WOOD RESEARCH
59 (2): 2014
359-372

THE STRENGTH PROPERTIES CHANGING ACCORDING TO TYPE CORNER JOINTS AND ADHESIVE OF THE WOOD-BASED FURNITURES UNDER THE EFFECT OF DYNAMIC FORCES

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(Received May 2012)

ABSTRACT

In this study it was examined the strength performance of a fully laden bookcase (TSE-5913 2009) in a single-storey building under the effect of horizontal earthquake forces. To this end, 180 test samples were produced from surfaced particleboard with three different joint and glue types. This study theoretically and empirically examined the changing effect of the theoretically-measured maximum moment caused by minor earthquake forces affecting the bookcase joints. The theoretical and experimental analysis showed that polyurethane glue had the highest (140690 Nmm), polyvinylacetate glue the lowest (115467 Nmm) adhesive performance and that a combined joint gave the highest (132081 Nmm), dowel joint the lowest (122305 Nmm) joint performance.

KEYWORDS: Earthquake effects, strength, case construction, particleboard.

INTRODUCTION

Furniture products are directly or indirectly exposed to various mechanical forces, which impose axial forces (compression and tensile), shear forces and moments on the joints of furniture elements. Depending on the effect of this load, openings and deformations (bending, breaking) may occur at the joints of the furniture elements. Various processes are employed during the design and manufacture of furniture to consider such deformations (Eckelman 1978). Many researchers have examined the design and mechanical features of furniture constructed with wooden and wood-based panels and different joints (Taş et al. 2007).

Previous studies reported that joint elements with different rigidities affected the rigidity of the furniture (Lin and Eckelman 1987). Some researchers reported that increased dowel diameter and length in single dowel-corner joints in particleboard also increased bending moment resistance (Zhang and Eckelman 1993a). Some researchers reported that the corner joints showed maximum resistance in cases where the distance between two dowels was 7.5 cm (Zhang and Eckelman 1993b). Studies examining the effect of glue type on the tensile strength of corner joints made from wood-base panels reported that the highest strength was achieved with fiberboards and PVA glues (Efe and Kasal 2000a). Some studies also examined the effect of L-profiled furniture joints on the load carrying capacity of case furniture. Experimental studies showed that L-profiled corner joints dramatically increased the load bearing capacity (Taş 2010a). There are studies examining the tension and compression strength of case construction furniture with fixed and demountable corner joints. Statistical analyses showed that demountable joints had higher strength than fixed joints and fiberboards had higher strength than particleboards (Efe 1999).

Some other studies examined the effects of combined usage of traditional adhesive joint methods (dowel + spline) in box construction on the strength of furniture. It was found that that combined joint type significantly increased the joint strength (Altınok et al. 2013). There are also studies examining the bending strength of demountable and fixed joints. Statistical analyses showed that demountable joints were stronger than the stable joints (Efe and Kasal 2000b).

Some studies examined the effects of tongue and groove type joints in wooden and wood based panels on the bending moment. The results showed that okume plywood showed the highest bending strength while the lowest bending strength was observed in poplar (Efe et al. 2003).

Some other researchers examined the effect of glue type on the maximum loading capacity of spline joints in certain wood-based panels. As a result of statistical analyses, it was reported that MDF-Lam had higher carrying capacity than melamine-coated chipboards, and that polymer glue had higher carrying capacity than PVA glue (Altınok et al. 2013). There are also studies examining the influence of dowel diameter on the fracture moment of glued doweled joints. An increase in the diameter of the dowel was shown to also increase the joint performance and the optimum dowel diameter varied according to the board thickness (Norvydays and Papreckis 2001). There are also studies examining the tensile strength of screw joints on furniture corner joints for case construction. It was reported that medium density fiberboard surfaced with synthetic resin sheet and 4 × 50 mm screws were more stronger than the other types tested (Örs et al. 2001).

Some other researchers examined the compression strength of dowel corner joints glued with different adhesives for case construction. As a result of statistical analyses, it was reported that fiberboard was stronger than particleboard and polyvinyl acetate was the strongest adhesive of those tested (Efe et al. 2002). There are also studies examining the changing strength characteristics of combined joint type (dowel+ spline) on melamine-coated chipboards depending of the adhesive type. As a result of statistical analyses, it was reported that silicone adhesive was stronger than polyurethane and PVA glues (Altınok and Taş 2009).

This study examined the strength of case furniture under the effect of external forces such as those experienced during an earthquake.

MATERIAL AND METHODS

Melamine-faced particleboard (YL Lam)

1830×3660 mm melamine - faced particleboard (YL Lam) of 18 mm thickness was chosen as the wood-based panel. Panels were acquired from Isparta Orma-Forest Products. Tab. 1 shows the mechanical characteristics of the panels used in the study.

Tab. 1: Mechanical characteristics of the YL lam panel.

	E.M ($N.mm^{-2}$)	B.S ($N.mm^{-2}$)	Perpendicular tensile ($N.mm^{-2}$)	Density ($kg.m^{-3}$)
Average	3180.02	16.07	0.68	616.18
Minimum	3002.88	13.85	0.55	578.52
Maximum	3439.24	18.59	0.78	635.97
Range	436.36	4.74	0.23	57.45
Standard deviation	148.41	1.84	0.10	26.32
Variation	0.05	0.11	0.14	0.04

E.M: Elastic modulus, B.S: Bending strength,

Glues

Polyvinyl acetate (PVA), polyurethane (PU) and silicone (SLC) glues were used as adhesives in the test samples. PVA glue does not corrode the cutters during use. It is odorless and non-flammable. It can be used cold and applied easily and hardens quickly. Despite such advantages, it becomes soft with increased temperature, thus reducing its resistance and losing its adhesive properties above 70°C. Depending on the material and surface features, an application of 150–200 $g.cm^{-2}$ glue on one of the adherence sides would be sufficient for good adhesion. PVA glue was applied to the test samples in accordance with the principles of TSI 3891 1963. It was determined that the density was 1.1 $g.m^{-3}$, viscosity was 160–200 cps, pH value was 5, holding period for clamping was 20 minutes when cold gluing at 20°C and 2 minutes at 80°C (TSI 3897 1963).

PU glue is a type of adhesive used to join many normal wooden materials in outdoor conditions and featured wooden materials for protection against seawater. Due to the harmful chemicals it contains, it may cause loss of sensitivity when in contact with the eyes and skin. In accordance with the manufacturer's instructions, it was applied on one of the adhesion sides and the two joint surfaces were clamped together for 2 hours (Anonymous 1999).

SLC glue is a silicone-looking polyurethane-based adhesive that has recently begun to be used in industrial furniture manufacture. It is used to bond many construction materials such as fiberboard, Formica, concrete, metal and plastic. It is transparent, non-dripping, and resistant to water and chemicals. It also permeates quickly in the adhesive cavities and can be applied at temperatures between 30 and 100°C. In accordance with the manufacturer's instructions, it was applied on one of the adhesion sides and the two joint surfaces were clamped together for 30 minutes (Anonymous 2006).

Theoretical calculations

Horizontal earthquake forces caused by maximum acceleration during an earthquake and the resulting moments were measured in order to examine the response of a 1900×900×400 mm YL-Lam bookcase structure with longitudinal doors that conformed to the TS 5913 2009 standards (Fig. 1) and its resistance to minor earthquake forces.

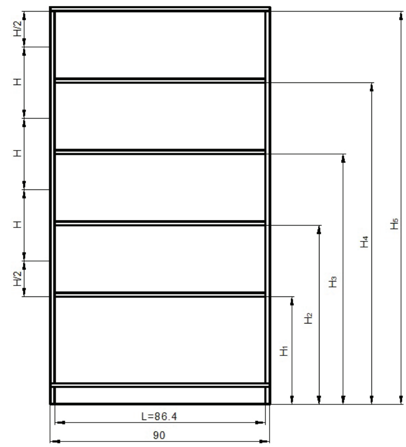

Fig. 1: Image of the bookcase.

Calculation of horizontal earthquake force distributions.

Calculation of horizontal earthquake force distributions.

W - bookcase weight (kg)

$$W = 2W_{H/2} + 3W_H \tag{1}$$

$$W = 2x(32.55\text{ kg}) + 3x(60.96\text{ kg}) = 248\text{ kg}$$

The horizontal earthquake force on the YL-Lam bookcase was calculated according to the maximum acceleration value (0.15-0.30 g) of a minor earthquake measuring 6.0 on the Richter scale.

$$Fd = m \times a = W / g \times a \tag{2}$$

where: Fd - maximum horizontal earthquake force (N),
g - gravitational force,
a - maximum earthquake acceleration,
Fd = 74.4 g = 744 N.

In accordance with the condensed mass matrix (ΣWi x hi), distribution of maximum horizontal forces to the shelves was calculated from the following equation:

$$\Sigma\, Wi \times h\,i = W5 \times h\,5 + W4 \times h\,4 + W3 \times h\,3 + W2 \times h\,2 + W1 \times h\,1 \tag{3}$$

where: Σ Wi x h i - total moment of the bookcase (kgm),

Wi - regional bookcase weight (H/2, H-kg),
h i - height of each shelve to the ground (m)
Σ Wi x h i = 289 kgm.

The distribution of maximum horizontal earthquake forces (Fi), horizontal cutting forces (Vi) caused by the horizontal earthquake forces on the case joints and the moment effects (Mi) on the case joints depending on these forces (Mi) were calculated from the following equations and the moment distribution is shown in Fig. 2.

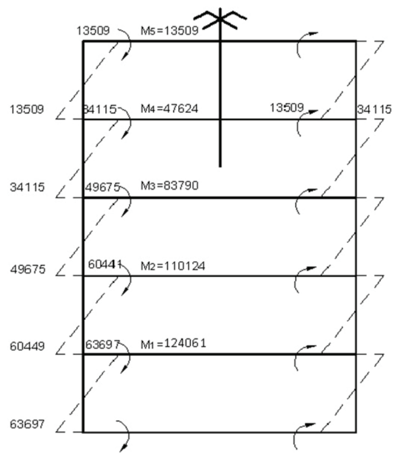

Fig. 2: Distribution of moment forces on the bookcase shelves (Nmm).

i = Wi x h i / Σ Wi x h i x Fd (N) (4)
Vi = Fi (N) (5)

where:

F5 = 158 N	V5 = F5 = 158 N
F4 = 241 N	V4 = F4+F5 = 241+158 = 399 N
F3 = 182 N	V3 = F3+F4 = 182+399 = 581 N
F2 = 126 N	V2 = F2+F3 = 126+581 = 707 N
F1 = 037 N	V1= F1+F2 = 37+707 = 744 N

M i = Vi x H x y (Nmm) (6)

where: M i - moment on the shelf (Nmm),
Vi - horizontal shear cutting,
Vi - horizontal shear cutting force on the shelf (N),
H - height between two shelves (mm),
Y - coefficient of distance.

Calculation of the moment of the theoretical internal bookcase area carried by the joints

The theoretical moment on the joints, which varies according to the joint and glue type, was calculated as the sum of moment values of the intersection surface area constituted by the joints and adherence surfaces (Figs. 3,4,5) and was analyzed according to the critical equilibrium state of "external moment (happened from earthquake forces at the per joined corner) ≤ internal moment (moment of adhesived total area at the per joined corner)". Samples of theoretical maximum moment effect are shown as (*) in Tab. 2 (Taş 2010).

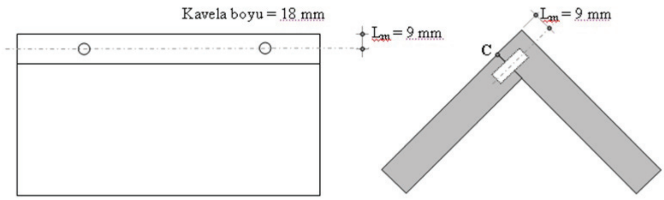

Fig. 3: Dowel joint.

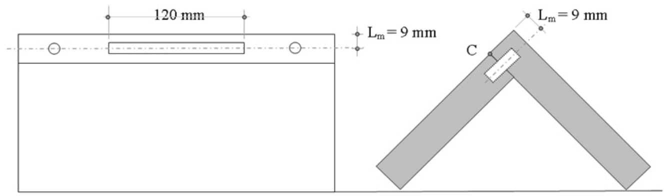

Fig. 4: Combined joint.

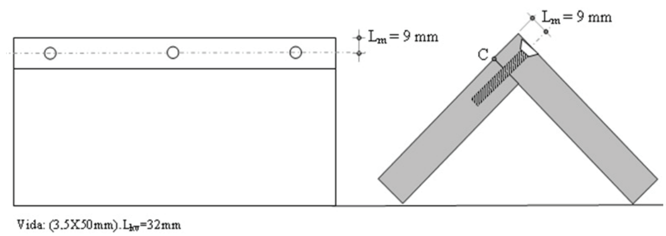

Fig. 5: Screw joint.

Tab. 2: Theoretical moment values calculated according to joint and glue type (Nmm.)

Joint	**Dowel**			**Combined**			**Screw**		
Glue	**PVA**	**Polyurethane**	**Silicone**	**PVA**	**Polyurethane**	**Silicone**	**PVA**	**Polyurethane**	**Silicone**
$M_{iç}$	105042	149214*	150533*	198733*	251993*	276116*	134505*	176256*	171628*
M_T	124061								

$M_{iç}$: Theoretical moment on the joint of backed bookcase M_T: Maximum theoretical earthquake moment (Taş, 2010b).

Preparation of the test samples

18×1830×3660 mm L-profiled test samples were prepared from the YL-Lam panel (Fig. 6). Tab. 3 shows the features, amounts and dimensions of the test samples.

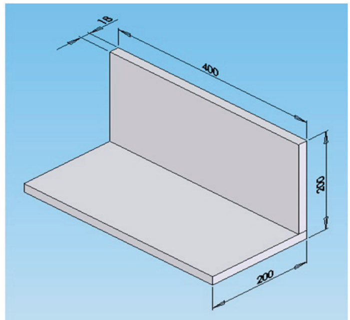

Fig. 6: Test sample (dimensions in mm).

Tab. 3: Features, amounts and dimensions of test samples.

Joint	Glue	Loading method and number of loading			Sample size (mm)			
		Compression <	Tensile ^	Depth	Width= Length	Dowel	Spline	Screw
Dowel	PVA	10	10	400	200	Ø 10x35		
	Polyurethane	10	10	400	200	Ø 10x35		
	Silicone	10	10	400	200	Ø 10x35		
Combined	PVA	10	10	400	200	Ø 10x35	9x18x120	
	Polyurethane	10	10	400	200	Ø 10x35	9x18x120	
	Silicone	10	10	400	200	Ø 10x35	9x18x120	
Screw	PVA	10	10	400	200			3.5x50
	Polyurethane	10	10	400	200			3.5x50
	Silicone	10	10	400	200			3.5x50

Aplication of the test

Instantaneous maximum moment effect of the horizontal earthquake forces causes one corner of the bookcase joint to close and one corner to open. Therefore, the study conducted diagonal compression and tensile tests representing the closure and opening of the joints (Fig. 7).

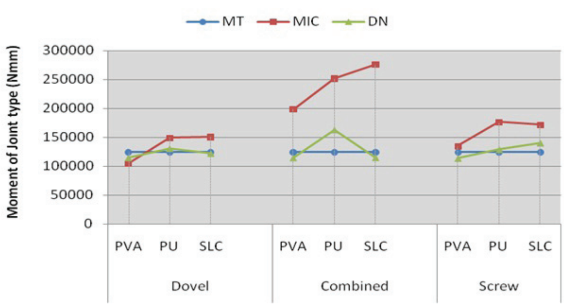

Fig. 7: Sufficiently of experimental joint moment to according theoretical earthquake moment.

Experiments were conducted using universal test equipment according to ASTM-D-1037 1998 from the laboratory of Suleyman Demirel University, Faculty of Forestry, Department of Forest Industry Engineering (ASTM-D-1037 1998). Static loading was conducted on test samples at a speed of 2 $m.s^{-1}$. During the test, first the theoretically calculated earthquake force was applied to the samples. The samples showing resistance to this force were continued to be loaded and the test was completed after losing the strength of the test sample. Maximum diagonal compression and tensile strengths during the opening or breaking of the test joints were recorded. Experimentally obtained diagonal compression or tensile strengths were converted into the moment of the test samples.

RESULTS

Tab. 4 shows theoretically calculated maximum earthquake moments and moments calculated according to the diagonal compression and tensile strength of the backed samples.

According to Tab. 4, the test samples with PU + combined joint, with PU + screw joint, and with SLC + screw joint were resistant to the maximum theoretical earthquake moment forces, while other variations failed at this load (Fig. 8).

Tab. 4: Diagonal compression and diagonal tensile moments according to maximum forces obtained from testing backed samples and theoretically calculated earthquake maximum moments (N).

B_T	Dowel			Combined			Screw		
$T_Ç$	PVA	Polyurethane	Silicone	PVA	Polyurethane	Silicone	PVA	Polyurethane	Silicone
M_{DB}	117508	142322	122496	111360	174812	111940	117392	133168	151380
$M_{DÇ}$	111198	118551	121518	117454	150736	117777	109392	124356	128677
M_T	124061								

M_{DB}: Experimental diagonal compression moment, $M_{DÇ}$: Experimental diagonal tensile moment, M_T: Theoretical earthquake moment.

Fig. 8: Diagonal compression and tensile test.

This study determined the distribution of theoretical earthquake moment according to the glue and joint type, internal theoretical moment on the joint points and experimental moments of YL-Lam construction bookcase structures exposed to the moment effects of a minor earthquake; the results are shown in Tab. 5.

Tab. 5: Distribution of theoretical earthquake moment according to glue and joint type, internal theoretical moment on the joint points and experimental moments.

Joint		Dowel			Combined			Screw		
Glue		PVA	Polyurethane	Silicone	PVA	Polyurethane	Silicone	PVA	Polyurethane	Silicone
Dn.	M_{DB}	117508	142322	122496	111360	174812	111940	117392	133168	151380
	$M_{DÇ}$	111198	118551	121518	117454	150736	117777	109392	124356	128677
Dn. Average		114353	130436	122007	114407	162774	114858	113392	128762	140028
$M_{iç}$		105042	149214*	150533*	198733*	251993*	276116*	134505*	176256*	171628*
Deviation %		+ 9	- 13	- 19	- 43	- 36	- 59	- 16	- 27	- 19
M_T		124061								

Dn.: Experimental moments (M_{DB}, $M_{DÇ}$), $M_{İÇ}$: Theoretical moment of the joint points of backed samples, M_T:Theoretical earthquake moment.

Due to the variety and different strength characteristics of the panels used as a backing element in case furniture, statistical studies were only conducted with the samples without backing elements.

Tab. 6 shows the average and standard deviation of the diagonal compression and tensile moments of YL-Lam samples without backing elements, and variations according to the glue and joint type.

Tab. 6: Average values and standard deviations of diagonal compression and diagonal tensile moments of samples without backing calculated according to maximum forces.

Joint Type	Experiment method	Glue type	X	S
Combined	M_{DB}	Polyurethane	174811	6349
		PVA	119818	28654
		Silicone	111940	5580
	$M_{DÇ}$	Polyurethane	150736	2670
		PVA	117454	2110
		Silicone	117725	2462
Dowel	M_{DB}	Polyurethane	142517	3620
		PVA	117535	8279
		Silicone	122496	6930
	$M_{DÇ}$	Polyurethane	118550	3272
		PVA	111210	1486
		Silicone	121517	3226
Screw	M_{DB}	Polyurethane	133168	7404
		PVA	117392	5155
		Silicone	151380	2809
	$M_{DÇ}$	Polyurethane	124355	4491
		PVA	109391	2196
		Silicone	128614	4414

M_{DB}: Experimental diagonal compression moment, $M_{DÇ}$: Experimental diagonal tensile moment X:Arithmetic mean S: Standard deviation.

As shown in Tab. 6, the highest average diagonal compression and tensile values for the combined joint type were observed in the samples with PU glue (174811 Nmm, 15736 Nmm).

For the dowel joint construction, the highest average diagonal compression of 142517 Nmm was observed in the samples with PU glue and highest average diagonal tensile value of 121517 Nmm was in the samples with SLC glue. The screw joint structures reached the highest average diagonal compression of 151380 Nmm in the samples with silicon glue and highest average tensile force of 124355 Nmm in the samples with PU. Tab. 7 shows the results of multiple analyses of variance (ANOVA) conducted to determine whether or not these differences were statistically significant.

Tab. 7: Multiple ANOVA of diagonal compression and tensile moments.

Variable	Sum of squares	S.D.	Average of squares	F - Value	P-Value
Joint type (A)	2868835709	2	1434417854	21.57	<0.0001
Experiment method (B)	4651433002	1	4651433002	69.95	<0.0001
Glue type (C)	19329280856	2	9664640428	145.34	<0.0001
A x B	299907576	2	149953788	2.26	0.1082
A x C	18827389277	4	4706847319	70.78	<0.0001
B x C	1737610431	2	868805215	13.07	<0.0001
A x B x C	2780960926	4	695240232	10.46	<0.0001

R^2 = 0.824172 (R-Square), Coefficient of variation = 6.408004

ANOVA showed that the difference between the individual groups is significant at the level of 5 % in terms of the joint type (A), experiment type (B) and glue type (C). The difference between the paired groups was significant at the level of 5 % in terms of joint type-glue type (A×C) and experiment method-glue type (B×C) while it was not statistically significant in terms of the joint type-experiment method (A×B). Inter-group comparison showed a significant variation at the level of 5 % in terms of the joint type-experiment method-glue type (A×B×C).

Tabs. 8, 9 and 10 show the results of Duncan's test, conducted to determine the minimum differences between all variables within the group.

According to the Tab. 8, the most powerful joint type is the combined joint (132081 Nmm) followed by the screw joint (127384 Nmm) and dowel joint (122305 Nmm).

According to Tab. 9, the test samples showed the highest moment in the diagonal compression application (132081 Nmm) and the lowest moment in the diagonal tensile application (122173 Nmm).

Tab. 8: Results of Duncan's test for joint type.

Joint type	Sample number	Average value (Nmm)	Duncan group
Combined	60	132081	A
Screw	60	127384	B
Dowel	60	122305	C

Tab. 9: Duncan's test of experimental method.

Experiment method	Sample number	Moment value (Nmm)	Duncan group
Compression	90	132340	A
Tension	90	122173	B

Tab. 10: Duncan's test of glue type.

Joint type	Sample number	Moment value (Nmm)	Duncan group
Polyurethane	60	140690	A
Silicone	60	125612	B
PVA	60	115467	C

As shown in Tab. 10, in terms of the glue type, the highest moment on the joints was found in PU glue joints (140690 Nmm), followed by SLC glue joints (125612 Nmm), while the lowest moment was found in PVA glued joints (115467 Nmm).

DISCUSSION

It was observed (Tab. 5) that samples with dowel joint+ PVA glue failed to withstand the theoretical moments on the joint points. All other combinations of joint types (dowel, combined or screw) and glue types (PVA, PU or SLC) withstood the theoretical moments. However, according to the experimental moment averages of these successful joints, it was established that only the samples constructed with dowel joint+PU; combined joint +PU; and screw joint +PU and SLC glue withstood the maximum moment effect equal to a minor earthquake event. Comparison of the theoretical moment ($M_{İÇ}$) on the backed bookcase joint, calculated on the basis of allowable adhesion stress of the glues, showed 12-58 % deviation. The deviation was lower in the samples with dowel and screw joints and higher in the samples with combined joints. The deviation (difference) between the theoretical and experimental results was thought to result from the non-homogenous structure of the joint elements and adhesion defects that occurred during the preparation of the samples. Manufacturers and designers should take such production variations into account.

According to the results of Duncan's test of the joint type, the strongest joint type was the combined joint (132081Nmm) followed respectively by the screw joint type (127384 Nmm) and the dowel joint type (122305 Nmm). The results support those reported in a previous study by Altınok et al. (2009a).

In case furniture, during the use or test of corner joints or shelf joints, the diagonal compression and the moment of the diagonal tensile force on the opposing joint should be equal orsimilar. However, during comparisons of the Duncan's test results, it was determined that average diagonal compression moment (132340 Nmm) was higher than the average diagonal tensile moment (122173 Nmm). This finding supports the results of previous studies (Taş 2010a, Güntekin 2003, Özcifçi et al. 1996). The reason may be the use of single bearing support in the diagonal compression test and two bearing supports in the diagonal tensile test, as well as disregarding the reaction forces occurring on the bearing supports in the moment calculations.

According to the results of Duncan's test regarding the glue type, PU glue showed the highest moment carrying capacity (140690 Nmm) followed respectively by SLC glue (125612 Nmm) and PVA (115467 Nmm). The results support those of a previous study (Altınok et al 2009b). The reason for this result may be the cellular structure of the particleboard and infiltration of the PU glue into the cavities on the intersection adhesion surfaces of the particleboard, thus expanding volumetrically and hardening. It may also the ability of PU adhesive to make both mechanical and specific adhesion bonds.

When results of the experimental studies are generally assessed, as it shows a higher moment carrying capacity, PU glue would be the first to be suggested to use among all three joint types and combined joint+PU glue which shows the best resistance for the YL-Lam bookcase which was exposed to the moment effect of a small-scale earthquake.

CONCLUSIONS

In this study, it was examined to which extend the strength properties of a standard-size (TSE–5913 2009) bookshelf, which suffered from maximum moment effect of a low-magnitude earthquake, vary theoretically and experimentally.

Theoretical and experimental studies demonstrate that the strength of the YL-Lam bookshelf changes with the type of the joint (treenail, composite, screw) as well as with the type of the binder (PVA, Polimarine, Silicone).

As a conclusion, in order to use YL-Lam bookshelf and similar wooden pieces after a low-magnitude earthquake, it is advised to use polyurethane as binder if treenail and composite are used as joint during the production stage. In case of the use of screw type joint, polyurethane and silicone binders are advised.

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