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Quantitative evaluation of beech and locust dowels in contemporary window systems

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Abstract

The increasing sizes of windows and their related glass panes including 3-pane insulating glass create higher static and dynamic stresses in the window corners. This trend emphasizes the use of durable wood species in the dowelled window corner joints. Locust (*Robinia pseudoacacia*) dowels with its pronounced technical performance in numerous applications and high natural durability has therefore become a competitor to the more traditionally used dowels made of European beech (*Fagus sylvatica*). However, so far, there have not been tests executed confirming the technical superiority of locust dowels applied in window corners. This study was conducted as a collaborative effort between the University of Applied Sciences Bern (BFH, Biel) and Eicher wood supplies (Eicher Holzwaren AG, Schwarzenegg), as a manufacturer of dowels. Eicher produces dowels made of European beech from local forests. The goals of the study were to determine the differences in performance of dowels made of locust and beech in respect to their performance in wooden window corners.

The main criteria in window construction are strength, durability, process ability and reliability. The study did subject triple-dowelled and glued window corners to standard and cyclic conditioning followed by the determination of their mechanical strength using commonly accepted standards. The analysis and interpretation of the test results was done using statistics and comparisons with the relevant literature.

Results from the tension and shear tests show that window corners with dowels made of beech did not perform significantly better in any of the five tests executed compared to the window corners with locust dowels. Nevertheless, when cyclic conditioning is employed, the strength properties of the window corners with beech dowels clearly exceed the results of the dowels made with locust. This finding is important, as cyclic climate conditions are present in all applications.

Keywords: window corner construction, strength, durability and process ability, cyclic conditioning, dowels

1. Introduction

The use of dowels to connect wood components such as windows or doors is a reliable and inexpensive technique that has been practiced for centuries. For the windows manufacturing industry, dowels have traditionally been used due to their simplicity, reliability, cost-effectiveness, and, maybe most important, their strength and fitting accuracy. Window manufacturers, due to the ever-increasing size of the windows and weight of the related glass panes including 3-pane insulating glass they produce, are understandably looking for the strongest possible way to connect the corners at a reasonable cost. Some window manufacturers, in their strive to improve the strength of the pegged window connection, believe that dowels made from locust (*Robinia pseudoacacia*) perform better than dowels made from European beech (*Fagus sylvatica*). However, this assumption has never been researched or proven, thus this study [1] was conducted to determine the differences in performance of dowels made of locust and beech in respect to their performance in wooden window corners.

2. Material and methods

This section describes the materials used in this study, their preparation, and the methods employed to investigate the influence of the species of the dowels (European beech and locust) on the performance of pegged window corners.

2.1 Standards

In Switzerland, no standards exist as to the testing of window corners in respect to strength, durability, process-ability and reliability. For this reason, this study used the standard FE-08/1 of ift Rosenheim [2], which has been used for previous research activities at Bern University of Applied Sciences [3,4].

2.2 Samples and materials used

Standardized sections of window frames were procured from a local window manufacturer made in spruce (*Picea abies*) with the dimensions 350 x 400 mm. Three dowels per corner were set. Gluing of the dowels and the corners was done with a commercially available water-based adhesive (Collano DW 2044) and corners were pressed according to industry practice. Dowels made from locust (*Robinia pseudoacacia*) and beech (*Fagus sylvatica*) were acquired for the pegging of the sample window corners.

2.3 Preparation of samples

2.3.1 Series of tests

Testing two different dowel species, two different types of strain applied on the corners and two different settings of conditioning results in eight test series. However, considering the lack of influence of the dowel type for shear strain, this test was only being executed with standard-conditioned samples. Thus, six tests were conducted, each with 12 repetitions (Figure 1).

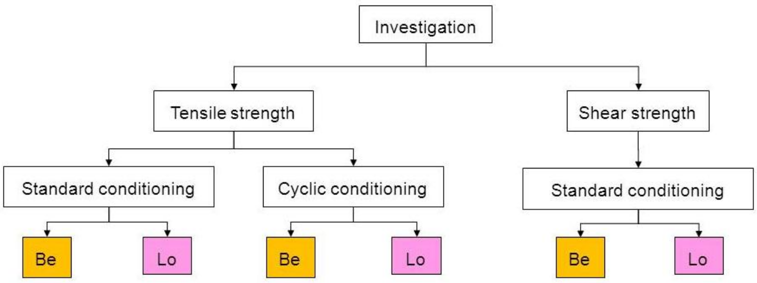

Figure 1: Tests conducted

2.3.2 Conditioning

According to the standard employed for this study (ift Rosenheim FE-08/1 [1]), half of the test samples are to be conditioned at a standard climate of 20°C and 65% relative humidity until they reach constant mass.

The study also investigated the influence of changing climate conditioning on the tensile and shear strength of the window corners, the other half of the samples were being exposed to cyclic test conditions. The periods of the cycle are as shown in Table 1.

Period no°	Climate [°C/%]	Intended wood moisture [%]
1	20/65	13±2
2	40/90	Ca. 20
3	40/30	Ca. 6
4	20/65	13±2

Table 1: Periods of cyclic conditioning

2.4 Experiment setup

In any window system, two window corners diagonally opposed to each other are stressed on tension and two on shear, as shown in Figure 2.

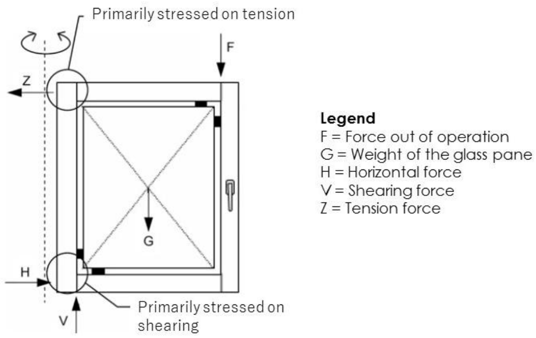

Figure 2: Load situation of window corners in practice [2]

The test is set up to simulate both strain types occurring, i.e. tensile and shear strain. Depending on whether the horizontal profile is traversing and therefore the joint at the meeting point is horizontal or vertical, the corner is either stressed in tension or in shear as shown in Figure 3. The force is introduced at the top end of the vertical profile and opposed at the position of the red block on the horizontal component in Figure 3. Pins at the location of the arrows attach the window corner tested onto the test jig. Figure 4 shows the actual test jig and a sample window corner installed for testing.

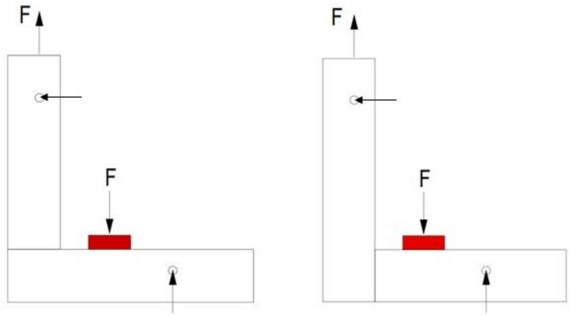

Figure 3: Window corner stressed on tension (left) and on shear (right) [3]

Figure 4: Photograph of the actual test setup in the laboratory

2.5 Equipment

The tests were conducted at the laboratory of the Department of Architecture, Wood and Civil Engineering, Bern University of Applied Sciences in Biel, Switzerland in 2016.

2.5.1 Test machine

A universal testing machine Zwick/Roell Z050 was employed for all the tests conducted. A jig used to hold the window corner tested and to guarantee the correct introduction of the force was also employed (Figure 4). Data was collected on a stationary PC-based computer using proprietary software from the universal testing machine.

2.5.2 Statistics and software

The data was analyzed using common statistical functions available in Microsoft Excel and were visualized in boxplots using the statistics programme NCSS 9 [5]. Statistically significant differences were established using t-Test and ANOVA at the 95% level of confidence. All results were assumed to follow a normal distribution and variances being equal.

3. Hypotheses

This study investigated the mechanical performance of wooden window corners connected with dowels made from two different species - European beech (*Fagus sylvatica*) and locust (*Robinia pseudoacacia*). The test hypotheses were set up assuming that locust's tannic components would have a negative effect on the strength of the window corners. Comparing the same wood species after different conditioning, the assumption was that the moisture due to increased relative humidity would weaken the bond between the dowel and the scantling in the corner joint. Thus, the hypotheses tested were as follows:

3.1 Tensile strength beech versus locust, standard conditioning

- *Null hypothesis (H_0): The mean tensile strength of a window corner pegged with beech dowels is equal to or lower than a window corner pegged with locust dowels after standard conditioning.*

- *Alternative hypothesis (H_A): The mean tensile strength of a window corner pegged with beech dowels is higher than a window corner pegged with locust dowels after standard conditioning.*

3.2 Shear strength beech versus locust, standard conditioning

- *Null hypothesis (H_0): The mean shear strength of a window corner pegged with beech dowels is equal to or lower than a window corner pegged with locust dowels after standard conditioning.*
- *Alternative hypothesis (H_A): The mean shear strength of a window corner pegged with beech dowels is higher than a window corner pegged with locust dowels after standard conditioning.*

3.3 Tensile strength beech versus locust, cyclic conditioning

- *Null hypothesis (H_0): The mean tensile strength of a window corner pegged with beech dowels is equal to or lower than a window corner pegged with locust dowels after cyclic conditioning.*
- *Alternative hypothesis (H_A): The mean tensile strength of a window corner pegged with beech dowels is higher than a window corner pegged with locust dowels after cyclic conditioning.*

3.4 Tensile strength beech, standard and cyclic conditioning

- *Null hypothesis (H_0): The mean tensile strength of a window corner pegged with beech dowels and standard conditioning is equal to or lower than a window corner pegged with beech and cyclic conditioning.*
- *Alternative hypothesis (H_A): The mean tensile strength of a window corner pegged with beech dowels and standard conditioning is higher than a window corner pegged with beech and cyclic conditioning.*

3.5 Tensile strength locust, standard and cyclic conditioning

- *Null hypothesis (H_0): The mean tensile strength of a window corner pegged with locust dowels and standard conditioning is equal to or lower than a window corner pegged with locust and cyclic conditioning.*
- *Alternative hypothesis (H_A): The mean tensile strength of a window corner pegged with locust dowels and standard conditioning higher than a window corner pegged with locust and cyclic conditioning.*

4. Results

Tests were conducted regarding tensile and shear strength of window corners pegged with beech or locust dowels under standard and cyclic conditioning.

4.1 Tensile strength beech versus locust, standard conditioning

The question investigated under Hypothesis 3.1 was if the mean value of the maximum tensile strength of window corners pegged with beech dowels is significantly higher than window corners pegged with locust dowels after standard conditioning. Results are shown in Figure 5 and Table 2.

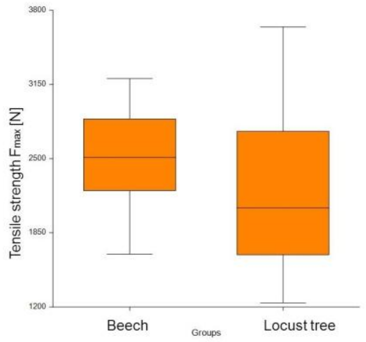

Figure 5: Boxplots tensile strength be/lo, standard conditioning

		Beech	Locust tree
Mean value (x)	[N]	2532.27	2187.73
Standard deviation (s)	[N	439.74	697.19
Coefficient of variation (VarK)	[%]	17.37	31.87
p-value	[%]	16.17	
Significance	[-]	no	

Table 2: Results tensile strength be/lo, standard conditioning

Figure 5 and Table 2 show that the mean tensile strength of a window corner pegged with locust dowels is somewhat lower and its standard deviation is higher compared to the results from beech. However, as t-tests on the results produced a p-value above 5%, the null hypothesis cannot be rejected. The tensile strength of a window corner pegged with beech dowels after standard conditioning is not significantly higher than a window corner pegged with locust dowels after standard conditioning.

4.2 Shear strength beech versus locust, standard conditioning

The question investigated under Hypothesis 3.2 was if the mean value of the maximum shear strength of window corners pegged with beech dowels is significantly higher than window corners pegged with locust dowels after standard conditioning. Results are shown in Figure 6 and Table 3.

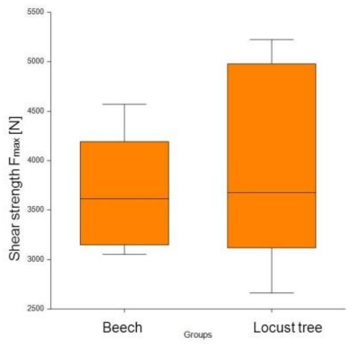

Figure 6: Boxplots shear strength be/lo, standard conditioning

		Beech	Locust tree
Mean value (x)	[N]	3677.5	3894.15
Standard deviation (s)	[N	530.54	944.93
Coefficient of variation (VarK)	[%]	14.43	24.27
p-value	[%]	49.58	
Significance	[-]	no	

Table 3: Results shear strength be/lo, standard conditioning

Results from the t-test show that the mean shear strength of the window corners pegged with locust dowels is slightly higher as is its standard deviation compared to the results from the window corners pegged using beech dowels (Figure 6 and Table 3). However, the results from these tests were found not to be significantly different (p-value 49.6%, Table 3) and the null hypothesis thus cannot be rejected.

4.3 Tensile strength beech versus locust, cyclic conditioning

The question investigated under Hypothesis 3.3 was if the mean value of the maximum tensile strength of window corners pegged with beech dowels is significantly higher than the mean value of the maximum tensile strength of window corners pegged with locust dowels after cyclic conditioning. Results are shown in Figure 7 and Table 4.

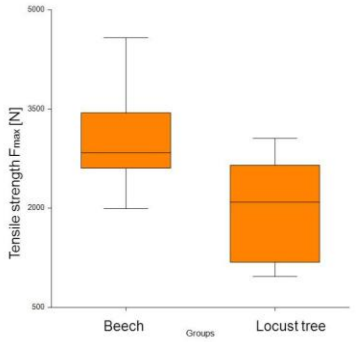

Figure 7: Boxplots tensile strength be/lo, cyclic conditioning

		Beech	Locust tree
Mean value (x)	[N]	3070.86	1973.59
Standard deviation (s)	[N	748.56	728.91
Coefficient of variation (VarK)	[%]	24.38	36.93
p-value	[%]	0.15	
Significance	[-]	yes	

Table 4: Results tensile strength be/lo, cyclic conditioning

The t-test produced rather large differences in mean values of tensile strength between window corners pegged with beech dowels as opposed to window corners pegged with locust dowels (Figure 7 and Table 4) and thus H_0 can be rejected (p-value 0.15%, Table 4). Thus, window corners pegged with beech dowels have a higher tensile strength than do window corners pegged with locust dowels.

4.4 Tensile strength beech, standard and cyclic conditioning

Hypothesis 3.4 researched if the mean value of the maximum tensile strength of window corners pegged with beech dowels after standard conditioning is significantly higher than window corners pegged with beech dowels after cyclic conditioning. Results are shown in Figure 8 and Table 5.

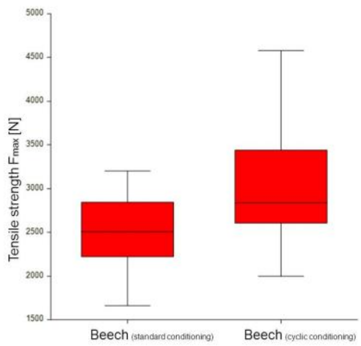

Figure 8: Boxplots tensile strength be, standard and cyclic conditioning

		Beech (standard conditioning)	**Beech** (cyclic conditioning)
Mean value (x)	[N]	2532.27	3070.86
Standard deviation (s)	[N	439.74	748.56
Coefficient of variation (VarK)	[%]	17.37	24.38
p-value	[%]	8.32	
Significance	[-]	no	

Table 5: Results tensile strength be, standard and cyclic conditioning

Figure 8 and Table 5 show that the mean tensile strength for window corners pegged with beech dowels after standard conditioning is lower (2532.3 N, Table 5) as for the same corners after cyclic conditioning (3070.9 N). However, as ANOVA-testing of the results produced a p-value of over 8%, the null hypothesis cannot be rejected at the 95% level of significance. The tensile strengths after standard conditioning and after cyclic conditioning are not significantly different.

4.5 Tensile strength locust, standard and cyclic conditioning

Hypothesis 3.5 researched if the mean value of the maximum tensile strength of window corners pegged with locust dowels after standard conditioning is significantly higher than window corners pegged with locust dowels after cyclic conditioning. Results are shown in Figure 9 and Table 6.

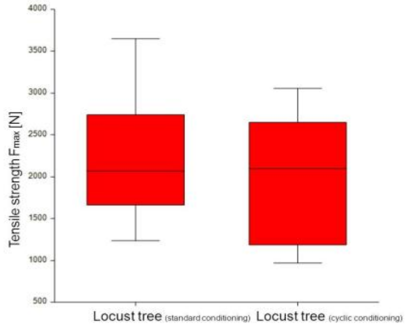

Figure 9: Boxplots tensile strength lo, standard and cyclic conditioning

		Locust tree (standard conditioning)	**Locust tree** (cyclic conditioning)
Mean value (x)	[N]	2187.73	1973.59
Standard deviation (s)	[N	697.19	728.91
Coefficient of variation (VarK)	[%]	31.87	36.93
p-value	[%]	52.54	
Significance	[-]	no	

Table 6: Results tensile strength lo, standard and cyclic conditioning

Figure 9 and Table 6 show that the mean tensile strength for window corners pegged with locust dowels after standard conditioning is higher (2187.7 N, Table 6) as for the same corners after cyclic conditioning (1973.6 N). However, with a p-value of over 52% after ANOVA-testing, the null hypothesis cannot be rejected at the 95% level of significance and thus the mean tensile strengths after standard conditioning and after cyclic conditioning are not found to be significantly different.

5. Discussion

Factors believed to influence the strength of window corners pegged with dowels made of different species (beech or locust) include, among others, the chemical properties of the adhesive, the density of the window scantlings and of the dowels, the behaviour of the natural wood components of beech and locust in the joint, the ability of the wood species in question as to let penetrate the adhesive as well as other process-related parameters such as temperature, relative humidity and the evenness and cleanliness of the surfaces on which adhesive is spread.

5.1 Tensile strength beech/locust, standard conditioning

Tensile strength is assumed to correlate to the amount of volume swelling upon the increase of moisture content (fluid of the adhesive) and the penetration of liquids of the dowels. Beech swells in volume up to β_V=17.9%, while locust swells up to β_V=11.4% [6], indicating the development of higher pressure in the dowel holes when using beech. Thus, beech should be forming a stronger bond to the adjacent surfaces because of the higher pressure and the deeper penetration of the adhesive into the dowel. Figure 10 supports these conclusions (pictures taken with 40x magnification). In both pictures, the luminescent blue light indicates the adhesive. Beech (right picture) shows numerous vessels along the dowel in luminescent light which are thus filled with adhesive. However, this specific luminance cannot be found in the picture of locust (left).

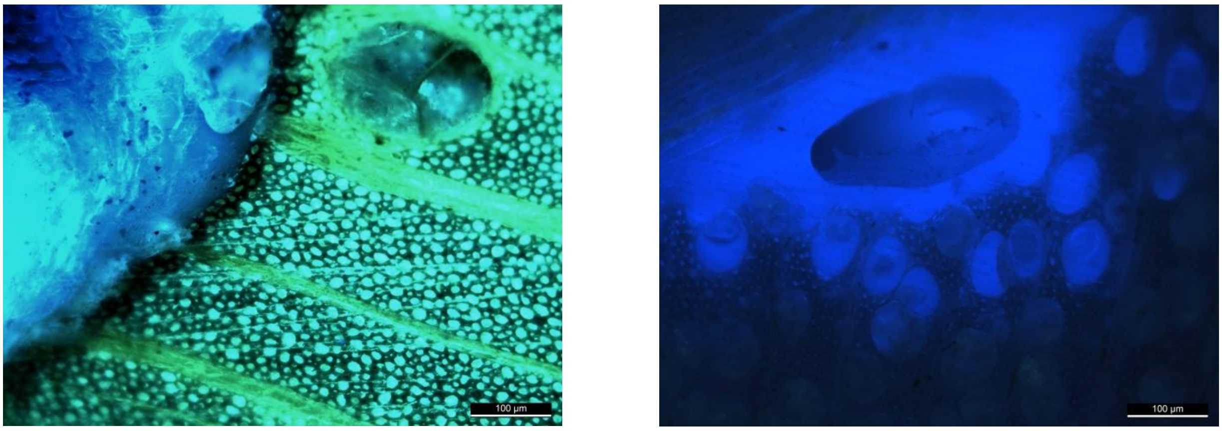

Figure 10: Transition adhesive - locust dowel (left) and adhesive - beech dowel (right)

Both species contain rather large vessels; however, the ones in beech appear to be better able to absorb the adhesive as compared to locust. It can be assumed that the tyloses, e.g., the closing of vessels in locust with extractives as visible in the upper right corner of the picture featuring the locust dowel (Figure 10), lowers locust's ability to absorb liquids (adhesives) even further. Thus, even though beech dowels do not achieve significantly higher strength in tensile tests, their results are less variable making their performance more predictable.

5.2 Shear strength beech/locust, standard conditioning

The load situation of the shear strength test is different to the tension test as in shear the main strain types are compressive strain on the dowels and transverse tensile strain on the profiles. The average compressive strength of beech is between σ_{Db}=41 and 99 N/mm^2 and for locust it is between σ_{Db}=62 and 81 N/mm^2 [6]. However, the average transverse tensile strength of spruce is between σ_{Zb}=1.5 and 4 N/mm^2 [6]. Therefore, shear strength is solely dependent on the density of the window scantling (spruce), which makes the wood species of the dowel irrelevant.

5.3 Tensile strength beech/locust, cyclic conditioning

The significant difference found between tensile strength of the two species when using cyclic conditioning may be related to the higher swelling volume of beech compared to locust. Beech with its larger volume swelling/shrinking coefficient appears to be better able to adapt to cyclic climate conditions. The moisture withdrawal in the junctions during the drying period in combination with the higher shrinkage of the beech dowels is likely to lead to a reinforcement of the glue joints of beech dowels as opposed to locust dowels. However, additional research is needed to satisfactorily explain the differences observed.

5.4 Tensile strength beech, standard and cyclic conditioning

Potential reasons for the nearly significant difference between the two different ways of conditioning have been mentioned in chapters 5.1 and 5.3. These are in particular the distinctive swelling behaviour of beech when in contact with moisture and the deeper penetration of the glue into the dowel with the consequently increased pressure on the joints. While beech was expected to reach higher tensile strength after standard conditioning, window corners pegged with beech dowels show a surprisingly high performance after cyclic conditioning as well.

5.5 Tensile strength locust, standard and cyclic conditioning

While cyclic conditioning has shown a large impact on the mean tensile strength of window corners pegged with beech dowels, this phenomenon does not appear in the same test executed on window corners pegged with locust. It is believed that the reinforcement of the glue joint after the drying period also takes place in the window corners pegged with locust but apparently there is another incident hindering the mean tensile strength to increase. It is believed that the natural wood components of locust are the reason for this barrier. However, this remains an assumption and more research is needed for a better comprehension of this interrelation.

6. Conclusions

Except for tensile strength after cyclic conditioning, window corners pegged with beech dowels have not shown significantly higher mean values than window corners pegged with locust dowels. However, in all tests, the coefficients of variation observed for window corners pegged with beech dowels were lower than the ones pegged with locust dowels, making the performance of beech dowels more predictable. Moreover, window corners pegged with beech dowels performed significantly better in tensile strength after cyclic conditioning. This appears to be an advantage of beech dowels over locust dowels as changing climate conditions between storage, production, transport and on-site are often the case. Also, even when built-in, climate conditions change with the seasons and thus the cycling continues. More research is needed to gain additional insight into the causes of failure due to tensile and shear stress. In particular, the fracture patterns have to be investigated and analyzed. Also, a chemical analysis of the natural wood components of locust and their interaction with the adhesive used might prove helpful for a better interpretation of the results obtained in this study.

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