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STRENGTH AND STIFFNESS OF DOWEL CORNER JOINTS – EFFECT OF JOINT DIMENSIONS

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The influence of joint dimensions on the bending strength and stiffness of dowel corner joints was investigated. Factors such as dowel diameter, depth of dowel embedment and dowel spacing were considered. The regression functions for the strength and stiffness of the joint were calculated.

Key words: dowel joint, corner joint, bending strength, stiffness, beech wood, regression formula

INTRODUCTION

Mechanical properties of dowel joints depend on many factors, that were discussed by Wilczyński and Warmbier (1996a). Dowel dimensions and dowel spacing are significant factors.

Several studies have been only made on the effect of joint dimensions on the strength and stiffness of dowel corner joints. Eckelman (1971) took into account various dowel spacings. In the research carried out in FIRA (Sparkes 1974) the influence of the depth of dowel embedment and dowel spacing was evaluated, however it was limited to two values of these dimensions only. More comprehensive investigations of the bending strength were carried out by Kamenicky and Paulenkova (1984) who took into account different depths of dowel embedment and dowel spacings. They worked out a formula for the ultimate bending strength of a joint made of spruce wood, assuming that this strength is a linear function od joint dimensions. The effect of dowel dimensions and dowel spacing on the bending strength and stiffness of dowel corner joints was also the subject of the previous study of the authors (Wilczyński and Warmbier 1997). Regression functions for the strength and stiffness of a joint were calculated as dependent on three variables : dowel diameter, depth of dowel embedment and dowel spacing. It was also assumed that these formulas had a form of a first power polynomials.

Linear characteristics for the strength and stiffness of dowel joints as functions of joint dimensions seem to be an excessive simplification. Considering the fact that the knowledge of these characteristics for the rational joint design is necessary, an experimental study was undertaken in order to determine the real effect of dowel diameter, depth of dowel embedment and dowel spacing on the bending strength and stiffness of dowel corner joints.

MATERIALS AND METHODS

The dowel corner joint specimen used in this study is shown in Fig.1. Beech wood (*Fagus sylvatica* L.) with the average density of 720 kg/m^3 and the moisture content of 8% was used as the material of both the joint members and dowels. Multigrooved dowels commonly used in Poland were used. The depth of their embedment in both joint members was the same. Dowel holes were drilled using drills whose diameters were 0.2 mm larger than the dowel nominal diameters. The hole-dowel differences varied from 0.2 to 0.3 mm. The specimens were assemb-

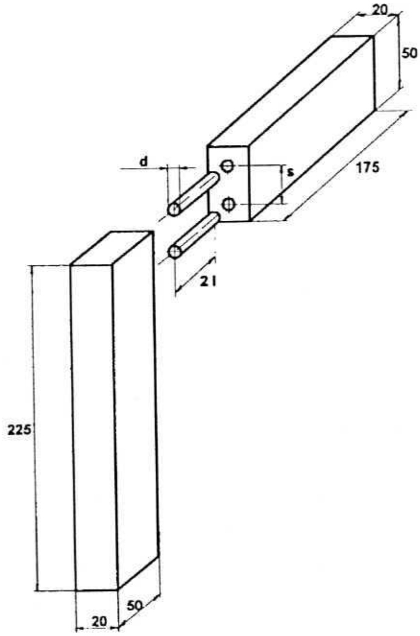

Fig. 1. Geometry and dimensions of the dowel corner joint specimens: d – dowel diameter, l – depth of dowel embedment, s – dowel spacing

Rys. 1. Kształt i wymiary próbek połączenia narożnikowego płaskiego o złączu kołkowym: d – średnica kołka, l – głębokość osadzenia kołka, s – rozstaw kołków led with a polyvinylacetate adhesive with trade name wikol®, made in Poland. Both the dowel and dowel hole were coated liberally with glue prior to assembly.

The dowel diameter d, the depth of dowel embedment l and the dowel spacing s (see Fig. 1) were assumed as variable factors. Four values of each dimension were taken into account so that non-linear regression functions for the strength and stiffness of the joint could be calculated. The dowel diameters were: 6, 8, 10 and 12 mm; the depths of dowel embedment: 16, 20, 24 and 28 mm; the dowel spacings: 20, 24, 28 and 32 mm. Because of a large number of possible combinations not a complete but a selected plan of tests was adopted (Polański 1984). It consisted of 26 selected test combinations.

Prior to the test, the specimens were left for two weeks to allow the adhesive to cure. Twenty six sets of specimens consisting of 10 specimens each were prepared altogether. Corner joints can be loaded in different ways (Wilczyński and Warmbier 1996b). The tension loading as shown in Fig. 2 was used. The forces P tend to open the joint and cause the bending moment M to appear in the corner of the joint:

$$M = 0.707\,P\,a \quad [\text{Nm}] \tag{1}$$

where: P – the applied force [N]
a – the distance from the point of force application to the middle of the corner of the joint [m].

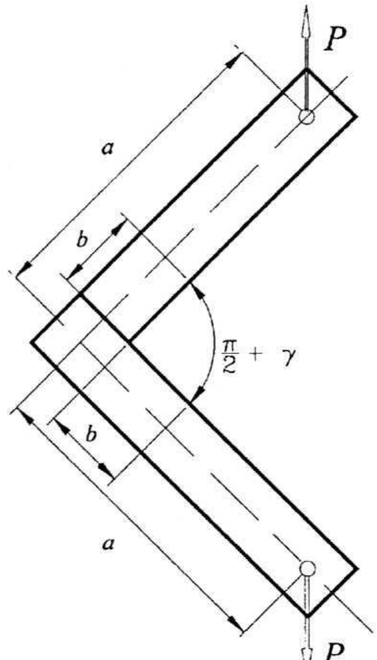

Fig. 2. Diagram of loading of the test specimen and measuring of the angle γ of relative rotation of specimen members: a = 175 mm, b = 30 mm

Rys. 2. Schemat obciążania i pomiaru kąta γ względnego obrotu ramion próbki: a = 175 mm, b = 30 mm

The bending strength was calculated from the formula (1) by measuring the force P which failed the joint. The angle of a relative rotation of joint members was assumed as a characteristic deformation of the studied joint. For small elastic deformations the relationship of the moment to the angle of rotation is linear:

$$M = k\gamma \quad \text{[Nm]} \tag{2}$$

where: k – the coefficient of joint rigidity [Nm/rad]
γ – the angle of a relative rotation of joint members [rad].

The angle γ was measured on the arm b of 30 mm long (see Fig. 2). The assumption of a relatively short arm of the angle was aimed at minimising the effect of the flexion of the joint members. The joint rigidity coefficient k was taken as a characteristic of the joint stiffness. It was calculated by means of the following formula:

$$k = \frac{\Delta M}{\Delta \gamma} \quad \text{[Nm/rad]} \tag{3}$$

where: ΔM – the moment increment [Nm]
$\Delta\gamma$ – the rotation angle increment caused by the moment increment [rad].

The moment increment was defined as :

$$\Delta M = M_2 - M_1 \quad \text{[Nm]} \tag{4}$$

where: M_1 – was about 10% and M_2 was about 40% of the mean value of the bending strength for a given test combination. All tests were carried out on a universal testing machine at a rate of loading of 2 mm per minute.

RESULTS

Based on the test results obtained in the study, regression functions were calculated for the bending strength M_f and the joint rigidity coefficient k as dependent on three variables: the dowel diameter d, the depth of dowel embedment l and the dowel spacing s. The computer program CADEX – ESDET (Polański and Górecka – Polańska 1992) was employed. It allows to calculate regression functions of different mathematical form using the method of least squares. After the analysis of the functions a second power polynomial with interactions turned out to be the most fitted to the results of the tests both for the strength and stiffness of the joint:

$$M_f = -60.59 - 7.135\,d + 8.116\,l - 0.9656\,s - 0.0679\,d^2 - -0.2670\,l^2 - 0.0346\,s^2 + 0.6454\,dl + 0.3781\,ds + 0.1064\,ls \tag{5}$$

$$k = 9077 + 370.8\,d - 93.03\,l - 815.0\,s - 42.37\,d^2 - 1.184\,l^2 + 13.72\,s^2 + 2.352\,dl + 33.07\,ds + 6.848\,ls \tag{6}$$

where: M_f [Nm], k [Nm/rad], d, l and s [mm].

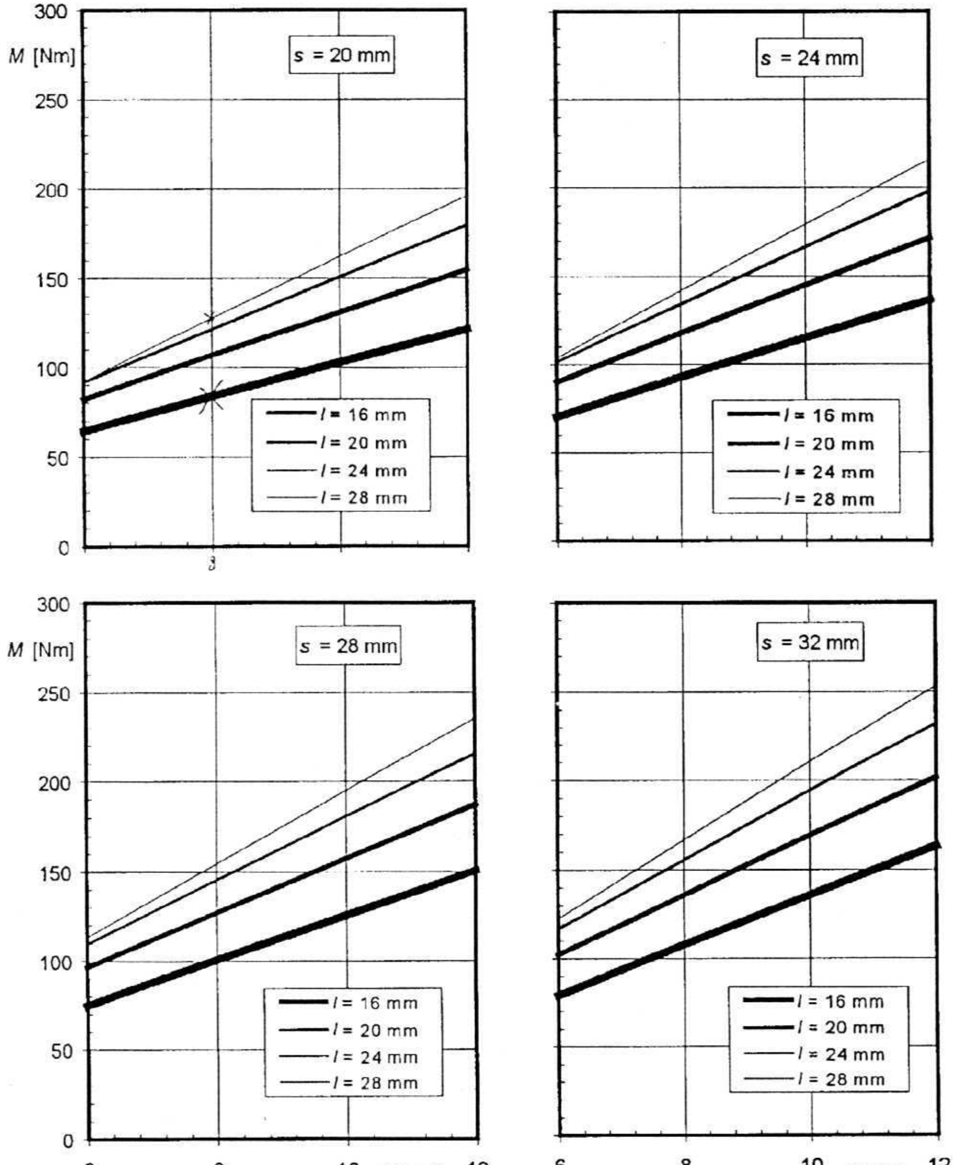

Fig. 3. Relationship of the bending strength M_f of the joint to the dowel diameter d for different depths of dowel embedment l and dowel spacings s

Rys. 3. Zależność wytrzymałości na zginanie M_f połączenia od średnicy kołków d dla różnych głębokości osadzenia l i rozstawów kołków s

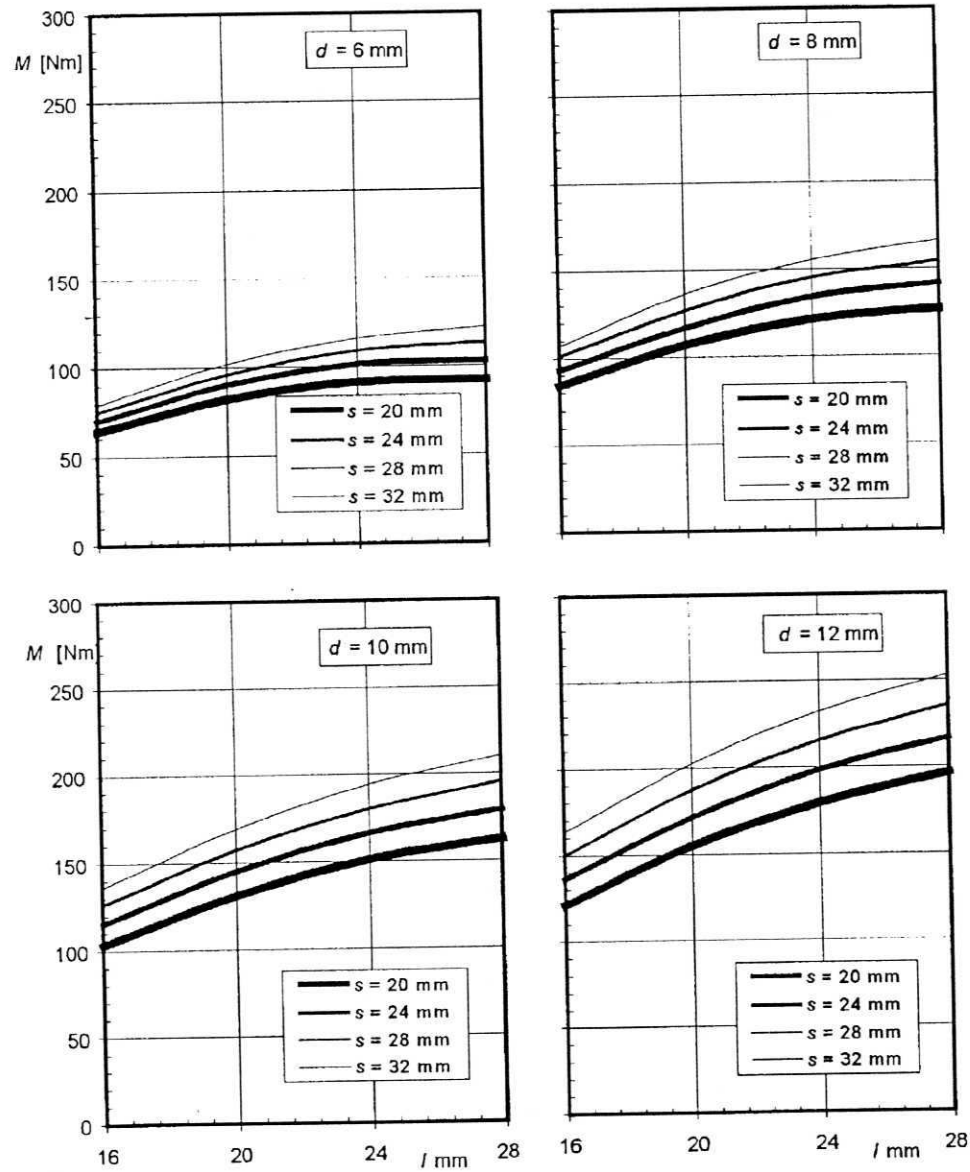

Fig. 4. Relationship of the bending strength M_f of the joint to the depth of dowel embedment l for different dowel spacings s and dowel diameters d

Rys. 4. Zależność wytrzymałości na zginanie M_f połączenia od głębokości l osadzenia kołków dla różnych rozstawów s i średnic kołków d

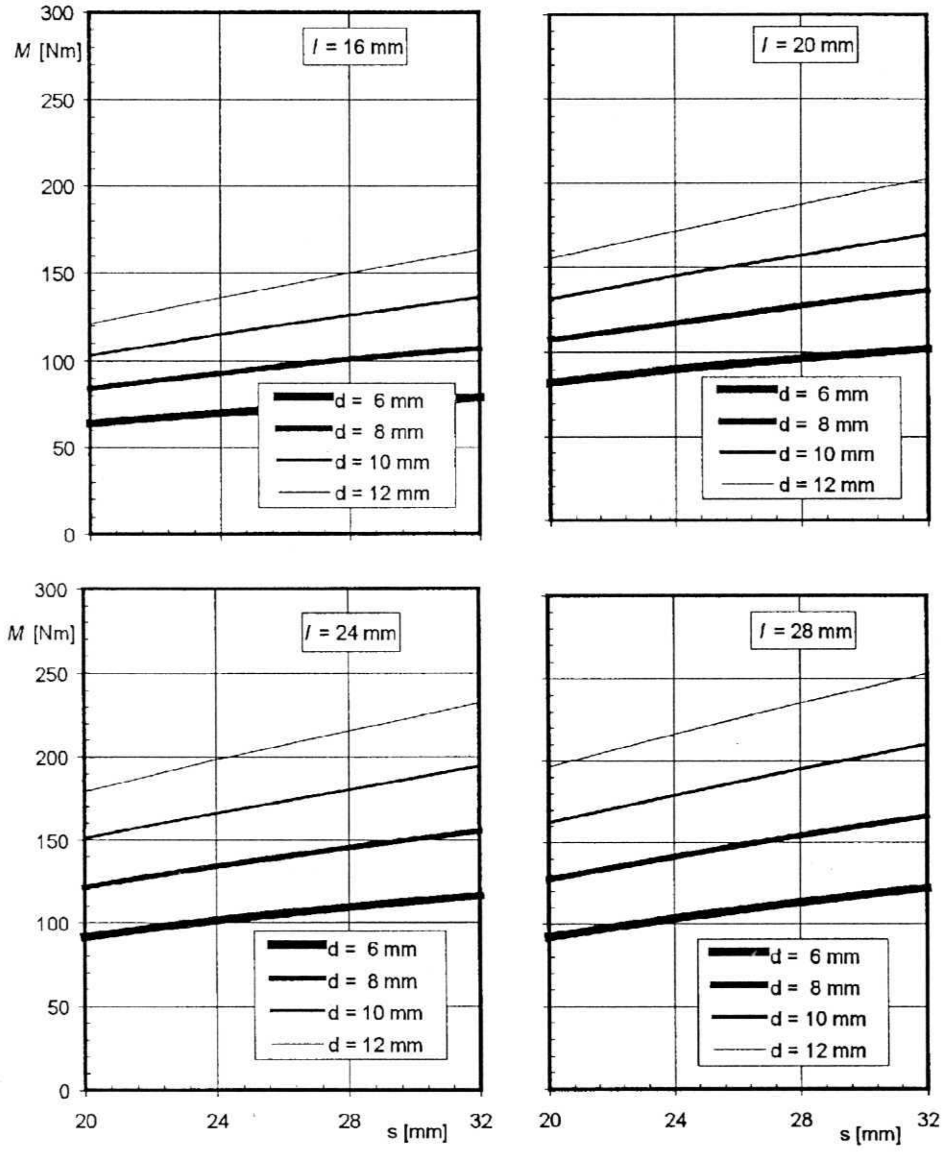

Fig. 5. Relationship of the bending strength M_f of the joint to the dowel spacing s for different dowel diameters d and depths of dowel embedment l

Rys. 5. Zależność wytrzymałości na zginanie M_f połączenia od rozstawu kołków s dla różnych średnic d i głębokości osadzenia kołków l

Based on the formulas (5) and (6), diagrams were drawn to present the relationship of the bending strength (Fig. 3-5) and the rigidity coefficient (Fig. 6-8) of the joint to the joint dimensions: dowel diameter, depth of dowel embedment and dowel spacing. The strength of the joint is approximately proportional to the dowel diameter (Fig. 3). The relation between the joint strength and the depth of the dowel embedment is non-linear. Together with the increase in the depth of dowel embedment the strength of the joint increases less and less effectively, especially for smaller dowel diameters. For example, the strength of the joint with the 8 mm dowel diameter and the 28 mm dowel spacing increases by 26.6 Nm, due to the increase in the depth of dowel embedment from 16 to 20 mm, by 17.9 Nm, due to the increase in that depth from 20 to 24 mm and by 9.5 Nm, due to the increase in that depth from 24 to 28 mm. The relation between the strength and the dowel spacing is also non-linear. Gradual increase in the dowel spacing causes the smaller and smaller increase in the joint strength. If one compares the influences of joint dimensions taken into account, one should note that the dowel diameter has the greatest, the depth of dowel embedment has a little smaller and the dowel spacing has the least influence on the strength of the joint. For example, the increase in dimension of the joint by 50% results in the following increase of the strength of the joint for the selected test combinations: the increase in the dowel diameter from 8 to 12 mm (for the joint with $l = 20$ mm and $s = 24$ mm) results in the increase of the joint strength by 45.9%, the increase in the depth of dowel embedment from 16 to 24 mm (for the joint with $d = 8$ mm and $s = 24$ mm) results in the increase of the joint strength by 44.4%,the increase in the dowel spacing from 20 to 30 mm (for the joint with $d = 8$ mm and $l = 20$ mm) results in the increase of the joint strength by 23.1%.

The joint rigidity coefficient increases together with the increase in the dowel diameter (Fig. 6), however a gradual increase in the diameter results in the smaller and smaller increase of this coefficient. The relation between the joint rigidity coefficient and the depth of dowel embedment is approximately linear (Fig. 7). The smaller the dowel spacing is, the smaller the influence of the depth of dowel embedment is. The relation between the joint rigidity coefficient and the dowel spacing is non-linear (Fig. 8), the increase rate of this coefficient raises with the increase in the dowel spacing. Comparing the influences of the joint dimensions taken into account, one has to note that the dowel spacing has the greatest, the dowel diameter has a smaller and the depth of the dowel embedment has the least influence on the stiffness of the joint. Using the same test combinations of the joints as above one can see that: the increase in the dowel diameter from 8 to 12 mm (for the joint with $l = 20$ mm and $s = 24$ mm) results in the increase of the joint rigidity coefficient by 27.3%, the increase in the depth of dowel embedment from 16 to 24 mm (for the joint with d = 8 mm and s = 24 mm) results in the increase of this coefficient by 6.8% and the increase in the dowel spacing from 20 to 30 mm (for the joint with $d = 8$ mm and $l = 20$ mm) results in the increase of this coefficient by 60.6%.

The formulas (5) and (6) are very complex and very inconvenient for practical use. Therefore, the following equations in a form of power functions product were calculated:

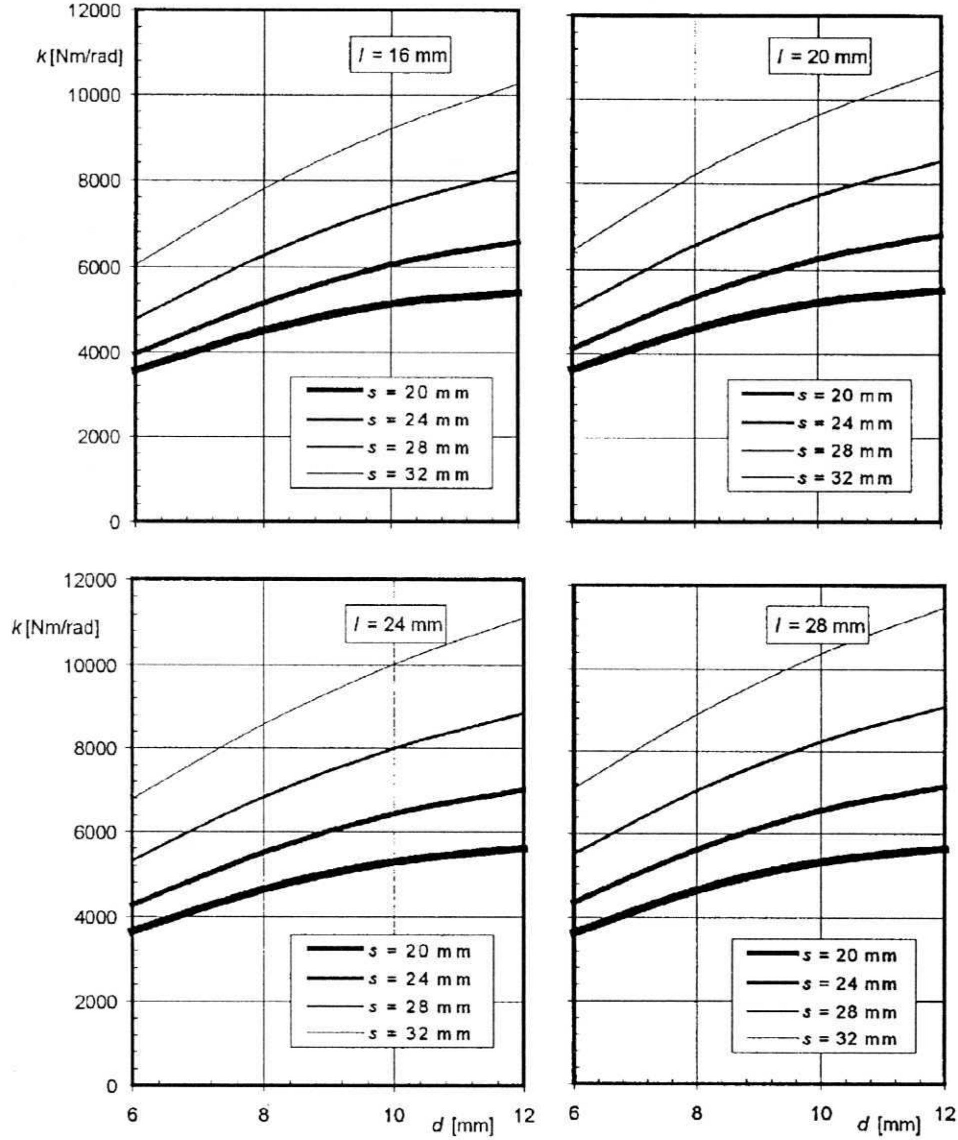

Fig. 6. Relationship of the rigidity coefficient *k* of the joint to the dowel diameter *d* for different dowel spacings *s* and depths of dowel embedment *l*

Rys. 6. Zależność współczynnika sztywności *k* połączenia od średnicy kołków *d* dla różnych rozstawów *s* i głębokości osadzenia kołków *l*

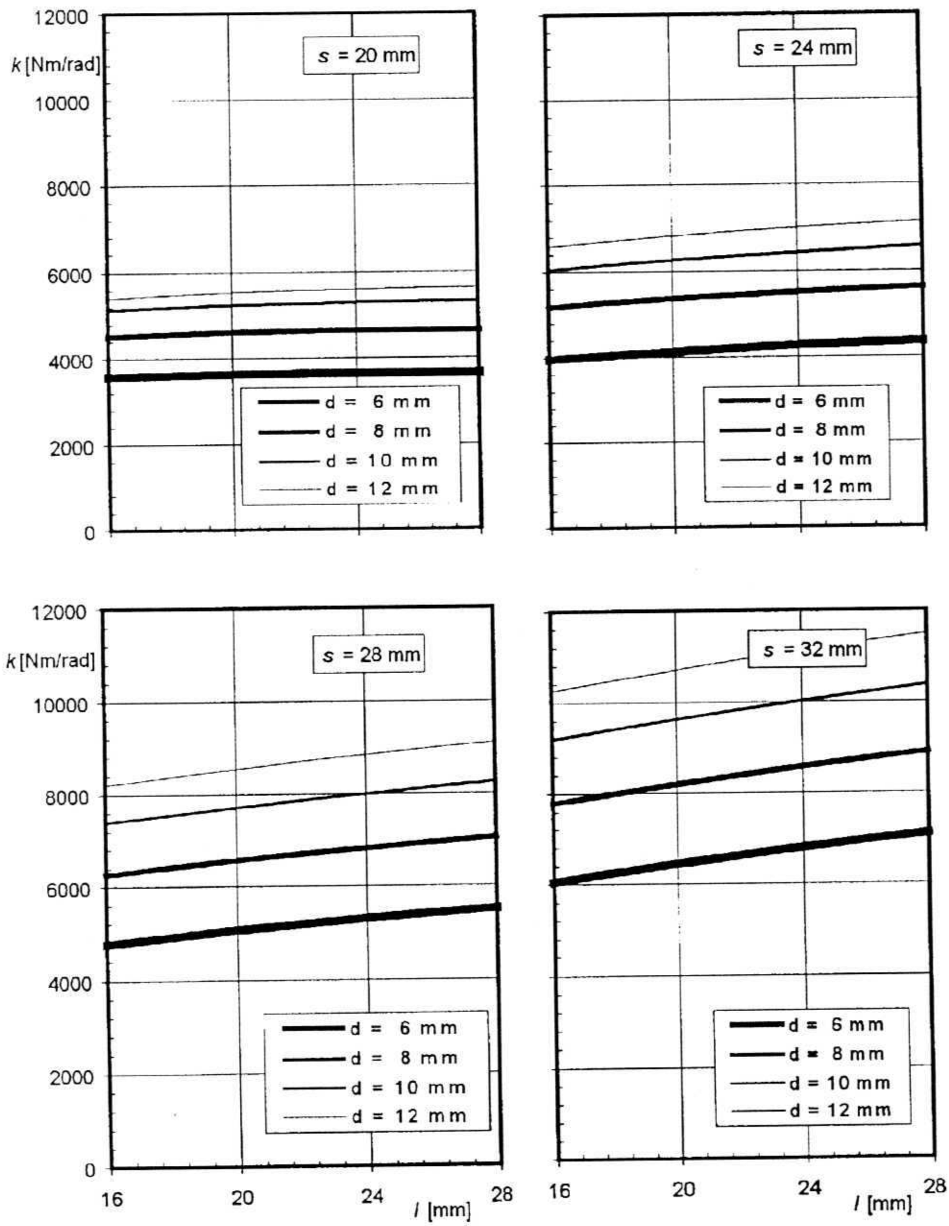

Fig. 7. Relationship of the rigidity coefficient k of the joint to the depth of dowel embedment l for different dowel diameters d and dowel spacings s

Rys. 7. Zależność współczynnika sztywności k połączenia od głębokości l osadzenia kołków dla różnych średnic d i rozstawów kołków s

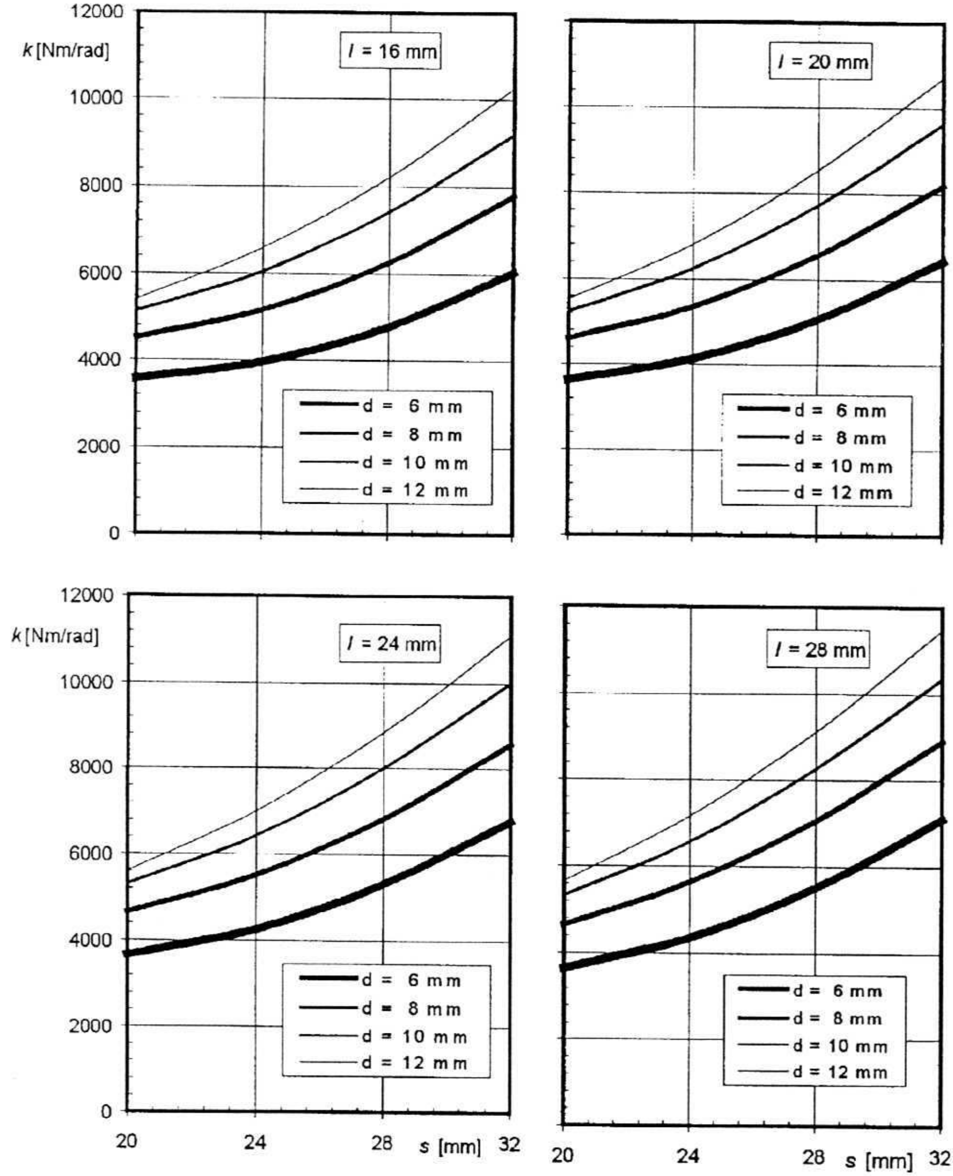

Fig. 8. Relationship of the rigidity coefficient *k* of the joint to the dowel spacing *s* for different dowel diameters *d* and depths of dowel embedment *l*

Rys. 8. Zależność współczynnika sztywności *k* połączenia od rozstawu kołków *s* dla różnych średnic *d* i głębokości osadzenia kołków *l*

$$M_f = 0.210\, d^{1.012}\, l^{0.802}\, s^{0.558} \quad (7)$$

$$k = 11.16\, d^{0.726}\, l^{0.168}\, s^{1.308} \quad (8)$$

where: M_f [Nm], k [Nm/rad], d, l and s [mm].

The calculated regression functions for the strength and stiffness of the dowel joint present very wide possibilities for a wood structures designer – from determining mechanical properties of a joint with given joint dimensions to choosing alternative combinations of a joint dimensions that ensure the required strength and stiffness of the joint. However, it is important to remember that the obtained formulas are valid for the given materials only: beech members glued with the use of the polyvinyl acetate adhesive with the necessary dowel-hole clearance.

CONCLUSIONS

1. The influence of joint dimensions on mechanical properties of the joint can be expressed by means of regression functions in the form of a second power polynomial with interactions or in the form of a power functions product.
2. The bending strength of the joint approximately linearly depends on the dowel diameter and non-linearly on the dowel spacing and the depth of the dowel embedment; however, their excessive increase is not very effective. The greatest increase in the strength of the joint is achieved by increasing the dowel diameter, an intermediate increase by the increase in the depth of dowel embedment and the smallest by the increase in the dowel spacing.
3. The stiffness of the joint non-linearly depends on the dowel diameter and dowel spacing and is approximately linearly dependent on the depth of dowel embedment. The influence of the dowel spacing is great, of the dowel diameter is smaller but still significant, whereas the influence of the depth of dowel embedment is very small.

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WYTRZYMAŁOŚĆ I SZTYWNOŚĆ POŁĄCZENIA KĄTOWEGO PŁASKIEGO O ZŁĄCZU KOŁKOWYM – WPŁYW WYMIARÓW ZŁĄCZA

Streszczenie

Przedstawiono badania dotyczące wpływu wymiarów złącza na wytrzymałość i sztywność połączenia kątowego płaskiego o złączu kołkowym. Próbki połączeń wykonano z drewna bukowego, używając do ich montażu kleju polioctanowinylowego. Czynnikami zmiennymi były: średnica kołków, głębokość ich osadzenia oraz ich rozstaw. Posługując się selekcyjnym planem badań określono eksperymentalnie wytrzymałości i sztywność połączenia dla wybranych kombinacji tych czynników. Wyprowadzono funkcje regresji dla wytrzymałości i sztywności połączenia. Mają one postać wielomianu drugiego stopnia z interakcjami lub iloczynu funkcji potęgowych. Największy wpływ na wytrzymałość połączenia wywiera średnica kołków – nośność jest do niej proporcjonalna, nieco mniejszy wpływ ma głębokość osadzenia kołków, przy czym jej nadmierne zwiększanie nie jest efektywne, zaś najmniejszy choć istotny wpływ wywiera rozstaw kołków. Jeśli chodzi o sztywność połączenia, to w największym stopniu zależy ona od rozstawu kołków, w mniejszym – od ich średnicy, natomiast w znikomym stopniu – od głębokości ich osadzenia.

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