ACTA UNIVERSITATIS AGRICULTURAE ET SILVICULTURAE MENDELIANAE BRUNENSIS

Volume LIX 9 Number 3, 2011

ANALYSIS OF CAUSES OF WARPING THE PLYWOOD SHEETS

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Received: September 3, 2010

Abstract

HRÁZSKÝ, J., KRÁL, P: *Analysis of causes of warping the plywood sheets.* Acta univ. agric. et silvic. Mendel. Brun., 2011, LIX, No. 3, pp. 59–72

The aim of the paper was to analyse the shape stability of plywoods. Following operations were monitored: storing the construction veneers, spreading the gluing mixtures, prepressing, pressing and the storage of plywoods. The shape stability of plywoods is affected by various factors and technological parameters of particular operations. It is one of the important parameters to assess the quality and use of plywood sheets in practice. On the basis of the analysis of the present condition of the problems a methodical procedure was prepared to determine causes of warping the plywood sheets. According to this procedure an experiment was created. Within this experiment parameters were determined, which affect warping the plywoods. The moisture and temperature of veneers and pressed plywood sheets rank among the most important parameters affecting shape stability. The size of the camber of pressed plywood sheets was also determined. Results showed that the warping of plywood sheets resulted particularly from the area distribution and variation of the moisture of veneers and plywoods, which was also related to temperature. These values of moisture and temperature result, e.g., from the relative air humidity and temperature, pressing parameters but also storing in stacks and appropriate storage. On the basis of the effect of determined parameters mentioned in this paper, the larger or smaller warping of plywood sheets originates, which is expressed by the shape change and size of their camber.

laminated massive materials, constructive veneer, plywood, number of layers, pressing, moisture content, temperature, warping, camber, density, mechanical properties

Plywoods are defined as sheets with plies glued each other the direction of fibres of neighbouring plies being usually perpendicular. Plywood as well as agglomerated materials are ranked among large-area materials. They are produced by pressing the sets of veneers, which are hot-treated with synthetic glue under the interaction of pressure (Král, Hrázský; 2005). Plywood materials overcome largely three main drawbacks of solid wood, viz. material anisotropy and heterogeneity, insufficient dimensional stability at moisture changes and problems relating to the creation of large areas through their construction lay-out.

Laminated massive materials are characterized by large-area dimensions, uniform mechanical properties and higher resistance to outer effects. As compared to solid wood glued laminated materials are characterized by higher stiffness and higher resistance to cleaving and warping. They are substantially lighter (due to lower density) showing higher values of particular mechanical and physical properties.

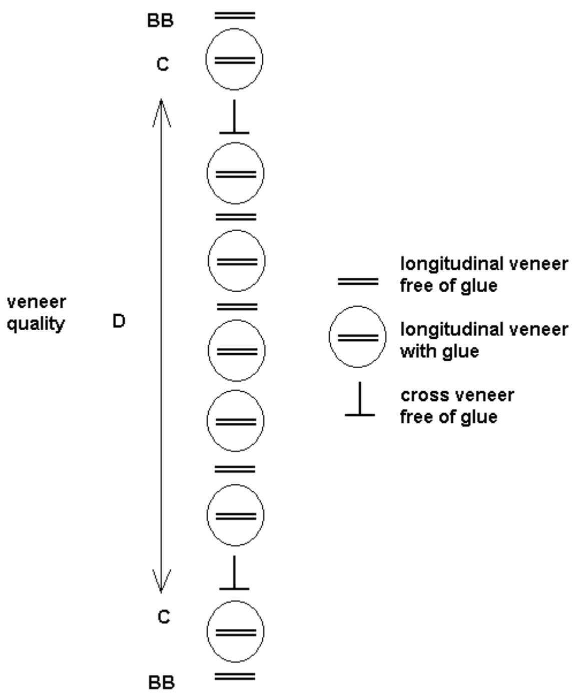
Mechanical and elastic properties of these materials depend in a large extent on the distribution of sets, which were used for their manufacture. Particularly the number of layers, their thickness and the lay-out of the veneer sets as well the kind of used wood and the quality of veneers rank among the main factors affecting mechanical properties of plywoods (the occurrence and number of defects).

The objective of the paper was to analyse the shape stability of plywood sheets manufactured by an important producer in the CR, to evaluate measured values and to propose recommendations to prevent from causes of the warping of plywood sheets. At the determination of technological parameters, attention was paid to the temperature and moisture of veneers and plywood sheets at particular technological stages of production (storing the construction veneers, spreading gluing mixtures, prepressing, pressing and storing the plywoods).

MATERIAL AND METHODS

To carry out the analysis of causes of warping Multiplex plywoods were selected. A urea-formaldehyde adhesive was used to glue the plywood sheet veneers. The Multiplex plywood is an initial half-finished product for the manufacture of frame moldings known under a trade name *Frame*. They are manufactured from beech veneers 1.5 mm in thickness. Most of veneers are of the same direction of the course of wood fibres whereby the high bending strength (along the grain) is achieved. After machining, plywood sheets are cut to required dimensions of frame moldings, which serve as an intermediate product for the manufacture of frames of beds and other suitable applications. Class of gluing 1 (IW 20) according to the ČSN EN 314-2 standard. Frame moldings designed for inner use, ie the dry environment according to the requirements of the ČSN EN 636 standard. They are not harmful from sanitary aspects corresponding to the emission class E 1 according to the ČSN EN 1084 standard.

In case of this experiment, a plywood sheet was used composed of 14 plies of beech veneers. The veneers differed from each other by the quality, orientation of wood fibres and the glue spread quantity (Fig. 1).



1: *The composition of a plywood sheet for the manufacture of frame moldings*

Types of veneers

a) Veneers of BB quality
   - veneers of the highest quality, which are used for surface layers of a plywood sheet. These veneers are without adhesive at the composition of sets.

b) Veneers of C quality
   - veneers of lower quality, which are used under the surface layer. They are two-side glue spread.

c) Veneers of D quality
   - veneers of the worst quality, which create the rest of central veneers in the plywood sheet. Half of them are two-side glue spread.

Veneers of the BB and C quality are lengthwise, ie the direction of wood fibres of veneers is parallel with the plywood sheet length. At the D quality, all veneers are lengthwise with the exception of two transverse veneers, which are laid as the third ply at each side from the plywood sheet surface. The transverse veneers are not glue-spread.

Particular veneers differ also in dimensions:	
BB without glue	longitudinal size 2 270 × 1 330 mm
C with glue	longitudinal size 2 270 × 1 330 mm
D without glue	longitudinal size 2 270 × 1 350 mm
D with glue	longitudinal size 2 270 × 1 330 mm
D without glue	longitudinal size 1 350 × 2 300 mm.

The warping of plywood sheets is affected by many surrounding factors during the whole process of their manufacture. Within this analysis, attention was paid to stages from the storage of construction veneers to the storage of finished plywood sheets.

The actual material for the manufacture of plywood sheets (veneers), which is characterized by moisture and temperature, is a basic monitored factor affecting the warping of plywoods. Moreover, parameters were also monitored, which did not directly refer to the material but affected more or less the shape stability of plywood sheets. The parameters include particularly the relative air humidity and temperature in a pressing shop and in the storage room, the quantity of the gluing mixture spread, pressing temperature, working pressure and time. The camber of a finished plywood sheet was monitored as well. The analysis was carried out on 6 plywood sheets. This number was also selected by reason of the maximum capacity of a multi-storeyed hydraulic pressure. With respect to the sufficient number of layers in plywood, the moisture and temperature of particular veneers was determined only at plywoods 1 to 3. The plywoods were marked at composing the set of veneers before pressing. The moisture, temperature and camber of plywoods were measured at all samples after pressing. To achieve the optimum number of moisture values the measurement of temperature was carried out within the whole area a veneer, namely always at 15 points. The veneers were deposited in bunches in a pressing shop and the veneer moisture was measured manually by an electric moisture meter

Aqua Boy HM I accurate to one decimal place. The extent of values of moisture at this moisture meter is 5–28%.

The temperature of veneers was also measured in a pressing shop together with moisture, however, only in one point, namely in the veneer centre. A manual digital thermometer SENSITEST 2000 was used. The measuring configuration consists of a digital thermometer SENSITEST and an appropriate probe SENSITERM.

Parameters of the ambient environment were determined by means of a digital hygrometer and air thermometer.

Spreading the gluing mixture was carried out on a double-sided cylindrical glue spreader. The quantity of the gluing mixture spread was 217 g/m^2.

Sets of veneers were pressed in a multi-storeyed hydraulic press HBR 6/15 storeys (260 × 170 cm), manufacturer KSB Brno. Filling the press proceeded manually by means of 3 workers and a lifting platform installed in front of the press.

Technological parameters:		
Pressing temperature:	113.6 °C	Pressing time: 17 min.
Temperature of the pressing plate edge:	108 °C	
Working pressure (manometric):	11 N/mm^2	
Working pressure:	1.2 N/mm^2	

Pressed sheets were cut off on a four-sided dimensioning saw to a final dimension 2 250 × 1 280 mm. This dimension corresponds to the standard setting of the saw for this product. For the purpose of checking the dimension was verified by a push-pull rule.

The determination of moisture and temperature of pressed plywood sheets was carried out using the same instruments and in the same way as in particular veneers before pressing. Values of moisture were measured again at plywoods No. 1 to 3 in 15 points to compare the moisture with the moisture of plywoods before pressing. Temperature was measured as in veneers, ie only in one point in the centre of a plywood. The measurement was carried out in a storage room after trimming to appropriate dimensions within an interval of 30 to 60 minutes after pressing and other measurement after 14 days at loading using a weight of 880 kg. The plywood sheets were not ground.

The determination of warping (camber) of plywood sheets was carried out according to the ČSN 49 0148 Standard by means of a measuring listel. A deviation of the plywood surface from a plane was measured perpendicular to the plane, namely in the centre of the length and width of the plywood. The value of a camber was determined by a dial deviation meter and a rule. The camber measurement proceeded in the same time intervals as at the determination of the plywood moisture and temperature.

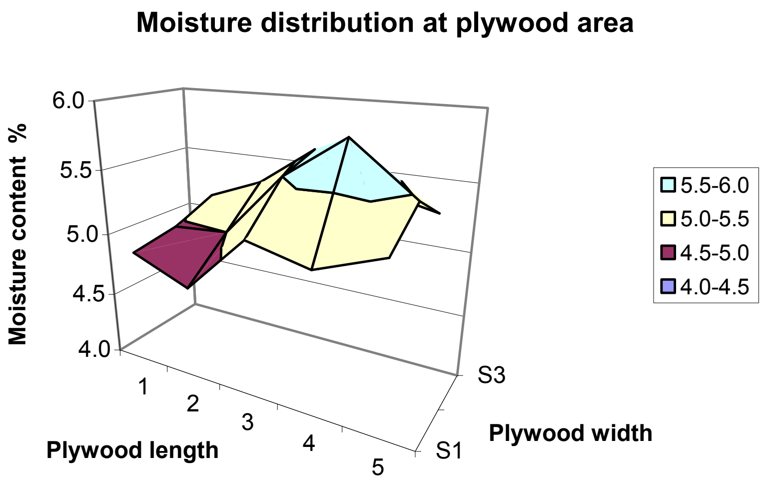
RESULTS

Based on the measured values of moisture in 15 points of particular veneers the lay-out of plywood sheets was calculated as mean values in these points at plywood sheets 1 to 3. These values are illustrated in Figs. 2–4.

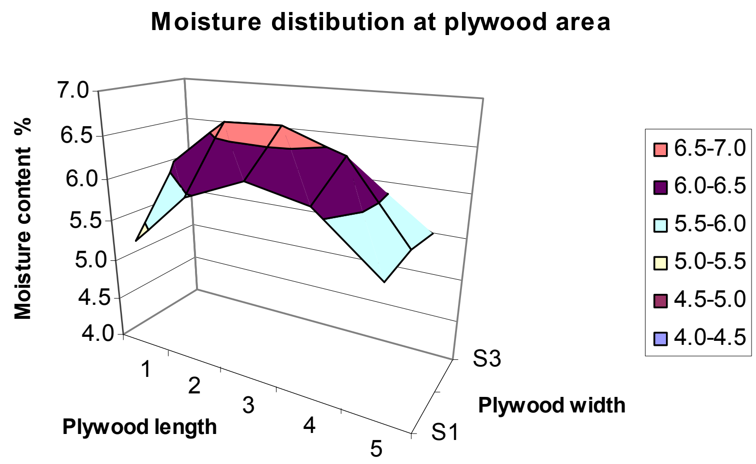
On the basis of measured temperatures in the centre of the area of particular veneers mean values were calculated (according to the layout of plywoods) in this point at plywood sheets Nos. 1 to 3. These values are demonstrated in Fig. 5.

To compare plywood sheets Nos. 1 to 3, values of moisture were determined (as before pressing) in the same way also in pressed plywood sheets, namely in 15 points of the plywood sheet area, namely in the storage room of plywood sheets within an interval of 30–60 minutes after pressing and then after 14 day.

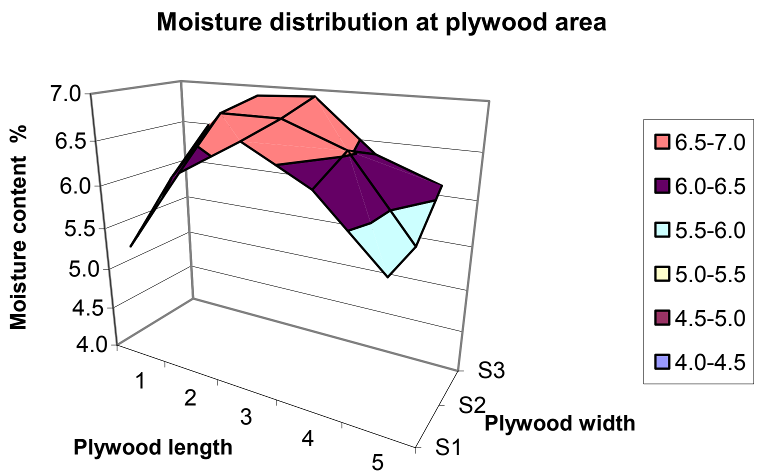
Thy plywood sheets were trimmed to a size of 2 250 × 1 280 mm. The sheets were not ground



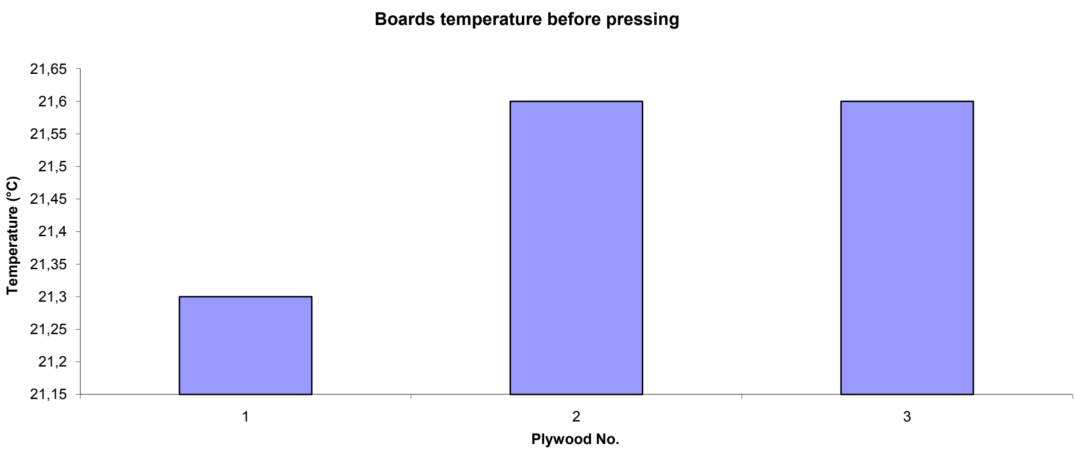
2: *Distribution of moisture content in the plywood sheet area before pressing – Plywood No. 1*



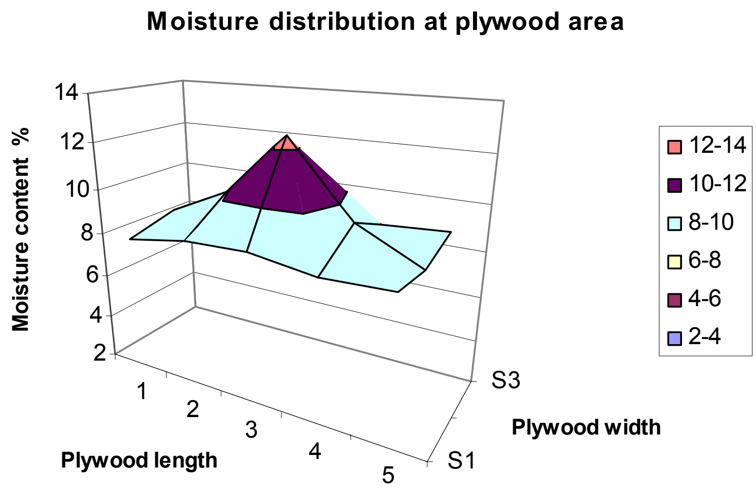
3: *Distribution of moisture content in the plywood sheet area before pressing – Plywood No. 2*



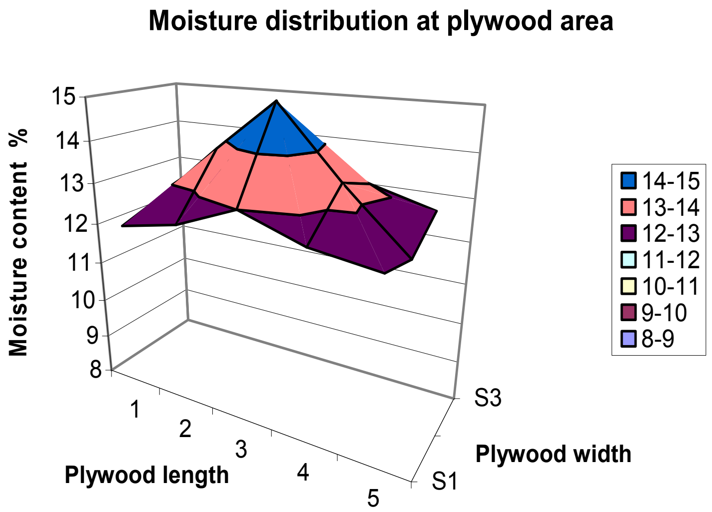
4: *Distribution of moisture content in the plywood sheet area before pressing – Plywood No. 3*



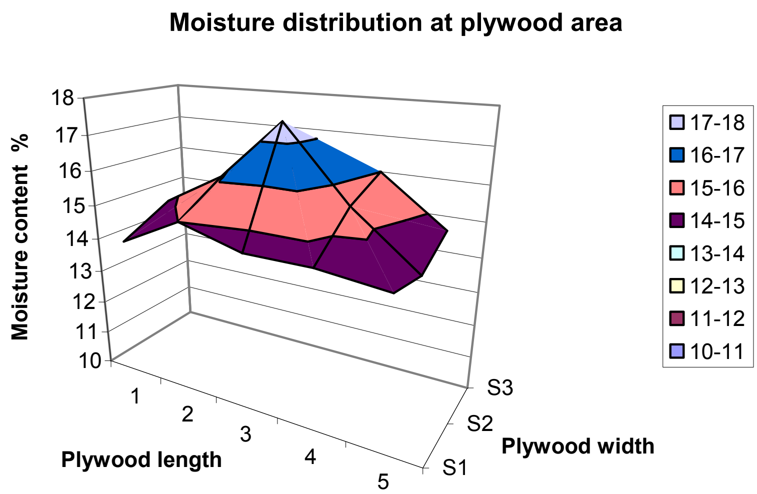
5: *Comparison of the plywood sheet temperature before pressing*



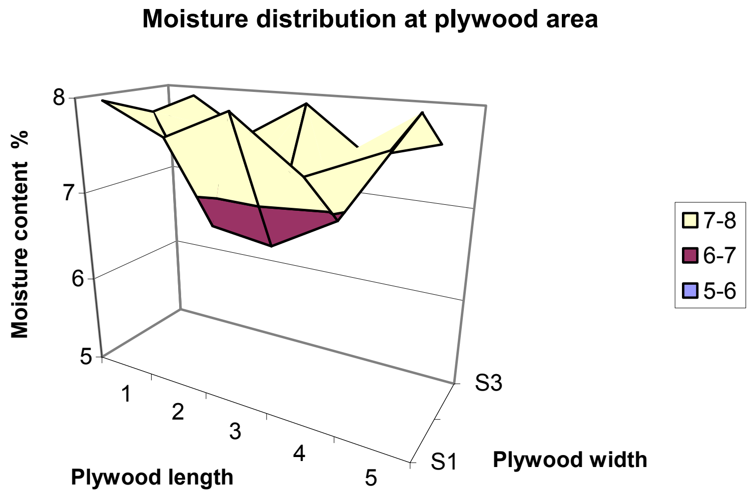
6: *Distribution of moisture content in the plywood sheet area after 30–60 minutes of storing in the storage room – Plywood sheet No. 1 (lower)*



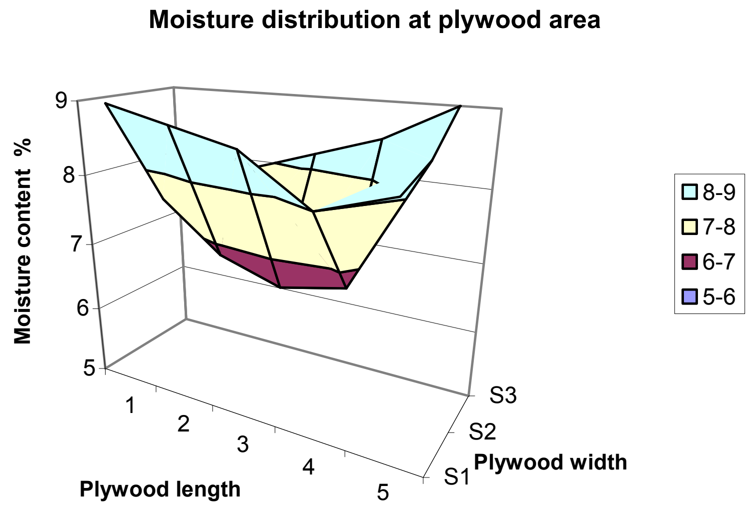
7: *Distribution of moisture content in the plywood sheet area after 30–60 minutes of storing in the storage room – Plywood sheet No. 2*



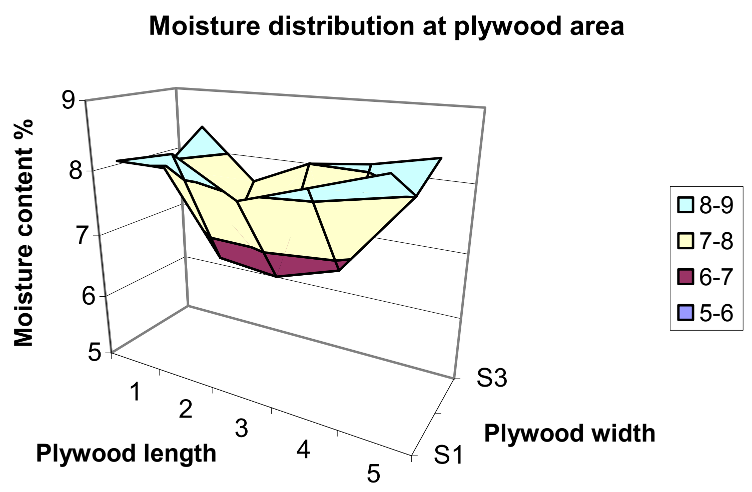
8: *Distribution of moisture content in the plywood sheet area after 30–60 minutes of storing in the storage room – Plywood sheet No. 3*



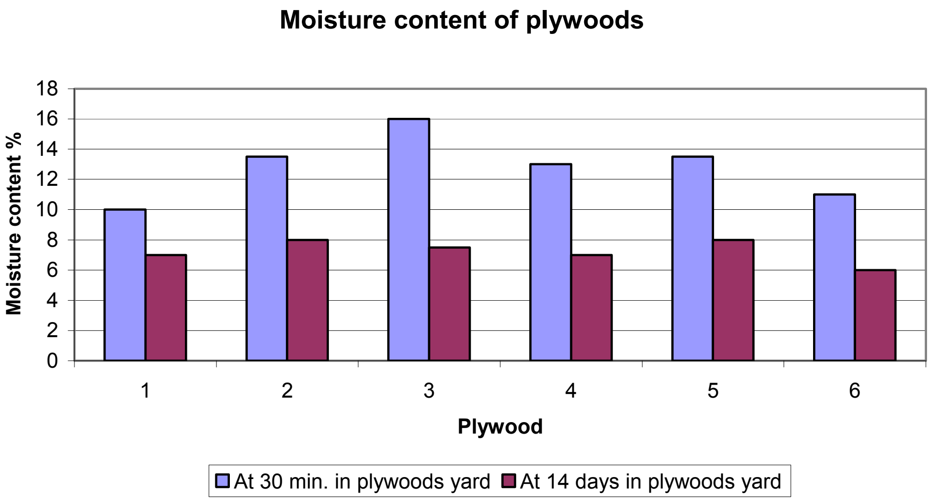
9: *Distribution of moisture content in the plywood sheet area after 14 days of storing in the storage room – Plywood No. 1 (upper)*



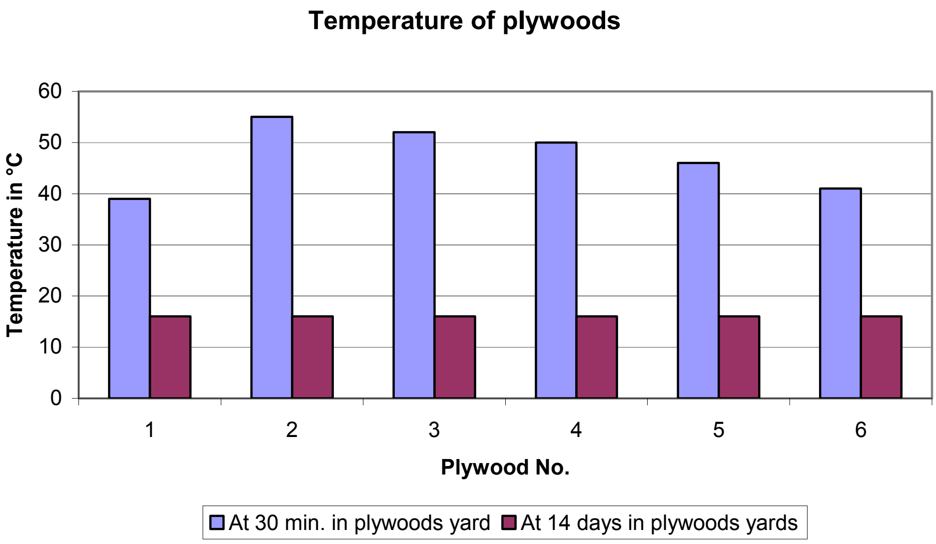
10: *Distribution of moisture content in the plywood sheet area after 14 days of storing in the storage room – Plywood No. 2*



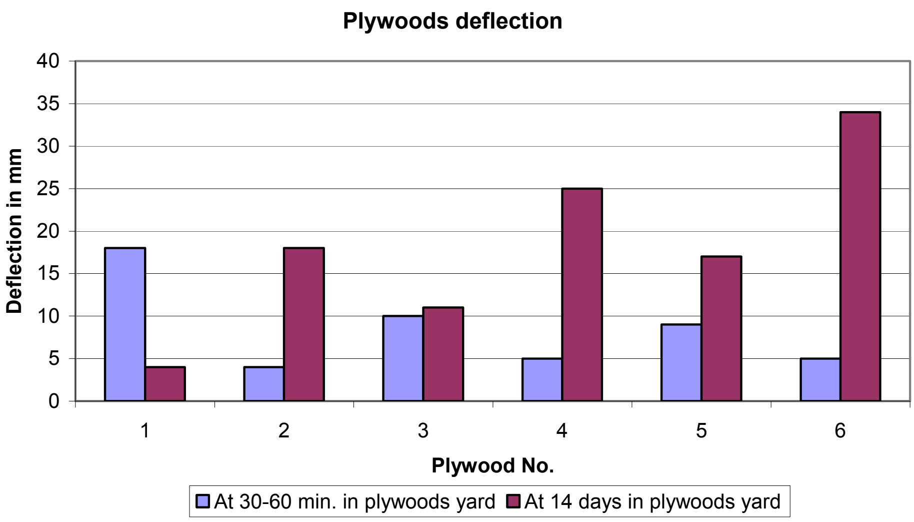
11: *Distribution of moisture content in the plywood sheet area after 14 days of storing in the storage room – Plywood No. 3*



12: *Comparison of the moisture content of pressed plywood sheets*



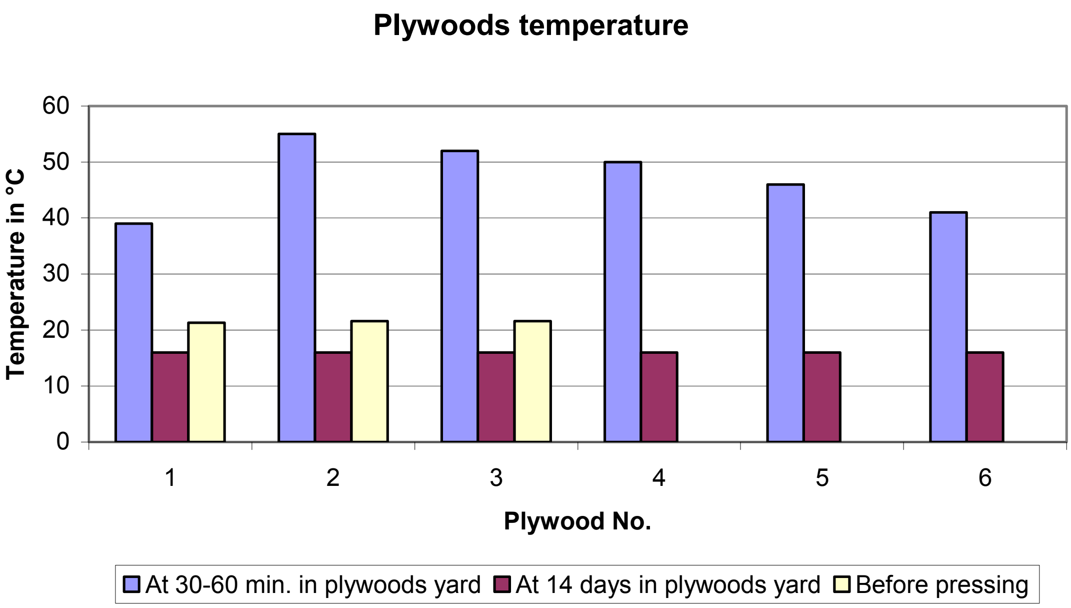
13: *Comparison of the temperature of pressed plywood sheets*



14: *Comparison of the deflection (camber) of pressed plywood sheets* (sanded) and before the second measurement they were loaded by the stack of plywood sheets of a weight of 880 kg for a period of 14 days. These values are illustrated in Figs. 6–12.

To compare the temperature of plywood sheets before and after pressing a diagram No. 15 has been constructed. Temperatures of plywood sheets before pressing were determined only at plywoods Nos. 1–3.

To compare basic statistic characteristics between two measured intervals, ie after 30–60 minutes and after 14 days in the storage room of plywood sheets, a descriptive statistics was created for the moisture, temperature and camber of pressed plywood sheets. Values of these characteristics are given in Tabs. I–III.



15: *Comparison of the temperature of plywood sheets before and after pressing*

I: *Descriptive statistics – moisture*

Plywood 1–6	Moisture	
Statistic characteristics	**after 30–60 min. in the storage room**	**after 14 days in the storage room**
Mean value	12.83	7.25
Mean value error	0.86	0.31
Median	13.25	7.25
Modus	13.50	7.00
Standard deviation	2.11	0.76
Sampling variance	4.47	0.58
Acuteness	−0.05	0.28
Skewness	0.11	−0.77
Difference between max. and min. values	6.00	2.00
Minimum	10.00	6.00
Maximum	16.00	8.00
Total	77.00	43.50
Number	6.00	6.00
Largest (1)	16.00	8.00
Smallest (1)	10.00	6.00
Confidence level (95.0%)	2.22	0.80

II: *Descriptive statistics – temperature*

Plywood 1– 6	Temperature	
Statistic characteristics	**after 30–60 min. in the storage room**	**after 14 days in the storage room**
Mean value	47.17	16.00
Mean value error	2.57	0.00
Median	48.00	16.00
Modus		16.00
Standard variation	6.31	0.00
Sampling variance	39.77	0.00
Acuteness	–1.70	–
Skewness	–0.20	–
Difference between max. and min. values	16.00	0.00
Minimum	39.00	16.00
Maximum	55.00	16.00
Total	283.00	96.00
Number	6.00	6.00
Largest (1)	55.00	16.00
Smallest (1)	39.00	16.00
Confidence level (95.0%)	6.62	0.00

III: *Descriptive statistics – camber*

Plywood 1–6	Camber (deflection)	
Statistic characteristics	**after 30–60 min. in the storage room**	**after 14 days in the storage room**
Mean value	8.50	18.17
Mean value error	2.14	4.28
Median	7.00	17.50
Modus	5.00	–
Standard variation	5.24	10.50
Sampling variance	27.50	110.17
Acuteness	1.95	–0.02
Skewness	1.42	0.28
Difference between max. and min. values	14.00	30.00
Minimum	4.00	4.00
Maximum	18.00	34.00
Total	51.00	109.00
Number	6.00	6.00
Largest (1)	18.00	34.00
Smallest (1)	4.00	4.00
Confidence level (95.0%)	5.50	11.01

DISCUSSION

In this paper, the shape stability or warping the plywood sheets produced by an important manufacturer in the CR were assessed. In the course of shrinking or swelling the wood changes in the shape of a product occur. This phenomenon is called warping. It originates because of the anisotropic character of wood hygroexpansion. The warping of wood can occur both in the transverse and longitudinal direction of products. The transverse warping is caused by different radial and tangential shrinkage of the studied product. The longitudinal warping originates by uneven lengthwise shrinking. Various parts of a plywood sheet do not shrink in the same way because main and general axes of the plywood sheet do not identify and “transformations” are used. Warping is a serious drawback, which makes difficult wood machining, utilization for constructions and wood products in the environment where the air temperature and humidity often changes.

Determination of plywood warping is carried out according to the ČSN 49 0148 standard. This standard applies to blockboards and particleboards, which are surface-untreated or treated, 16 mm or more in thickness, and plywoods 12 mm or more in thickness (Král, Hrázský, 2006). The warping of plywoods was affected by various factors, viz. both by an actual material and its physical properties such as moisture and temperature. Of course, there are other values and parameters, which are not related to the actual material; however, they affect more or less the shape stability of plywood sheets. For example, the relative humidity and temperature of air in a pressing shop and in the plywood sheet room, the size of the gluing mixture spread, pressing temperature, working pressure and time rank among these parameters.

Laminated pressed wood of beech veneers was selected as a material for experimental purposes. It is an initial intermediate product for the manufacture of frame moldings known under a trade name *Frame* being manufactured of various types of beech veneers 1.5 mm in thick. Construction differences compared to plywood consist in a fact that nearly all veneers show the same course of wood fibres whereby the high bending strength along the fibres is achieved. In this case, a plywood sheet of 14 beech veneers was used. The veneers differ from each other by their quality, orientation of wood fibres and also by the gluing mixture spread. This plywood was selected for that reason that it ranks among the most problematic product as for shape stability in a production plant. The problem of shape instability is caused particularly by the lay-out of a plywood sheet, ie by the number of veneer plies and direction of their fibres. A urea-formaldehyde adhesive was used as a bond medium to glue the veneers into a plywood sheet.

A methodical procedure to determine the warping of plywood sheets was prepared on the basis of the analysis of a present condition of studied problems. It includes the determination of technological parameters and the measurement of values at particular technological stages of production. The highest attention was paid to the moisture of starting veneers and the moisture of pressed veneers. On the basis of this procedure an actual experiment was carried out. Results of this experiment consist in data, which are given in tables and diagrams and to a certain extent are also statistically processed.

Warping the plywood sheets is affected by many factors during the whole process of production. In this experiment, attention was paid to particular stages from the storage of construction veneers to the storage of finished plywood sheets. An actual material for the production of plywood sheets (veneers), which is characterized by moisture and temperature, is a basic monitored factor. Thus, the highest attention was paid to these parameters. Moreover, also other values and parameters were determined, which were not directly related to the material, however, they also affected the shape stability of plywood sheets. Relative moisture and air temperature in the pressing shop and in the storage room, the size of the gluing mixture spread, pressing temperature, working pressure and time rank among them. The camber of finished plywood sheets was determined as a last parameter. Depending on the time consumption of the experiment, the amount of monitored factors and the informative value of the examined population it was determined that the experiment would be characterized by 6 plywood sheets. This number was also selected on the ground of the maximum capacity of a multi-storeyed hydraulic press.

Measurements of the veneer moisture were carried out throughout its area, viz. in 15 points. Veneers were placed in bunches in a pressing shop and their moisture was measured manually by an electric moisture meter Aqua Boy HM I accurate to one decimal place. Thus, it is evident that values of moisture differ both between particular veneers of the same and various type (lengthwise, transverse, quality BB, C, D), but also in the veneer area. It is caused primarily by placing the veneers in the bunch but also by their storage, ie appropriate storing the veneer bunches and ambient conditions (relative air humidity and temperature in the plywood sheet storage area). Veneers in the middle of the veneer bunch show higher values of moisture than veneers placed on its edges. Edges of veneers with the higher access of air show again lower values of moisture than other areas of the veneer. At lengthwise veneers of the D, C and BB quality, values of moisture varied between 4.5 and 8%. At transverse veneers of quality D, moisture was determined within the limits 5–8.5%.

The temperature of veneers was measured also in the pressing shop together with moisture, of course, only in one point, namely in the veneer centre. Values obtained differ similarly as in moisture between particular veneers of the same and different type, however. Causes are similar as in moisture (placing the veneers in a bunch, appropriate storing, relative moisture and temperature of air in the storage room). Values of temperature ranged from 21 to 22 °C with the exception of one lengthwise veneer of quality D, which showed 23 °C.

Parameters of ambient air affect also to a certain degree the warping of plywood sheets. The relative humidity and temperature of air was determined at every measurement in the pressing shop before the measurement of veneers and then in the plywood storage room.

At the measurement of veneers, which was carried out in the pressing shop on 10/2/ 2009, the relative humidity of air was 38% and temperature 22.2 °C. In the same day, of course after 30–60 minutes, these parameters were 40% and 14.8 °C. After 14 days, ie on 24/2/ 2009, the relative humidity of air was the same, ie 40%, however, the value of temperature increased to 15.9 °C.

Spreading the gluing mixture was carried out on a double-sided cylindrical glue spreader. The quantity of the gluing mixture amounted to 217 g/m^2. This value should not have a negative effect on the plywood sheet warping because the size of spreading for urea-formaldehyde adhesives is used within the limits 150 to 240 g/m^2.

Sets of veneers were pressed in a multi-storeyed hydraulic press HBR 6/15 storeys (260 × 170 cm) manufactured by KSB Brno Co. Feeding the press was done manually by means of 3 workers and a lifting platform installed in front of the press. At pressing, technological parameters were measured such as pressing temperature reaching 113.6 °C and a temperature of the pressing plate edge 108 °C. Moreover, a manometric working pressure reaching 11 N/mm^2 was recorded and pressing time amounting to 17 minutes was determined. These parameters are used on a regular basis at pressing this line of plywoods.

Pressed plywood sheets were trimmed using a four-sided dimensioning saw to a finished size 2 250 × 1 280 mm. This size corresponds to the standard set of a saw for this product assortment. For the purpose of verification it was measured by a tape rule.

Values of moisture were calculated at plywoods 1 to 3 as mean values of the moisture of veneers in particular points according to the lay-out of plywood sheets. These values are demonstrated in Figs. 2–4. The values differed in the area of each of the plywood sheets as well as between particular plywoods, which resulted of course from previous determined values of the moisture of veneers. At plywood 1, values of moisture ranged within the limits 4.7–5.8, at plywood 2 from 5.3 to 6.7 and at plywood 3 from 5.4 to 6.9. Values of the temperature of plywood sheets before pressing were calculated at plywoods 1 to 3 as mean values of the temperature of veneers in one point, namely in the veneer centre according to the lay-out of a plywood sheet. They are demonstrated in Fig. 4. The value of the plywood 1 temperature was 21.3 °C. At plywoods 2 and 3, the values were the same, viz. 21.6 °C. Similarly as in moisture, these values result from previously measured values of the temperature of veneers.

To compare plywoods 1 to 3, values of the plywood sheet moisture were determined after pressing in the same way as before pressing also at pressed plywood sheets, ie in 15 points of the plywood area, namely in the storage room of plywood sheets at an interval of 30–60 min. after pressing and then after 14 days. The plywood sheets were trimmed to a size 2 250 × 1 280 mm. The sheets were not ground. Before the second measurement, they were loaded by a stack of plywood sheets 880 kg in weight for a period of 14 days. These values are illustrated in Figs. 5–10.

Comparing the moisture of pressed plywood sheets after storing 30–60 min. in the storage room and the sheets before pressing it was found that values of moisture at all pressed plywood sheets were lower, which resulted from the glue spread and the whole course of pressing (increasing the temperature, pressure etc.). The values were higher on average by 5% at plywood 1, by 8% at plywood 2 and by 9% at plywood 3. At the moisture of plywood sheets after 14 days of storing in the storage room differences were not already marked. Values were higher on average by 1.5% at all plywoods.

The distribution of moisture in the plywood area after 30 to 60 minutes in the storage room is evident from Figs. 6–8. It is possible to see the variation of moisture in marginal parts of plywoods as against central parts. It is caused by the uneven release of moisture in these parts of plywood. At plywood 1, moisture on edges was 8–9.5% while in the central part 9.4–12.5%. This plywood was stored in a stack as a lower one and, thus, it showed the lowest values of moisture on the ground of the access of air from below the stack and, thus, also the highest release of moisture. Plywood 2 showed higher values, its edges had 12.1–13.5% and its central part 13.4–15%. Plywood 3 showed the highest moisture, edges within the limits 14.1–16% and the plywood central part 15.5–17.5%. Higher values of moisture at plywoods 2 and 3 are given by the nearer placing to the stack centre, whereby the release of moisture from plywoods is made difficult.

The distribution of moisture in the area of plywood after 14 days in the storage room is evident in Figs. 9–11. After this time, the plywood moisture decreased but fundamental changes occurred in the area distribution of moisture. In this case, the release of moisture changed and centre values varied as against edge values. Plywood 1 showed moisture 6.5–6.9 and 7.4–8% in the central part and at edges of the plywood sheet, respectively.

After the first measurement, the stack was disarranged and transported and so plywood 1 was stored as the first. After this time, such differences in moisture are not so obvious among plywoods 1 to 3. At plywood 2, moisture in the central part was 6.5–6.8% and in edge parts 7.5–9%. Plywood 3 showed moisture reaching 6.5–6.8% in the central part and 7.6–8.5% at the plywood edges. Thus, the area distribution of moisture after 14 days of storage changed fundamentally, which could be considered to be the most important factor affecting warping the plywood sheets.

Mean values of moisture were compared at all pressed plywoods (1 to 6) among each other and in both determined intervals of storing in the storage room. Their values are given in Fig. 12. At plywoods measured after 30–60 minutes and placed in the storage room, these mean values ranged within the limits 10–16%, at next measurement the interval was smaller, viz. 6–8%.

The temperature of plywood sheets was measured in one point in the centre of the plywood. Values of the temperature of plywoods are illustrated in Fig. 13. At plywoods measured after 30–60 minutes in the plywood storage room, these values ranged from 39 to 55 °C, the upper and lower plywood sheets showing the lowest values, which was given by their placing in the stack similarly as in case of moisture. At other measurements, determined values at all sheets were identical, viz. 16 °C.

Thus, it is evident that temperatures of plywoods adapted to the tempered storage room the temperature of which was 15.9 °C. In Fig. 15, temperatures of all plywood sheets are compared in both measured intervals in the storage room with temperatures of plywoods 1 to 3 before pressing. The figure shows that the temperature of pressed plywoods after 30–60 minutes in the plywood room was markedly higher than before pressing (at plywood 2 even by 34 °C), which is given (as in case of moisture) by the course of pressing (particularly by high pressing temperature). Of course, at plywoods stored for 14 days, their final temperature was lower than at plywoods before pressing, namely by about 5.5 °C.

Determination of the rate of warping the pressed plywood sheets was carried out by means of a measuring bar. A deviation of the plywood surface from a plane was measured perpendicular to the measuring plane, namely in the centre of the plywood length and width. The value of a camber (deflection) was determined by a dial deviation meter and ruler. The measurement was carried out in the same time intervals as at the determination of the plywood sheets moisture and temperature. The values are illustrated in Fig. 13. Based on the diagram it is evident that the camber markedly differs between particular plywood sheets in the certain interval of measurement and between both intervals. At the first measurement, plywood 1 was stored as a lower one and the camber reached a value of 18 mm while plywood 6 was upper one and the camber was only 5 mm. Of course, after 14 days of storing, these values reversed absolutely. At plywood 1, which was stored as the upper one, the camber decreased from 18 only to 4 mm and at plywood 6 (lower), the camber increased from 5 even to 34 mm. It can be explained by a fact that the plywoods were loaded by a stack of plywood sheets of a weight of 880 kg whereby the shape deformation but also the release of moisture was reduced at plywood 1 in contrast to plywood 6, which was placed on stickers. It did not reduce anyway shape deformations or the release of moisture. Other marked changes were found at plywood 2 and 4 while plywood 4 showed little better parameters and the smallest changes occurred at plywood 3 (only 1 mm). It is necessary to point out that the change of camber to a lower value was found only at plywood 1. At other plywoods, the camber more or less increased. To eliminate courses of warping the plywood sheets we propose to realize following recommendations during their production:

At the preparation of plywood sheets for pressing to determine the moisture of veneers both on their surface and in the middle of a stack. To monitor the use of the whole size of veneers into particular layers of plywood. At the operation of spreading gluing mixtures, to test the methodology of determining the spread size with an objective to achieve constant spread. To check the composition of a gluing mixture. In the course of pressing, to check pressing parameters, to carry out the measurement of thickness and moisture of plywoods. To change the method of storing the plywood sheets after pressing, to place the sheets on a sufficient number of stickers of the same dimension according to the size of plywood sheets and to load the plywood sheets after pressing as soon as possible.

A possibility to use the cold pre-pressing of plywood sheets should be considered as an important recommendation. It means to compress groups of veneers nearly to a final thickness without reaching the final curing of the glue mixture. Thus, applying this operation it is possible to eliminate a drawback of the uneven distribution of moisture in the plywood area. Air-conditioning of finished plywoods in the tempered and covered environment using appropriate stickers for plywood sheets should be carried out according to standard specified methods.

CONCLUSIONS

The aim of the paper was to analyse the shape stability of plywood sheets manufactured by an important producer of plywoods in the Czech Republic. Shape stability is one of important parameters to assess the quality and use of plywoods in practice. All values of factors and technological parameters, which are used in this paper, were measured in a concrete production plant. They are processed and presented in tables and diagrams.

Deformations of plywood sheets are caused by many reasons, for example by the structure of wood (the course of fibres), construction of a plywood sheet (the construction evenness of dimensional and material regularity), moisture of processed veneers and plywoods and the spread of a glue mixture, the actual pressing cycle or storing and air- conditioning of finished plywoods.

On the basis of the analysis of a present condition of studied problems a methodical procedure was prepared to determine causes of warping plywood sheets. According to this procedure, the actual experiment was created. Within this experiment parameters affecting warping the plywood sheets were determined. The moisture and temperature of veneers and plywoods rank among the most important factors affecting shape stability. The size of camber of pressed plywood sheets was also determined. Thanks to the graphical processing of measured data it is possible to compare particular parameters (moisture, temperature and camber) both among examined plywood sheets and between time intervals when these values were determined.

Results obtained showed that warping the plywood sheets was caused particularly by the area distribution and fluctuation of the moisture of veneers and plywoods, which was also related to temperature. These values of moisture and temperature result, e.g., from the relative humidity and temperature of air, pressing parameters but also storing in stacks and appropriate storage.
Results of the analysis show that on the basis of effects of all determined factors mentioned in this paper the larger or smaller warping of plywood sheets originates, which is expressed by shape changes and the size of their camber.

Acknowledgement

Supported by the Czech Republic Ministry of Education, Youth and Sports, Project No. MSM 6515648902.

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