

## DONIESIENIA NAUKOWE – RESEARCH REPORTS

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### STRENGTH COMPARISON OF JOINTS AT WINDOW FRAMES

*The strength of joints with a wooden ring, which are protected by international patent was compared with the strength of tenon and dowel joints, and consequently the applicability and suitability for producing such window frames was established. The strength of different implementations of angular joints of window profiles was tested on a tensile-testing machine. It was established that the average ultimate strength of joints with a wooden ring was higher than the ultimate strength of tenon joints, which was chosen as an upper reference limit.*

**Keywords:** wood, window, joint, strenght, mechanical properties

#### Introduction

Mortise and tenon joints are a typical example of the implementation of angular joints in window frames (fig. 1). It is known that the surface of gluing dictates joint strength. Many scientists [Vince 1975; Wang, Yuang 1994; Prekrat et al.

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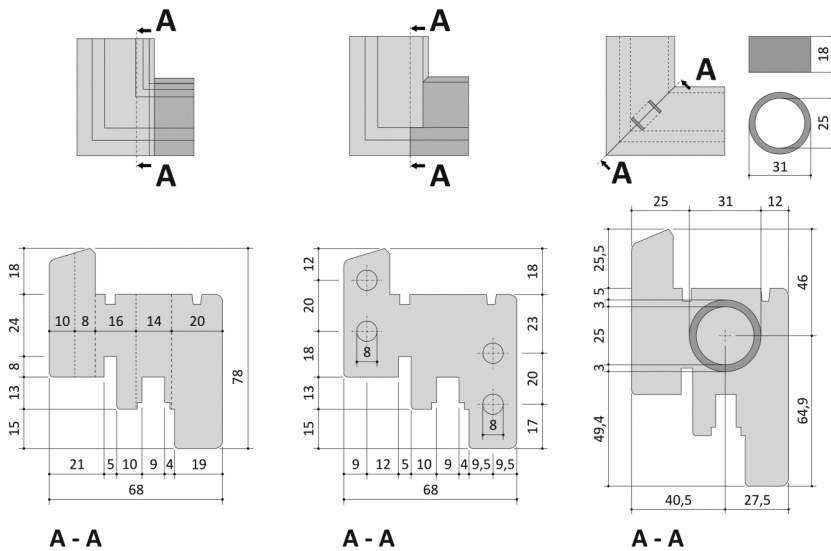
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2004] have researched the influence of the construction of different corner joints, and it has been determined that the area of glued surface is one of the most significant factors in terms of construction, and that the strength of adhesion and the area of glued surface are significantly interdependent. Dziegelewskia and Zenkteler [1975] confirmed the aforementioned assertion comparing the strength of a tested single- and twin-dado and rabbet joint with a round head tenon, whereas the joint with the twin-dado and rabbet tenon demonstrated the maximum strength, and in addition having the largest surface of gluing. Numerous authors have analysed the strength of angular junctures on the basis of different aspects. Hill and Eckelman [1973] delineated the impact of tenon dimension on the stiffness of joints. Tankut and Tankut [2005] determined the impact of tenon and mortise geometry on joint strength. Irrespective of the fact that the joints boasted the same surface of gluing, the round head tenons and dados provided 15% less strength than those with even tenons. The strength of joints with square tenons in a rounded groove was reduced by 30%. Wilczynski and Warmbier [2003] proved that the stiffness and strength of joints increases with an increase in joint dimension; however, the impact of tenon thickness on the coefficient of joint stiffness is linear. In their paper, Prekrat et al. [2004] proved that the same or even better results might be achieved with an innovative composition of amended geometry and a smaller surface of gluing. Dowel joints, joints with lenticular wooden rabbets and wedge-shaped finger joints are less frequently used (fig. 1). The dimension and distance between the dowels have the most significant impact on the strength of dowel joints. The impact of wood species and the adhesive used for corner joints with mortise and tenon was investigated by Altnok et al. [2010]. For their experiment they used Scotch pine (*Pinus Sylvestris* L.) and Uludag fir (*Abies bornmulleriana*). As adhesive they used two types of PVAc adhesives. They determined that the highest performance was determined at double mortise and tenon joint when Scotch pine was used. Eckelman [1970] carried out a test of the bending of T-joints with dowels and established an increase in bending strength with an increase in the width of the window frame. Moreover, Eckelman [1971] established that the bending strength may increase by increasing the distance between the dowels by 40%. Hoffmann's joint may be regarded as an alternative implementation, where the cross-section of joining element is in the form of a double dovetail [Hoffmann-Schwalbe 2008]. In our research focused on mechanical properties of a newly developed angular juncture with a wooden ring (fig. 1). The invention was patented with WIPO (World Intellectual Property Organization) [Govže 2005].



**Fig. 1. Type and dimension of angular joints in groups A, B and C**  
*Rys. 1. Rodzaj i wymiary połączeń kątowych w grupach A, B i C*

The quest for energy efficient windows with regard to air- and watertightness is also related to the quality and strength of the joint as determined by Skogsrad and Uvsløkk [2010].

The joint with a wooden ring is an indirect angular juncture with a wooden joining element in the form of a ring, which is glued into a ring-shaped groove and fixed with a screw. The screw undertakes the role of a clamp in the gluing phase. When the glue hardens, the main load is borne by the glued joint and the screw may be removed.

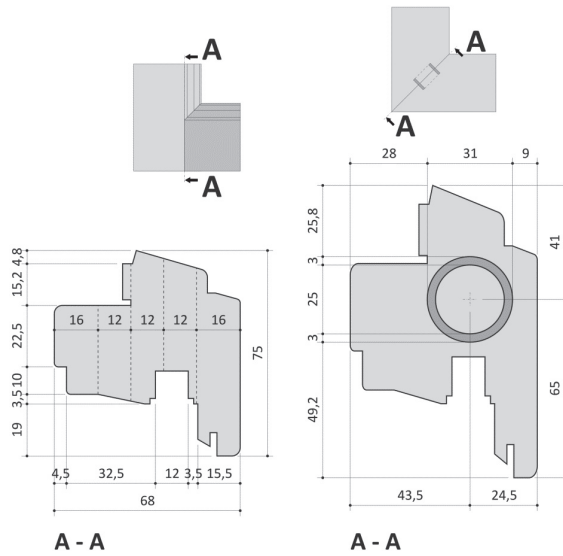
It was envisaged that the values of the ultimate strength of joints with a wooden ring would be somewhat lower than those recorded with the classical tenon joint and higher than those recorded for a dowel joint. Similar, it was expected that the suitability of using such a joint in the production of window frames would be confirmed experimentally.

Global trends in the production of window frames dictate the installation of energy-efficient window frame. Frequently, the frame is no longer composed of wood but encompasses a number of layers of different insulating materials. So far it is conceivable that the currently predominantly used tenon and dowel joints may no longer be used in particular cases due to the composite structure of window frame.

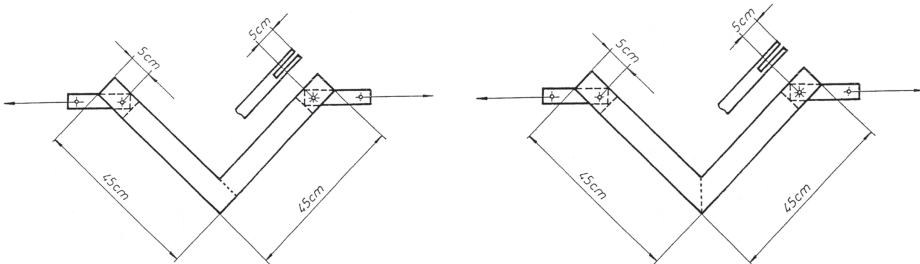
The objective of our research was to establish firstly whether the strength of an angular joint with a wooden ring is comparable in strength with the classical tenon and dowel joint. Secondly, whether such a joint would at the same time be strong enough to be used in the production of window jambs and frames.

## Materials and methods

We are interested in the comparison of the strength properties of three different wooden joints, i.e. a tenon, dowel and ring joint (fig. 2 and 3). The samples with tenon and dowel joints were made of industrially-produced window frames manufactured by two different producers. The same profile cross-sections and the same glue, as used in the tenon and dowel joints, were used in the samples with a wooden ring joint. The experiment involved 6 samples from each group (table 1). The samples with tenon joints composed groups A and D, differing in the glue used and the form of the profiles. Group B encompassed the samples with dowel joints, while the groups C and E were composed of samples with a wooden ring joint.



**Fig. 2. Type and dimension of angular joints in groups D and E**  
*Rys. 2. Rodzaj i wymiary połączeń kątowych w grupach D i E*



**Fig. 3. Drawing with sample dimensions (a – implementation of juncture with tenon and dowel joint, b – implementation of juncture with the joint with a ring)**  
*Rys. 3. Rysunek obrazujący wymiary próbek (a – zastosowanie złącza z połączeniem na czop i kolek, b – zastosowanie złącza z połączeniem z pierścieniem)*

**Table 1. Characteristics of PVAc glues used**  
**Tabela 1. Charakterystyka użytych klejów PVAc**

	PVAc 1	PVAc 2
	Mekol 1141	Duplit AL-NEU
Density <i>Gęstość</i>	≈1.1 g/cm <sup>3</sup>	≈1.1 g/cm <sup>3</sup>
pH value (ISO 976) <i>Wartość pH (ISO 976)</i>	≈5.5	≈6.0
Viscosity (ISO 2555) <i>Lepkość (ISO 2555)</i>	12000...15000 mPa.s	≈12000 mPa.s
Chalk point <i>Punkt kredowania</i>	≈4°C	≈7°C

All the samples were made of pinewood. Two commercial polyvinyl acetate (PVAc) glues (PVA glue 1 and PVA glue 2) with an additional firming agent, were used (table 2). The PVAc preparations were a polymeric dispersion in water. The viscosity was between 12000 and 15000 mPa.s. (these glues applied in our research are the ones currently used in mass production of window frames). The samples were conditioned in a laboratory and tested 7 days after gluing.

**Table 2. Properties of samples from different groups**  
**Tabela 2. Właściwości próbek z różnych grup**

Group <i>Grupa</i>	Wood <i>Drewno</i>	Joint <i>Połączenie</i>	Glue <i>Klej</i>
A	pinewood <i>sosna</i>	tenon <i>czop</i>	PVA glue 1 <i>Klej PVA 1</i>
B	pinewood <i>sosna</i>	dowel <i>kolek</i>	PVA glue 1 <i>Klej PVA 1</i>
C	pinewood <i>sosna</i>	with a ring <i>z pierścieniem</i>	PVA glue 1 <i>Klej PVA 1</i>
D	pinewood <i>sosna</i>	tenon <i>czop</i>	PVA glue 2 <i>Klej PVA 2</i>
E	pinewood <i>sosna</i>	with a ring <i>z pierścieniem</i>	PVA glue 2 <i>Klej PVA 2</i>

The ultimate strength of the differently implemented angular joints of the window profiles was tested on the tensile-testing machine in the laboratory of the company Jelovica d.d. in Slovenia. The research methodology adopted was in accordance with other published work [Korzeniowski 1982; Warmbier, Wilczynski 2000]. The samples were prepared as demonstrated in fig. 1. The wings of the samples were 450 mm long and glued together at a right-angle. At the end of wings the bores of 8.5 mm in diameter were drilled for the grips of tensile-testing machine. The equilibrium moisture content of the

samples was 12%. The samples were then gripped into the tensile-testing machine and tested in the tensile direction until failure of joint. The value of the ultimate tensile strength was measured in Newtons (N) and concurrently recorded. Upon the destruction of a joint, the test was stopped. The strength recorded at the destruction of the joint was taken for evaluating the ultimate strength of the tested joint.

## Results and discussion

Ultimate strength recorded on the tensile-testing machine while testing six samples from each group are demonstrated in table 2.

**Table 3. Ultimate strength of samples in Newton (N)**  
*Tabela 3. Wytrzymałość graniczna próbek w Newtonach (N)*

Group <i>Grupa</i>	Individual strength value <i>Poszczególne wartości wytrzymałości</i> (N)						Average strength value <i>Średnia wartość</i> <i>wytrzymałości</i> (N)	Standard deviation <i>Odchylenie</i> <i>standardowe</i>
	1	2	3	4	5	6		
A	835	920	820	840	830	750	832.5	54.199
B	480	540	600	500	510	550	530	42.895
C	1020	1160	1250	1250	1090	1250	1170	98.184
D	880	980	1100	1160	990	1070	1030	100.000
E	1260	1080	1000	1120	1070	1160	1115	88.938

If comparing the average values of measured strength at which the destruction occurred, it may be established that the strength of the samples in group A (tenon joint) proves to be 36% higher than the strength of the samples in group B (dowel joint). The average values of ultimate forces with samples in group C (joint with a wooden ring) proves to be 29% higher than the samples in group A and 55% higher than in the samples in group B. Given the fact that the same glue and profiles were used in all three groups, it may be concluded that the tenon joints were substantially stronger than the dowel ones, which was expected. The results showed that the joints with a wooden ring were stronger than the tenon ones; this was somewhat surprising.

Similar results to those recorded in the samples in groups A and C were obtained also when comparing average ultimate forces in groups D (tenon joint) and E (joint with a wooden ring), where different glue and window frame were used. The average value of ultimate strength in the samples in group E (joint with a wooden ring) is 8% higher than in the case of the samples in group D. The ultimate strength in the samples in groups D and E are slightly greater than with the

samples in groups A and C, which is probably the consequence of the application of glue and not the type of window profile.

The comparison of average values of ultimate forces with the test items from all five groups reveals that the greatest strength was achieved with the test items with a wooden ring; however, the values recorded in Groups C and E slightly differ, since different glues and window profiles were used. Consequently, the impact of different glues on the strength of joints with a wooden ring shall be researched in one of our subsequent researches.

## Conclusions

Test results reveal that the average ultimate strength of a joint with a wooden ring is greater than the ultimate strength of tenon joint with the same profile cross-section and with the application of the same glue. Furthermore, as was to be expected, the results clearly indicate that the dowel joints are the weakest in strength.

The work established that the joint with a wooden ring is suitable for the production of window frames, because it is superior in its strength relative to the dowel and tenon joints, both of which are currently predominantly applied in window frame mass production.

The advantage of joints with a wooden ring is in its universality, i.e. its independence of dimensions, profile cross-section, its composition and the simple technology, which offers the possibility of changing the cross-sectional profile or its composition, whilst maintaining the angular joint intact. The work has particular implementation for window frame producers, seeking to use multilayer construction and composite elements in the production of window frames and jambs to reduce heat loss at windows.

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## PORÓWNANIE WYTRZYMAŁOŚCI POŁĄCZEŃ W OŚCIEŻNICACH OKIENNYCH

### Streszczenie

Połączenia na czop są typowym przykładem zastosowania belek kątowych w ościeżnicach okiennych. Wytrzymałość ościeżnicy okiennej zależy także od lepszca i powierzchni, na którą je naniesiono. W niniejszym referacie przedstawiono wyniki badań równych połączeń drewnianych, tj. na czop, kolek i pierścieni oraz dwóch komercyjnych klejów na bazie dyspersji poliocetanowinylowej (PVAc). Drewniane ościeżnice zostały wykonane z drewna sosnowego w lokalnych zakładach. Ramiona próbek miały 450 mm długości i zostały sklejone razem pod kątem prostym. Wilgotność równowagowa próbek wynosiła 12%. Wytrzymałość graniczna belek kątowych różnie zastosowanych w profilach okiennych została przebadana na maszynie do testowania wytrzymałości na rozciąganie. Na końcach ramion próbek wywiercono otwory o średnicy 8.5 mm do zamocowania uchwytów maszyny do testowania wytrzymałości na rozciąganie. Następnie próbki zainstalowano w maszynie i poddano badaniu, zwiększając stopniowo siłę rozciągającą, aż do zniszczenia połączenia. Wartości wytrzymałości granicznej na rozciąganie zostały zmierzone w Newtonach (N) i jednocześnie zapisane. Wyniki badań pokazują, że średnia wytrzymałość graniczna połączenia z drewnianym pierścieniem jest większa niż wytrzymałość graniczna połączenia na czop, przy tym samym przekroju poprzecznym



profilu i zastosowaniu tego samego kleju. Co więcej, zgodnie z oczekiwaniami wyniki jasno wskazują, że wytrzymałość połączeń na kołek była najmniejsza z trzech przebadanych profili okiennych. Ustalono, że połączenie z drewnianym pierścieniem jest odpowiednie do zastosowania w produkcji ościeżnic okiennych, ponieważ wytrzymałość tego połączenia okazała się większa niż wytrzymałość połączenia na czop, które jest obecnie przeważnie stosowane w produkcji okien, oraz znacznie większa niż wytrzymałość połączenia na kołek, które również jest stosowane w produkcji masowej. Przewagą połączenia z zastosowaniem drewnianego pierścienia jest jego uniwersalność, tj. niezależność od wymiarów czy przekroju poprzecznego profilu i jego struktury, co oznacza uproszczenie technologii, gdyż przekrój poprzeczny profilu lub jego strukturę można zmienić w każdym momencie, natomiast produkcja złącza kąтового powinna pozostać bez zmian. Okazuje się to szczególnie istotne wtedy, gdy producenci poszukują rozwiązań pozwalających zredukować ulatnianie się gazów cieplarnianych przez okna i w rezultacie stosują wielowarstwową konstrukcję ościeżnic okiennych lub elementy kompozytowe w produkcji ościeżnic okiennych i stojaków ościeżnicy.

**Słowa kluczowe:** drewno, okno, łącznik, wytrzymałość, właściwości mechaniczne