Development of Testing Frame for Diagonal Shear Test of Composite Panels and Engineered Wood Products

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Abstract

This paper reports the development of a testing frame for diagonal in-plane shear test of composite panels and engineered wood products. The study was divided into two subsequent experimental works. The first experiment was conducted by assessing several frame configurations with small-scale frame test. The second experimental work was conducted by applying the selected frame obtained from the first stage experiment to assess the in-plane shear performance of medium density fibre (MDF) board. The result shows that the developed testing frame has been able to generate a pure shear mechanism which is extremely important in the investigation of in-plane shear behaviour of composite panels and engineered wood products. Other important findings are includes; 1) frame with pin at all four corners and the tested panel located in between the upper and bottom frame and connected with bolts is the best choice for inducing in-plane shear mechanism, 2) the developed frame that has all four corners pin-jointed using bolts to obtain free-movement to vertical and horizontal directions works better than those with only two pin-jointed corner at the top and bottom corners that formerly developed by other reseachers.

Keywords: diagonal shear test, engineered wood, in-plane shear, testing frame

Abstrak

Artikel ini melaporkan tentang hasil studi pengembangan bingkai pengujian untuk melakukan uji geser diagonal pada panel komposit dan produk kayu olahan. Penelitian dilakukan melalui dua tahapan eksperimen. Eksperimen pertama dilakukan dengan cara menguji beberapa alternatif konfigurasi bingkai pengujian menggunakan prototipe skala kecil. Eksperimen tahap kedua dilakukan dengan cara mengaplikasikan bingkai pengujian terbaik yang direkomendasikan dari eksperimen tahap pertama untuk menguji perilaku geser diagonal dari panel MDF. Hasil penelitian menunjukan bahwa bingkai pengujian yang dikembangkan mampu menciptakan kondisi geser murni yang merupakan prasyarat sangat penting dalam melakukan investigasi perilaku geser dari panel komposit dan produk kayu olahan. Hasil temuan lain yang cukup penting adalah; 1) bingkai pengujian yang dipasang pada bagian atas dan bawah panel dan dihubungkan dengan pin pada ke-empat pojoknya mampu menciptakan kondisi geser murni yang paling baik, 2) bingkai pengujian dengan empat pojok yang dihubungkan dengan baut untuk menciptakan kondisi bebas bergerak pada arah vertikal maupun horisontal bekerja lebih baik dibandingkan dengan bingkai pengujian yang hanya menggunakan 2 pin pada pojok bagian atas dan bawah yang telah dikembangkan oleh peneliti lain sebelumnya.

Kata kunci: bingkai testing, geser diagonal, panel komposit, kayu olahan

Introduction

Diagonal shear testing is commonly performed to measure the in-plane shear properties of a material. Shear testing has proven to be one of the most difficult areas of mechanical property testing. While shear modulus measurements are considered accurate, there is difficulty in measuring shear strength. The presence of non-pure shear loading, non-linear behaviour, edges, material coupling, or the presence of normal stresses makes shear strength determination questionable. Ideally, for quantitative shear measurements, the shear stress must be uniform in the test section of the specimen throughout the linear and non-linear response regimes. This region should be located in one of the maximum shear stress areas relative to all other regions of the specimens. In addition, a unique relationship should exist between the applied load and the magnitude of the shear stress in the test section.

There are several terms given by researchers to this test such as picture-frame shear test (Lee & Munro 1986), deformable square test (Castenie *et al.* 2004), diagonal shear test (Mosalam *et al.* 2008) and even small-scale racking test (Bi & Coffin 2006). Based on the way the load is transmitted to the specimen, the diagonal in-plane shear test can be divided into two categories; diagonal tension and diagonal compression test.

The diagonal tension shear test is performed using deformable square panels. The frame transfers the tension load vertically to the specimen and at the same time the compression load along the horizontal axis produces a pure state of shear within the specimen. Usually, the loads are transmitted from the frame to the specimen by bolting (Castenie *et al.* 2004). An appropriate design of the testing frame is very important to ensure that a uniform stress develops in the sample. A poorly made frame will cause excessive stress in the corners and premature local failures.

As the name implies, the diagonal compression test involves applying a vertical load in a compression direction which creates a horizontal tension load distribution within the specimen. The concept is, however, similar to that of the diagonal tension test with the exception for the direction of the applied load. For a sandwich structure however, the best way to investigate the in-plane shear under diagonal test scheme may be to use tension apparatus as suggested by Kuenzi *et al.* (1962). They noted that in the early sandwich work, a compression type of loading apparatus was commonly used to induce shear. However, it was found later that the compression arrangement was unsatisfactory because it tended to amplify initial eccentricities and, for that reason, produced a low result. They also mentioned that a tension type of apparatus would develop the same quality of shear and would also produce greater buckling loads than would apparatus of the compression type. While the diagonal in-plane shear test on sandwich structures is mostly conducted with a tension load arrangement, the diagonal compression test remains important to investigate the in-plane shear of masonry structure.

In a symposium on shear and torsion testing held by ASTM, Youngquiest and Kuenzi (1961) presented their work at the U.S. Forest Products laboratory on shear and torsion testing of wood, plywood and sandwich construction. This paper briefly described the test method, traced the history of some of the methods, and presented a discussion of their advantages, disadvantages and suitability. For the tensile loading method, the specimens were glued to a hardwood loading blocks. Strain measurements taken at various points on the panel showed that within the elastic range a nearly uniform strain distribution was possible. They also suggested that a great care must be given in the alignment of the holes for the loading pins and in the proper location of the text fixtures. Bryan (1961) carried out a photo-elastic investigation of the stress distribution in the panel and found that the stress distribution deviated substantially from pure shear; accordingly the method was not appropriate for measuring the in-plane shear modulus. However, they showed that at the critical region (which along the edge) the stress state was essentially uniform pure shear and thus recommended that this test should be an accurate method for determining the in-plane shear strength.

De-Iorio *et al.* (2002) noted that the shear test can be carried out on a rectangular or square thin panel where the panel edges were joined along to form a mechanism by four rigid rods which are mutually hinged at their ends. If the material is orthotropic, with two principal directions parallel to the panel edges, or if it is isotropic, it is possible to impose the displacements that correspond to a uniform shear stress distribution in the panel. Bi and Coffin (2006) applied a tension load scheme to the specimen panels in order to investigate their racking performance. They called the test as a small-scale racking test developed to evaluate paperboard-based sheathing materials used in framed wall-construction.

After reviewing a number of studies dealing with in-plane shear test of sandwich panels available in the literatures, some findings can be summarized as follows. First, there are two types of diagonal in-plane shear test based on the way the load is applied to the specimen; diagonal tension and diagonal compression test. The diagonal compression test is more frequently used in the testing of concrete and masonry structure. While diagonal tension is often used for wood based panels or sandwich panels that naturally week in compression. Second, there are two boundary conditions related to the jointing system of the testing rig. The first type has four pin jointed corners (Morgenthaller *et al.* 2005, Bi & Coffin 2006, Hossain *et al.* 1998) and the second type employs 2 pin jointed corners at the location where the load is applied (Castenie *et al.* 2004, Kuenzi *et al.* 1962, Youngquest & Kuenzi 1961, Bryan 1961). The first type was designed based on the assumption that in the real industry application of wall panel, all the edges are clamped using a rigid border. However, during the panel test the specimen may experience lower stress since part of load was transferred directly to the other load pin without passes through the specimen. The second type was designed to overcome this shortcoming. Third, the typical panel test specimens for the diagonal shear test are in the range of 300-850 mm in size which is significantly smaller than the typical size of a racking wall test. Lastly, the typical failure modes of diagonal tension test are typically crimping, sudden failure of the core, skin shear failure shear buckling of the panel and skin wrinkling.

The outcomes from the review are considered in the design and development of testing rigs by the authors. This paper reports the development of a testing frame for diagonal in-plane shear test of composite panels and engineered wood products.

Experimental program

The experiment was conducted in two stages. First, assessing several configurations of frame with small-scale frame test. Second, applying the selected frame from first stage to assess the in-plane shear performance of medium density fiber (MDF) board, which is an engineered wood product.

For the firt stage, five different configurations of testing frames were developed and assessed. The specimens used in the testing were prepared from a polyethylene sheet. The reason of using this specimen material was to observe the likely pattern of deformation during the progress of the testing. The basic idea of this evaluation was based on the work of Cao *et al.* (2008), Sun and Pan (2005), Zhu *et al.* (2007) and Mohammed *et al.* (2000), where the in-plane shear deformation of woven fabric composite was assessed. The configuration of the test rig itself was based on the work of other researchers who were investigating the in-plane shear test of sandwich panel as presented in Table 1.

The frames were prepared using Balsa wood with the size of (220x220) mm^2. The specimens were attached to the loading rail using either glue or small bolts. The specimens were tested in a Hounsfield Testing Machine, with a maximum load capacity of 10 kN, which was adequate for the testing arrangement. The front and side views of each prototype of testing rig are shown in Figure 1. For the experiment in the second stage, the MDF board was cut to the required size into two shapes; one as a whole panel specimen and the other one was a specimen with the corners cut. The setting up and the final condition of the panels after the completion of the test is presented in Figure 2.

Table 1 The configuration of small-scale testing rig prototypes

Frame types	**Description**	**References**
Frame A	Single discontinuous frame with pin at upper and bottom corners only. No pin was placed at side corners. Panel was placed inside and glued within the frame. Light wood stiffeners were glued around the edge to perfectly fit the panel inside the frame.	Kuenzi *et al.* (1962), Youngquest and Kuenzi (1961), Bryan (1961)
Frame B	Double continuous frame with pin at all four corners. Panel was placed in between the upper and bottom frame and connected with bolts.	Morgenthaler *et al.* (2005), Hossain and Wright (1998)
Frame C	Single continuous frame with pin at all four corners. Panel was sitting on the frame and connected with bolts with upper unconnected frame.	Bi and Coffin (2006)
Frame D	Single continuous frame with pin at all four corners. Panel was placed inside the frame by gluing it to the frame.	Modification to the work of Kuenzi *et al.* (1962)
Frame E	Single discontinuous frame with pins at upper and bottom corners only. Panel was placed inside by gluing it side by side with the frame. Similar to Frame A, but the frame members were shorter to avoid stress concentration at the side corner and also without light edge stiffeners.	Modification to the work of Kuenzi *et al.* (1962)

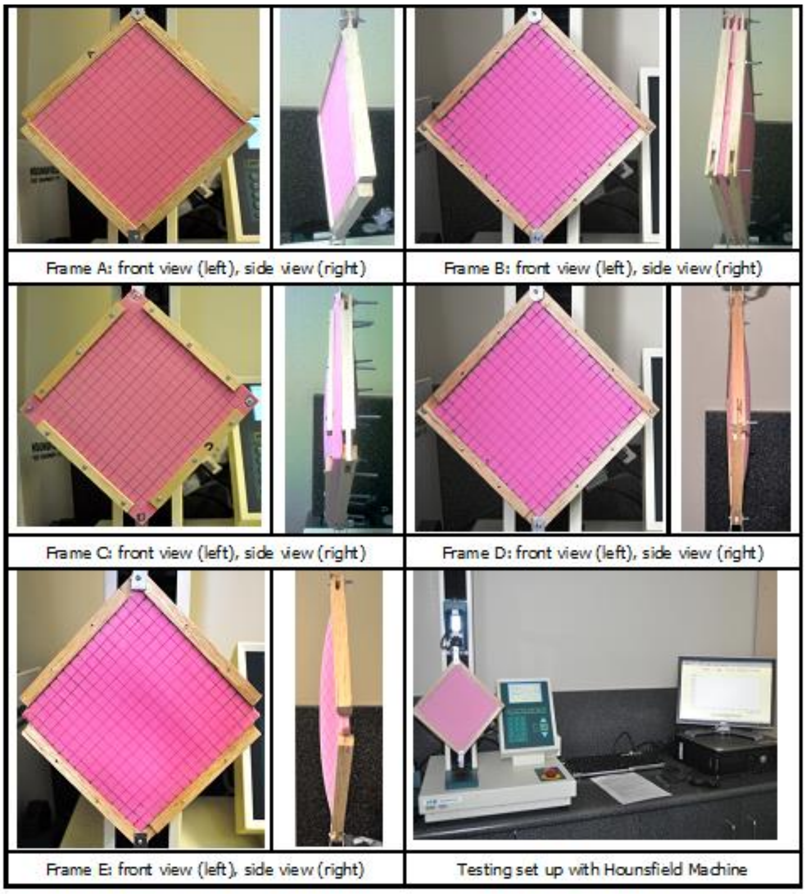

Figure 1 Front and side view of each prototype of testing rig

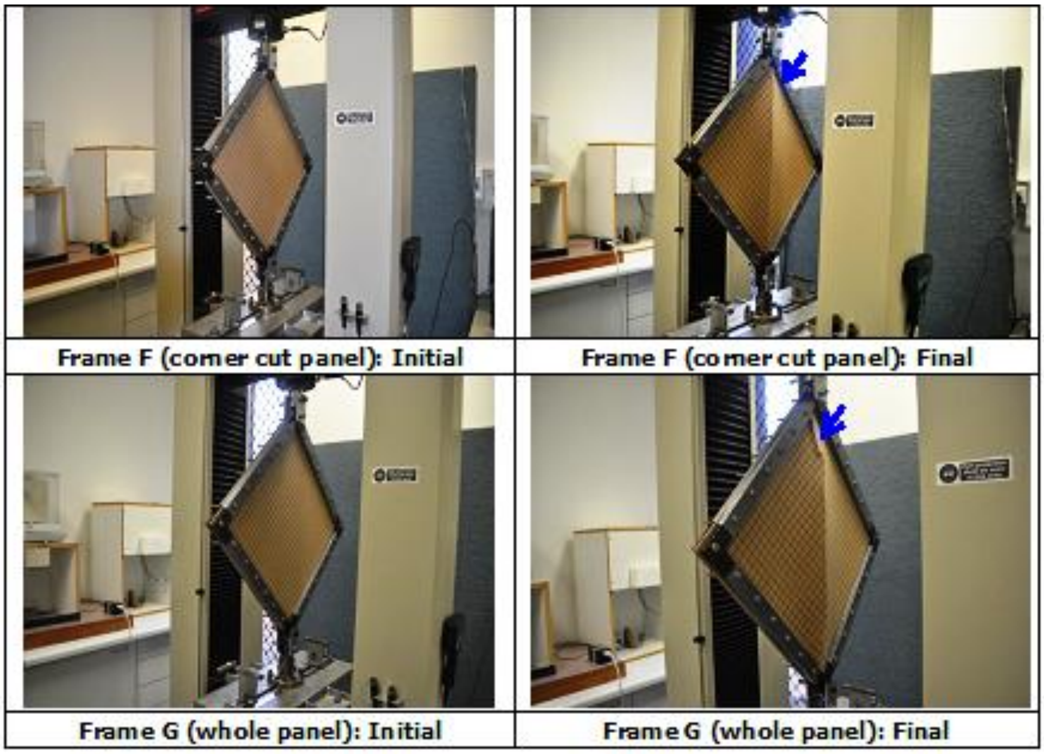

Figure 2 The setting-up of the trial test with MDF board specimens.

Results and Discussions

Preliminary assessment using small-scale testing frame

Figure 3 shows the bar-chart of the testing results while Figure 4 presents the load-deformation curves. Some important findings from the testing are summarised as follows: Frames A and E demonstrated similar performance for both load and extension as their configuration were almost identical. The maximum load reached by Frame A and E was 97.3 N and 96.9 N, respectively. While the extension for both Frame A and E was 65 mm and 67 mm, respectively. Frames C and D achieved almost similar failure load but the extension was different. The maximum load achieved was 68.9 N for Frame C and 64.4 N for Frame D. The extension of Frame D is, however, only approximately 2/3 of Frame C. Meanwhile, Frame B obtained the lowest failure load among all testing specimens while the extension was higher than Frame D but lower than the rest specimens. Although Frame B provided the lowest load transferred to the polyethylene sheet material, the fact that the frames did not fail during the testing process suggested that it might be producing a uniform shear distribution within the specimen.

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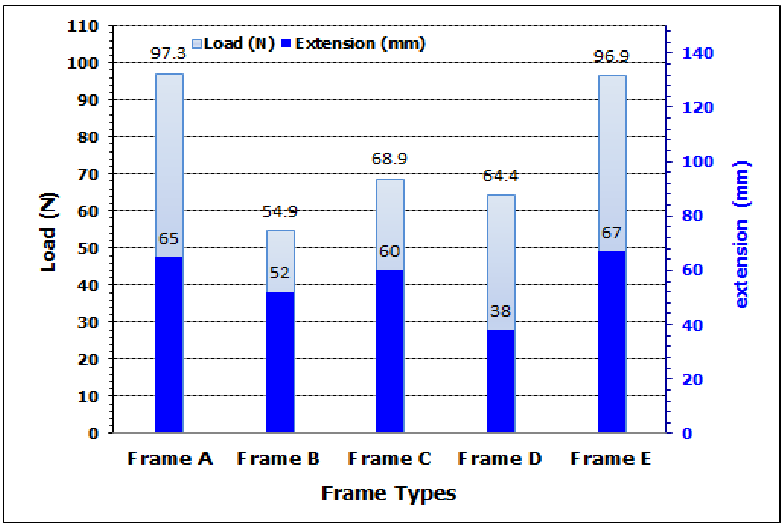

Figure 3 The bar-chart of the testing results for each frame prototype.

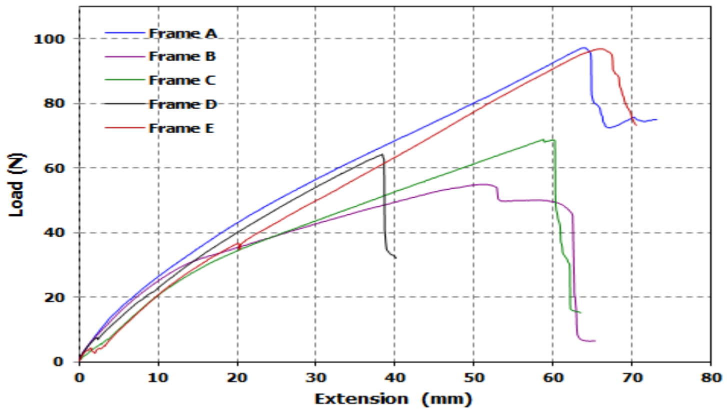

Figure 4 Load-extension graph of the testing results for each frame prototype.

As it can be seen from the failure mechanism showed in Figure 5, all four frames (A, C, D and E) failed suddenly which indicated that those attained higher loads might also be contributed by the frame, which is not preferred in this type of test. Following this testing result, the prototype Frame B was selected for further investigation for the in-plane shear testing of the sandwich panel.

It is also clearly shown in Figure 4 that the load-extension graph of Frame B provides a typical load-extension graph of ductile material that possessed by polyethylene sheet. All the rest frames failed in brittle manner, which is definitely not the typical behaviour of polymer material such as polyethylene. It means that the sudden failure occurred at Frame A, C, D and F was likely contributed by the frame that has to be avoid in the characterisation of material properties.

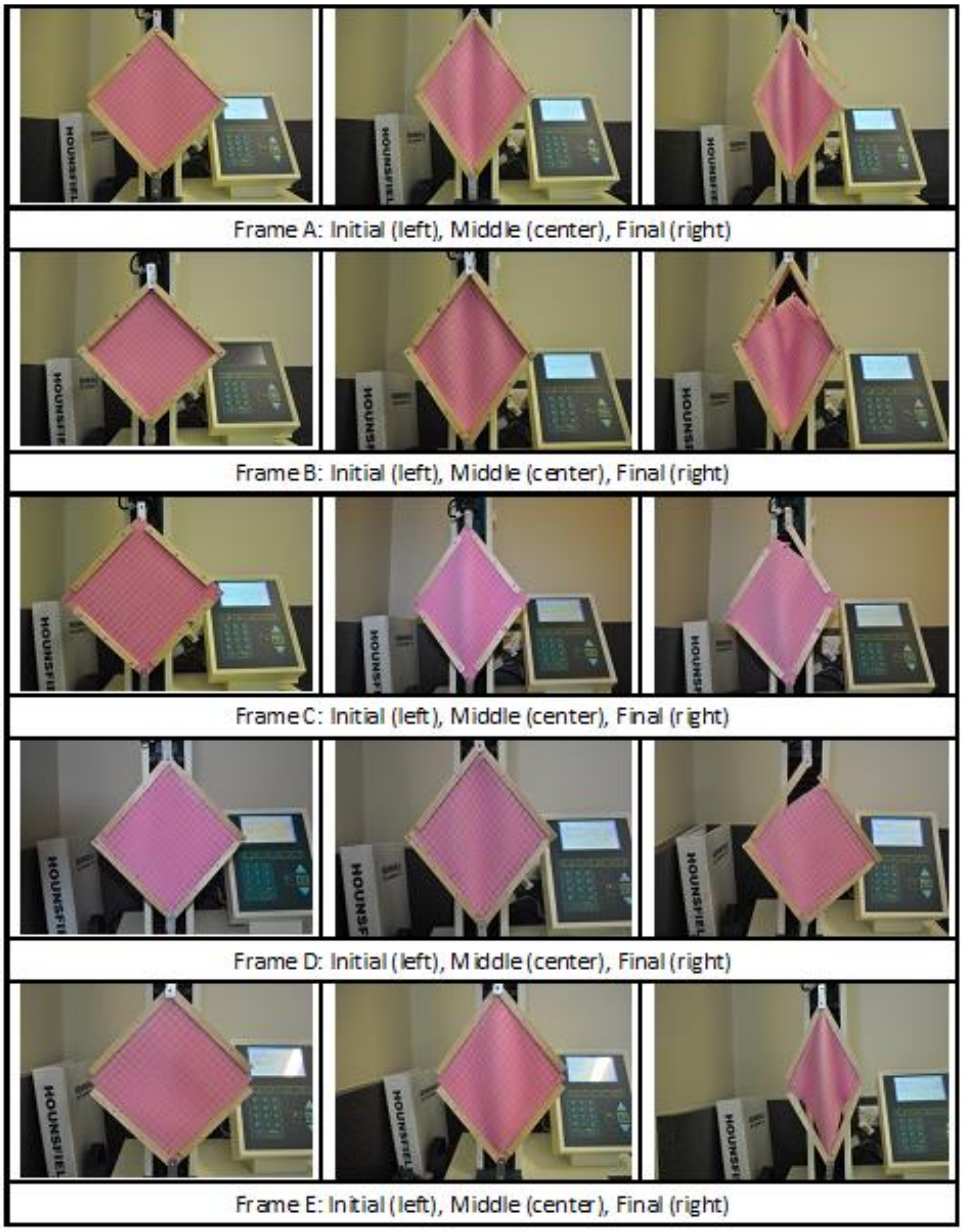

Figure 5 Failure mechanism for each frame prototype.

Trial testing with MDF specimens

The results of the trial tests are presented in Figure 6 and Figure 7. It can be observed from the bar-chart, Figure 6, that the whole panel showed a slightly higher load carrying capacity, which was 27616 N. This value was only about 8.39% higher compared to the load carrying capacity of the corner cut panel. However, if a carefully attention is given to the curves provided by both specimens, as shown in Figure 7, it can be noticed that an early failure was occurred inside the whole panel at much lower load of approximately 19800 N compared to the first sign of failure existed in the corner cut panel specimen which was approximately 24400 N. The early failure occurred at the whole panel specimen was most likely due to the stress concentration at the corner of the testing frame.

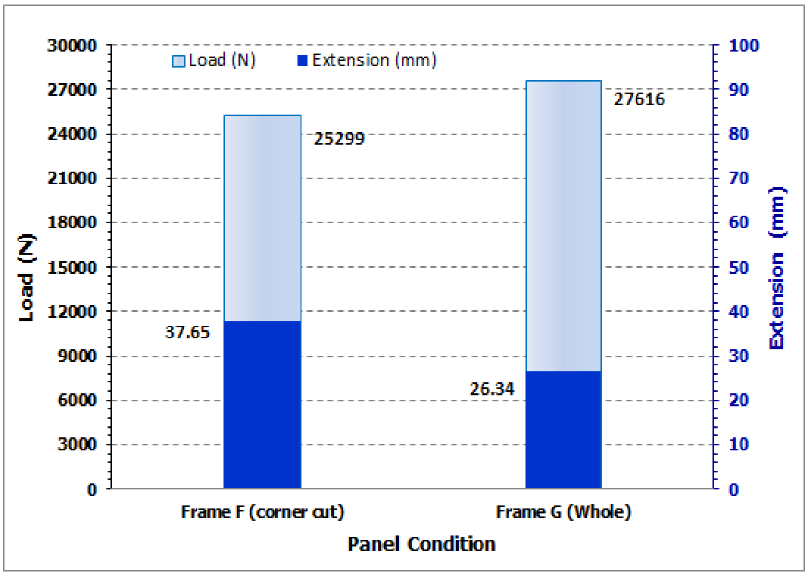

Figure 6 The bar-chart of the trial test results with MDF panels.

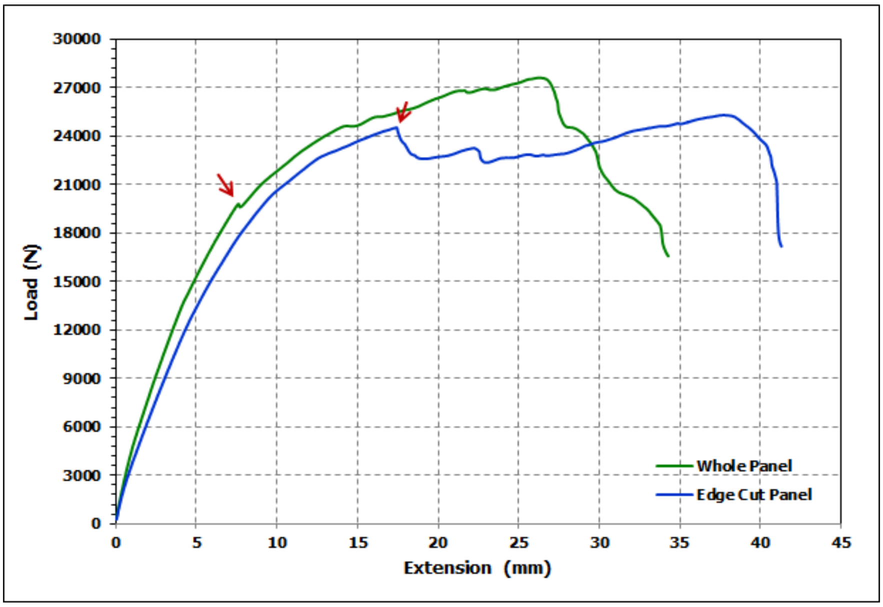

Figure 7 The load-deflection curves of the trial test results with MDF panels.

After removing the panels from the testing frame, a thorough examination was carried out of the failure pattern of the panels. The observation was based on the cracking path as it progressed during the test and for this purposes the cracking patterns were carefully marked to obtain a clear failure maps. The results of this work are presented in Figures 8 and 9.

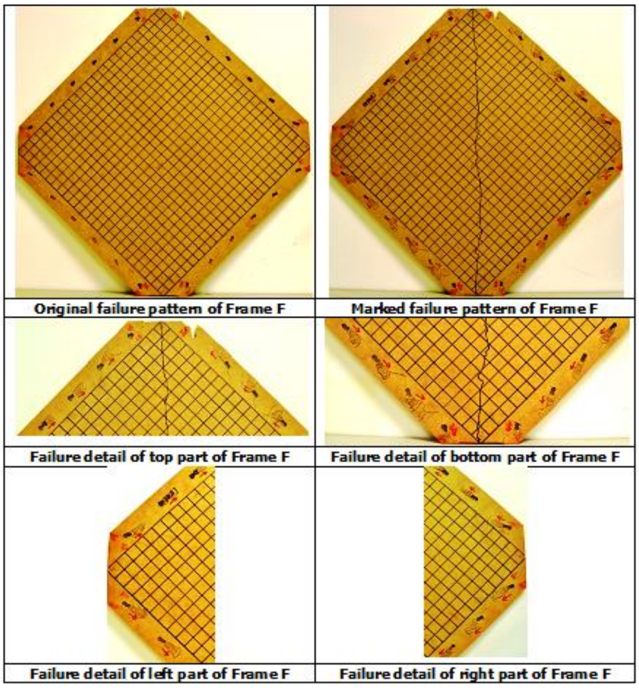

Figure 8 Post-test failure patterns of corner-cut MDF panels.

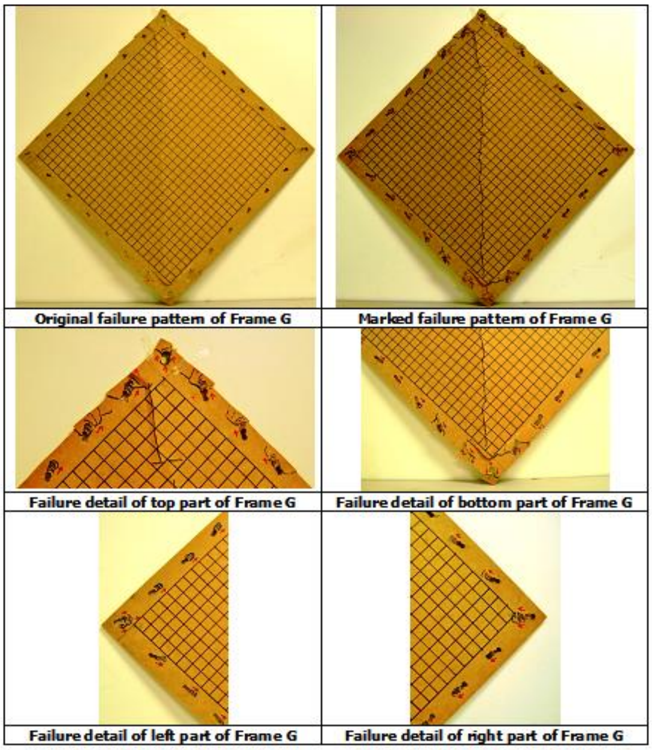

Figure 9 Post-test failure patterns of whole MDF panels.

It is clearly seen in Figures 8 and 9 that the frame has successfully transferred the shear load along the edge of the panel as indicated by the failure patterns. The trial test using MDF board confirmed that the frame was able to transfer the shear load along the side of the panel producing pure shear inside the panel. It is also important to note that cutting the corners of the panel specimen has reduced the stress concentration at the corners, preventing the occurrence of early failure inside the tested specimen.

Conclussion

The main conclusion that can be drawn from this work is that the developed testing frame has been able to investigate the in-plane shear behaviour of composite panel and engineered wood products. The diagonal tension shear test has been re-considered by some researchers for both cost and resources reasons to investigate the in-plane shear behaviour of wall panels, especially at the initial development of a product. Such a test only requires a smaller size specimen than the standard racking test which may reduce the cost. Frame with pin at all four corners and the tested panel located in between the upper and bottom frame and connected with bolts is the best choice for inducing in-plane shear mechanism. The developed frame has all four corners pin-jointed using bolts to obtain free-movement to vertical and horizontal directions. This works better than those with only two pin-jointed corner at the top and bottom corners. In addition, cutting the corners of specimen has prevented the presence of early failure mechanism due to stress concentration.

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