LOAD-CARRYING CAPACITY OF AXIALLY LOADED RODS GLUED-IN PERPENDICULAR TO THE GRAIN

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Abstract

Glued-in rods have been used for several decades in timber structures to transfer concentrated forces from one member to another. Furthermore they have been applied as a reinforcement of timber members loaded in tension perpendicular to the grain.

The European Union supports the research project GIROD, in which design rules for glued-in rods will be drafted for Eurocode 5.

This paper presents results of tests with glued-in rods performed within GIROD and proposes a mechanical model describing the load-carrying capacity of glued-in rods which are glued-in perpendicular to the grain and loaded axially. The mechanical model takes into account the tensile perpendicular to the grain failure observed in tests.

1 Introduction

The objective of GIROD (Glued-in Rods in Timber Structures) is to provide the information required to prepare standards that will allow an increased, more advanced and more reliable use of glued-in rods in timber structures. The steps involved in achieving this objective are:

1. Perform theoretical and experimental work leading to a calculation model for axially loaded glued-in rods based on the adhesive bond properties as well as the wood and rod material properties. This must take into account the effect of varying climatic and loading conditions as well as fatigue. This step will provide information required by CEN.TC250/SC5 in the preparation of Eurocode 5 - Design of Timber Structures.
2. Develop test methods for the evaluation of adhesives for glued-in rods with respect to strength, durability, creep and creep rupture behaviour under different climatic conditions. This will support the work of CEN.TC193/SC1 (Wood adhesives).
3. Derive test methods for the production control of structural glued-in rod connections. This will support the work of CEN.TC124/WG6 (Glued-in rods in timber structures).

The objective of the third working package of GIROD is to study and to quantify the effect of the spacing between rods and the distance to the timber edges on the axial and lateral load-carrying capacity. Tests were performed by University of Karlsruhe with glued-in rods parallel and perpendicular to the grain loaded axially as well as laterally.

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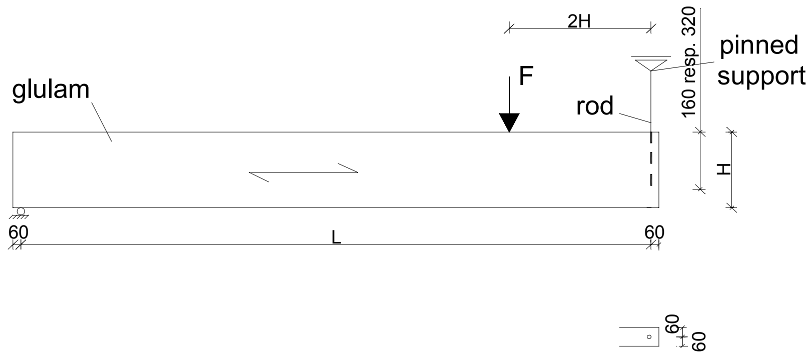
Furthermore some theoretical investigations were carried out to describe the behaviour of glued-in rods depending on rod spacings and distances.
This paper describes the test results and the theoretical investigations for rods glued-in perpendicular to the grain and loaded axially.

2 Test results with rods glued-in perpendicular to the grain

In order to make the results comparable with those of other working packages involved in GIROD it was agreed to use glued laminated timber made of lamellas of strength class C35. The moisture content of the timber was about 12 %. The threaded rods corresponded to strength class 8.8 and were zinc-coated (galvanised) and not degreased. The nominal diameter of the rods was 16 mm. They were to be glued-in in oversized holes of 17 mm diameter drilled perpendicular to the grain. The adhesive was a Casco PRF phenolic resorcinol formaldehyde. The rods had pinned supports to avoid moments at the support.
The dimensions and the test set-up are shown in figure 1. An overview of the test program is given in table 1. The depths and the lengths of the beams were varied. The glued-in length was either 160 mm or 320 mm. The distance to the edge of the rod was chosen to be 60 mm to avoid any influence of the edge on the load-carrying capacity. The length between the supports was defined to be ten times the depth of the cross-section of the specimens.



dimensions in [mm]

Figure 1: Test set-up

Table 1: Test program

	H [mm]	B [mm]	L [mm]	glued-in length l_0 [mm]
GIq-1	320	120	3200	320
GIq-2	400	120	4000	320
GIq-3	480	120	4800	320
GIq-4	560	120	5600	320
GIq-5	240	120	2400	160
GIq-6	280	120	2800	160
GIq-7	320	120	3200	160
GIq-8	500	120	5000	160

Table 2 shows the individual test results. The mean shear strength of the bond line according to the outer rod diameter is given as τ. The failure mode was pulling-out the rod combined with wood splitting for the test series with a glued-in length that was the same as the height of the beam. With increasing beam depth, the observed failure mode changed from pulling out the rod towards tensile perpendicular to the grain failure of the beam. The corresponding crack occurs always at the end of the rod. The pull-out strength of the rods which are glued-in perpendicular to the grain over the full beam depth are similar to those results achieved in tests with rods glued-in parallel to the grain. Figure 2 shows a failed specimen. The failure was reaching the tensile strength perpendicular to the grain.

Figure 2: Tensile failure perpendicular to the grain

Table 2a: Test results (mean values, glued-in length l_0=320 mm)

Test series	F_{max} [kN]	τ [N/mm²]	α (l_0/H)	Density [kg/m³]	Moisture Content [%]
GIq-1	84.0	5.22	1.00	445	11.3
COV [%]	5.2	5.2	-	-	-
GIq-2	80.7	5.02	-	430	10.9
COV [%]	5.3	5.3	-	-	-
GIq-3	70.4	4.37	-	428	10.8
COV [%]	12.8	12.8	-	-	-
GIq-4	66.0	4.10	-	433	10.9
COV [%]	12.6	12.6	-	-	-

Table 2b: Test results (mean values, glued-in length l_0=160 mm)

Test series	F_{max} [kN]	τ [N/mm²]	α (l_0/H)	Density [kg/m³]	Moisture Content [%]
GIq-5	42.4	5.27	-	443	11.5
COV [%]	13.1	13.1	-	-	-
GIq-6	36.5	4.54	-	461	11.5
COV [%]	10.8	10.8	-	-	-
GIq-7	37.7	4.69	-	443	11.2
COV [%]	9.7	9.7	-	-	-
GIq-8	29.7	3.70	-	435	11.4
COV [%]	10.8	10.8	-	-	-

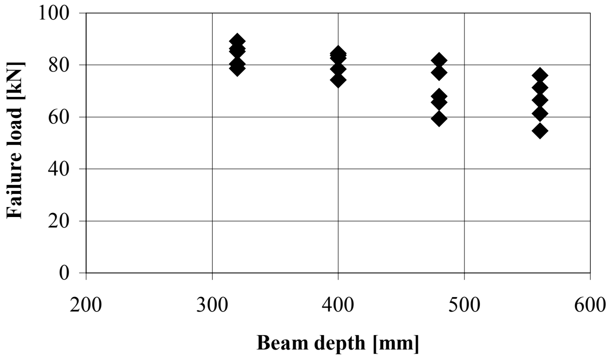


Figure 3: Test results for a glued-in length of 320 mm

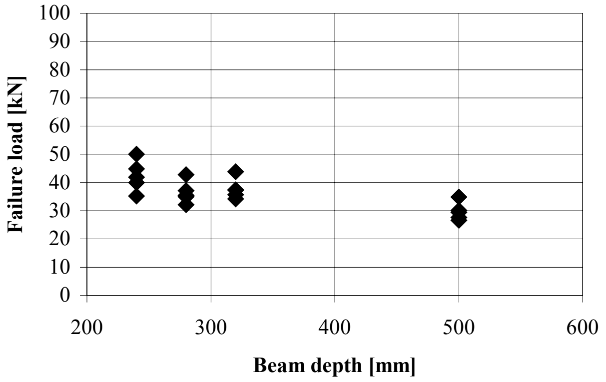


Figure 4: Test results for a glued-in length of 160 mm

Figures 3 and 4 show the test results for the glued-in lengths of 320 mm and 160 mm. It is obvious that the load-carrying capacity decreases with increasing beam depth or a descending ratio of the glued-in length l_0 to the beam depth H.

3 Calculation Model

The test results with tensile failure perpendicular to the grain were evaluated both on the basis of the work of Ehlbeck, Görlacher and Werner [1] and using a fracture mechanics approach (Eurocode 5 [2]). The failure is similar to that of notched beams and therefore the fracture mechanics approach seems to provide an adequate solution. In Eurocode 5 the design rules for notched beams are also based on fracture mechanics. Nevertheless it is also possible to describe the load-carrying capacity of the tested specimens by using the design rules for connections loaded perpendicular to the grain. The load-carrying capacity of the specimens which failed due to pulling out the rod can be described by using the design rules for glued-in rods given in the draft of the German Timber Design Code DIN 1052 [3]. First the design rules for connections loaded perpendicular to the grain are regarded. The ultimate load for a rod glued-in perpendicular to the grain may be calculated as

$$F_{90} = \frac{13A_{ef}^{0.8} f_{t,90}}{\eta k_r} \tag{1}$$

where $\eta = 1 - 3\left(\frac{l_0}{H}\right)^2 + 2\left(\frac{l_0}{H}\right)^3$

l_0: glued-in length
H: Height of the beam

$$k_r = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{h_1}{h_i}\right)^2 = \frac{H - l_0}{H}$$

$$A_{ef} = l_{r,ef} \cdot t_{ef}$$

$$l_{r,ef} = \sqrt{l_r^2 + (cH)^2}$$

$$l_r = d$$

$$c = \frac{4}{3}\sqrt{\frac{l_0}{H}\left(1 - \frac{l_0}{H}\right)^3}$$

$$t_{ef} = \min\begin{cases} b \\ 6 \cdot d \end{cases} \text{ (draft DIN 1052)}$$

b: Width of the beam

d: Outer diameter of the rod

Figure 6 shows a comparison between the failure loads reached in the tests and the calculated failure loads. The horizontal lines describe the pull-out capacity according to the draft of DIN 1052:

$$R_{ax} = l_0 \pi d f_{k1} \qquad (2)$$

with f_{k1} bond strength.

Görlacher's model assumes a tensile stress distribution perpendicular to the grain at both sides of the connection reaching a maximum at the end of the glued-in rod and decreasing with increasing distance from the rod (see figure 5). Since an undisturbed distribution is only possible in one direction, the calculated load carrying capacities are divided by 2, although a certain amount of stresses is also transferred between rod and end grain surface. These stresses are disregarded in the following.

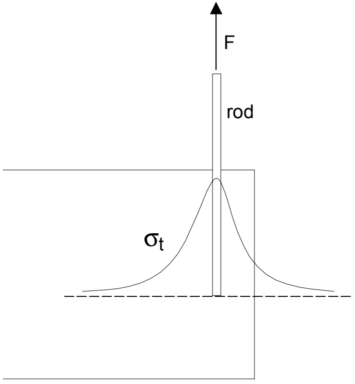


Figure 5: Tensile stress distribution

Characteristic values of the material properties according to the draft DIN 1052 were used when evaluating the load-carrying capacities. The tensile strength perpendicular to the grain is 0,5 N/mm² and the shear strength is 3,8 N/mm² for Gl 32h.

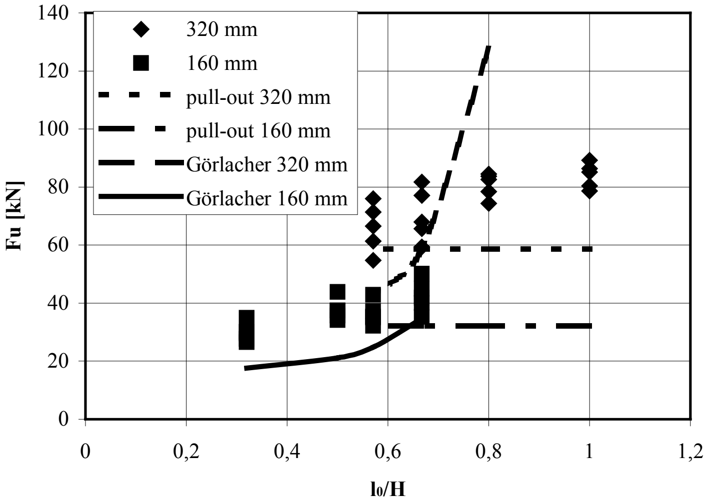


Figure 6: Test results compared to equations according to Ehlbeck, Görlacher and Werner [1]

For $\alpha = \frac{l_0}{H}$ approaching 1 the calculated load-carrying capacity reaches infinite values. In this case α is the ratio of the glued-in length to the beam depth. In the case of a notched beam $\alpha = 1$ would represent a beam without a notch. Therefore it is obvious that the model used gives infinite values. In reality the ultimate load is limited by rod pulling-out. The horizontal lines describe the pull-out strengths of rods glued-in perpendicular to the grain according to the draft DIN 1052. Considering the fact that the calculated results are based on characteristic material properties, Görlacher's equations describe the behaviour quite well.

The second calculation model evaluated here is the design rule for notched beams according to Eurocode 5 which is based on a fracture mechanics approach. The equation to describe the load-carrying capacity is

$$V = \frac{2}{3} \cdot k_v f_v b l_0 \tag{3}$$

where $k_v = \min\begin{cases} 1 \\ \dfrac{k_n}{\sqrt{H \cdot \alpha(1-\alpha)}} \end{cases}$

$k_n = 6.5$ (for glulam)

$\alpha = \frac{l_0}{H}$.

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k_v as a factor to describe the geometry of the notch is simplified related to the tested geometry. An advantage of this calculation model is that the width of the beam is taken into account more precisely.

Figure 7 shows a comparison between the failure loads from the tests and the calculated failure loads. The horizontal lines describe the pull-out strength according to equation 2 as described before.

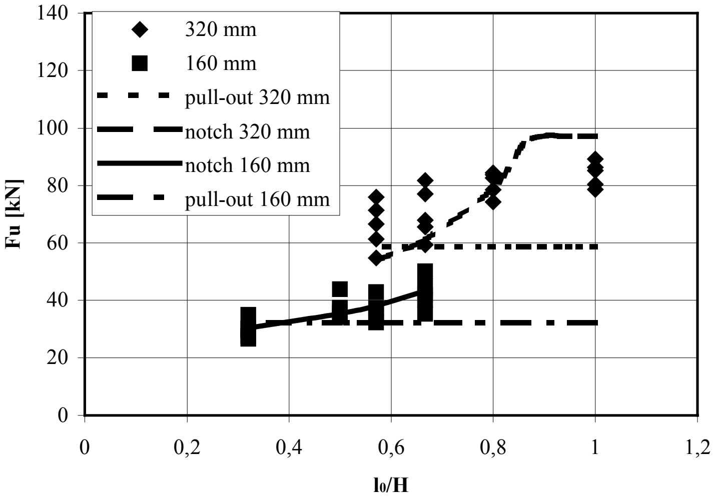

Figure 7: Test results compared to equations according to Eurocode 5 [2]

Although characteristic values were used to calculate the ultimate loads, especially for small ratios l_0/H the calculation model for notched beams overestimates the ultimate loads from the tests. The derivation of the ultimate loads according to the fracture mechanics approach is based on the deformation of a cantilever beam. If the cantilever beam length approaches zero, the calculation model is not valid anymore. Therefore the calculation model of Görlacher is suggested to describe the load-carrying capacity of rods glued-in perpendicular to the grain.

In the draft DIN 1052 simplified equations based on the theory of Görlacher are given. Figure 8 shows the comparison of the test results with the design rules of DIN 1052. The difference between the original and the simplified equations in DIN 1052 is not significant.

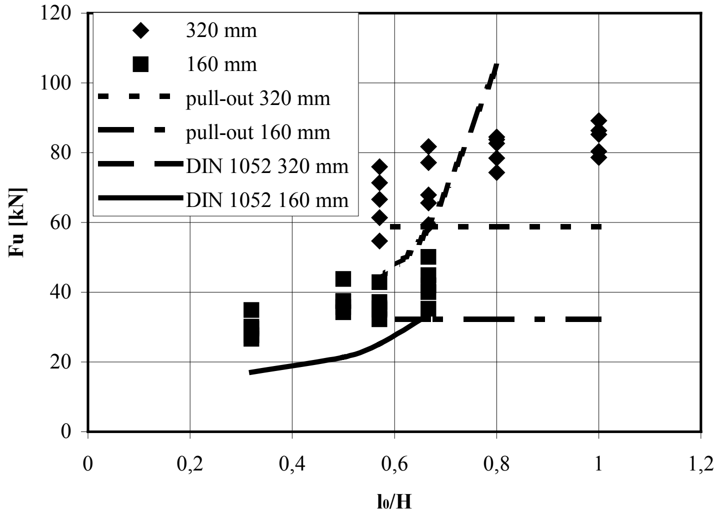

Figure 8: Test results compared to equations according to DIN 1052 [3]

4 Conclusion

Tests with rods glued-in perpendicular to the grain and loaded axially were performed. The observed failure, namely reaching the tensile strength perpendicular to the grain, in most cases was similar to the failure of notched beams. Nevertheless the equations of Eurocode 5 do not fit the test results well in comparison to the equations to describe the load-carrying capacity of connections loaded perpendicular to the grain. These equations are based on the research of Görlacher [1]. A simplified version may be found in the draft of the German design code DIN 1052 [3].

References

[1] Ehlbeck, J., Görlacher, R., Werner, H. *Determination of perpendicular-to-grain tensile stresses in joints with dowel-type fasteners; a draft proposal for design rules.* CIB-W18A, proceedings, Berlin, GDR 1989

[2] Eurocode 5: Design of Timber Structures

[3] Draft of DIN 1052, May, 2000

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