

## DOWEL CORNER JOINTS IN CASE CONSTRUCTION – EFFECT OF DOWEL DIMENSIONS ON STRESSES AND JOINT DEFORMATION

*by Arnold Wilczyński and Marek Kociszewski*

Institute of Technology, Bydgoszcz University

The dowel corner joint in case furniture in, which pine wood was material of joint members, was investigated. The effect of variable dimensions of the joint: the dowel diameter and the depths of dowel embedment in the face and the edge member, on stresses in selected places of the joint and its deformation was determined. The finite element method was applied, assuming the three-dimensional state of stress. The deformation of the joint, which was the angle of the relative rotation of joint members, was also determined experimentally.

**Key words:** dowel joint, corner joint, case construction, glue line, finite element method, stresses, joint deformation

### INTRODUCTION

Despite the fact that dowel corner joints are widely used in the construction of case furniture, the knowledge of the strength and stiffness of these joints and the stresses and deformations of these joints is insufficient. This particularly concerns the influence of dimensions of the joint.

In the previous paper of the authors (Wilczyński and Kociszewski 2000) were presented the investigations of the dowel corner joint in case construction, in which pine wood members were joined by beech dowels and a glue line of polyvinyl acetate adhesive. The stresses in glue lines of the joint were determined by using the finite element method. The influence of the variable dowel dimensions: the diameter and the depth of embedment in the elements joined, on these stresses was investigated. The distributions of normal and tangential stresses in glue lines along the dowel were presented. It was ascertained that these stresses concentrate at the point of junction of the elements

joined, and that the peak values of these stresses considerably depend on the dowel diameter, but insignificantly on the depth of dowel embedment in the elements joined.

The analysis of stress in the glue lines of the dowel corner joint did not allowed to explain all the mechanical problems of this joint. Therefore, it was decided to make a wider analysis, including stresses in other essential places of the joint. The first aim of this study was to determine stresses in the transverse cross-section of the dowel and in the cross-section of the face member adjoining the bottom of the dowel hole for various joint dimensions: the dowel diameter and the depth of dowel embedment in the members joined.

Another problem important for rational design of case furniture is deformation of dowel corner joints. In several hitherto made investigations (Albin et al. 1987, Gressel and Kleinsorge 1989, Cai and Wang 1993, Kociszewski and Wilczyński 1998) deformations of dowel corner joints in case construction were experimentally determined, but they limited themselves to the joints with constant dimensions. Only Swaczyna and Piekacz (1996) took into consideration the variability of the dowel diameter: 6 and 8 mm, examining corner joints made of particleboard, medium density fibreboard and beech wood.

The second aim of this study was to determine deformation of the joint for various dowel diameters and depths of dowel embedment in the members joined.

The same model of the joint as in the previous paper of the authors (Wilczyński and Kociszewski 2000) was investigated. The finite element method (FEM) was used to determine the stresses and deformations of the joints. Besides, the deformations of the joint were determined experimentally.

## MATERIALS AND METHODS

The dowel corner joint, whose construction and dimensions are shown in Fig. 1, was investigated. It consisted of two wood boards: the face member and the edge member, which were joined by means of two plain dowels and glue lines of the thickness of 0.05 mm. The 0.1 mm gap between the joined members was assumed, which enabled a fuller representation of mechanical work of the joint.

The boards to be of Scots pine wood (*Pinus sylvestris* L.), the dowels of beech wood (*Fagus sylvatica* L.) and the glue line of polyvinyl acetate adhesive were assumed. The directions of wood for the face and the edge member were as shown in Fig. 1. In turn, the directions of wood for the dowels were the same as for the edge member. The dowel diameter, the depth of dowel embedment in the face member and the depth of dowel embedment in the edge member were varied. The range of the variability of these dimensions is given in Table 1. The free end of the face member was assumed to be fixed rigidly at the length of 30 mm with zero displacements in all directions. The edge member was subject to the force  $P$  of 20N, which was perpendicular to its surface and evenly distributed along its width, at 30 mm away from the free end of this member (Fig. 2).

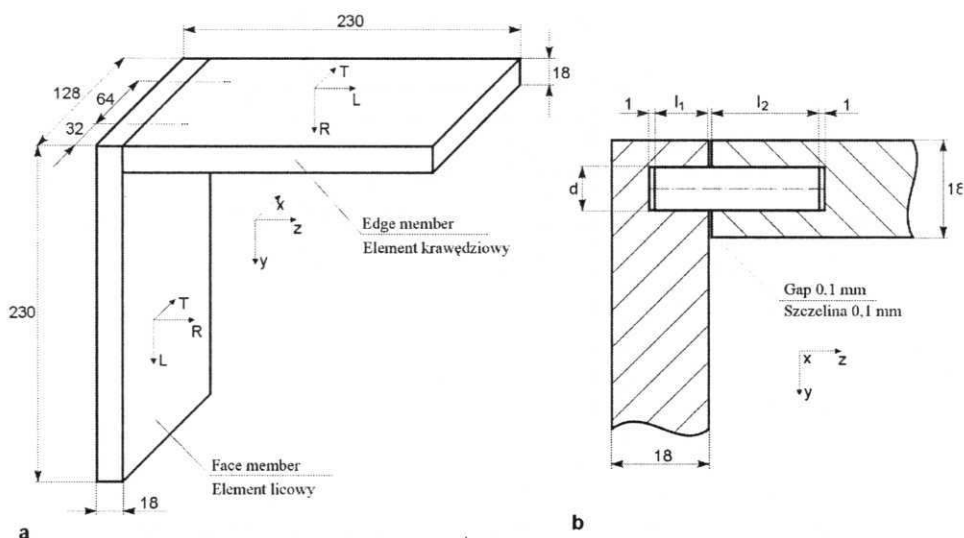


Fig. 1. Dowel corner joint in case construction: a) joint structure; b) cross-section showing details of joint structure (dimensions  $d$ ,  $l_1$  and  $l_2$  – see Table 1); L, R, T – directions of wood: L-longitudinal, R-radial, T-tangential

Rys. 1. Połączenie narożnikowe ściennie o złączu kołkowym: a) konstrukcja połączenia; b) przekrój pokazujący szczegóły złącza (wymiary  $d$ ,  $l_1$  i  $l_2$  – patrz tabela 1); L, R, T – kierunki drewna: L-wzdłużny, R-promieniowy, T-styczny

Table 1

Tabela 1

#### Variable dimensions of joints Zmienne wymiary złącza

Dowel diameter, mm Średnica kołka, mm	D	6, 8, 10
Depth of dowel embedment in face member, mm Głębokość osadzenia kołka w elemencie licowym, mm	$L_1$	8, 12, 16
Depth of dowel embedment in edge member, mm Głębokość osadzenia kołka w elemencie krawędziowym, mm	$L_2$	8, 16, 24

The finite element model of the studied joint, the used computer program and the elastic properties of the joint materials were described in the previous paper of the authors (Wilczyński and Kociszewski 2000).

One of the objectives of the study was to determine the effect of the joint dimensions on its deformation. The angle of the relative rotation of joint members was assumed as a characteristic deformation of the studied dowel corner joint.

The method of determining the angle of rotation is shown in Fig. 3. Points K and L are situated at the inner edge of the face member, and points M and N at the inner edge of the edge member. The lengths of KL and MN sections are the same and equal to 30 mm. The assumption of

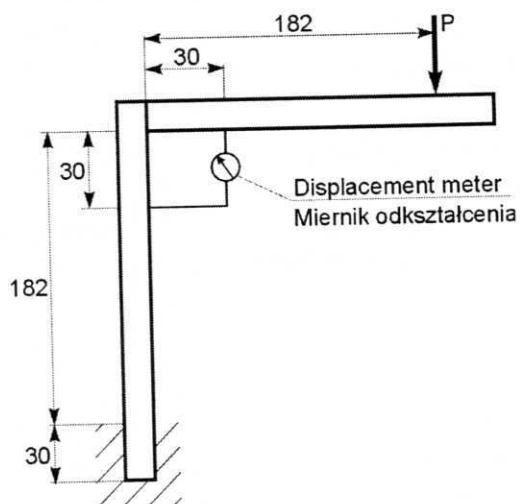


Fig. 2. Scheme of loading and measuring deformation of the joint specimen

Rys. 2. Sposób obciążenia i pomiaru odkształcenia próbki połączenia

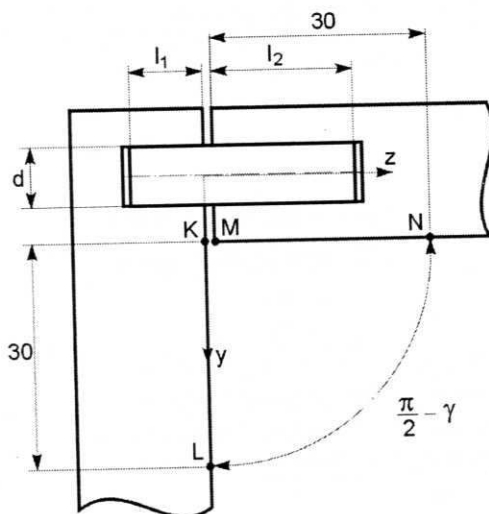


Fig. 3. Diagram showing the way in which the angle of joint rotation was determined

Rys. 3. Sposób określania kąta obrotu połączenia

relatively short arms of the angle was aimed at minimising the effect of the flexion of members of the joint. The angle of rotation  $\gamma$  was calculated by means of a formula:

$$\gamma = \frac{\pi}{2} - \operatorname{arctg} \frac{m_f - m_e}{1 - m_e m_f} \quad (1)$$

where:

$$m_e = \frac{Y_N + DY_N - (Y_M + DY_M)}{Z_N + DZ_N - (Z_M + DZ_M)} \quad m_f = \frac{Y_L + DY_L - (Y_K + DY_K)}{Z_L + DZ_L - (Z_K + DZ_K)} \quad (2)$$

$Y_K, Y_L, Y_M, Y_N$  and  $Z_K, Z_L, Z_M, Z_N$  – co-ordinates of points K, L, M, N

$DY_K, DY_L, DY_M, DY_N$  and  $DZ_K, DZ_L, DZ_M, DZ_N$  – displacements of these points.

In order to verify the results of the calculation by means of FEM, a decision was made to experimentally determine the angle of rotation for joints with selected dimensions. The specimens of joints were prepared according to Fig. 1, using the same materials, which were assumed in the numerical model. The face and the edge members were constructed of pine wood, and the dowel of beech wood. A polyvinyl acetate emulsion WIKOL made in Poland adhesive was used to assemble the specimens. The following dimensions were assumed: 8 mm for the dowel diameter  $d$ , 16 mm for the depth of dowel embedment in the edge member  $l_2$ , and three various depths of dowel embedment in the face member  $l_1$  – 8, 12, and 16 mm. Five replications were made for each combination so that a total of 15 specimens were tested.

The loading of specimens was similar to that of the numerical model. The force  $P$  (Fig. 2) of 20 N was evenly distributed along the width of the edge member. The relative displacement  $\Delta Y$  [mm] of specimen arms was measured (Fig. 2) and the angle of rotation  $\gamma$  of the joint was calculated by means of a formula.

$$\gamma = \arctg \frac{\Delta Y}{30}$$

## RESULTS

Stresses in selected places of the joint were determined through numerical calculations. One of the important places is the cross-section of the dowel between the face and the edge member. Distributions of stresses along the vertical dowel diameter BF contained in this cross-section are shown in Fig. 4. Considering that the effect of the depths of dowel embedment  $l_1$  and  $l_2$  is insignificant, only the distributions of stresses for the joint with  $l_1=l_2$  and  $l_2=16$  are shown. The distributions of normal stresses  $\sigma_z$  (Fig. 4a) are non-linear, the peak values of these stresses occur at the bottom point of the dowel cross-section. These values significantly decrease from 155.8 to 40.1 MPa as the dowel diameter  $d$  increases from 6 to 10 mm. The distributions of tangential stresses  $\tau_{yz}$  along the dowel diameter BF (Fig. 4b) also depend considerably on the dowel diameter. These distributions are irregular, the more, the smaller is the dowel diameter.

The second selected place of the joint was the vertical section DE in the face member near the bottom of the dowel hole. There is a possibility of fracture in this plane because the tensile strength of wood in perpendicular direction to this section, i.e. in radial direction, is low. The distributions of normal stresses  $\sigma$  and tangential stresses  $\tau_{yz}$  along the section DE for various dowel diameters  $d$  and depths of dowel embedment in

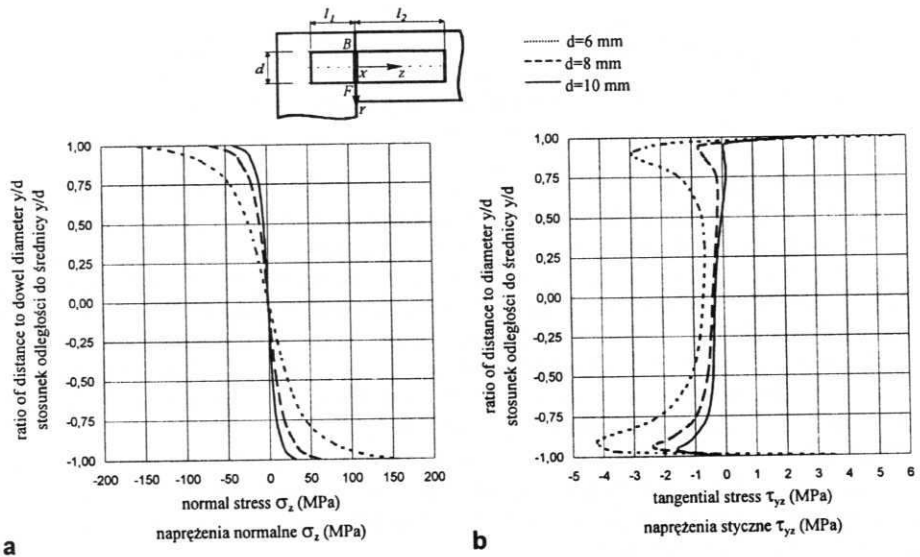


Fig. 4a-b. Distributions of stresses along the vertical dowel diameter BF for various dowel diameters (for  $l_1=l_2$  mm and  $l_2=16$  mm): a) normal stresses  $\sigma_z$ ; b) tangential stresses  $\tau_{yz}$   
 Rys. 4a-b. Rozkłady naprężeń wzdłuż pionowej średnicy kołka BF dla różnych średnic kołka (dla  $l_1=l_2$  mm i  $l_2=16$  mm): a) naprężenia normalne  $\sigma_z$ ; b) naprężenia styczne  $\tau_{yz}$

the face member  $l_1$  are shown in Fig. 5. They are determined for the depth of dowel embedment in the edge member  $l_2$  equal to 16 mm only, because as it was determined, the depth  $l_2$  does not have an effect on the stresses in the section DE. The values of normal stresses  $\sigma_z$  are low in a central fragment of the section DE and increase considerably for  $l_1$  equal to 8 and 12 mm near the points whose co-ordinate  $\gamma$  amounts to  $\pm 1/2 d$ . The variation of tangential stresses is different. Their values are high in a central fragment of the section DE (for  $l_1=8$  and 12 mm) and considerably decrease for the points whose co-ordinate  $y > 1/2 d$  and  $y < -1/2 d$ . The effect of the depth of dowel embedment in the face member  $l_1$  on the peak values  $\sigma_z$  and  $\tau_{yz}$  is significant. The larger the depth  $l_1$ , the lower the peak values of stresses  $\sigma_z$  and  $\tau_{yz}$ . For example, for the dowel diameter of 8 mm the peak values of normal stresses  $\sigma_z$  are 2.9, 1.4 and 0.3 MPa for  $l_1$  equal to 8, 12 and 16 mm respectively. Regarding the effect of the dowel diameter  $d$ , it is visible only for the depth of dowel embedment  $l_1=8$  mm whereas it is slight for  $l_1=12$  and 16 mm.

The values of the angle  $\gamma$  of the relative rotation of joint members for various dimensions of the finite element model of the joint, calculated by means of the formula (1), are given in Table 2. The effect of the dimensions of the joint for selected combinations of these dimensions is also shown in Fig. 6. Taking both depths of dowel embedment  $l_1$  and  $l_2$  into account, one should note that the depth  $l_1$  has greater effect on the angle of rotation  $\gamma$  than the depth  $l_2$ . The lengthening of  $l_1$  from 8 to 16 mm results in

decreasing the value of the angle  $\gamma$  on the average by 12.8%, while the lengthening of  $l_2$  from 8 to 24 mm causes the decrease in the value of the angle  $\gamma$  on the average by 4.4%. Nevertheless, the effects of the depths of embedment of both  $l_1$  and  $l_2$  should be regarded as insignificant.

In contrast to the effects of the depths of embedment, that of the dowel diameter  $d$  on the angle of rotation is considerable. The increase in the diameter results in the marked decrease in the value of the angle  $\gamma$ . For the joints with 8-mm-diameter dowels, the angle  $\gamma$  is on the average 2.2 times smaller than for the joints with 6-mm-diameter dowels. In turn, for the joints with 10-mm-diameter dowels, the angle  $\gamma$  is on the average 1.7 times smaller than for the joints with 8-mm-diameter dowels. Therefore, when one wants to enlarge the stiffness of the joint, that is to diminish the angle of rotation  $\gamma$ , one should primarily use possibly large diameters of the dowel.

The mean values of the experimentally determined angle of rotation  $\gamma$  for the joint with selected dimensions are given in Table 3. They were compared with the values calculated by means of FEM. The relative differences of these values are 11.2%, 10.1% and 7.5% for the joints with the depths of dowel embedment in the face member  $l_1$  equal to 8, 12, and 16 mm respectively. The differences can be regarded as comparatively small, thus it can be stated that the results of the analysis by means of FEM were confirmed.

Table 2

Tabela 2

Angle of joint rotation  $\gamma$  for various joint dimensions

Kąt obrotu połączenia  $\gamma$  dla różnych wymiarów złącza

Dowel diameter, $d$ [mm] Średnica kołka, $d$ [mm]	Depth of dowel embedment in face member, $l_1$ [mm] Głębokość osadzenia kołka w elemencie licowym, $l_1$ [mm]	Depth of dowel embedment in edge member, $l_2$ [mm] Głębokość osadzenia kołka w elemencie krawędziowym, $l_2$ [mm]		
		8	16	24
		Angle $\gamma$ [ $10^{-3}$ rad] Kąt obrotu $\gamma$ [ $10^{-3}$ rad]		
6	8	21.09	20.66	20.64
6	12	19.94	19.50	19.49
6	16	19.57	19.14	19.13
8	8	10.25	9.83	9.80
8	12	9.31	8.88	8.85
8	16	8.97	8.54	8.52
10	8	6.15	5.84	5.82
10	12	5.41	5.10	5.08
10	16	5.11	4.79	4.77

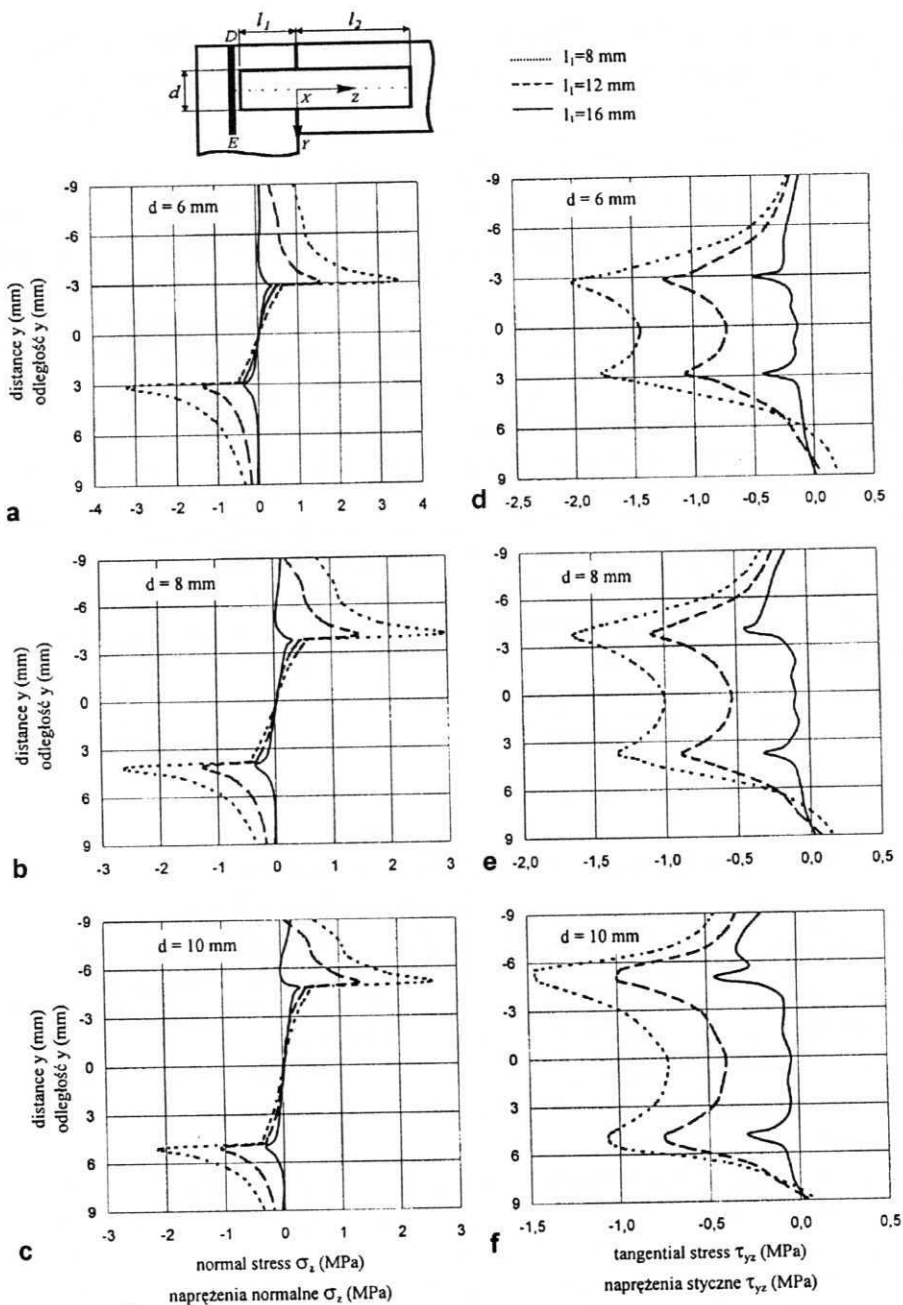


Fig. 5a-f. Distributions of stresses along the section ED for various dowel diameters and depths of dowel embedment in the face member (for  $l_2=16$  mm): a, b, c) normal stresses  $\sigma_z$ ; d, e, f) tangential stresses  $\tau_{yz}$

Rys. 5a-f. Rozkłady naprężeń wzdłuż odcinka ED dla różnych średnic kołka i głębokości jego osadzenia w elemencie licowym (dla  $l_2=16$  mm): a, b, c) naprężenia normalne  $\sigma_z$ ; d, e, f) naprężenia styczne  $\tau_{yz}$



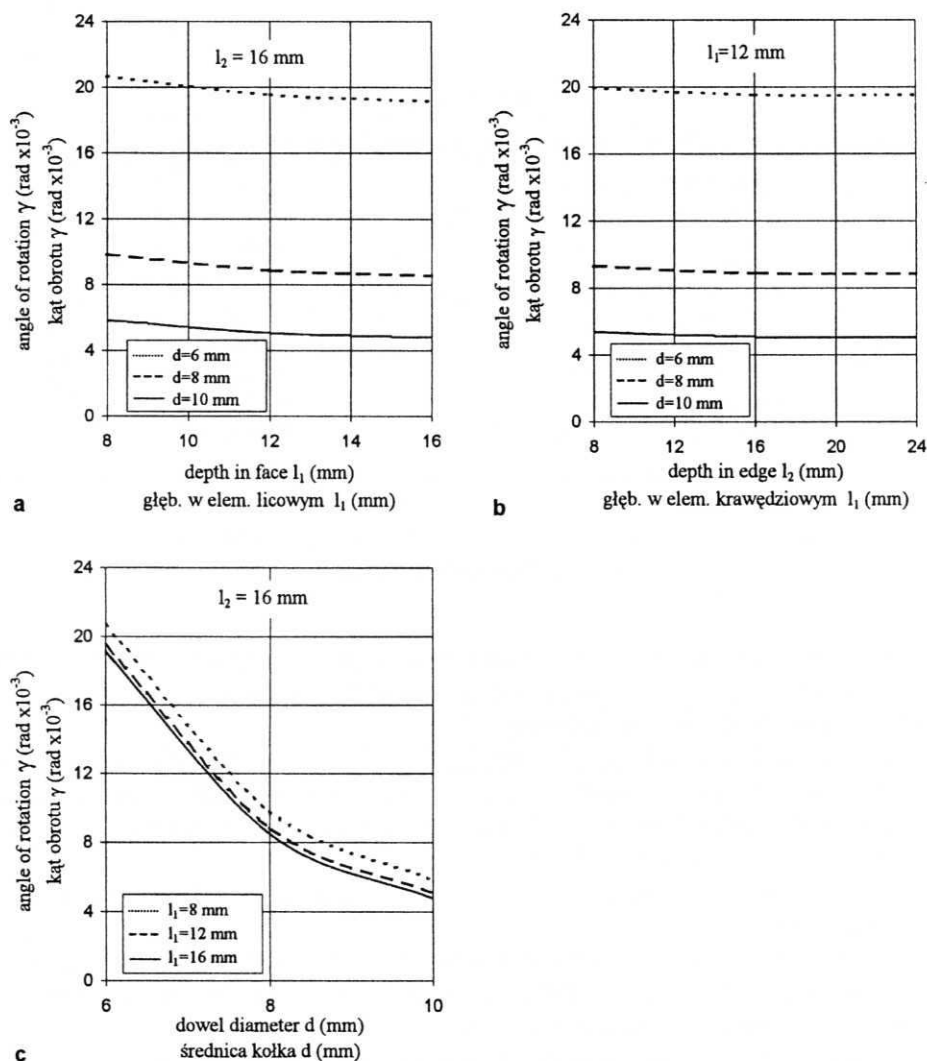


Fig. 6a-c. Effect of joint dimensions on the angle of joint rotation: a) effect of the depth of dowel embedment in the face member  $l_1$  for various dowel diameters  $d$  (for  $l_2=16$  mm); b) effect of the depth of dowel embedment in the edge member  $l_2$  for various dowel diameters  $d$  (for  $l_1=12$  mm); c) effect of the dowel diameter  $d$  for various depths  $l_1$  (for  $l_2=16$  mm)

Rys. 6a-c. Wpływ wymiarów złącza na kąt obrotu połączenia: a) wpływ głębokości osadzenia kołka w elemencie licowym  $l_1$  dla różnych średnic kołka  $d$  (dla  $l_2=16$  mm); b) wpływ głębokości osadzenia kołka w elemencie krawędziowym  $l_2$  dla różnych średnic kołka  $d$  (dla  $l_1=12$  mm); c) wpływ średnicy kołka  $d$  dla różnych głębokości  $l_1$  (dla  $l_2=16$  mm)

Experimental values of angle  $\gamma$ Uzyskane eksperymentalnie wartości kąta obrotu  $\gamma$ 

Joint dimensions [mm] Wymiary złącza [mm]			Angle of joint rotation $\gamma$ [ $10^{-3}$ rad] Kąt obrotu połączenia $\gamma$ [ $10^{-3}$ rad]	
d	$l_2$	$l_1$	mean value wartość średnia	standard deviation odchylenie standardowe
8	16	8	10.93	0.99
8	16	12	9.78	0.83
8	16	16	9.18	0.65

## CONCLUSIONS

The results of the analysis of the stresses in the glue lines of the dowel corner joints in case construction, in which pine wood was material of joint members, make it possible to draw the following conclusions:

1. The stresses in a dowel cross-section between the face and the edge members decrease considerably as the dowel diameter increases. The peak value of normal stress for the dowel diameter of 10 mm is almost four times smaller than that for the dowel diameter of 6 mm.
2. These stresses in the dowel do not depend on the depth of dowel embedment in the elements joined.
3. The stresses in a vertical section of the face member near the bottom of the dowel hole depend primarily on the depth of dowel embedment in the face member. The greater the depth, the lower the stresses.
4. These stresses in the face member do not depend on the dowel embedment in the edge member and the influence of the dowel diameter is rather slight.
5. The angle of joint rotation decreases significantly as the dowel diameter increases.
6. The increases in the depths of dowel embedment in the face and the edge members result in the decrease in the angle of rotation of the joint, but it is slight.

## REFERENCES

- Albin R., Müller M., Scholze H. (1987): Festigkeitsuntersuchungen an Flächeneckverbindungen im Korpusmöbelbau. Holz als Roh- und Werkstoff 45 (5): 171-178.
- Cai L., Wang F. (1993): Influence of the stiffness of corner joint on case furniture deflection. Holz als Roh- und Werkstoff 51 (6): 406-408.
- Gressel P., Kleinsorge M. (1989): Vergleichende Untersuchungen mit eingeleimten und nicht eingeleimten Dübelverbindungen. Holz-Zentralblatt 48: 785-788.
- Kociszewski M., Wilczyński A. (1998): Wykorzystanie metody elementów skończonych do badania połączeń kątowych ściennych o złączu kołkowym. Materiały 12 Konferencji WTD SGGW "Innowacyjność badań w przemyśle i nauce", Warszawa: 35-43.
- Swaczyna I., Piekacz J. (1996): Badanie nośności i sztywności narożnikowych połączeń z płytą MDF. Materiały 10 Konferencji WTD SGGW "Drewno – tworzywo inżynierskie", Warszawa: 271-283.
- Wilczyński A., Kociszewski (2000): Dowel corner joints in case construction – effect of dowel dimensions on stresses in a glue line. Folia Forestalia Polonica. Ser. B 31: 17-27.

## POŁĄCZENIE NAROŻNIKOWE ŚCIENNE O ZŁĄCZU KOŁKOWYM – WPLYW WYMIARÓW KOŁKA NA NAPRĘŻENIA I ODKSZTAŁCENIA

### Streszczenie

W pracy analizowano wpływ zmiennych wymiarów złącza: średnicy kołka, głębokości osadzenia w elementach łączonych, na naprężenia w przekroju kołka i elemencie licowym. Ponadto określono wpływ wymienionych wymiarów złącza na sztywność połączenia mierzoną kątem obrotu jego ramion. Przyjęto następujące materiały połączenia: drewno sosnowe na elementy łączone, drewno bukowe na kołki i klej poliocetanowinyłowy. W badaniach zastosowano metodę elementów skończonych. Wyznaczone numerycznie odkształcenia złącza zostały zweryfikowane eksperymentalnie.