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Influence of the time between machining and assembly of mortise and tenon joints on tension strength of T-type joints

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Abstract: The strength of mortise and tenon joints depends on a variety of factors. In this study, we examined the influence of the delay of the joints assembly, from the machining time of the mortise and the tenon, for months 1, 3 and 12, to the tension strength of the T-type mortise and tenon joints. We proved that the increase of assembly delay contributes to the decrease of the tension strength of the joints. The way of storage of the joints members, open in air and closed in plastic bags, also seemed to affect strength significantly. Finally, the use of D3 durability class PVAc adhesive showed higher strength values compared with the respective D1 durability class PVAc adhesive.

Keywords: mortise and tenon, tension strength, T-type, middle joint, delay of assembly, PVAc.

INTRODUCTION

People's everyday life is intimately related to the utilization of furniture. Consequently, furniture has to satisfy functional needs in such ways as to offer safety and comfort through quality of structure and long life duration. The strength and stability of furniture highly depend on the way joints are made, i.e the way wooden parts are connected to each other.

A fundamental way of connection is the mortise and tenon joint which has been widely used for centuries and continues to be used despite the development of a considerable number of variations of the basic joint (Wilczynski 2003). Regarding the mortise and tenon joint type, parts of wooden frames are joined together by the insertion of a suitably constructed wooden edge (mortise) into the respective opening of another frame piece (tenon) usually by means of an adhesive (Efe, 2005). There are various forms of this joint type such as the "occult" form in which the mortise ends up in the inner part of the wooden frame, the "visible" form where mortise continues up to the external part of the wooden frame, the "double mortise and tenon" joint and many others (Hill and Eckelman 1973). The manufacturer takes into consideration the dimensions of the wooden elements to be joined together, the density of the wooden material, the loadings that the construction is under and chooses the mortise and tenon joint type accordingly.

A lot of investigations on mortise and tenon joints that have been conducted so far contributed considerably in the definition of factors affecting joints bending moment capacity and firmness. In 1973, Hill and Eckelman examined the bending moment capacity and firmness of the mortise-tenon joint and they evaluated the importance of the mortise length ranging from 0.5 to 2 inches with a standard 2 inches width. They also conducted experiments using different types of wood and adhesives aiming to access bending moment capacity and they found out an increase in joint stability based on shoulders formation in the mortise. In a similar study Erdil et al. (2005) concluded that the larger the dimensions (length, width, depth) of the mortise are, the higher the joint bending moment capacity gets. They also confirmed the increase in joint strength by applying adhesives on the surface of the mortise and also inside the tenon. Kamenicky (1975) studied the elasticity of this specific joint while Smardewski (2002) analyzed the loadings exerted on different parts of the mortise and tenon joint assays.

Dupont (1963) concluded that the optimum joint strength is achieved when the adhesive is applied both in the mortise and the sides of the tenon. Additionally, he found that the wooden elements about to be joined together would better be at a humidity level of 7-9%. Sparkes (1968) concluded that square-end mortise and tenons are stronger than round-end mortise and tenons although square-end joints inserted in a round-end tenon are weaker by 15%. Willard (1966) manufactured and then tested mortise and tenon joints showing that joints with compressed mortise before insertion in the tenon are not superior in firmness than the conventional mortise and tenon joints. Mihailescu (2001) used finite element methods (FEM) to obtain additional information about the bending moment capacity of mortise and tenon joints. The purpose of that study was to develop a predictive expression for mortise and tenon joints that would take into account wood species, adhesives, and joint geometry specifically, tenon depth, tenon shoulder width, and tenon length. Yang and Lin (1986a, b) found that maximum bending moment capacities were obtained with tenon/mortise fits of -0.008 to $+0.012$ inches. Tankut and Tankut (2005) also studied square and round mortise and tenon joints and they concluded that by increasing the mortise dimensions the bending moment capacity is consequently increased due to an increase of the adhesive area. An increase in bending moment capacity has been also observed after increasing the width of the wooden elements participating in the joint construction. Aman et al (2008) as well as Efe et al. (2005) proved the superiority of the traditional mortise and tenon joint against other types of this joint.

The assembly of mortise and tenon joints in previous studies, following the guidelines of the European and International standards that referred to wood bonding, were made as soon as possible and not later than 24 hours after joint members cutting. In actual production conditions sometimes a significant time delay from the time of machining of joint members to the time of bonding is detected. Researches regarding the influence of the delay of assembly to the strength of mortise and tenon joints have not been found in the literature.

In the present research it was studied how time, from the moment of machining the mortise and the tenon, up to the moment of assembly them to each other, affects the tension strength of the T-type mortise and tenon joints.

MATERIALS AND METHODS

Experiments were carried out with unsteamed beech (*Fagus sylvatica* L.) solid wood originated from Greece. The material was placed in a conditioning room at $20\pm 2^{\circ}$ C and $65\pm 5\%$ relative humidity and allowed to reach a nominal equilibrium moisture content (EMC) of 10-12%. Afterwards, in a frames factory for upholstered furniture, wood pieces were produced with a cross section 24 x 48 mm and the machining of mortise and tenon for the T-type (middle) joints samples were done. Totally, 210 couple samples of mortise and tenon were prepared and they were divided in 14 groups. The samples of 6 groups that were put into plastic bags with other 6 groups that were without any protection (open in air) remained at the factory until to assembly the T-type joints. Each T-type specimen consisted of two (2) structural members, a horizontal (the mortise) and a vertical member (the tenon). Holes of 18 mm in diameter were drilled in the vertical member of each specimen. The details of configuration and dimensions of the specimens used in the study are shown in Figure 1.

The assembly of specimens were done in four different periods after machining of mortise and tenon, as follow: 1) two groups of specimens direct after machining, 2) four groups of specimens, two from open in air and two from closed in bags, one month after machining, 3) four groups of specimens, as previous, three months after machining and 4) four groups of specimens, as previous, one year after machining.

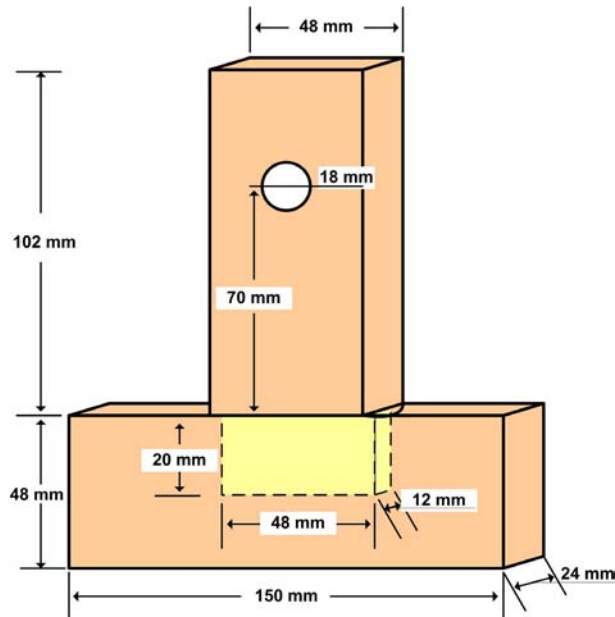


Figure 1. Configuration of the T-type specimens used to determine middle joint strength in tension

Before assembling all the samples were cleaned with compressed air to remove dust and 6 ml PVAc adhesive D1 (solids 51.3%) or D3 (solids 43.2%) durability class (according to EN 204:2001 standard) were applied in every couple of mortise and tenon under cold conditions.

The prepared bonded joints (15 samples for each parameter) were remained at $20 \pm 2^\circ \text{C}$ and $65 \pm 5\%$ relative humidity conditions for seven days. After that, the tensile shear strength test was carried out on a Shimadzu testing machine with a constant speed of 6 mm/min. The way of loading the samples in tension is given in Figure 2.

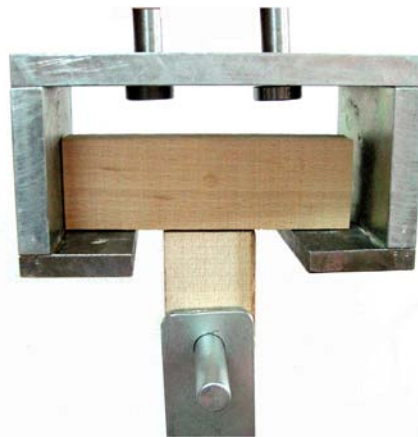


Figure 2. Method of loading in tension the T-type joints

Before assembling of the T-type joints and also after the test, samples were cut from the specimens and the density and moisture content (MC) were determined. The mean density of the beech wood was measured as 0.688 g/cm^3 (s.d. 0.021) for 11.34 % (s.d. 0.428) mean moisture content. In all cases the percentage of moisture content did not differ significantly. The tensile shear strength was expressed as the maximum load applied in Newtons (N).

RESULTS AND DISCUSSION

Mean values of the tension strength of the tested T-type mortise and tenon joints are shown in the following Table 1

Table 1. Tension strength (N) of T-type mortise and tenon joints

Storage	Time from machining to assembly							
	0 days		1 month		3 months		1 year	
	D1	D3	D1	D3	D1	D3	D1	D3
Open in air	7571.2*	8815.3	6536.6 (1227.2)	7261.4 (1240.2)	4611.6 (821.8)	5402.2 (1078.0)	2270.3 (688.8)	3556.1 (730.0)
Closed in bag	(1098.9)	(1208.4)	7092.6 (722.0)	8787.2 (1328.2)	5252.1 (932.3)	7281.2 (787.9)	4573.5 (860.1)	6552.2 (904.8)

* Mean values of 15 samples and standard deviation in parenthesis

According to these results, the highest mean value of tension strength (8815.3 N) of the joints was recorded by the specimens which were assembled directly after the machining of the joint parts and the PVAc adhesive used was of D3 class, while the lowest mean value (2270.3 N) was measured in the specimens assembled one year after the machining of the joint parts and all that period had remained exposed in air conditions (open in air) and the adhesive used was that of D1 class.

Obviously, the main factors that greatly affected the strength of the middle joints were the time between the machining and the assembly of the joint specimens, the durability class of the adhesive used and finally, the way that the T-type joint parts were kept (open in air/closed in bags). The increase of the storage time of the specimen parts, from the machining time of the mortise and tenon forms, up to the assembly time of the joint parts, was proved to gradually decrease the tension strength of the T-type joint. The lowest percentage of tension strength decrease (0.3%) was demonstrated by the specimens that were assembled one month after the machining of their parts, using D3 class adhesive and during this month the joint parts have been maintained closed in plastic bags. On the contrary, the highest percentage of tension strength decrease (70%) was marked by the specimens, which were assembled one year after the machining of the joint parts, using D1 class adhesive and the wooden joint parts have been maintained open in air conditions till the assembly time. In all cases, the joint specimens that were assembled one month after the machining of the parts presented lower mean tension strength values compared to the respective values of the specimens assembled directly after the machining procedure, but that difference did not seem to be statistically significant. Contrarily, the mean strength value of the specimens that were assembled one year after the parts manufacturing recorded statistically significant difference from the respective values of the specimens assembled one month after the machining and also the specimens assembled directly after the machining procedure, as well. This is attributed to the aging and inactivation of the wood surfaces that start to occur through different mechanisms immediately after their preparation (Custódio et al. 2009).

Furthermore, in all cases, the joint specimens that were assembled with wooden parts that have been kept in closed plastic bags (Figure 3) resulted in higher mean strength values, than the respective values of the specimens assembled with the wooden parts that have been remained exposed in open air conditions (open in air). Although, only the specimens assembled one year after the machining procedure showed statistically significant difference from all the other joint cases. The aging of surfaces seemed to deteriorate in the presence of dust, which was difficult to be totally removed.

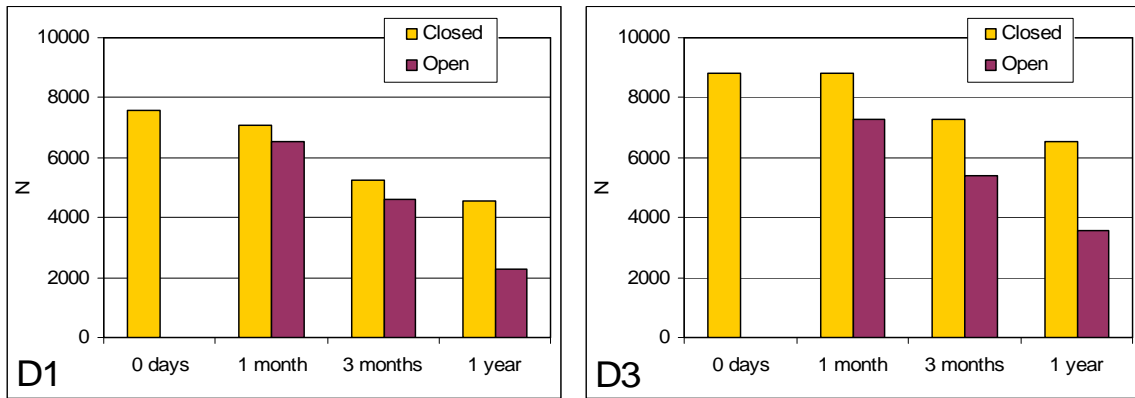


Figure 3. Effect of method of storage the samples before gluing with PVAc class D1 and D3 on tension strength

The use of D3 durability class adhesive contributed to the construction of powerful joints and specifically, showed in all cases higher mean strength values (Figure 4), than the values of the respective specimens, where D1 durability class adhesive was used. Statistically significant difference appeared only in the case of the specimens, assembled with wooden parts that have been maintained in closed bags.

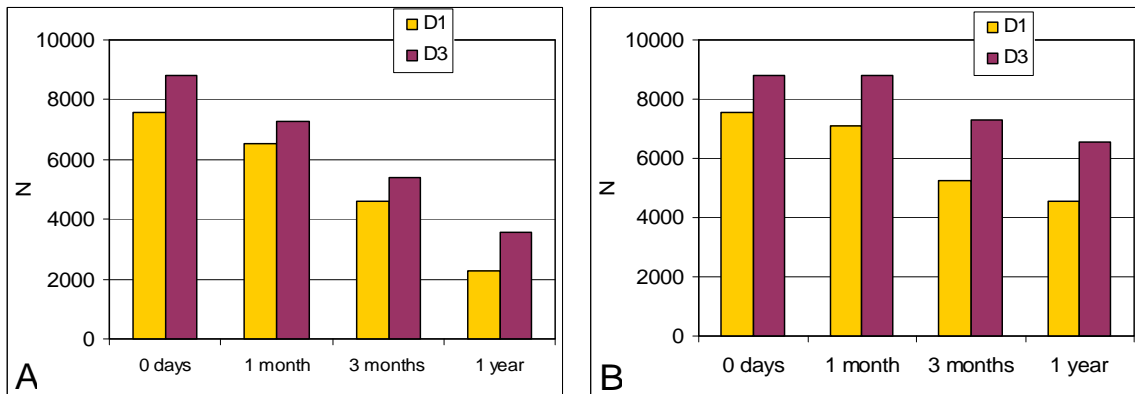


Figure 4. Effect of glue on tension strength (N) of the (A) open in air and (B) closed in bag samples

CONCLUSIONS

The mortise and tenon joint is widely used in the furniture construction, in order to connect the solid wooden parts. The main conclusion, which can be drawn from the completion of this research, is that the tension strength of T-type mortise and tenon joints is strongly affected by the time that mediates from the machining of the parts, till their assembly in a stable joint, after the adhesive application. Any increase in the delay of assembly contributed to the further decrease of the tension strength of the joints.

Not only time, but also the way of storage of the machined members of T-type joints till their assembly time affects the tension strength of the joints. The results of this research showed that the joints that were assembled with members kept into plastic bags, recorded higher tension strength than the joints assembled with members which had remained open in air without any protection.

The tension strength of T-type joints was also affected by the durability class of the PVAc adhesive used in the assembly of the joints. The use of D3 durability class adhesive resulted in stronger joints in tension strength than the use of D1 durability class adhesive.

According to these results, it could be maintained that the assembly of joints must be done directly after the machining of the joint parts. If this is not possible to happen, the

machined members of the joints must be kept clean into plastic bags, but not longer than 1 month. Finally, the use of D3 durability class adhesive seems to improve the tension strength of the joints.

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Streszczenie: *Wpływ czasu pomiędzy obróbką a montażem na wytrzymałość na rozciąganie połączeń półkrzyżowych o złączach czopowych.* Wytrzymałość połączeń czopowych zależy od wielu czynników. Celem niniejszej pracy było określenie wpływu czasu pomiędzy obróbką a montażem na wytrzymałość na rozciąganie połączeń półkrzyżowych o złączach czopowych. Wykazano, że wzrost czasu pomiędzy obróbką a montażem tych połączeń powoduje obniżenie ich wytrzymałości na rozciąganie.

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