Mechanical Properties of Knock-down Joints in Honeycomb Panels

Adam Koreny,[a] Milan Simek,[a] Carl A. Eckelman,[b] and Eva Haviarova [b]

This study focuses on the use of demountable furniture joints in combination with 38-mm-thick honeycomb panels. These fittings were incorporated into L-shaped corner joints and then tested to determine their bending moment capacity. Overall, seven combinations of demountable fittings were tested. These groups of connectors consisted of solution non-glued, partly-glued connectors, and fully-glued connectors. All of the connectors were positioned in the test samples as they are commonly located in furniture construction. The highest capacities were obtained with glued connectors, followed by partly glued and then non-glued connectors. The difference in capacity between the inside and outside positions was insignificant for the non-glued and fully-glued connectors. A large difference between connectors in different positions was found for the partly glued connectors and for the second type of unglued connectors. The modes of failure were analyzed for each connector, and the possibilities for use in construction are described.

Keywords: Fittings; Cam; Honeycomb; Joint; Bending; Angular axis

*Contact information: a: Department of Furniture, Design, and Habitation, Mendel University in Brno, Czech Republic, MS 621 00; b: Department of Forestry and Natural Resources, Purdue University, West Lafayette, IN; *Corresponding authors: xkoreny@node.mendelu.cz*

INTRODUCTION

An important issue for the furniture industry is reducing material consumption and shipping weight while being able to maintain inherent product quality and function. A possible solution is the incorporation of lightweight sandwich composites into furniture construction. These materials, however, have different mechanical properties than do commonly used wood-based materials and thus require different design, construction, and production technologies. Information concerning the structural characteristics of joints constructed with honeycomb materials and knock-down fasteners – which are commonly used to join these materials – is sparse.

Related studies have dealt with knock-down joints constructed of chipboard (Vassiliou and Barboutis 2009; Tankut and Tankut 2009; Kureli and Altinok 2011). The relationship regarding joint strength in chipboard construction as a function of the number of fasteners used in the construction has been investigated (Liu and Eckelman 1996). Withdrawal strength of fasteners has been explored (Vassiliou and Barboutis 2005). The behavior of the dowels and L joints (Tas 2010) and lamina in chipboard and MDF boards (Atar *et al.* 2009), as well as its behavior in combination with honeycomb panel constructions (Petutschnigg *et al.* 2004), has been described. The properties of honeycomb panels have been discussed by Sam-Brew *et al.* (2010). These authors studied framed honeycomb panels, which, unlike frameless construction panels, are reinforced by a wooden frame. Petutschnigg and Ebner (2007) investigated material/fastener relationships in joints. Finally, the mechanical properties of the frameless panels have been modeled via a finite element method (Smardzewski 2013).

If honeycomb materials are to be incorporated into case furniture constructions on a rational basis, information will be needed concerning the capacities of the fasteners that are used to join the associated panels together. The goal of this exploratory study was to obtain pioneer estimates of the bending moment capacities of joints constructed of honeycomb panel materials joined together with knock-down fasteners and is limited to a) an evaluation of fasteners that are now in common use and b) an evaluation of the suitability of honeycomb panels for use in furniture construction from a joint strength perspective.

EXPERIMENTAL

The fasteners used in this study are shown in Fig. 3; the geometry of the joints is shown in Fig. 1. Six specimens were constructed with each type of fitting—three of which were tested in compression and three in tension—for a total of 42 specimens.

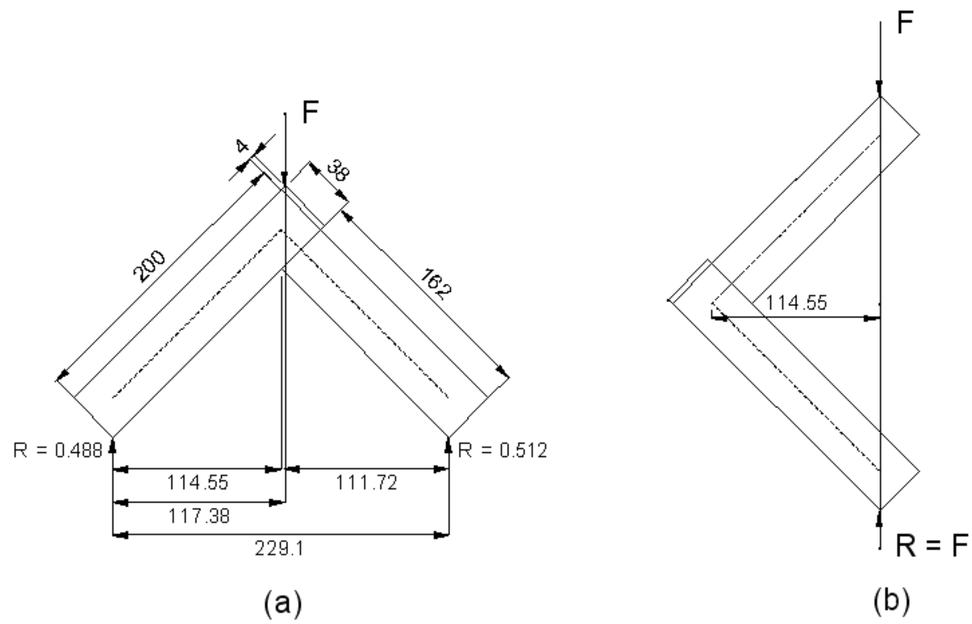

Fig. 1. Joint (a) loaded in tension, and joint (b) loaded in compression (units – mm)

Joint Design

Side views of the specimens are given in Figs. 1a and 1b. Each specimen consisted of a "bolt" panel (to which the connector bolt was attached) that measured 204 mm wide by 400 mm long by 38 mm thick and a "cam" panel (which contained the cam housing) that measured 162 mm wide by 400 mm long by 38 mm thick. An exploded view of the frameless honeycomb board used for the “cam” panel is given in Fig. 2. The panels themselves were made up of a paper-based honeycomb core with 15-mm diameter (corner to corner) by 22-mm long cells. Eight-millimeter thick particleboard laminates were glued to the top and bottom surfaces of the honeycomb core (using a two-component polyurethane glue consisting of polyol-type elastopor H1101/5 and isocyanite IsoPMDI 92140) so that the laminate was glued to the open faces of the cells. The honeycomb board had an average MOR of 9 N/mm^2 and an average MOE of 2300

N/mm^2. Two-millimeter thick acrylonitrile butadiene styrene edge-banding was bonded to all edges of the face and cam panels using ethylene vinyl acetate glue.

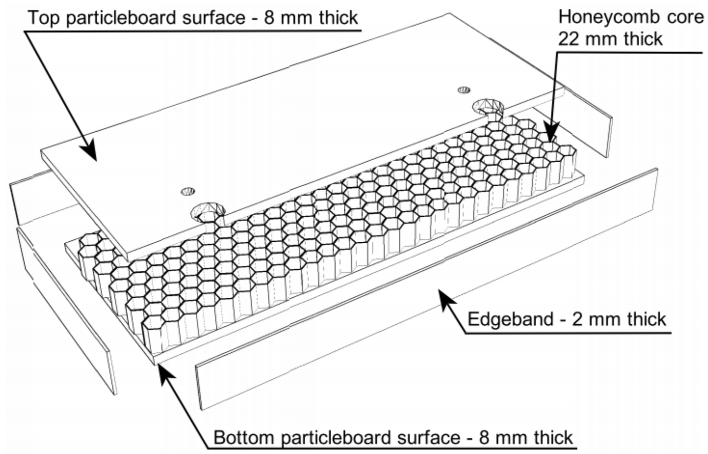

Fig. 2. Cam panel exploded view

Each bolt panel was joined to a corresponding cam panel with two knock-down fittings spaced 256 mm apart, so that each fastener was located 72 mm from the ends of the panel. The threaded connector-bolt was screwed into a 5-mm predrilled pilot hole in the bolt panel, whereas the corresponding cam housing was inserted into a mortise machined in either the top or bottom surface of the cam panel. After the head of a connector bolt was inserted into the corresponding cam housing, the cam was tightened by means of a torque wrench to complete the assembly of the joint.

Seven joint types were constructed with use of parts listed in Table 1, which included two types of connector bolts, 3 types of cam housings, one type of sleeve insert, and 3 cam housing positions in the cam panels. Figure 3 presents the connector combinations and additional information for each joint type.

Table 1. Overview of Components 1 – 6 from which Joints A – G are Assembled

Type	Main material / connector type	Position in panel	Fixing
1.	Metal cam, plastic body	Cam panel central axis	mechanical
2.	Metal cam, plastic body	7.5 mm offset to bolt axis	mechanical
3.	Metal cam, plastic body	Cam panel central axis	glue
4.	Metal connector bolt	Bolt panel plane	mechanical
5.	Metal connector bolt	Bolt panel plane	mechanical
6.	Plastic sleeve	Bolt panel plane	glue

a) The connector bolt (type 4, as seen in Table 1 and Fig. 3) is screwed into a pilot hole in the bolt panel with the corresponding cam housing (type 1) located in mortises on the top surface of the cam panel and with the bolt axis coinciding with the central axis of the cam panel.
b) The connector bolt (type 4) is screwed into a pilot hole in the bolt panel with the corresponding cam housing (type 1) located in mortises on the bottom surface of the cam panel and with the bolt axis coinciding with the central axis of the cam panel.

c) The connector bolt (type 4) is screwed into a plastic sleeve (type 6) that has been inserted in a predrilled (10-mm) hole in the bolt panel – and glued in place – with the corresponding cam housing (type 1) located in mortises on the top surface of the cam panel and with the bolt axis coinciding with the central axis of the cam panel.
d) The connector bolt (type 4) is screwed into a plastic sleeve (type 6) that has been inserted into a predrilled hole (10-mm) in the bolt panel – and glued in place – with the corresponding cam housing (type 1) located in mortises on the bottom surface of the cam panel and with the bolt axis coinciding with the central axis of the cam panel.
e) The connector bolt (type 5) is screwed into a plastic sleeve (type 6) that has been inserted in a predrilled hole (10-mm) in the bolt panel – and glued in place – whereas the cam housing (type 3) is inserted into and glued in place. There is a mortise machined in the end of the cam panel and bolt axis and housing axis are coinciding with the central axis of the cam panel.
f) The connector bolt (type 4) is screwed into a pilot hole in the bolt panel with the corresponding cam housing (type 2) located in mortises on the top surface of the cam panel and with the bolt axis offset 7.5 mm from the cam panel central axis.
g) The connector bolt (type 4) is screwed into a pilot hole in the bolt panel with the corresponding cam housing (type 2) located in mortises on the bottom surface of the cam panel and with the bolt axis offset 7.5 mm from the cam panel central axis.

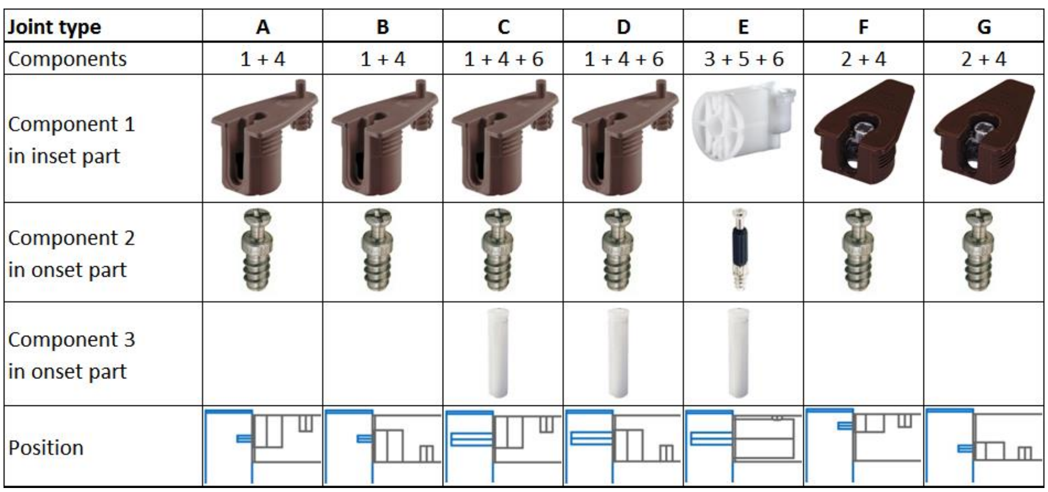

Fig. 3. Knock-down fittings used in construction of joints and their position in the panels

Method of Testing

Testing methods for the joints described above have not been standardized; therefore, procedures were followed that were similar to those described by other authors (Smardzewski and Prekrad 2002; Tankut and Tankut 2004; Zhang and Eckelman 1992). The cited tests correspond to the most common loadings (Joščák 1999). Tests were conducted in a Zwick Z050 universal testing machine (with a load cell accuracy of 0.4%) at a rate of 10 mm/min. Machine loads that tended to increase the angle between the faces of a joint (hereafter termed tension loads) were applied to the specimens as shown in Fig. 1a. Likewise, loads that tended to decrease the angle between the faces of a joint (hereafter termed compression loads) are shown in Fig. 1b. Tests were continued until a major material or fastener failure occurred.

Moment Calculation

Machine loads were converted into bending moments acting at the intersection of the central axes of the panels, as seen in Fig. 1. Compression moments that resulted from the loads decreasing the angle between joint faces, as in Fig. 1b, are given by the expression,

$$M_C(Nm) = 0.115 \times F \quad (1)$$

where M_C refers to the compression moment (Nm), F is the applied load (N), and 0.115 is the moment arm (m).

In the case of loads tending to increase the angle between joint faces (tension), the vertical machine load was applied slightly off center, as in Fig. 1a, with the result being that the left hand reaction force amounted to 0.488×F, whereas the right hand reaction force was 0.512×F, where F is the machine load acting on the specimen. Calculating tension moments in terms of the left hand reaction force gives the expression,

$$M_T(Nm) = \left(\frac{F}{2.05}\right) \times 0.115 = 0.056 \times F \quad (2)$$

where M_T refers to the tension moment (Nm), F/2.05 is the left reaction force (N), and 0.115 is the left moment arm (m).

RESULTS AND DISCUSSION

Although the number of joints included in the tests was too small to permit meaningful statistical analysis, the authors feel the results were sufficiently consistent to permit rational empirical deductions concerning the factors that affected joint capacities.

In this respect, the results obtained in the tests can perhaps be best understood from a consideration of the internal forces operating within a joint. Thus, the bending moment capacities of the joints can be considered as equal to the tensile force acting along the axis of the connector bolt multiplied by an internal moment arm where the length of the internal moment arm is equal to the distance from the axis of the bolt to the opposing resultant compressive force.

In joints A and B, the bolt axis coincides with the central axis of the cam panel so that the internal moment arms of the joints should be equal (ignoring any +/- stiffening effects of the cam housing or its mortise). Furthermore, the bolt axis is also parallel to the honeycomb cell axes, so that the threaded portion of the bolt embedded in the cell core would be expected to contribute little to the withdrawal capacity of the bolts. Thus, the bolt withdrawal capacity would presumably be a function of surface laminate characteristics. It can be inferred, on the other hand, that the cam housing dowel, which is embedded in the surface laminate with its axis perpendicular to that of the bolt axis, would be expected to have substantial shear capacity with respect to the loads applied to it by the connector bolt. Thus, assuming the shear capacity of the housing dowel is greater than the withdrawal capacity of the bolt, joints A and B would be expected to fail due to connector bolt withdrawal from the bolt panel. Furthermore, the joints should have similar but reversed capacities in compression and tension. Specifically, the compression capacity of joint A should be similar to the tension capacity of joint B, and the tension capacity of joint A should be comparable to the compression capacity of joint B.

In the cases of joints C and D, which have glued-in plastic inserts, the withdrawal capacity of the bolts is presumably substantially enhanced by the inserts. Thus, failure of joints C and D could occur either from bolt withdrawal or from cam housing withdrawal (or fracture). A possible tendency of the cam housing to disengage from the cam panel when joint C is loaded in tension or joint D is loaded in compression could cause the compression capacity of joint C to be greater than its tension capacity and the tension capacity of joint D to be greater than its compression capacity. Otherwise, as in the case of joints A and B, the results for joints C and D would be expected to be the reverse of each other.

Joint E also has a glued-in plastic insert in the bolt panel. The compression and tension moment capacities of the joint would be expected to be similar, as the internal moment arms are identical in both cases, assuming that the structural characteristics of the bolt panel at the rim are the same as those of the rest of the panel.

In joints F and G, the bolt axis is offset from the central axis of the cam panel, so that the internal moment arm of joint F is greater in compression than in tension, whereas the moment arm of joint G is greater in tension than in compression. Thus, the compression capacity of joint F would be expected to be greater than its tension capacity – with the reverse being true for joint G. The results for joints F and G, meanwhile, would be expected to be the reverse of each other. Furthermore, without glued-in plastic inserts in the bolt panels and with cam housing dowels in the cam panels, joint failure would be expected to result from bolt withdrawal.

The bending moment capacities of the joints are illustrated in Fig. 4 and are listed in Table 2. As can be seen in Fig. 4, joint E had the highest bending moment capacity in both compression (53.6 Nm) and tension (55.7 Nm).

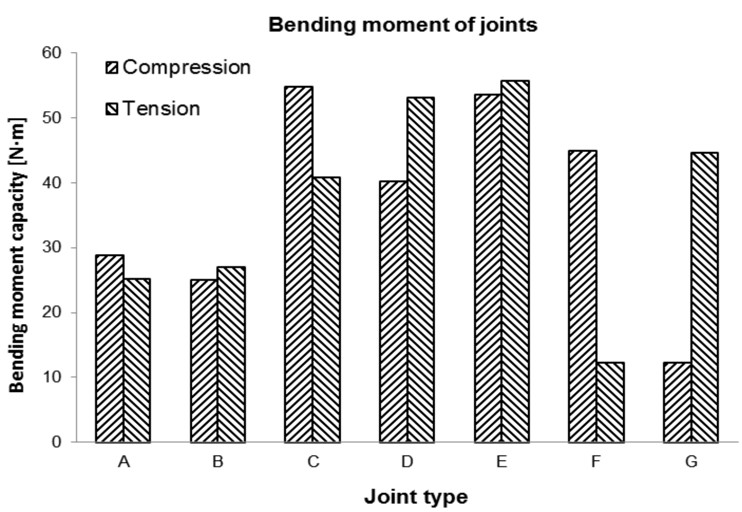

Fig. 4. Moment capacities of joints

Joint types A and B failed due to the withdrawal of the connector bolt from the bolt panel (Fig. 5 b). Joints C and D, however, failed due to fracture of the cam housing (the bolt connector had been withdrawn from the cam housing) and partly due to the withdrawal of the glued-in plastic insert (Fig. 5 a). Joint E failed due to the withdrawal of the plastic insert (Fig. 5 c). Finally, joints F and G had essentially mirror-image results in compression and tension. These joint failed due to the withdrawal of the bolt.

Table 2. Ultimate Bending Moment Values under Compression and Tension Loads

Joint Type	A	B	C	D	E	F	G
Compression							
Ult. Load-N	250.86	212.24	467.46	361.88	465.86	391.07	106.74
Moment-Nm	28.85	25.05	54.91	40.25	53.57	44.97	12.38
Tension							
Ult Load-N	449.8	481.88	727.38	948.68	992.8	218.15	765.16
Moment-Nm	25.23	27.03	40.8	53.21	55.68	12.24	44.57

Fig. 5. a) Deformation of joint type D in compression; **b)** Deformation of joint type A in tension/compression; **c)** Deformation of joint type E in tension/compression

As shown in Fig. 4 and Table 2., the moment capacities for joints A and B were comparable in that the moment capacity of joint A in compression (28.9 Nm) was essentially equal to that of joint B in tension (27.0 Nm), and the capacity of joint A in tension (25.2 Nm) was essentially equal to that of joint B in compression (25.0 Nm). The compression/tension ratio (1.14) for joint A compared closely with the tension/ compression ratio (1.08) for joint B. Thus, for design purposes, at lower load levels, the fastener capacities could be assumed to be about the same in both tension and compression.

Similar observations held for joints C and D, as can be seen in Fig. 4 and Table 2. The moment capacity of joint C in compression (54.9 Nm) was essentially the same as that of joint D in tension (53.2 Nm), and the moment capacity of joint C in tension (40.8 Nm) was essentially equal to that of joint D in compression (40.3 Nm). The compression/ tension ratio (1.35) and tension/compression ratio (1.32) for joints C and D, respectively, were substantially greater than for joints A and B, however, which would need to be taken into consideration during furniture design. This difference (along with that in joints A and B) is presumably related to fastener characteristics rather than to position-related mechanical-property differences in the boards, as comparable capacities were obtained for joints C and D when the unmortised rim of the cam panel was butted up against the bolt panel.

The moment capacity of joint E in compression (53.6 Nm) was essentially equal to its moment capacity in tension (55.7 Nm). Because of the symmetry of the joint, these results indicated (as above) that the structural characteristics of the bolt panel at its rim were essentially the same as those at the point of contact of the lower rim of the cam panel.

Finally, the moment capacity of joint F in compression (45.0 Nm) was essentially the same as the moment capacity of joint G in tension (44.6 Nm); similarly, the moment capacity of joint F in tension (12.2 Nm) was nearly the same as the moment capacity for joint G in compression (12.4 Nm). The low tension capacity of joint F and the compression capacity of joint G for these two joints presumably reflected the placement of the connector bolt close to the top face (F) and lower face (G) of the cam panels, with resulting small internal moment arms. Again, the nearly equal moment capacities of joint F in compression and joint G in tension did not indicate any major position-dependent panel property differences. The compression/tension ratio (3.67) and tension/compression ratio (3.60) for joints F and G, respectively, dictate that use of these fasteners take into account whether the anticipated joint loadings would tend to open or close the joint.

Overall, those joints in which the connector bolts were screwed into plastic sleeves glued in place in the connector-bolt panels (joints C, D, E) had the highest moment capacity. This would be expected since the sleeves were glued to the interior cell walls as well as the particleboard face laminate so that the force required for the extraction of the sleeve from these elements would be expected to be greater than that of a bolt from the particleboard face alone.

To put these results in perspective, consider the simple desk with shelf construction shown in Fig. 6, in which the top and shelf are secured to the end panels with two knock-down fittings at each end (located on the bottom surface of the top and shelf as in joints B, D, or G, or centered on the end as in E). Suppose that a user attempts to slide the desk across the floor, and in so doing, exerts a force of 400 N on the edge of the desk as shown in Fig. 6.

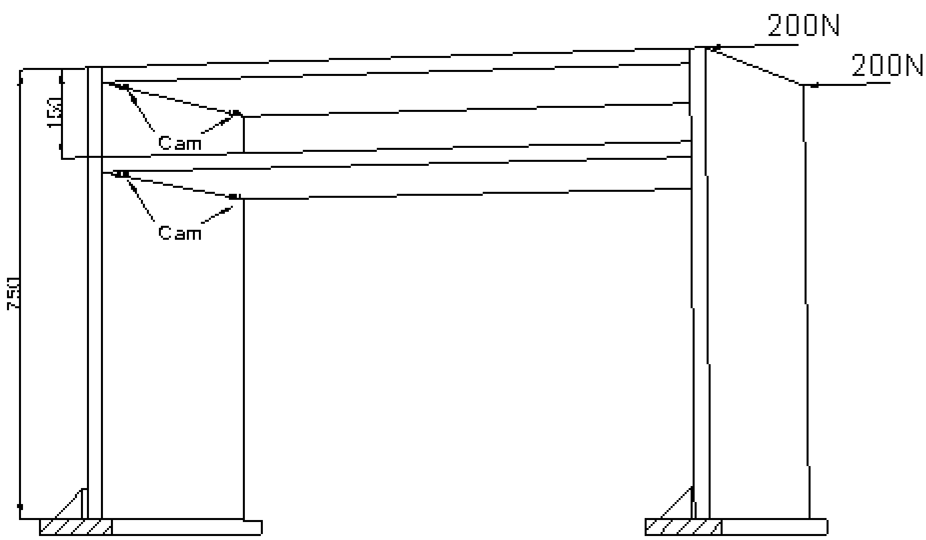

Fig. 6. Illustration of desk with panels joined together with knock-down fittings

The external bending moment acting on the desk amounts to 400 N × 0.75 m, or, 300 Nm. Assuming rigid joints, the absolute values of the internal resisting moments acting on each end of the shelf amount to 88.75 Nm, whereas those acting on each end of the top amount to 61.3 Nm (for a total internal resisting moment of 300 Nm). The internal resisting moment acting on each of the shelf fasteners, accordingly, amounts to

88.75/2, or, 44.8 Nm; likewise, the moment acting on each of the top fasteners amounts to 61.3/2, or, 30.7 Nm. It should be noted that these joints are, in fact, semi rigid rather than rigid so that the deflection of the top would be greater than estimated by rigid joint analysis, but the total of the internal resisting moments must remain constant and their distribution is not greatly affected unless the joints are quite flexible.

Referring to Fig. 4 and Table 2, it can be seen that only joint E is predicted to have sufficient capacity in both compression and tension to carry the design load. The load used in the example is realistic, and the results indicate that the honeycomb construction with knock-down fittings may be feasible; however, each design should be carefully analyzed to ensure that the capacity of the fittings is not exceeded. In this respect, it should be pointed out that rational use of additional fittings can reduce the moment on individual fittings. If three fittings had been used at each end of the top and shelf, for example, then the moment exerted on each joint would have been reduced by a third, but at an increase in product cost.

From a production viewpoint, the construction of joints with glued components is more time-consuming than the construction of those without glue. Thus, joints C and D, which have one glued element but high moment capacity, are presumably the best production-oriented choices of all the joints tested.

CONCLUSIONS

1. For optimum moment capacity, cam housings and the plastic sleeves for connector bolts should be glued in place in their respective panels.
2. For a near equal plus/minus bending moment capacity, the axes of the connector bolt and the central axis of the cam panel should coincide.
3. Moment capacities (in one direction) can be increased when the bolt and cam panel axes are offset.
4. Overall, the results of the tests indicate that the knock-down fittings tested along with the honeycomb panels would have sufficient bending moment capacities for furniture applications that are consistent with their structural capacities. The withdrawal capacities of the knock-down fittings, and in particular, the shear capacity of the fittings, remain to be determined.

ACKNOWLEDGMENTS

The authors thank the Internal Grant Agency (IGA) of Mendel University in Brno, project IGA 16/2012.

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Article submitted: May 16, 2013; Peer review completed: June 26, 2013; Revised version received and accepted: July 25, 2013; Published: August 7, 2013.