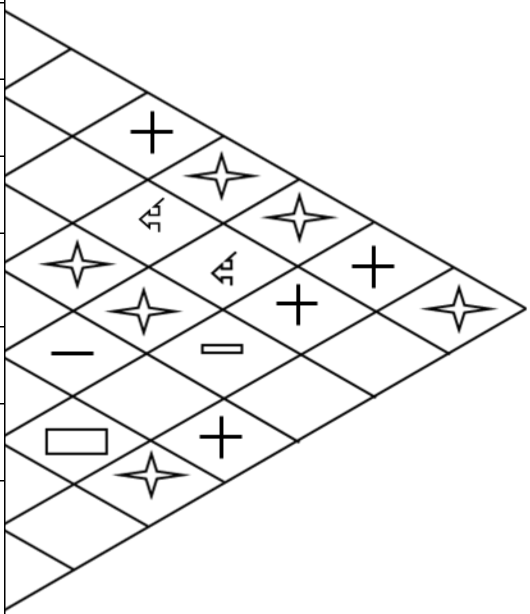
A matrix diagram reflecting the influence between the main indices characterising the UFR quality is presented in Table 1.

From the interrelations between the indices, shown in Table 1, it may be summarised that:

- The dry substance content in the resin as a main standardised index (BDS 5266-1981) has a strong positive correlation with respect to bonding strength, gel time and resin density. Actually paid is the dry substance, so in case of less dry substance content, loss is realised. It may, however, be easily manipulated with fillers and that is why it may not be judged only by this index of the quality of the resin offered;
- The molar ratio between urea and formaldehyde exercises very strong positive relationship with the gel (gluing) time and the bonding strength, but it is known that with the increase of this ratio, the release of the free formaldehyde injurious to human health also increases. The resin samples subjected to comparison are with an equal molar ratio;

Table 1: A matrix diagram (correlation matrix) of the UFR indices – with assessments: – weak negative; + weak positive; ✧ strong positive; ▭ strong negative; very strong positive; □ very strong negative relationships between indices.

Required	Index
Max.	Dry substance content
	Molar ratio urea/formaldehyde
Min.	Viscosity at 20 °C
Max.	Bonding strength (BDS EN 302-1:2013)
Min.	Gel time at a temperature of 100 °C
	pH
Max.	Resin density at 20 °C



- The resin viscosity has a strong correlation relationship with the bonding strength and the resin gel time, as well as a strong negative one with pH, i.e. the decrease of pH leads to the fast increase of the viscosity and resin hardening. Viscosity is also an important manufacturing factor determining the uniform application of the resin on the particles and is most often controlled by diluting the resin with water. This, however, also leads to an increase of the hardening time of the glue mixture and delays the manufacturing process, i.e. the productivity is decreased;
- The resin bonding strength is an index that is not observed. One judges of it indirectly after the wood-based boards have already been manufactured. At the same time, this is may be the most important index. Besides the above-mentioned relationships with the indices, the weak negative relationship with the gel time and the positive relationship with the resin density should be also added;
- The gel time, as an indirect index of the bonding speed, is strongly influenced by pH. The decrease of pH accelerates the resin polymerisation. The resin hardening speed, as said above, is also strongly positively influenced by the molar ratio of urea/formaldehyde. The gel time is decreased by adding salts of acids (ammonium chloride, ammonium sulphate, etc.), but, as known, the addition of a hardener quantity of more than 2–2.2 % with respect to the resin does not accelerate the resin hardening process;
- The effect of pH has already been stated. It is important to say that, in the process of storage, the resin pH

and viscosity change. This is observed under manufacturing conditions, and the striving for delivery "just in time" and its control in the process of glue application, by means of the quantity of the hardener introduced, decrease considerably the significance of this factor;

- The density, normally, is in strong positive correlation with the resin dry substance and gel time.

After analysis of the matrix diagram, four indices have been selected by which the potential resin suppliers are to be assessed, viz.: dry substance content; viscosity; bonding strength and resin gel time. These indices reflect most and strongest interactions.

The most important requirements put forward to the adhesives used in the PB manufacture are related to cost price, bonding strength and necessary bonding time. On this basis, the assessment of the losses from deviation in the raw materials quality is also made.

Assessment of losses and selection of a UFR supplier

The results for assessment of UFR suppliers by losses/lost profit are presented in Table 2.

Table 2: Assessment of UFR suppliers by losses/lost profit

Index	Unit	Requirement	Tolerance zone	Meaning	Data about supplying company				Losses/lost profit by companies				Unit
					A	B	C	D	A	B	C	D	
Dry substance content	*%*	*66*	±1	Grater is better	64.2	65.0	64.0	65.2	0.547	0.259	0.474	0.213	lev/m^3
Viscosity at 20 °C (VS 4)	s	55-65	10	Less is better	59.2	61.4	63.5	62.4	8.329	12.615	16.659	14.547	lev/m^3
Gel time at a temperature of 100 °C	s	45-65	20	Less is better	47.0	49.0	46.0	51.0	7.937	15.700	3.990	23.297	lev/m^3
Bonding strength (BDS EN 302-	N/mm^2	above 10	4	Grater is better	13.53	12.05	11.40	13.97	0.028	0.100	0.122	0.001	lev/m^3
								∑	16.84	28.67	21.25	38.06	lev/m^3

The deviation of the dry substance content from the required 66 % leads to a necessity of increasing the resin quantity put in, i.e. to additional expenditure (loss). As seen from Table 2, it is biggest in supplier A, and smallest in supplier D. This assessment is based not only on a deviation from the percentage of dry substance, but also on price, i.e. it encompasses both the technical requirements and the financial aspect. The loss by this criterion is relatively low and lies within the range of 0.22–0.55 lev/ m^3.

The resin viscosity affects mostly the process of glue application. In case of storage and higher storage temperatures, as known, the viscosity increases. To bring to a viscosity suitable for glue application, the resin is diluted with water. This on its part leads to an increase of the duration of the hot pressing process or necessitates drying the particles to lower values of moisture content, which leads to a decrease of the productivity and an increase of the energy expenditure. The delivery of resin with higher viscosity means losses. It has been established from observations that in order to compensate the addition of more water to the resin (in order to correct the viscosity within the tolerance range of

10 s), it is necessary to increase the hot pressing duration by 5 s). From the obtained data (Table 2) about the viscosity of the compared resins it has been established that in supplier The hot pressing process is delayed by 2.1 s, which means lost profit of 8.33 lev/m³ (least with respect to this index). For supplier B the delay is by 3.25 s, for supplier C – 4.25 s, and for supplier D – 3.7 s. The biggest lost profit, with respect to this index, is present if resin from supplier C is used – to the amount of 16.66 lev/m³.

The slower resin hardening also means higher hot pressing duration and lower productivity. In case of increase of the pressing cycle by 1 s, the lost profit is to the amount of 3.99 lev/m³ – supplier C. Highest resin gel time is found in supplier D – increased by 6 sec., respectively highest lost profit – 23.3 lev/m³.

The bonding strength reflects the most important index of the glues, namely their ability to bond. The results from the four series of UFR samples tested for longitudinal tensile shear strength (BDS EN 302-1:2013) are presented in Table 3. In order to accept the results of each series as plausible, at least ten samples destroyed along glue layer are necessary. This has been realised. The data about the resin of supplier D is with a higher mean value – 13.97 N/mm², whereas for the resin of supplier C they are lowest from among the compared four suppliers – 11.40 N/mm².

In order to assess the loss from each supplier, it is necessary to disclose the relationship between the longitudinal tensile shear strength and the resin quantity to ensure the minimum values of tensile strength perpendicular to the plane of the board (0.35 N/mm² for boards of type R2).

Observation under manufacturing conditions has been performed for the period of use of resin from the four suppliers. The resin percentage ensuring values close to the minimum ones for transverse tension has been compared to the results for longitudinal tensile shear strength. The results are presented in Figure 1.

Table 3: Results for longitudinal tensile shear strength (BDS EN 302-1:2013)

	Supplier			
	A	B	C	D
	N/mm²	N/mm²	N/mm²	N/mm²
n	18	15	21	17
$\overline{X}$	13.535	12.051	11.397	13.974
S	2.258	1.951	1.769	1.898
s/√n	0.532	0.504	0.386	0.460
Vc,%	16.686	16.192	15.522	13.581
Px,%	3.933	4.181	3.387	3.294

The equation obtained (Fig. 1) is used to assess the losses with respect to this index. The value of the coefficient of concordance $R^2 = 0.994$ shows the high degree of approximation of experimental and theoretical losses (calculated according to the equation).

From Table 2 is seen that the losses at lower values of bonding strength are highest in supplier C to the amount of 0.122 lev/m³, and lowest in supplier D – 0.001 lev/m³. These losses reflect the increased resin quantity to compensate the lower values of bonding strength.

The total amount of losses/lost profit by deviation from the optimum requirements to UFR (TABLE 2) is highest in supplier D to the amount of 38.058 lev/m³, and lowest in supplier C – 16.84 lev/m³. It is obvious that highest share (96-99%) of losses/lost profit is in deviation from viscosity and resin gel time, whereas the other two indices form a loss of less than 0.6 lev/m³.

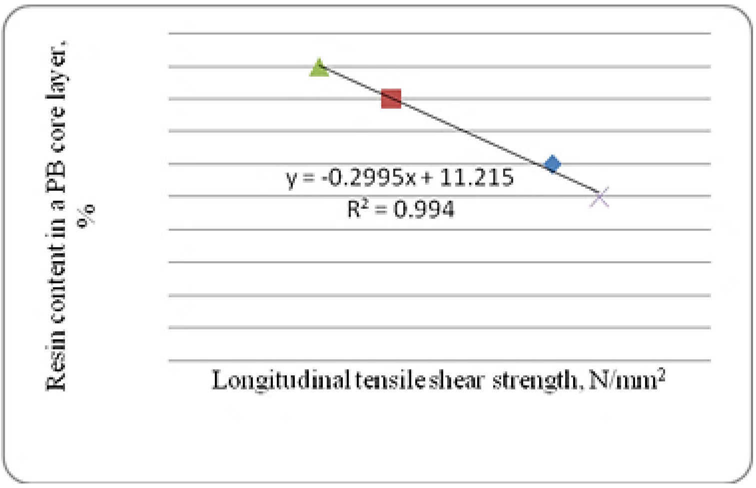


Figure 1: Relationship of longitudinal tensile shear strength and resin quantity in a PB core layer to ensure the minimum requirements for transverse tension

CONCLUSION

The presented methods reflect the relationship between manufacturing and financial indices (price, expenditure, lost profit) when assessing the losses from deviation in the raw materials quality. For assessment of suppliers, a combination of several methods is used – a matrix diagram, calculation of loss/lost profit caused by deviation from the optimum parameters for each index, a planned experiment. The use of planned experiments to reveal the relationships between manufacturing and financial indices gives an advantage to other methods based on ranking of factors by importance and determination of weight coefficients. The planned experiments allow giving more precise quantitative relationship (by means of a mathematical equation), whereas in the case of ranking of factors there is subjectivity that depends on the experts' opinion.

Actually, the main losses/lost profit are due to a delay of the manufacturing process. Based on the data from Table 2, resin from supplier A should be selected.

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