Sigma J Eng & Nat Sci 10 (1), 2019, 1-9

Publications Prepared for the Sigma Journal of Engineering and Natural Sciences
Publications Prepared for the ORENKO 2018 - International Forest Products Congress Special Issue was published by reviewing extended papers

Research Article

EXPERIMENTAL ANALYSIS OF CONNECTIONS MADE WITH WOOD-BASED PANELS AND BRACKETS UNDER CYCLIC LOADING

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Received: 20.08.2019 Accepted: 12.09.2019

ABSTRACT

The aim of this research was experimentally examination the behavior of metal brackets and wood-based panel connections under cyclic loading. For this purpose, different connections were manufactured using three types of brackets (4, 6 and 8 screws) and particleboard (PB) and medium density fiberboard (MDF). The connections were tested under monotonic and cyclic loading according to EN12512 standard and the mechanical properties such as maximum load, impairment of strength, equivalent viscous damping, ductility and the stiffness were determined. The results have shown that in both PB and MDF the brackets with 8 screws provide maximum strength. MDF and PB exhibited similar ductility and most of the connections exhibited viscous damping of less than 20%, which indicates that they have great potential to withstand against cyclic loading. The mechanism of failure was different for connections with 8 screws and connections with 4 and 6 screws.
Keywords: Cyclic loading, MDF, particleboard, bracket, ductility, impairment of strength, viscous damping.

1. INTRODUCTION

Generally a building includes the structural and nonstructural elements. Structural members are the primary load bearing components of a building. Beams, roof, floor, columns, foundations, walls, braces are structural elements. Non-structural elements are not the part of structural (main-load resisting) systems. Architectural components, electrical and mechanical equipment and building contents (such as tall and heavy book shelves, partitions, refrigerator, TV…) are some examples of non-structural elements. Typical investment of building contents in new construction accounts for about 20% of the total cost for an office building, and can be as high as 44% for a hospital [1]. Overturning the non-structural elements during earthquake causes significant human and financial losses, suspending the business and causes delaying search and rescue missions due to the problem of access into the building and consequently increased casualties [2]. Previous earthquakes have shown that falling furniture is an important factor in many casualties and injuries [3]. Nearly half of the indoor injuries were due to falling or overturning of furniture [4, 5]. For this reason, the design provisions are needed for non-structural elements to decrease the

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damages during earthquake. Depending on size and type of non-structural elements, the provisions should be provided or developed to protect the building contents during earthquake. The attaching or supporting the non-structural components to the floors, roof, and or together can protect them against overturning and moving during earthquake. Various materials including the metal hooks, plastic fasteners and bracket are used to attach the non-structural elements in building. Brackets are available in various sizes, shapes and designs and it is easily used to install the non-structural elements such as book shelves. The main role of the L-shaped metal bracket is to resist the shear force caused by a seismic event [6]. Metal brackets have some advantages including elasticity in tension and pressure, low cost, cheap, shock and shear force resistance [6]. According to earlier researches, the number of nails or screws on bracket-shape fasteners significantly influence on behavior of wood-based materials under cyclic loading [7-8].

Generally there is no single method for fixing nonstructural elements. In other side, depending on the type of nonstructural components, the behavior of the connections is different under seismic loads. Regarding a considerable amount of building contents especially shelves are made of wood-based panels including MDF and particleboard, it is necessary to analyze the behavior of such types of elements under seismic forces, but first of all and before developing a provision for such items, it needs to study the connection made with wood-based materials and the fastener under dynamic loads. Thus, the purpose of this study was to investigate the behavior of wood-based composites (MDF and particleboard) in connection with various angle brackets under cyclic loading (a simple way to simulate seismic loads) according to EN 12512 [9].

2. MATERIAL AND METHODS

2.1. Test configurations and setups

In this study, the MDF and particleboard panels were prepared from local producers in Iran. Angular brackets encoding AB-543, AB-645 and AB-993 were manufactured accordance to ETA-09/0322 [10] (Table1). The 18 mm panel screws were used to fix the bracket on wooden materials and the bolts were used to connect the bracket to metal plate. Figure 1 shows the used metal angle brackets as fasteners. The MDF and particleboard panels were conditioned to the lab environment in relative humidity of 65 % ±5 % at a temperature of 20 °C ±3ºC.

Totally, six different configurations were used for tests as shown in Table 2.

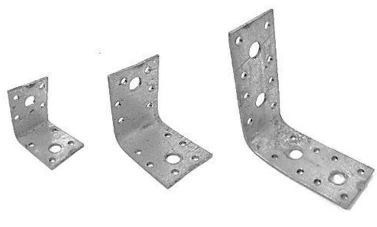

Figure1. Metal brackets according to ETA-09/0322

Table 1. Angle bracket geometries according to ETA-09/0322

Angle Bracket	Thickness (mm)	width (mm)	height (mm)	Connector screws	
				number	size
AB-543	2.5	40	50	4 × 18	4
AB-645	2.5	45	60	4 × 18	6
AB-993	3	40	90	4 × 18	8

Table 2. Tes t configurations and information

Angle Bracket	Wood material	connection
AB-543	Particle board (PB)	PB-543
AB-645	Particle board (PB)	PB-645
AB-993	Particle board (PB)	PB-993
AB-543	MDF	MDF-543
AB-645	MDF	MDF-645
AB-993	MDF	MDF-993

2.2. Monotonic and cyclic loading tests

Figure 2 illustrates the test configuration for monotonic and cyclic loading. Cyclic loading test was carried out according to EN 12512. In this test, the displacement control system (V) was used. Figure 3 illustrates the cyclic loading protocol. The yield point (Vy) as reference displacement during cyclic loading was determined by monotonic loading test according to method described by Munoz et al. (2008). Generally different methods are used to determine the yield point of timber structures and connections [11-13]. In this research, the CEN procedure was used to estimate yield point of the connections during monotonic test. CEN uses a secant and a tangent line to two sections of the load-deformation curve to determine the yield point. The first line represents the initial stiffness (Kα), which is usually calculated from 10% to 40% of the peak load. This secant line forms an angle with the displacement axis. The second line (Kβ), is drawn at a slope equals to one sixth of the slope of the secant line of the load–displacement curve. The yield point is determined as the intersection of those two lines (Kα and Kβ) as can be seen in Figure 4 [14].

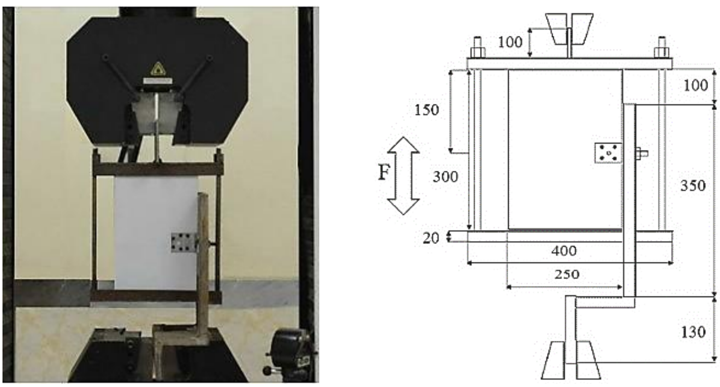

Figure 2. Test setup used for monotonic and cyclic loading

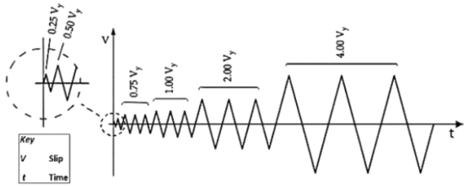

Figure 3. Cyclic procedure according to EN 12512

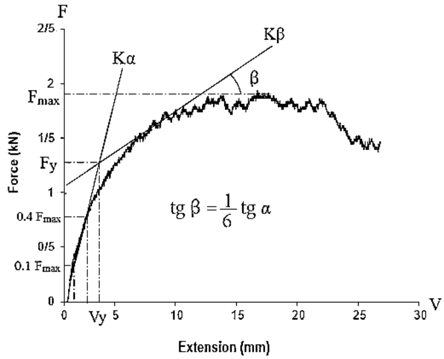

Figure 4. Determination of yielding point according to EN 12512

After each cyclic test, several mechanical properties were determined or calculated using load–displacement hysteresis loop curves. A typical used curve is shown in Figure 5. These parameters are maximum load (Fmax) and displacement (Vmax), ultimate load (Fu) and displacement (Vu), yielding load (Fy) and displacement (Vy), initial (Kel) and plastic stiffness (Kpl), ductility ratio (D), the average strength degradation between the 1st and the 3rd maximum load cycle (ΔF1-3) and the energy dissipation properties are (measured by the quantities νeq (1st) and νeq (3rd)).

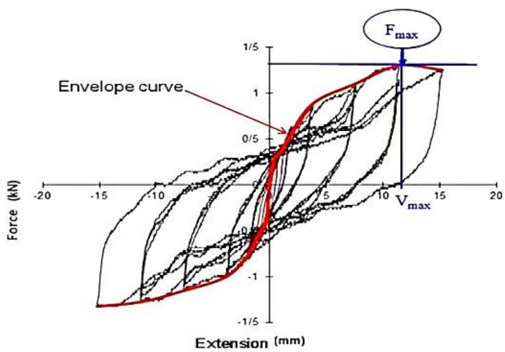

Figure 5. Typical cyclical behavior of a bracket connection

Eq. (1) was used to calculate the ductility. Ductility is the extent to which material can plastically deform without losing its load bearing capacity (Malo et al. 2011).

$$D = {V_u}/{V_y} \tag{1}$$

Dissipation of energy during cyclic loading is quantified by the equivalent viscous damping ratio (νeq). This non-dimensional factor demonstrates the hysteresis damping properties of connections under a specified loading regime and is determined by the methods specified in EN 12512 (2001) as the ratio between dissipated energy (Ed) of a half cycle and the relevant available potential energy (Ep) multiplied by 2π (Figure 6). The available potential energy (Ep), can be determined as Ep = 1/2 F.V, where F and V are the maximum force and maximum displacement attained in cycle, respectively.

$$\nu_{eq} = \frac{E_d}{2\pi . E_p} \tag{2}$$

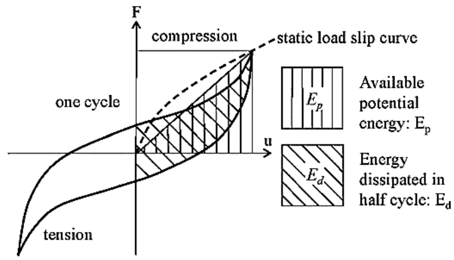

Figure 6. Definition of Ed and Ep for the determination of the equivalent viscous damping ratio for one cycle

The rate of displacement in monotonic test was set at 0.05 mm/s. In cyclic loading, the rate of displacement was varied from 0.05 mm/s to 0.2 mm/s within each cycle during the entire process (Table 3).

Table 3. Displacement rates in each cycle

Cycle	Rate
$0.25V_y$	0.05 (mm/s)
$0.5V_y$	0.05 (mm/s)
$0.75V_y$	0.05 (mm/s)
$1V_y$	0.10 (mm/s)
$2V_y$	0.20 (mm/s)
$4V_y$	0.20 (mm/s)
$6V_y$	0.20 (mm/s)

3. RESULTS AND DISCUSSION

Figure 7 presents the monotonic load-displacement curves of the joints manufactured by MDF and particleboard and different brackets. It can easily seen that in both MDF and particleboard, the connections made with 8 screws brackets (AB-993) significantly exhibited higher strength than those made with 4 and 6 screws brackets. The connections made with 4 and 6 screws exhibited similar behavior in both MDF and particleboards.

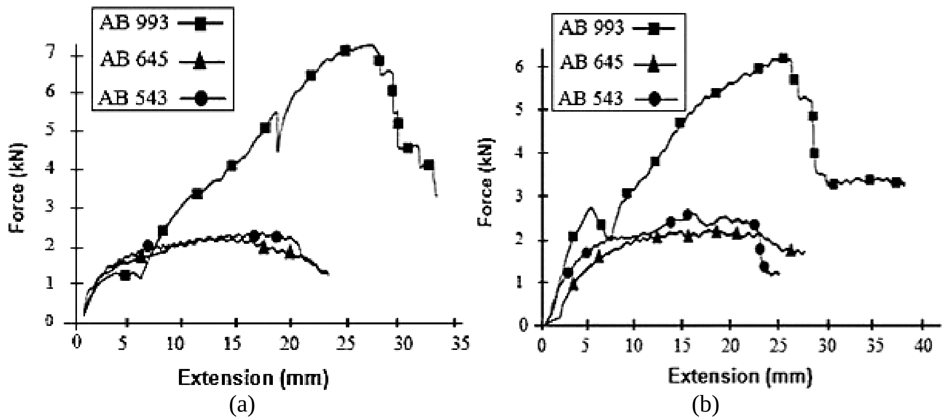

Figure 7. Load–displacement curves of connection made of brackets and (a) particleboard and (b) MDF under monotonic loading

Figure 8 shows load-displacement curves of various connections under cyclic loading. Table 4 illustrates the data extracted from load-displacement hysteresis loop curves in cyclic loading. In all connections, the joints manufactured by AB-993 bracket exhibited the maximum displacement and load. The AB-993 bracket also exhibited the highest yield point displacement and yield point load; thus it can be conclude that this connection has a high load capacity in the elastic region; and the higher load is required to reach the plastic limit. The minimum yield point displacement and yield point load was obtained for AB-543 bracket.

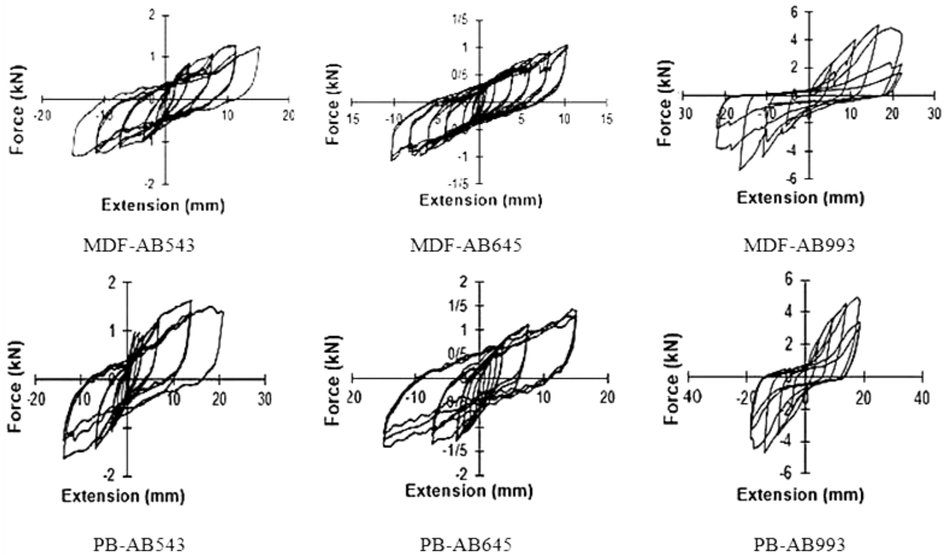

Figure 8. Load-displacement hysteresis loop curves of connections under cyclic load

Table 4. Mechanical properties of angle bracket connections according to EN 12512

Mechanical property	MDF-543	MDF-645	MDF-993	PB-543	PB-645	PB-993
K_{el} (kN/mm)	0.64	0.49	0.37	0.6	0.49	0.47
K_{pl} (kN/mm)	0.1	0.08	0.06	0.1	0.08	0.07
F_y (kN)	0.75	0.67	3.3	0.7	0.79	3.68
V_y (mm)	1.7	3.1	10.8	1.74	4.1	11.7
F_{max} (kN)	1.52	1.11	4.43	1.51	1.36	4.9
V_{max} (mm)	13.2	8.9	16.4	13.1	14	16.8
F_u (kN)	1.49	1.11	3.94	1.42	1.29	4.54
V_u (mm)	13.8	8.9	20	14.9	17.5	19.4
D	10.1	10.7	2	11.3	10.5	2
D_{mon}	11	20.1	1.3	6.9	7.1	2
ΔF_{1-3} (%)	7	3.8	50.2	11.5	8	28.3
$\nu_{eq\ (1st)}$ (%)	21.1	19.2	16.9	19.7	21.9	15.5
$\nu_{eq\ (3st)}$ (%)	18	18.9	17	15.8	18.9	13.2

The maximum load of MDF-993 connection was 74.7% and 65.6% higher than MDF-645 and MDF-543 connections, respectively. Similar results have been observed for particleboard and the maximum load of PB-993 connection was 72.2% and 69.1% higher than PB-645 and PB-543 connections, respectively. Although the connections made with AB-645 bracket exhibited higher yield load than those made with AB-543 brackets, but they had lower maximum and ultimate load. This behavior can be attributed to influence of wooden material on the connection strengths. A comparison between connections manufactured by AB-543 and AB-645 shows that the AB-543 connections with 4 screws exhibited higher maximum load than AB-645 connections with 6 screws. This difference can be explained by higher bracket area to number of screw ratio. This ratio was than 12.5 and 10.0 for AB-543 and AB 645, respectively.

Table 5 shows the comparison of maximum load in monotonic and cyclic loading. It is obviously seen that the maximum loads in cyclic loading are significantly lower than those of static loading for all connections. In most cases, the maximum loads of connections in cyclic loading are about two third of monotonic loads. The higher (42.8%) and lower (12.0%) decrease were obtained for MDF-543 and PB-993 connections, respectively. The lower maximum load in cyclic test can be attributed to fatigue of the connections during cyclic loading which causes connection failure in lower load values.

Table 5. Comparison of the maximum load of connections during monotonic and cyclic loading

Connection	Fmax (KN)		Decrease in load(%)
	Monotonic	Cyclic	
MDF-543	2.09	1.52	27.3
MDF-645	1.94	1.11	42.8
MDF-993	6.31	4.43	29.8
PB-543	2.28	1.51	33.8
PB-645	1.93	1.36	29.5
PB-993	5.57	4.9	12.0

According to Table 4, the connections manufactured by brackets with 4 screws (AB-543) exhibited the highest initial and plastic stiffness. The highest stiffness in connections with AB-543 can be probably attributed to the shorter length of this type of bracket. MDF and particleboard exhibited very similar stiffness in all connections.

Table 4 shows that the reduction of strength [ΔF1-3 (%)] in connections made with AB-993 is significantly higher than those made with AB-543 and AB-645 and the highest strength reduction of 43.7% was obtained for MDF-993 connection. In MDF-993 and PB-993 connections, screw failure was observed in all tests; whereas no failure in screws was observed for connections with AB-543 and AB-645. Actually the broken screws could not provide any strength; and the strength suddenly and significantly decreased (Figure 9). The strength reduction in MDF-993 was 43.7% higher than PB-993. This difference can probably relate to the mode of failure in screws in connections.

(a) (b) (c) (d)

Figure 9. Failure modes of connection: screw failure in PB-993 (a) and MDF-993 (B) and panel failure in PB-543 (c) and MDF-645 (d)

The experimental results demonstrate remarkably higher ductility ratios for connection with 4 and 6 screws in both particleboard and MDF. Although the connections with 8 screws exhibited the higher maximum load but they provided lower ductility since failure was occurred in screws. From Table 4, most of the connections have a viscous damping of less than 20%, which indicates that they have great potential to with stand against cyclic loading. Also the results showed that dissipation of energy in the third cycle was always lower than the first cycle which indicates that the energy dissipation in the connections under cyclic loading decreases after several cycles the connections manufactured by both MDF and particleboard and AB 993 bracket exhibited lower damping in first and third cycles than the other brackets.

4. CONCLUSIONS

In this paper, the main results of the experimental research on the mechanical behavior of metal angle bracket and screwed joints under monotonic and cyclic tests were presented. The joints were manufactured by two different types of wood-based panels (MDF and particleboard). From the test results, following conclusions can be derived:

- The maximum loads in cyclic loading were significantly lower than those of static loading for all connections.
- In MDF and PB, the connections with 8 screws exhibited considerably higher strength and lower ductility.
- MDF and PB exhibited similar ductility.
- Most of the connections exhibited viscous damping of less than 20%, which indicates that they have great potential to withstand against cyclic loading.
- The mechanism of failure was different for connections with 8 screws and connections with 4 and 6 screws.

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