# AXIAL LOAD CAPACITY OF DOWEL JOINT IN PINE WOOD

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A dowel joint with a multigroove dowel embeded into pine wood by means a polyvinyl acetate glue was investigated. The dowel diameter, the depth of dowel embedment and the dowel – hole clearance were variable factors. Using a selected plan of tests the regression formulas for load capacity of beech and birch dowels were calculated.

**Key words**: dowel joint, pine wood, multigroove dowel, load capacity

## INTRODUCTION

The basic mechanical property of the dowel joint is the axial load capacity of a dowel which is expressed as axial load necessary to withdraw the dowel from wood. This strength depends on many factors which were described by Wilczyński and Warmbier (1996). The joint dimensions – the dowel diameter and the depth of dowel embedment in wood are significant factors. The effect of these factors on the load capacity was a subject of several investigations (Eckelman 1969, Kamenicky and Paulenkova 1984, Sparkes 1974, Warmbier and Wilczyński 1997, Wilczyński 1998a,b). Another important factor is the dowel – hole clearance that was taken into account by Konjer et al. (1986), Korzeniowski and Szulc (1992), Nearn and Clarke (1958) and Warmbier and Wilczyński (1997). The results of both investigations are differentiated. This is caused by the fact that various research methods and different material combinations (of the material of the dowel and of its embedment and of a type of glue) were adopted.

As a material of the dowel embedment different species of hardwood were usually used. Pine wood was only used by Korzeniowski and Szulc (1992). The effect of dowel material on the load capacity was only taken into account by Eckelman (1969).

Former investigations have not sufficiently explained the problem of the load capacity of dowels in wood. Taking into account that the knowledge of this strength for the rational design of furniture is needed, an experimental study was undertaken to determine the effect of the dowel diameter, the depth of dowel embedment and the dowel – hole clearance on the load capacity of dowels in pine wood. This species of wood is widely used in furniture industry. Two species of dowel wood were employed.

## MATERIALS AND METHODS

Pine wood (*Pinus sylvestris* L.) with an average density of 480 kg/m³ and a moisture content of 8% was used as the material of the dowel embedment. Two species of dowel wood: beech and birch were used as recommended by Polish standards.

Four dowel diameters: 6, 8, 10 and 12 mm were used. Depths of dowel embedment were from 8 to 40 mm. Three ranges of the dowel – hole clearance were used: the first from 0.05 to 0.10 mm, the second from 0.20 to 0.25 mm and the third from 0.40 to 0.50 mm.

Because of a large number of test combinations not a complete but a selected plan of study was adopted as shown in Table 1. This plan concerned both joints with the beech dowel and those with the birch dowel.

Table 1

Tabela 1

Plan of tests

Plan badań

| Depth of dowel embedment L [mm] Głębokość osadzenia kołka L [mm] | Dowel – hole clearance C [mm] Luz C między kołkiem a gniazdem [mm] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0.05 ÷ 0.10 | | | | 0.20 ÷ 0.25 | | | | 0.40 ÷ 0.50 | | | |
| | Dowel diameter D [mm] Średnica kołka D [mm] | | | | | | | | | | | |
| | 6 | 8 | 10 | 12 | 6 | 8 | 10 | 12 | 6 | 8 | 10 | 12 |
| 8 | | x | | | x | | | | | | | |
| 12 | x | | x | | | x | | | x | | | |
| 16 | | x | | x | x | | | | | x | | |
| 20 | x | | x | | | x | | x | | | x | |
| 24 | | x | | | | | | x | | x | | x |
| 32 | | | x | | | x | | x | | | | |
| 40 | | x | | | | | | x | | | | |

The specimen used in this study is shown in Fig. 1. It consisted of a test block (a bottom part of the specimen) from which the dowel was to be withdrawn, a load block (a top part of the specimen) whose purpose was to provide a structure to which the other end of the dowel could be fixed, a dowel pin, and a piece of wax paper (WP) whose purpose was to separate the load block from the test block and thus to keep the members themselves from adhering together. The grain direction of the test block was

perpendicular to the axis of the dowel joint. The test blocks were made of pine wood whereas the load blocks – of beech wood.
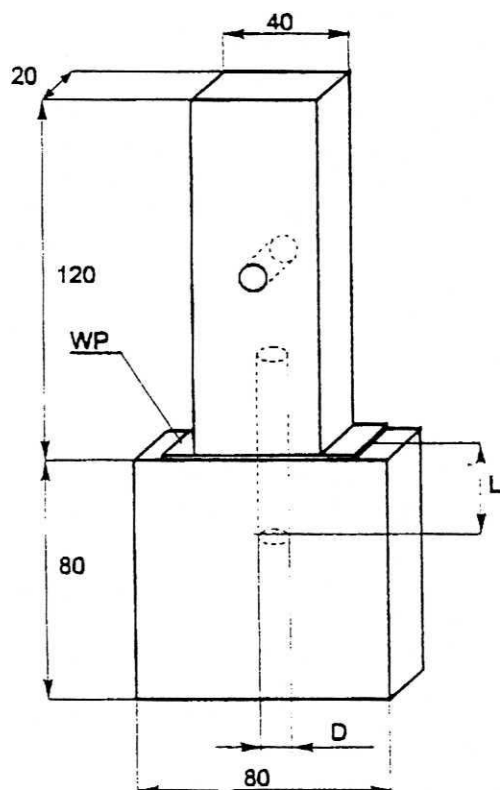


Fig. 1. Dowel test specimen: $D$ – dowel diameter, $L$ – depth of dowel embedment, $WP$ – wax paper
Rys. 1. Próbka złącza kołkowego: $D$ – średnica kołka, $L$ – głębokość osadzenia kołka, $WP$ – papier woskowany
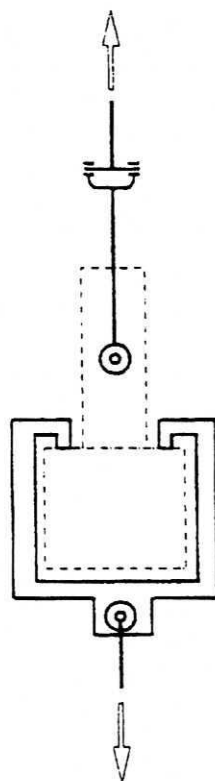
Fig. 2. Diagram of axial loading of dowel joint
Rys. 2. Schemat osiowego obciążenia złącza kołkowego

Multigrooved dowels commonly used in Poland were employed. All dowels were cut from dowel rods which had been obtained from a commercial manufacturer. Dowel holes were drilled using drills whose diameters were: $D, D + 0.2$ mm, $D + 0.4$ mm, where $D$ – the diameter of a dowel. One type of adhesive, polyvinyl acetate made in Poland was used in the tests. Both walls of the holes and sides of the dowels were coated liberally with glue i. e. the specimens were assembled using excess glue.

Prior to tests, the specimens were allowed to cure for two weeks. Altogether, 50 sets of specimens consisting of 10 specimens each were prepared. All tests were carried out on a universal testing machine at a rate of loading of 2 mm per minute. A special loading grip was used to hold the specimen as shown in Fig. 2.

## RESULTS

Based on the values of failure load obtained in the study, regression functions were calculated for the load capacity $F$ as dependent on three variables: the dowel diameter $D$, the depth $L$ of its embedment and the dowel – hole clearance $C$. The computer program CADEX – ESDET (Polański and Górecka – Polańska 1992) was employed. It allows to calculate regression functions of different mathematical forms, using the method of least squares. A second power polynomial with interactions turned out to be the most fitted to the results of the tests, an R squared equal to 0.98. This polynomial had the following forms:

$$F_1 = - 0.737 - 0.150\,D + 0.150\,L + 5.61\,C + 0.0198\,D^2 - 0.00281\,L^2 -$$
$$- 9.21\,C^2 + 0.00957\,DL - 0.117\,DC + 0.00493\,CL \qquad (1)$$

$$F_2 = - 2.605 - 0.345\,D + 0.130\,L + 5.17\,C - 0.0121\,D^2 - 0.00290\,L^2 -$$
$$- 8.11\,C^2 + 0.0121\,DL - 0.158\,DC + 0.0123\,LC \qquad (2)$$

where: $F_1$ – the load capacity of beech dowels in pine wood [kN],
$\qquad\quad$ $F_2$ – the load capacity of birch dowels in pine wood [kN],
$\qquad\quad$ $D$, $L$ and $C$ [mm].

Based on the formulas (1) and (2), diagrams were drawn to present the relationship of the load capacity $F$ to the depth of dowel embedment $L$ for different dowel diameters $D$ and dowel – hole clearances $C$ (Fig. 3 and 4). As the depth of dowel embedment gradually increases, the load capacity increases less and less effectively, especially for smaller dowel diameters. For example, the load capacity of beech dowels rises by 0.93 kN due to increasing the depth dowel embedment from 16 to 24 mm and increases by 0.56 kN due to increasing that depth from 24 to 32 mm. Let's use a ratio which is expressed as the quotient of the depth of dowel embedment and the dowel diameter. The load capacity increment caused by the increment of this ratio is only effective up to a definite limit of this ratio. The following values of the effective limit of this ratio can be taken: 3.5 for 6 and 8 mm diameter dowels, and 3.0 for 10 and 12 mm diameter dowels. This statement is valid for the joints with both beech and birch dowels.

Regarding the influence of the dowel – hole clearance $C$, the maximum load capacity is provided by the clearance $C = 0.20 - 0.25$ mm, and the minimum by the clearance $C = 0.40 - 0.50$ mm (Fig. 5). One should note that with the slight clearance $C = 0.05 - 0.10$ mm the load capacity is smaller than for the clearance $C = 0.20 - 0.25$ mm. The clearance $C$ is the difference between the hole diameter and the dowel diameter in dry state, prior to glue coating. Because of the swelling of wood moistened with glue, the clearance diminishes while assembling the dowel joint, and consequently for the clearance $C = 0.05 - 0.10$ mm excessive glue displacement from the hole takes place, and a glue line is less continuous than for the clearance $C = 0.20 - 0.25$ mm. In turn, with the clearance $C = 0.40 - 0.50$ mm we have to do with too thick glue line characterised by reduced shear strength.
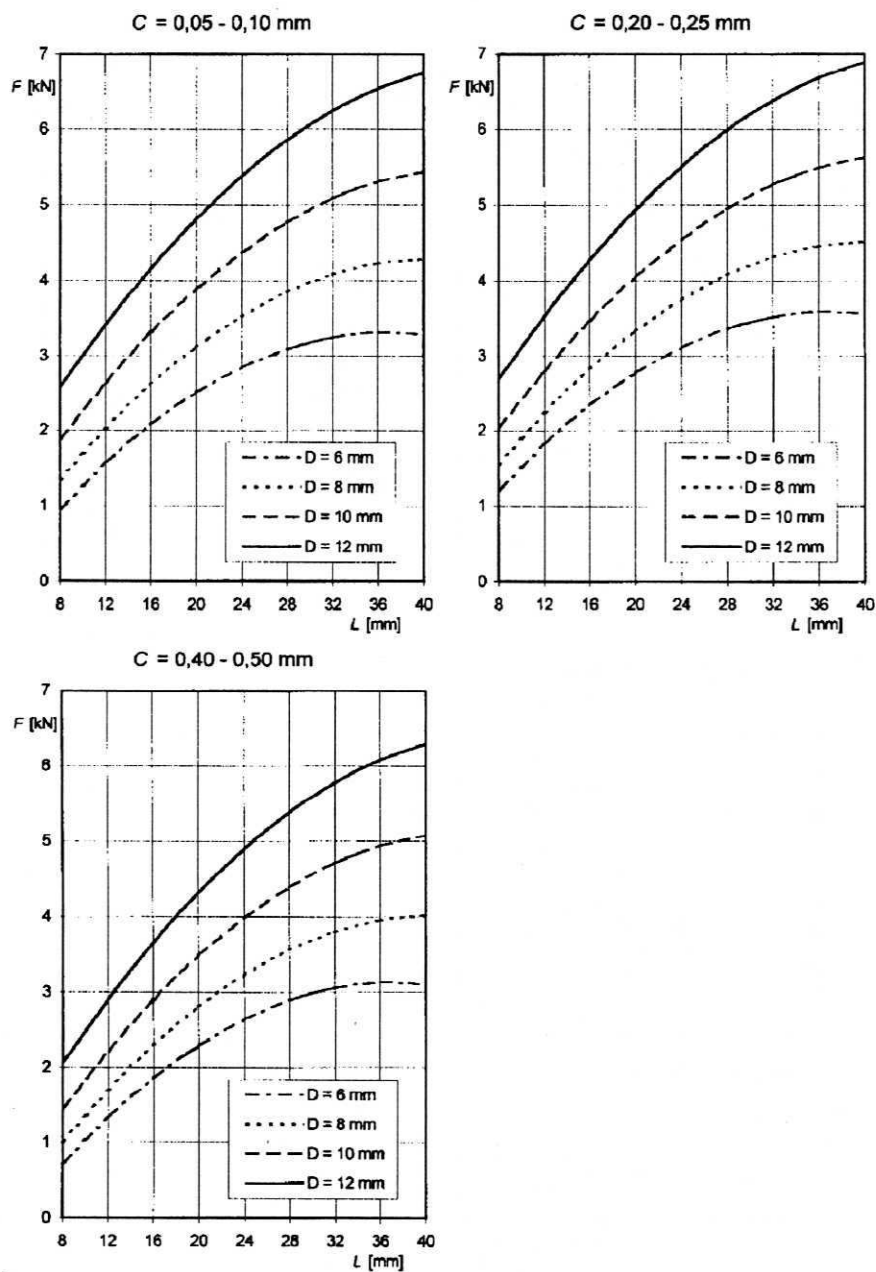
Fig. 3. Relationship of the load capacity $F$ of beech dowels to the depth of dowel embedment $L$ for different dowel diameters $D$ and dowel – hole clearances $C$

Rys. 3. Zależność nośności osiowej $F$ złącza z kołkiem bukowym od głębokości $L$ osadzenia kołka dla różnych średnic $D$ kołka i luzów $C$ między kołkiem a gniazdem
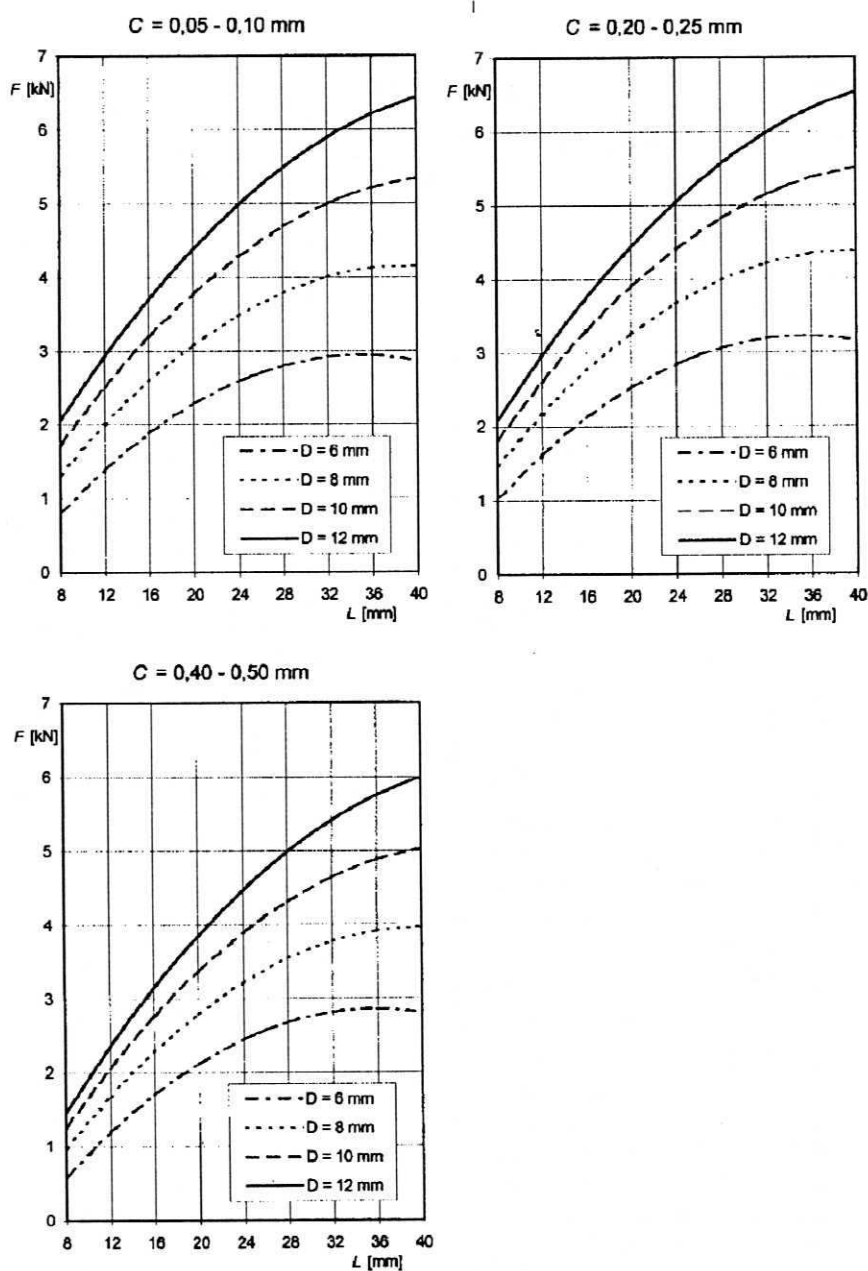
Fig. 4. Relationship of the load capacity $F$ of birch dowels to the depth of dowel embedment $L$
for different dowel diameters $D$ and dowel – hole clearances $C$
Rys. 4. Zależność nośności osiowej $F$ złącza z kołkiem brzozowym od głębokości $L$ osadzenia kołka
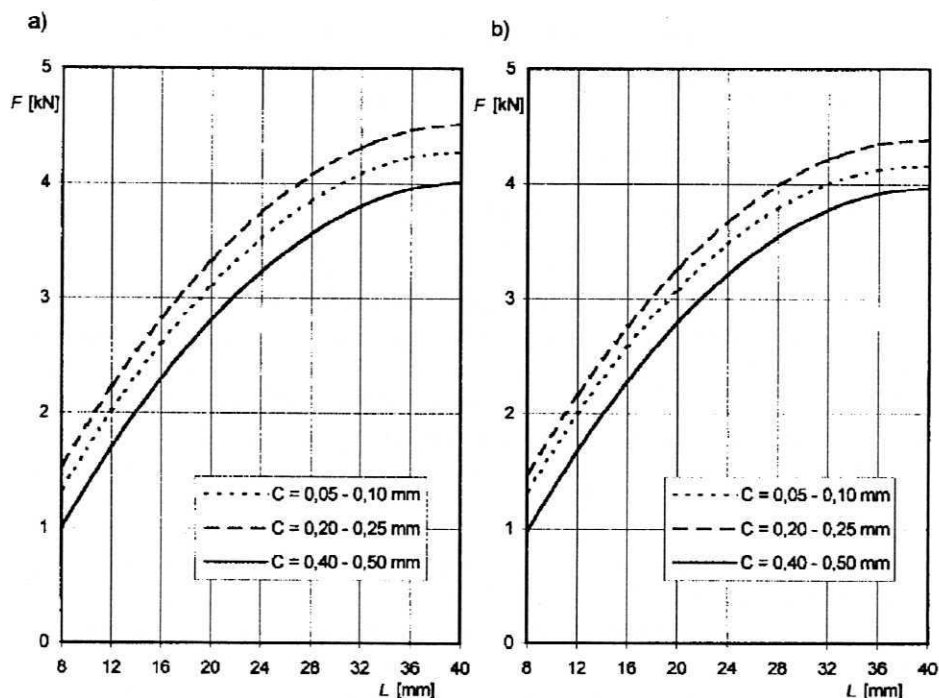dla różnych średnic $D$ kołka i luzów $C$ między kołkiem a gniazdem

a) b)



Fig. 5. Relationship of the load capacity $F$ of 8 mm diameter dowels to the depth of dowel embedment $L$
for different dowel – hole clearances $C$: a) for beech dowels, b) for birch dowels
Rys. 5. Zależność nośności osiowej $F$ złącza z kołkiem o średnicy 8 mm od głębokości $L$ osadzenia
kołka dla różnych luzów $C$ między kołkiem a gniazdem: a) dla złącza z kołkiem bukowym,
b) dla złącza z kołkiem brzozowym

The comparison of the load capacity for dowels made of beech and birch shows advantages of the first dowel material. For all dowel diameters, depths of dowel embedment and dowel – hole clearances, the load capacity of birch dowels is smaller than that of beech dowels. Relative differences of these strengths range from 0.6 to 22.5 %, on the average the load capacity of birch dowels is smaller by 9.2 % than that of beech dowels. It can be explained by the fact that the shear strength of birch wood is smaller than that of beech wood.

The formulas (1) and (2) have complex structure and are inconvenient for practical use. Thus, restricting oneself to the dowel joints with clearances from 0.20 to 0.25 mm, the expressions in a form of power functions product were calculated:

$$F_1 = 0.0561 \, D^{0.88} \, L^{0.75} \tag{3}$$
$$F_2 = 0.0464 \, D^{0.92} \, L^{0.75} \tag{4}$$

where: $F_1$ and $F_2$ [kN], $D$ and $L$ [mm].

The expressions (3) and (4) are simpler but less fitted to the experimental results than the (1) and (2), an R squared equal to 0.96.

One should note that the presented formulas are valid only for the materials, the dowel type and the gluing technique used in the tests. To other cases they should be applied with caution.

## CONCLUSIONS

The results of the tests for dowel joints in which beech or birch multigroove dowels were inserted into pine wood by means of the polyvinyl acetate glue, allow to draw the following conclusions:

1. Influence of the dowel diameter, of the depth of dowel embedment and of the dowel – hole clearance altogether on the load capacity of dowels can be expressed by means of the regression function in a form of a second power polynomial with interactions.
2. The influence of the dowel diameter and of the depth of dowel embedment can be also expressed by means of the equation in a form of a power functions product.
3. The load capacity of dowels increases as the depth of dowel embedment increases, with gradual depth increments determining smaller and smaller strength increments.
4. The effective limit of the dowel embedment depth to dowel diameter ratio is 3.5 for 6 and 8 mm diameter dowels, and 3.0 for 10 and 12 mm diameter dowels.
5. Out of the dowel – hole clearances considered in the tests the maximum load capacity is provided by the clearances from 0.20 to 0.25 mm, and the minimum by the clearances from 0.40 to 0.50 mm.
6. The load capacity of birch dowels is smaller, on the average by 9.2 %, than that of beech dowels.

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## NOŚNOŚĆ OSIOWA ZŁĄCZA KOŁKOWEGO W DREWNIE SOSNOWYM

### Streszczenie

W pracy przedstawiono badania nośności osiowej złącza kołkowego dla układu: drewniany kołek rowkowany wklejony za pomocą kleju polioctanowinylowego w drewno sosnowe prostopadle do jego włókien. Czynnikami zmiennymi były: średnica kołka, głębokość jego osadzenia i luz między kołkiem a gniazdem. Posługując się selekcyjnym planem badań określono eksperymentalnie nośność osiową złącza dla wybranych kombinacji zmiennych czynników. Uwzględniono dwa rodzaje materiału kołka: drewno bukowe i drewno brzozowe. Na podstawie wyników badań eksperymentalnych wyprowadzono funkcje regresji dla nośności złącza. Mają one postać wielomianu drugiego stopnia z interakcjami lub iloczynu funkcji potęgowych. Wzrost nośności złącza wynikający ze stopniowego wzrostu średnicy i głębokości osadzenia kołka jest coraz mniejszy. Kołki bukowe zapewniają większą nośność złącza niż kołki brzozowe.

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