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DOWEL CORNER JOINTS IN CASE CONSTRUCTION – EFFECT OF DOWEL DIMENSIONS ON STRESSES IN A GLUE LINE

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The dowel corner joint in case furniture in which pine wood was a 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 the joint were determined. The finite element method was applied assuming the three-dimensional state of stress.

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

INTRODUCTION

Dowel joints are widely used in the construction of case furniture. The knowledge and understanding of the strength and stiffness of these joints are necessary for the rational design of case furniture. The knowledge of stresses in dowel joints is also important and can be used for design purposes.

There are only several studies that have been carried out to obtain the strength and stiffness characteristics of dowel corner joints made of wood. Eckelman (1971) investigated the effect of the dowel spacing and the thickness of the edge member of the joint on the shear strength. He used several wood species to construct the edge member. Eckelman and Hincz (1971) evaluated the bending strength and stiffness of dowel joints made of black walnut for various gaps between the edge and the face member, and the thickness of the edge member. Gressel and Kleinsorge (1989) carried out tests on corner joints constructed of typical wood dowels and new ASTL – plastic dowels. They took two wood species of joint members into account: beech and spruce apart from particleboard and MDF.

More studies have been carried out to determine the strength and stiffness of dowel corner joints made of particleboard. Bachmann and Hassler (1975, 1976) evaluated the bending strength of joints constructed of various numbers of dowels. Albin, Müller and Scholze (1987) studied many types of corner joints, among others dowel joints. They carried out tests on dowel joints constructed of 19 mm wide particleboard and 10 mm diameter dowels, and of 16 mm wide particleboard and 8 mm diameter dowels. Various methods of loading the joints were used. Gressel and Kleinsorge (1989) investigated the bending strength and stiffness of dowel joints constructed of three types of particleboard and two types of fasteners: typical wood dowels and the ASTL-plastic dowels. Cai and Wang (1993) evaluated the effect of the number of dowels on the stiffness of dowel joints. Zhang and Eckelman (1993b) carried out tests to determine the bending strength of dowel joints. The number of dowels in joints and the spacing between dowels were variable factors. Two methods of loading the joints: in compression and tension, were used.

In the above described investigations the dimensions of corner joints such as: the dowel diameter, the depth of dowel embedment in the edge member and the depth of dowel embedment in the face member were usually invariable. Only Zhang and Eckelman (1993a) took into consideration and evaluated their effect on the bending strength of single-dowel corner joints constructed of particleboard.

The research on dowel corner joints in case construction carried out so far has aimed to obtain their strength and stiffness. Another important problem is the distribution of stresses in these joints. The information about these stresses will enable to understand better and predict dowel corner joint behaviour under load.

The objectives of this study were to determine stresses in dowel corner joints constructed of wood for various joint dimensions: the dowel diameter, the depth of dowel embedment in the face member and the depth of dowel embedment in the edge member.

The finite element method (FEM), which was developed by Zienkiewicz (1971), was used in this study. This method is applied in the field of stress analysis of various joints. It has already been used several times to determine stresses in wood joints: Gogolin and Wilczyński (1992), Jauslin, Pellicane and Gutkowski (1995), Nakai and Takemura (1996), Smardzewski (1996, 1998). It was also used in the previous research by the authors of this study (Kociszewski and Wilczyński 1998), in which stresses in a dowel corner joint constructed of particleboard were determined. The study confirmed the usefulness of FEM in the analysis of three-dimensional state of stresses which is characteristic of dowel joints.

MODELLING

In this study 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 at a right angle by means of two plain dowels. Thin glue lines which were 0.05 mm thick were assumed. They resulted from the fact that the diameters of the holes were 0.1 mm bigger than those of the dowels. The 0.1 mm gap between the joined members was taken into consideration, which enabled a fuller representation of mechanical work of the joint.

It was assumed that 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.

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.

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

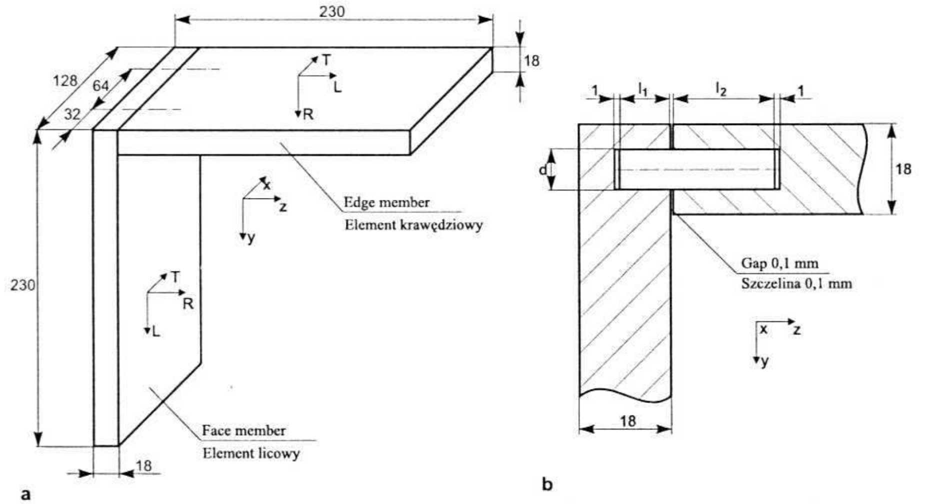

Fig. 1. Dowel corner joint in case construction: a) joint structure; b) cross-section showing details of joint structure (dimensions d, l_1 and l_2 – see Table 1); L, R, T – directions of wood: L-longitudinal, R-radial, T-tangential

Rys. 1. Połączenie narożnikowe ścienne 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

In order to subject this model of a joint to FEM, its discreet model was worked out. Regarding the structure of the materials of the joint, certain simplifications were assumed, which was necessary to make a simple but correct computational model: all the materials were homogeneous, continuous and linearly elastic, the wood was orthotropic, and the glue line was isotropic.

The computer programme ALGOR which is based on FEM was used for the analysis of the model. The finite element model was worked out with the preprocesor SD2, whose network, boundary conditions and loadings are shown in Fig. 2. It contains 16400 three-dimensional 20-node brick elements. Because of the symmetry of the joint, the finite element model comprises only half of the joint and that is why all points

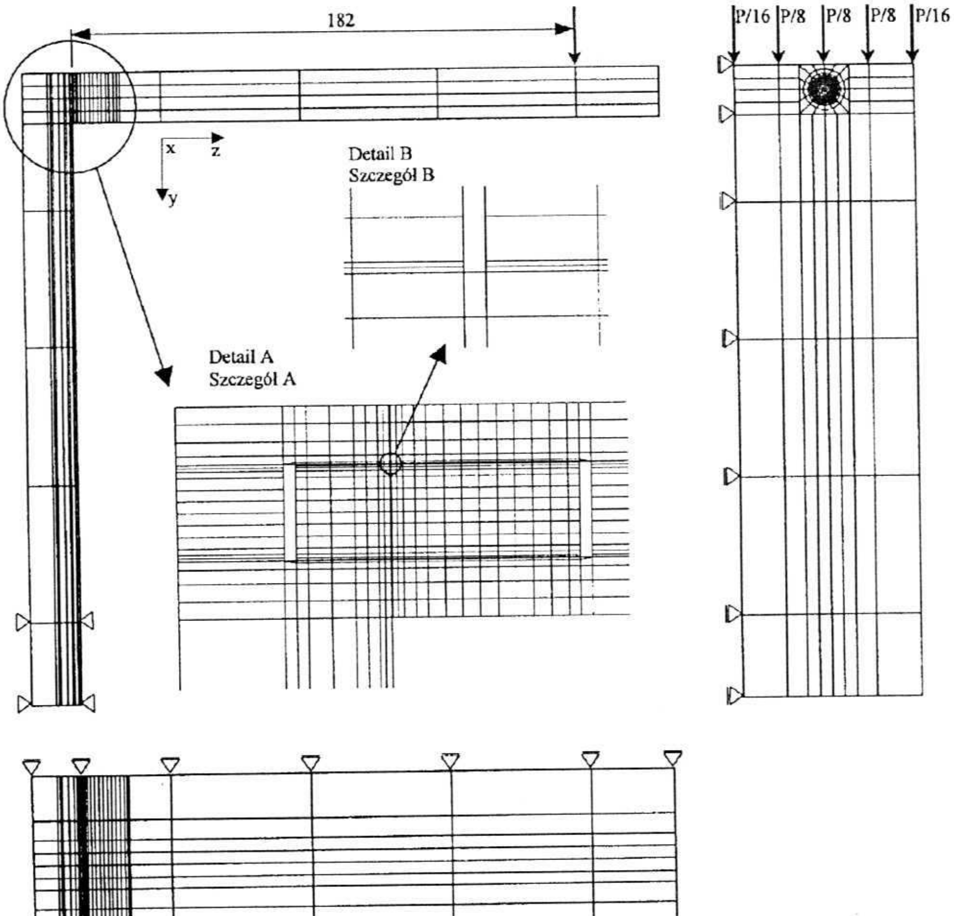

Fig. 2. Finite element model, loading and boundary conditions for the studied joints. Because of a symmetry of these joints, the model includes half of the joint
Rys. 2. Model elementów skończonych, obciążenia i warunki brzegowe dla analizowanego połączenia. Ze względu na symetrię model obejmuje tylko połowę połączenia

in the symmetry plane lost their ability to translate in the direction perpendicular to this plane.

The glue line was divided into two layers (Fig. 3), which made it possible to find stresses inside it. The dowels with various diameters and depths of embedment in the joint members were modelled by using the same number of finite elements, which required changing the distances between selected nodes.

Appropriate properties were attributed to a group of finite elements corresponding to particular elements of the joints. They are listed in Table 2. The elastic properties of wood were determined using the method of electric resistance tensommetry in compression test. The properties of the glue line were taken after Wilczyński (1988).

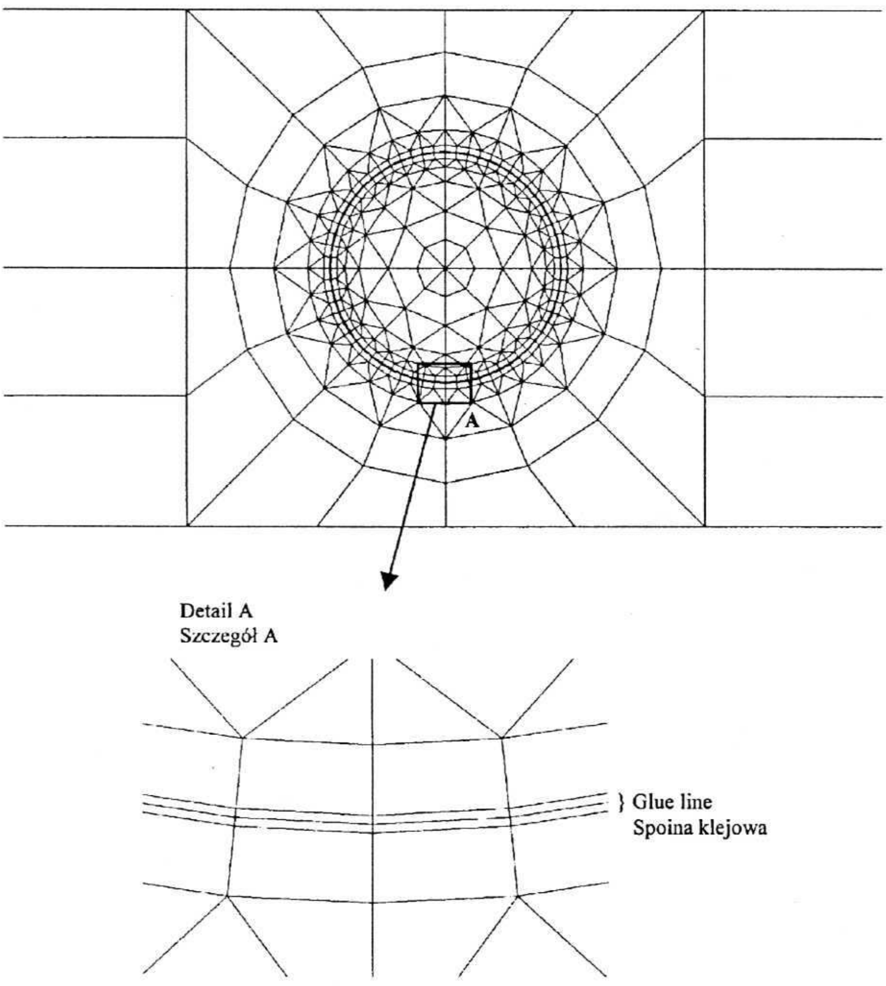

Fig. 3. Finite element mesh for a cross-section of the dowel in the edge member
Rys. 3. Siatka elementów skończonych dla przekroju kołka w części krawędziowej

Table 2
Tabela 2

Assumed mechanical properties of joint materials
Przyjęte właściwości mechaniczne materiałów połączenia

Elements of the joint Element połączenia	Material Materiał	Modulus of linear elasticity Moduł sprężystości liniowej			Poisson's ratio Współczynnik Poissona			Modulus of shear Moduł ścinania		
		E_x	E_y	E_z	ν_{xy}	ν_{xz}	ν_{yz}	G_{xy}	G_{xz}	G_{yz}
		MPa			-			MPa		
Face member Element licowy	Pine wood Drewno sosnowe	410	11700	940	0.46	0.65	0.03 5	780	105	950
Edge member Element krawędziowy	Pine wood Drewno sosnowe	410	940	11700	0.65	0.46	0.43	105	780	950
Dowels Kołki	Beech wood Drewno bukowe	950	1640	14700	0.71	0.52	0.41	330	950	1100
Glue line Spoina klejowa	Polyvinyl acetate adhesive Klej polioctano--winylowy	400	400	400	0.30	0.30	0.30	154	154	154

RESULTS

Stresses in different places of the joint were determined as a result of numerical calculations. In this paper the presentation of results was limited those concerning the stresses in the glue line between the dowel and the dowel hole. Two sections of the glue line, one above and one under the dowel, were assumed as the representative places of the glue line.

Fig. 4 and 5 show only stress distributions along the sections of the glue line above the dowel, because they were almost identical in the sections of the glue line under the dowel. These stresses occur in the nodes in the middle of the thickness of glue lines. Because the effect of the depth of dowel embedment in the edge member l_2 on the stresses in the section AB of the glue line in the face member is negligible, these stresses were shown only for one, selected value l_2 equal to 16 mm. Similarly, because of the negligible effect of the depth of dowel embedment in the face member l_1 on stresses in the section BC of the glue line in the edge member, the stresses in this section were shown only for one value l_1 equal to 12 mm.

Distributions of tangential stresses in the section AB of the glue line for various dowel diameters d and depths of dowel embedment in the face member l_1 are shown in Fig. 4a-c. Distributions of these stresses in the section BC of the glue line for various dowel diameters d and depths of dowel embedment in the edge member l_2 are shown in Fig. 4d-f. The stresses τ_{yz} are concentrated near the point B situated in the glue line be-

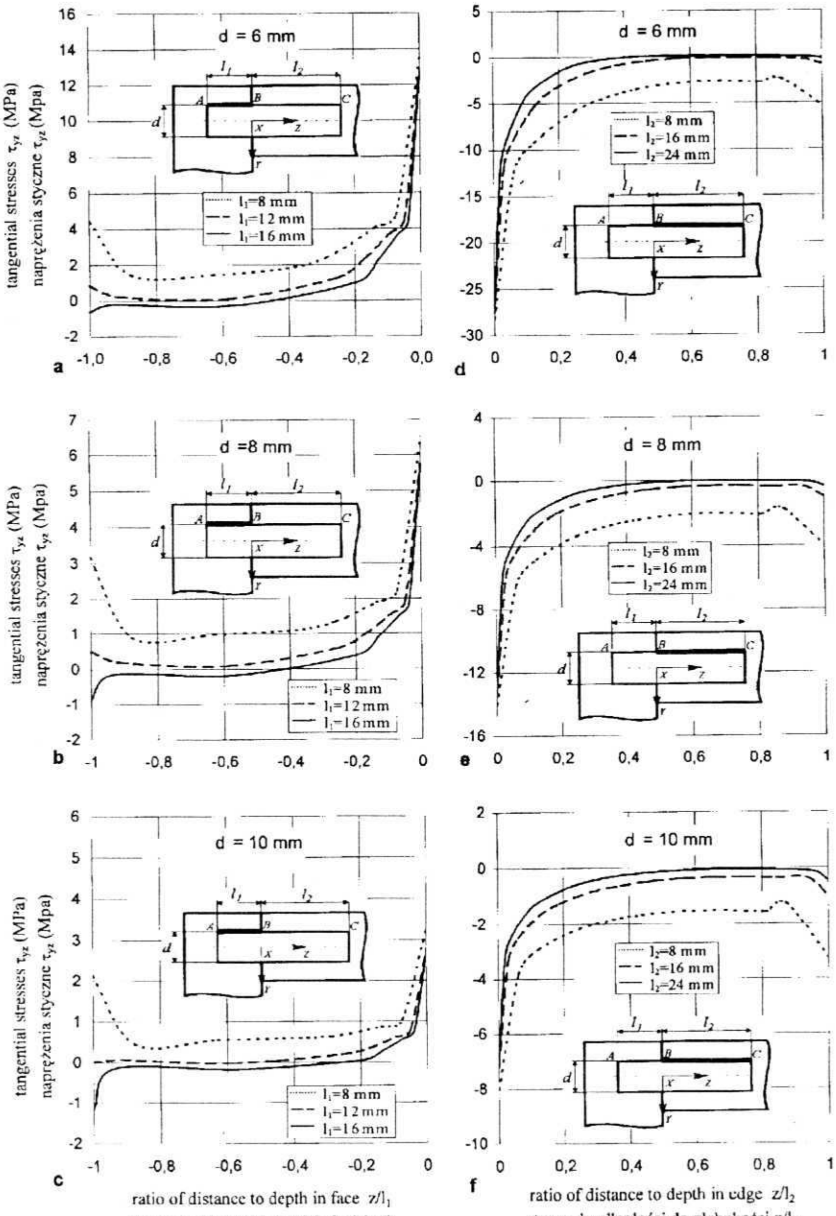

Fig. 4. Distributions of tangential stresses along the glue line above the dowel for various dowel diameters and depths of dowel embedment: a, b, c) for the section AB of the glue line (for l_2=16 mm); d, e, f) for the section BC of the glue line (for l_1=12 mm)

Rys. 4. Rozkłady naprężeń stycznych wzdłuż spoiny klejowej nad kołkiem dla różnych średnic i głębokości osadzenia kołka: a, b, c) na odcinku AB spoiny klejowej (dla l_2=16 mm); d, e, f) na odcinku BC spoiny klejowej (dla l_1=12 mm)

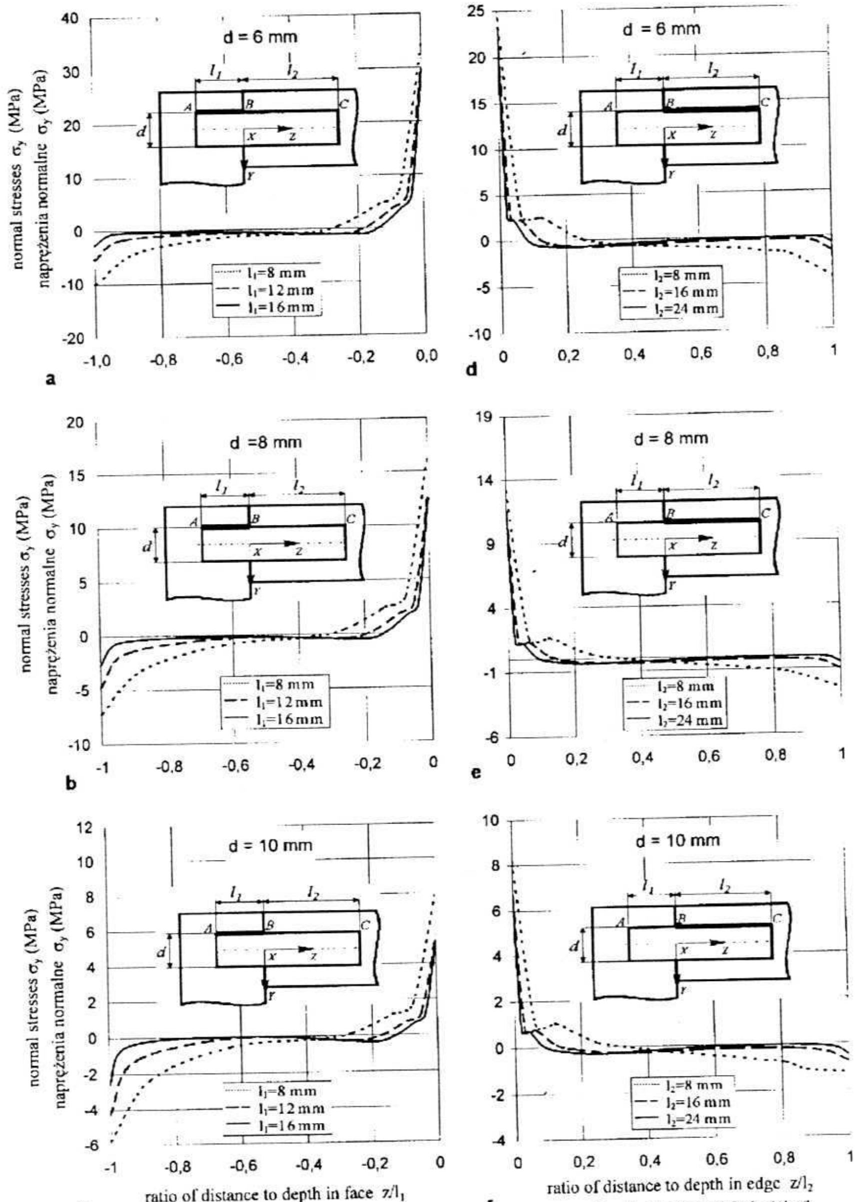

Fig. 5. Distributions of normal stresses along the glue line above the dowel for various dowel diameters and depths of dowel embedment: a, b, c) for the section AB of the glue line (for l_2=16 mm); d, e, f) for the section BC of the glue line (for l_1=12 mm)

Rys. 5. Rozkłady naprężeń normalnych wzdłuż spoiny klejowej nad kołkiem dla różnych średnic i głębokości osadzenia kołka: a, b, c) na odcinku AB spoiny klejowej (dla l_2=16 mm); d, e, f) na odcinku BC spoiny klejowej (dla l_1=12 mm) tween the face and the edge member. It is characteristic that higher concentrations of the stresses τ_{yz} occur in the glue line contained in the edge member. The peak values of τ_{yz} in this glue line are about twice as great as in the glue line contained in the face member. The lower the depth of dowel embedment in the face member l_1, the larger the stresses τ_{yz} in the section AB of the glue line. However, the peak values of τ_{yz} are approximately identical for the joint with the given dowel diameter d. A similar relationship occurs for the stresses τ_{yz} in the section BC of the glue line in the function of the depth of dowel embedment in the edge member l_2. The peak values of τ_{yz} in the glue line depend considerably on the dowel diameter d. The increasing the dowel diameter d from 6 to 10 mm causes the significant reduction of these values. For example, for the section BC and l_2=16 mm, l_1=12 mm, these stresses amount to 27.5, 13.2 and 7.2 MPa for the joints with a dowel diameter of 6, 8 and 10 mm respectively. It can finally be said that the peak values of tangential stresses in the glue line of the studied dowel joint in fact do not depend on the depths of dowel embedment l_1 and l_2 while they crucially depend on the dowel diameter – these peak values markedly decrease as the dowel diameter increases.

Distributions of normal stresses σ_y in the section AB of the glue line for various dowel diameters d and the depths of the dowel embedment in the face member l_1 are shown in Fig. 5a-c. Distributions of these stresses in the section BC of the glue line for various dowel diameters d and the depths of the dowel embedment in the edge member l_2 are shown in Fig. 5d-f. Normal stresses σ_y concentrate, as in a case of tangential stresses τ_{yz}, near the point B of the glue line. There are higher peak values of stresses σ_y in the glue line in the face member for the joints with dowels with 6 and 8 mm in diameter, while for the joints with dowels 10 mm in diameter in the edge member. The greater the depth of dowel embedment in the face member l_1, the lower the stresses σ_y in the section AB of the glue line. However, their peak values differ insignificantly for the given dowel diameter. Similarly, the greater the depth of dowel embedment in the edge member l_2, the lower the stresses $_y$ in the section BC of the glue line, but their peak values differ insignificantly for the given dowel diameter. For example, for the dowel diameter d=8 mm and the depth of dowel embedment in the face member l_1=12 mm, the peak values σ_y in the section BC of the glue line amount to 13.2, 11.5 and 11.4 MPa for the depths of dowel embedment in the edge member l_2 equal to 8, 16 and 24 mm respectively. The peak values σ_y considerably depend on the dowel diameter d. The increasing the dowel diameter results in the significant decreases in these peak values. For example, for the section BC of the glue line and l_1=12, l_2=16 mm, the peak values σ_y amount to 22.8, 11.5 and 6.7 MPa for the joints with dowel diameters equal to 6, 8 and 10 mm respectively. It can be concluded that the peak values of normal stresses in the glue line for the studied dowel joint significantly depend, similarly as in a case of tangential stresses, on the dowel diameter d, whereas the effect of the depths of dowel embedment l_1 and l_2 on these peak values of normal stresses is slight.

CONCLUSIONS

1. The stresses in the glue line concentrate near the place between the face and the edge members.
2. The concentration of tangential stresses in the glue line that is contained in the edge member is higher, about twice, than that in the glue line that is contained in the face member.
3. The peak values both of tangential and normal stresses in the glue line considerably depend on the dowel diameter. The larger the diameter, the lower the peak values of stresses.
4. The effects of the depths of dowel embedment in the face and the edge members on values of stresses in the glue line are insignificant.

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POŁĄCZENIE NAROŻNIKOWE ŚCIENNE O ZŁĄCZU KOŁKOWYM – WPŁYW WYMIARÓW KOŁKA NA NAPRĘŻENIA W SPOINIE KLEJOWEJ

Streszczenie

Przedstawiono badania naprężeń występujących w połączeniu narożnikowym ściennym o złączu kołkowym. Przyjęto następujące materiały połączenia: drewno sosnowe na elementy łączone, drewno bukowe na kołki i klej polioctanowinylowy. W badaniach zastosowano metodę elementów skończonych. Analizowano wpływ zmiennych wymiarów złącza: średnicy kołka, głębokości osadzenia w elementach łączonych, na naprężenia w spoinie klejowej. Wyniki w postaci rozkładów naprężeń normalnych i stycznych w spoinie klejowej wzdłuż długości kołka przedstawiono na wykresach. Potwierdzono, że naprężenia w spoinie klejowej, zarówno styczne jak i normalne, koncentrują się przy styku elementów połączenia. Wykazano że wartości tych naprężeń silnie zależą od średnicy kołków, a w niewielkim stopniu od głębokości ich osadzenia w elementach łączonych.

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