ISSN 1392–1320 MATERIALS SCIENCE (MEDŽIAGOTYRA). Vol. 12, No. 4. 2006

Strength and Stiffness Properties of Furniture Panels Covered with Different Coatings

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Received 06 September 2006; accepted 11 October 2006

The paper analyses changes of the properties of particleboard furniture panels depending on the type and thickness of the coating material. As far as there is no standard regulating the structure and properties of differently coated construction panels, it is important to study the bending strength of panel details on the type and thickness of the coating material. The obtained results allow to ascertain rational type, structure and thickness of the coating material for panels (produced from the most often used for furniture manufacture 18 mm thick particleboard). Particleboard furniture panels were coated using paper-based film, compensatory paper, laminated plastics, 0.6 mm thick mahogany veneer (1 to 8 outer layers) and coated with acrylic paint. The specimens were constructed from the particleboard 18 mm thickness, produced at J/V "Girių Bizonas". The studies have ascertained changes in the modulus of elasticity and bending strength of particleboards covered by different coating materials, depending on the type and thickness of the coating material.

Keywords: particleboard, veneer, modulus of elasticity in bending, mode of failure, bending strength.

INTRODUCTION

Most details of case furniture are panel elements. Basic material for the production of furniture panels is particleboard. The properties of this material are regulated by the standard LST EN 312:2004 "Particle panels. Technical requirements" [1]. However, having covered particleboard by different coatings (enamel paints, by sliced or sliced veneer, laminated plastics, roll laminting films, compensatory paper, etc.), its main mechanical properties (modulus of elasticity E and bending strength f_m) undergo significant changes [2]. It is very important to determine the values of these parameters and their possible changes in the construction of panels. Exploitation loadings of the construction elements (drawers, shelves, horizontal partitions) of case furniture are known and chosen from the standard tables [4]. During furniture designing it is important to check loadings, the type and treatment method of the supporting panels (shelves, horizontal panels and partitions). The quality of case furniture is determined not only by a properly designed construction and joining strength, which depends on different parameters or particleboard characteristics, but also by the coating material and thickness of panel details. The main mechanical properties hypothetically will depend on these parameters.

There is no standard regulating the construction and properties of construction panels covered by different coatings. Most similar studies were conducted using plywood [3]. It is especially important to study the dependence of the bending strength of panel details on the type and thickness of the coating material, and to determine rational type and thickness of the coating material for panels.

Today's case furniture is produced from panels which are painted, covered by paper-based or synthetic films, laminated plastics, or simply by compensatory paper and sliced veneer [6]. Applying panel painting technology, a panel is first of all primed, later daubed and only then it is painted. In this way, panel receptivity and paint consumption is reduced. The prime closes the pores of wood, the daub smoothes out roughness, while acrylic paint provides final decorative touch to the surface [7]. Entire panels are painted using rollers or flooding with paint. Separate panel details are most often painted by spraying. The advantage of this treatment method is a very wide range of colours and required surface lustre.

In furniture industry, due to a simple technology and low panel treatment costs, furniture panels are most often covered by paper-based or synthetic films. Visually these films have an embossed surface, imitating the texture of solid wood, therefore, panels covered by such a film practically have the same appearance as panels covered by solid wood veneer. Paper-based films, which weight is $60\ g/m^2 – 120\ g/m^2$, are used. They are soaked in carbamate formaldehyde (UF) or melamine formaldehyde (MF) resin [8, 12]. If soaked in MF resin paper-based film is used for panel treatment then adhesives to stick the film to the base are not necessary: MF resin, which is in the film, melts under the impact of temperature and adheres to the surface of the panel [6, 9]. If for the treatment paper-based film soaked in UF resin is used, then adhesives are used to glue it to the base, i.e. thermoreactive up to 70 % concentration of carbamide formaldehyde resin with a hardener. Films are used for the treatment of both faces of panels. It is an essential condition, because treatment of only one face leads to asymmetry, increases tension, which cause inward bend of panel. Sometimes one face of the treated panel is invisible during exploitation, thus, instead of more expensive films, compensatory paper is used.

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Continuous Pressure Laminate (CPL) is a collection of pressed special paper sheets, soaked in phenol and melamine formaldehyde resines. These plastics are 0.5 mm – 2.0 mm thick and of not less than 1.4 g/cm^3 density, resistant to chemical materials and mechanical impact (scratches, friction), significantly increasing panel bending strength [6]. However, this is one of the more expensive materials. Plastics are glued to the panel by UF, latex, melting adhesives.

Particleboard panels are coated also with sliced solid wood veneer. This process is called veneering, i.e. gluing of the sliced veneer to the particleboard surface [6]. Applying this method of treatment, detail looks as if it is made of solid wood panel, however, owing to its base – particleboard, it is considerably cheaper. Besides, the layer of sliced veneer increases bending strength. This method of treatment is widely applied in furniture industry. Sliced veneer most often is 0.2 mm – 2.0 mm thick, its moisture content is 8 ±2 %, adhesives used are mostly UF resins.

The aim of the study was to determine the changes of panel element properties, when the base of the panel, i.e. particleboard remains the same, while only the coating type and structure changes.

EXPERIMENTAL PART

An 18 mm thick three-layered untreated particleboard of plane pressing, manufactured at J/V "Girių Bizonas" was used for all specimens (Table 1).

Table 1. Technical properties of 18 mm thickness chipboard according to LST EN 312-3:1998 standard

Mean	Modulus of elasticity, MPa	Density, kg/m^3	Resistance to perpendicular tensile stress, MPa	Bending strength, MPa
Standard	1600	570 – 680	0.35	13.0
Experimental	2001	641	0.39	18.5

All the below listed materials were glued on or used to coat this particleboard.

Coating of the panel (painting) with enamel paint and paper-based film (roll laminting) was done at J/V "Freda". During painting, prime – 30 g/m^2, daub – 40 g/m^2 and alcidic paint – 22 g/m^2 were applied. During roll laminting, paper-based WKP film was used with the weight of 60 g/m^2. This film was glued in roll laminating line ECOLINE-900-D-SI by hot rollers, applying the following gluing regime: the temperature of the first and the second rollers respectively 60 °C and 80 °C, general speed of the line 18 m/min, the output of adhesives 50 g/m^2, amount of the hardener 8 g/m^2 – 10 g/m^2. UF resin "Prefere 4111" and hardener "Prefere 5220" by "DYNEA" firm were used. The ratio of the resin and the hardener was 5 : 1. These adhesives were used also in the laboratory, gluing compensatory paper, sliced veneer and laminated plastic. The process of gluing was carried out in the press "PL100" according to the following regime: gluing temperature was 100 °C, working pressure 1 MPa, gluing process lasted 2 min.

Some specimens were coated with sliced 0.6 mm thick mahogany veneer. Moisture content of the veneer comprised 6 %, density 512 kg/m^3 [10]. Particleboard specimens were coated also with compensatory paper, the weight of which was 134 g/m^2. For the treatment 0.5 mm thick CPL cover by the Italian firm "Abet Laminati" (behavior against shock loading ≥ 15 N according EN 438-2:2005 if thickness ≥ 0.40 mm; density 1350 kg/m^3 according EN 323:1999; flash point > 204 °C) was used also.

The least number of specimens pointed out in the LST EN 326-1:1999 standard [15] is 6 units. To ascertain the dependence of modulus of elasticity and bending strength of panel details on the type of coating, a collection of 8 specimens was accepted [11, 13, 14]. The speciemens were prepared according to the requirements of the LST EN 310:1999 standard [16]: the length of specimen was 410 mm, width – 50 mm. The specimens before testing were conditioned in 20 ±2 °C temperature, under 65 ±5 % relative air humidity. The loading scheme is provided in Fig. 1.

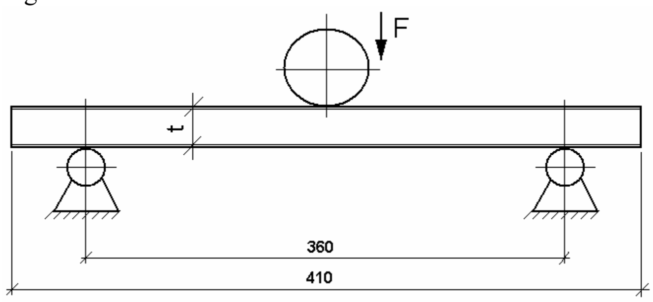

Fig. 1. Specimen loading scheme

The face of specimen was placed on supports so that its longitudinal axis was perpendicular to the longitudinal axes of the supports, while the centre was under loading. The experiment was done in the tension machine "P5", using reverse clutches. Loading speed was 5 mm/min, the highest loading was achieved over 60 ±30 s. Modulus of elasticity in bending is determined (calculated) by using the slope of the linear region of the load-deflection curve (at 10 % and 40 % of the maximum load). The inward bend was measured in the centre of the specimen with 0.1 mm accuracy, and the dependence of this value on corresponding loadings, measured with 1% value accuracy, was drawn. Standard deviation of strength values comprised 1.16 ÷ 4.65.

RESULTS AND DISCUSSIONS

Having conducted studies, modulus of elasticity E and bending strength f_m for the following types of panels was ascertained: CPL – 18 mm thick particleboard coated with laminated plastic on both faces (CPL); P&1L – panel coated with compensatory paper and one layer of sliced veneer; Foil – panel coated with paper-based film; P – panel covered with compensatory paper; UV – panel covered with enamel paint; 0L – untreated panel; 1L – panel covered with 1 layer of sliced veneer; 2L – panel covered with 2 layers of sliced veneer; 3L – panel covered with 3 layers of sliced veneer; 4L – panel covered with 4 layers of sliced veneer; 5L – panel covered with 5 layers of sliced veneer; 6L – panel covered with 6 layers of sliced veneer; 7L – panel covered with 7 layers of sliced veneer; 8L – panel covered with 8 layers of sliced veneer.

Modulus of elasticity E in bending for fourteen different types of coating material is presented in Fig. 2.

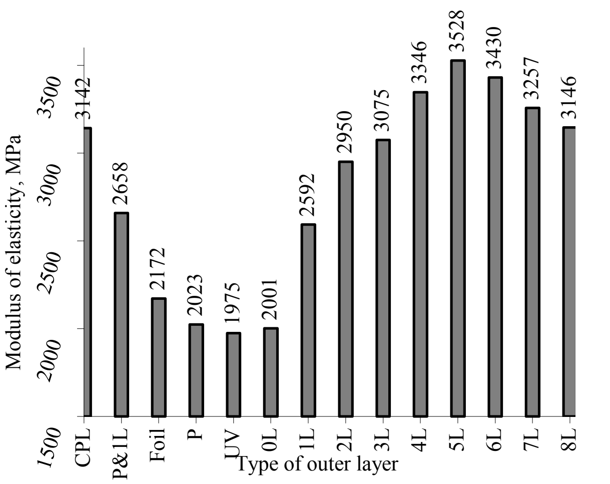

Fig. 2. Dependence of the modulus of elasticity in bending on the type of coating material

Bending strength f_m for fourteen different types of coating material is presented in Fig. 3.

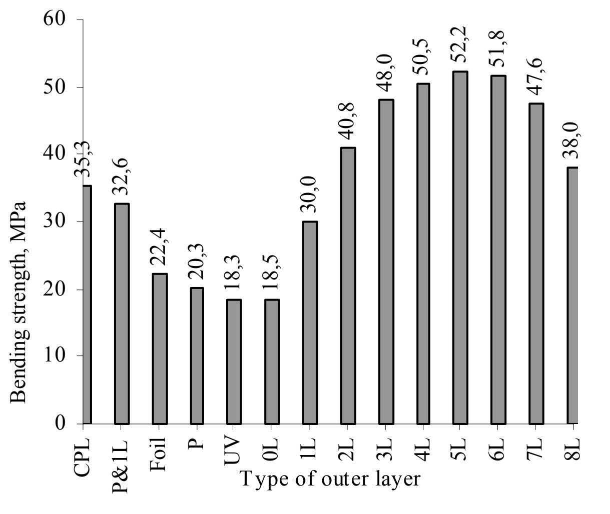

Fig. 3. Dependence of bending strength on the type of coating material

Fig. 2 and Fig. 3 show that bending strength and modulus of elasticity are closely interrelated and depend on the type, structure and thickness of coating material. Correlation of both the characteristics may be described by correlation coefficient – 0.9635. It is possible to state that the treatment of panel details with enamel paints has no influence on the mechanical properties of panels, except surface strength and moisture resistance, but they are not the object of this study. All the rest coatings have significant influence on the main mechanical indices of panel details, i.e. modulus of elasticity E and bending strength f_m considerably increase, as compared to the untreated particleboard (see Figs 2, 3).

Coating panel with compensatory paper, increases panel bending strength by 10 %. Coating with roll laminating film increases strength by 21 %, coating with 1 layer of sliced veneer – by 63 %, while coating with laminated plastic (CPL) – by 91 % (almost twice). A study was also conducted by covering panels with two different coatings, i.e. firstly panels were covered with compensatory paper and afterwards with 1 layer of sliced veneer. Panel bending strength increased by 77 % (coating with compensatory paper increased strength limit by 10 %, while coating with one layer of sliced veneer – by 67 %,). It is possible to state that the influence of two different coatings on panel element strength limit is summed up. The highest strength value is attained when panel is covered with 5 layers of sliced veneer – 52.2 MPa, i.e. the strength increases almost 3 times as compared to the untreated panel.

Modulus of elasticity, depending on the treatment method of panel details, increases not so intensively as the bending strength: if bending strength limit may be increased up to 2.8 times, the modulus of elasticity only up to 1.7 times, or almost by 50 % – 60 % less. Such an uneven change of the parameters (i.e. covering panel details with different coatings, bending strength increases more than modulus of elasticity) may be explained by the fact that modulus of elasticity is ascertained in the zone of elastic deformations.

Covering of panel details with different coatings increases panel modulus of elasticity bending it statically. Having covered panel surface with compensatory paper, panel modulus of elasticity in bending increased by 1 %. Panel coating with roll laminting film increased modulus of elasticity by 9 %, coating with one layer of sliced veneer – by 30 %, while coating with laminated plastic (CPL) – by 57 %. Having covered panels with two different coatings, i.e. compensatory paper and then one layer of sliced veneer, panel modulus of elasticity in bending increased by 33 %. It was found that the influence of two different coatings on the modulus of elasticity of panel element are summed up. The highest value of modulus of elasticity is reached when the panel is coated with 5 layers of sliced veneer – 3528 MPa, i.e. modulus of elasticity increases almost 2 times as compared to the untreated panel.

The dependence of panel element bending strength f_m on coating thickness was determined when panel surface is covered with a 1 to 8 coating layers of mahogany veneer (Fig. 4).

Bending strength f_m dependence on coating thickness may be described by regression equation (determination coefficient $R^2 = 0.995$):

$$f_m = -4\,t^2 + 23.55\,t + 18.04\,, \qquad (1)$$

where t is coating thickness.

The calculated function extreme was $t = 2.94$ mm. As it can be seen in Fig. 4, the most intensively panel strength increases when coating thickness augments up to 1.8 mm, while the highest strength value − 52.2 MPa is attained when coating thickness reaches 3 mm. Further increasing coating thickness up to 4.8 mm, panel strength decreases by 1.37 times. Such a decrease may be explained by the fact that when the thickness and stiffness of coating increases, shear occurs between inner layers of the panel, causing failure of the inner layers.

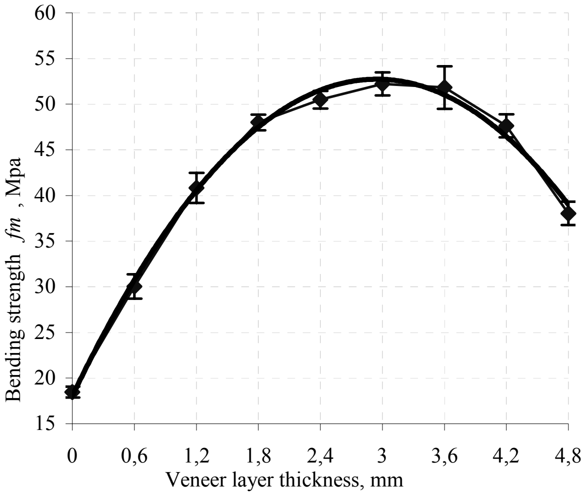

Fig. 4. Dependence of panel element bending strength on coating thickness

Analysing the failure of specimens, it was observed that all specimens failed according to two failure schemes. Specimen failure schemes are provided in Fig. 5.

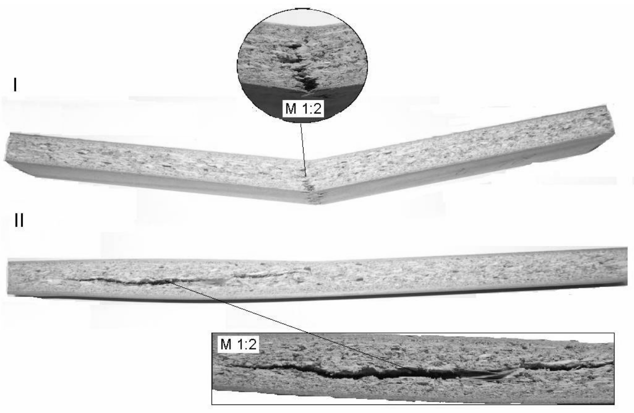

Fig. 5. Specimen failure scheme: I – specimen failed during fracture of the coating i; II – specimen failed during separation of inner layers

The greatest portion of specimens (55 %) fails during fracture of the coating, while the rest portion (45 %) fails due to separation of inner layers.

During statical bending of specimens, bottom layer of particleboard and its coating undergo tension, while upper layers undergo compression. When loading exceeds strength limit of the bottom layers, they break and the specimen fails according to scheme I of failure. When a specimen is covered with several layers of sliced veneer, the stiffness of outer layers considerably increases, due to which, under the appearance of inner shear, the specimen fails when inner layers fall apart according to scheme II of failure. Based on the data of literature sources [5], modulus of elasticity of a multilayered element equals the sum of *i* layer modulus of elasticity E_i and inertia moment I_i products divided by the total cross-section inertia moment I_c:

$$E_c = \frac{1}{I_c}\sum_{i=1}^{n} E_i I_i \, , \tag{2}$$

where *i* is layer index, E_i is modulus of elasticity of *i* layer, I_i is inertia moment of *i* layer, I_c is inertia moment of cross-section of the specimen.

Knowing the values of modulus of elasticity of particleboard and sliced veneer, theoretical modulus of elasticity for multilayered element is calculated (Fig. 6).

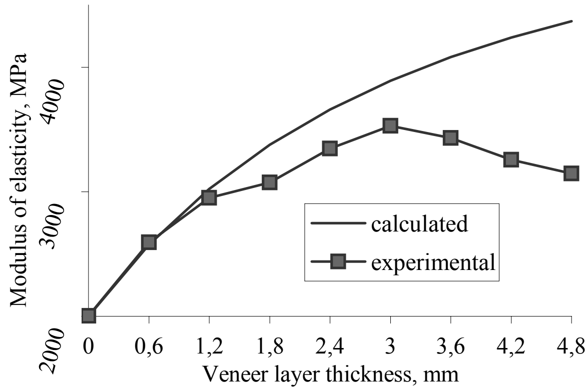

Fig. 6. Dependence of the modulus of elasticity for multilayered element on coating thickness

Fig. 6 shows that the calculated modulus of elasticity corresponds the one ascertained during studies, when coating thickness augments up to 3 mm. When coating thickness increases from 3 mm to 4.8 mm, modulus of elasticity decreases, although theoretically it should increase. This is caused by the appearance of shear inside particleboard. As far as this layer is characterized by the lowest strength, thus, when specimens fail according to scheme II, lower values of modulus of elasticity are obtained.

CONCLUSIONS

1. Coating of particleboard with laminated plastic, sliced veneer, compensatory paper, paper-based film essentially increases modulus of elasticity and bending strength limit.
2. Coating of particleboard with enamel paints fail to change the strength properties of material.
3. Panel coating with compensatory paper increases its bending strength by 10 %, with roll lamininting film – by 21 %, with one layer of sliced veneer – by 63 %, with laminated plastic (CPL) – by 91 % (almost twice).
4. Analysing the structure of different materials it was observed that the influence of different coatings on panel strength is summed up. Having covered panel surface with compensatory paper and one layer of sliced veneer, panel bending strength increased by 77 %.
5. The highest strength value is attained when panel is coated with five layers of sliced veneer – 52.2 MPa, i.e. strength increases almost 3 times as compared to the untreated panel. Further increasing coating thickness up to 4.8 mm, panel strength decreases by 1.37 times.

6. Modulus of elasticity in bending, depending on the coating method of panel details, increases by 50 % – 60 % less intensively than bending strength.

7. The increase of modulus of elasticity, results on the proportional decrease of horizontal panels deflection. The obtained results can be used for the practical calculations during design furniture with longer shelves at the same thickness of board.

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Presented at the National Conference "Materials Engineering'2006" (Kaunas, Lithuania, November 17, 2006)