Scientific Research and Essays Vol. 8(8), pp. 325 -339, 25 February, 2013
Available online at http://www.academicjournals.org/SRE
DOI: 10.5897/SRE12.419
ISSN 1992-2248 ©2013 Academic Journals

Full Length Research Paper

Failure load of corner joints, which are reinforced with glass-fiber fabric in case-type furniture

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Accepted 18 February, 2013

In this study, the failure load of L-type corner joints, which are reinforced with glass-fiber fabric, of the case-type furniture have been analyzed experimentally and statistically in laminated medium-density fiberboard (LMDF) material. The failure loads of corner joints have been analyzed experimentally under compression and tension loads. Dowels (D), dowel + glass fiber composite layer from the outside (DCO), dowel + glass fiber composite layer from the inside (DCI), dowel + glass fiber composite layer from the outside and inside (DCOI) and dowel + glass fiber composite layer from the edge (DCE) are used as joint methods. Tests were carried out according to ASTM Standards. The test results were analyzed statistically by Weibull distribution to obtain a 95% reliability level for failure load. Results show that the failure load takes its highest value for DCOI joints and lowest value for D joints for both average values of the test results and 95% reliability of Weibull distribution. In addition, results show that while the average failure load values of reinforced corner joints (for DCO, DCI, DCOI, and DCE joints, respectively) in tension situations increased by factors of 1.78, 2.69, 3.34 and 2.11 the average failure load values of unreinforced corner joints (D joints), the average failure load values of reinforced joints in compression situation are 7.98, 1.12, 6.08 and 3.06 times as much as the average failure load values of unreinforced joints. In addition, the 95% reliability value for each corner joint configuration is approximately equivalent to the 0.53 average value of the failure load.

Key words: Reinforced, glass-fiber fabric, dowel, failure analysis, case-type furniture, laminated medium-density fiberboard, Weibull distribution.

INTRODUCTION

Production of furniture adequate to meet even the basic needs of an ever-increasing world population in the face of an ever-shrinking traditional resource base as well as increase its quality of life requires better product engineering, more efficient use of composite materials and better “proofing” of the furniture to ensure its durability (Eckelman and Erdil, 1999).

The mechanical property tests of wood-based composite boards do not necessarily evaluate those characteristics of the board that are most important to its use in furniture. Test indicate that at least three other characteristics govern the performance of composite-based constructions, namely, edge splitting strength, edge breaking strength, and edge pull out strength. Edge splitting strength is an important characteristic of composites used in furniture. Tests indicate that when a case fails owing to racking forces, either the end of one panel splits, or, the edge of the mating panel breaks (Eckelman and Erdil, 1999). In furniture construction technology too, the weakest points against heavy weights are indicated as the corner joints of the furniture. Therefore, to strengthen furniture corner joints have a great deal of importance. For this purpose, many researchers tested strength of many fasteners in the furniture corner joints. Recently, many engineering fields have used to glass-fiber fabrics to improve the resistance of the material. In this study, therefore, the joint method of glass fiber composite which is different from the joint methods which have been tested by many researchers up to now is tested.

Fiber reinforced polymer (FRP) composites have the potential to replace some conventional construction materials in both new construction and retrofitting applications (Bakis et al., 2002). Fiber-reinforced plastic is a composite material made of a polymer matrix reinforced with fibers. The fibers are usually glass, carbon, or aramid, although other fibers such as paper or wood or asbestos have been sometimes used. The polymer is usually an epoxy, vinylester or polyester thermosetting plastic, and phenol formaldehyde resins are still in use. FRPs are commonly used in the aerospace, automotive, marine, and construction industries (Masuelli, 2013). The fibers provide the strength and stiffness, while the resin holds the fibers and transfers stresses between the fibers. Two major advantages of FRP composites are the high strength-to-weight ratio and non-corrosive characteristics (Fam et al., 2005; Kim and Hefferman, 2008).

Acceptable reinforcement systems and processes would also permit structural use of poorer quality wood, including short lengths. Additional advantages and savings could be realized by reinforcing and thereby strengthening mechanical fasteners, regions of stress concentration, and finger and butt joints (Rowlands et al., 1986).

Researchers have conducted several studies related to glass fiber. Ghassan (2011) determined the effect of FRP on the structural properties of a single piece of wood identified as southern pine wood. He concluded that addition of FRP has significant impact on strength and behavior of structural wooden elements. He also concluded that testing results revealed a 14% increase in compression, 18% increase in bending, and 10% increase in tension. Stevens and Criner (2000) determined that the FRP-reinforced beams are stronger than non-reinforced glulam beams because the reinforcement absorbs some of the most damaging tension stresses endured by conventional wooden glulam beams. In the study by Rowlands et al. (1986), the technical feasibility of producing internally reinforced laminated wood was evaluated experimentally. They concluded that glass-fiber reinforced Douglas fir (18% glass by volume) produced a 40% stiffness enhancement and doubled the strength over similar unreinforced wood. Windorski et al. (1997) investigated the use of fiberglass reinforcement to enhance the load-carrying capacity of bolted wood connections. They concluded that the ultimate strength of a three-layer reinforced connection was 33% greater than the unreinforced connection for parallel-to-grain loading and more than 100% for perpendicular-to-grain loading. Heiduschke and Haller (2010) discussed the load carrying behavior of lightweight columns with circular hollow cross sections. They concluded that when compared to unreinforced tubes, the ultimate load of FRP reinforced tubes is increased by about 60%. Cabrero et al. (2010) investigated the outcomes of a parametric study on the performance of reinforced wood tubes submitted to axial compression. They explained that the failure response stress for the corresponding unreinforced tube was also depicted; a clear improvement of the performance of the tube in the material controlled area was noticed; and the strength of the unreinforced material was about 2/3 of the reinforced. Heiduschke et al. (2008) investigated to provide engineered wood products on the basis of formed wood profiles being optionally reinforced with technical fibers and textiles for structural purposes. They concluded that when compared to the unreinforced columns, the load-carrying capacity of the reinforced columns increased by factors of 1.46 and 1.22, respectively.

Researchers have conducted several studies related to the dowel joints. Tankut (2005) examined optimum dowel spacing for corner joints in 32 mm cabinet construction. He determined that maximum moment is obtained in joints when the spacing between dowels is at least 96 mm.

Liu and Eckelman (1998) carried out study in order to determine the bending strength of case joints constructed with multiple fasteners in 19 mm thick particleboard (PB) and 22 mm thick MDF. They tested both dowels and screw joints under compression load. They concluded that probably because of the adhesive added to the joint area, corner joints constructed with dowels could exceed the bending strength of the board itself.

Tankut and Tankut (2010) have carried out study to determine the effects of the edge banding material, namely polyvinyl chloride (PVC), melamine and wood veneer, thickness of edge banding material, and wood composite panel type on the diagonal compression and tension strength properties of LPB and LMDF. They found that samples with edge banding gave higher diagonal tension and compression strength than control samples. In compression tests of control specimens, they concluded that the edge of the face member split within its thickness and the split was continuous, parallel and very close to the glue line throughout the length of the specimens. In the tension test, they concluded that butt members split inside the corner of the joints near the glue line and linearly continuously throughout the length of specimens.

Glass-fiber fabric has been examined by many researchers. On the other hand, many fastener components were examined for effect of corner joints in case-type furniture by many researchers. But, the effects of reinforcing available corner joining methods with glass-fiber fabric in terms of the strengthening of case-type furniture products are not known for wood-based materials. The reinforcement with fabric of corner joints in case-type furniture is a new research topic. The study by Yerlikaya and Aktas (2012) in this topic, the failure loads of L-type corner joints in case-type furniture have been analyzed experimentally and statistically in laminated medium-density fiberboard material. For this purpose, they used dowel, minifix and glass-fiber fabric were used as fastener components. They were analyzed statistically, the test results by Weibull distribution to

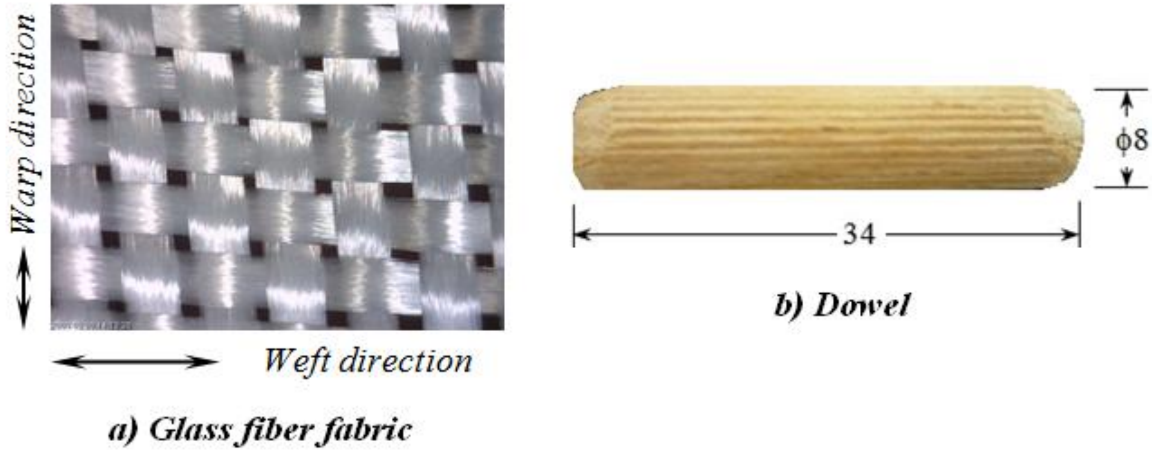

Figure 1. Fastener materials (dimensions in mm).

obtain a 95% reliability level for failure load. They concluded that the failure load takes its highest value in the dowel+minifix+composite layer (DMC) case for both average values of the test results and for 95% reliability under Weibull distribution, while it takes its lowest value in the dowel (D) case. In addition, they concluded that the 95% reliability value for each corner joint configuration is approximately equivalent to the 0.53 average value of the failure load.

Researchers who have studied the effects of corner joints, mentioned above, have taken the strength as an average of the experimental results. But, this is not completely reliable. This leads to the necessity to employ statistical analyses for their safe utilization in design and manufacturing. One of these analyses is the Weibull distribution. Weibull distribution has the ability to model experimental data of very different characters. This is one of the reasons for its wide utilization today. Dodson (1994) has defined the developments regarding the estimation approaches for Weibull distribution parameters. Barbero et al. (2000) have applied this analysis in modeling the mechanical properties of composite materials and suggested Weibull distribution as a practical method in the determination of the 90 and 95% reliability values used in composite material mechanics. Yerlikaya and Aktas (2012) were analyzed statistically, the test results by Weibull distribution to obtain a 95% reliability level for failure load. They concluded that the 95% reliability value for each corner joint configuration is approximately equivalent to the 0.53 average value of the failure load.

All studies except for Yerlikaya and Aktas (2012), which are related to the strength of furniture, concluded by researchers are based on average strength values. The reliability of these values is not known or determined. Probably, the highest reliability of these values is 50 to 55%. Average strength values obtained with this reliability level lead to errors in point of strength for corner joints in case-type furniture. Therefore, strength values must be determined to a 95 to 99% reliability level in order to safely use produced furniture. To satisfy this problem, that is to say, to obtain strength at the 95 to 99% reliability level, Weibull distribution can be used.

The presented research work deals with investigation of failure loads of L-type corner joints reinforced with a glass-fiber composite layer (fabric) in laminated medium density fiberboard (LMDF). The current study addresses the following research objectives: (1) to determine the effects of glass-fiber composite layer (fabric), (2) to determine the effects of the joint type, namely dowels (D), dowel + fabric from the outside (DCO), dowel + fabric from the inside (DCI), dowel + fabric from the outside and inside (DCOI), dowel + fabric from the edge (DCE) on failure loads in L-type corner joints in case-type furniture, (3) to statistically analyze, using Weibull distribution, the effects of failure loads in L-type furniture corner joints.

MATERIALS AND METHODS

Specimens were constructed from 18 mm thick LMDF, which is in common utilization by most manufacturers. The LMDF panels were tested for specific gravity (SG), moisture content (MC), and modulus of elasticity (MOE) in accordance with ASTM D1037 (1973).

In this study, dowels and glass fiber composite layers (fabrics) were used as fastener components (Figure 1). Glass-fiber fabrics having 400 g/m^2 and multi-groove beech dowels 8 mm in diameter and 34 mm in length were used (Figure 2(a), (b)). Dowels were assembled with the polyvinyl acetate (PVAc) adhesive. Fabrics were fastened with epoxy resin and hardener. The type of epoxy resin used in the matrix material was Bisphenol ACY-225 and the hardener was Anhydride HY-225. In general, each specimen consisted of two principal structural members, a face member and a butt member.

In order to investigate failure load of L-type corner joints reinforced with glass-fiber fabric, D, DCO, DCI, DCOI and DCE corner joint methods were used (Figure 2). Five specimens were prepared and tested for every configuration. Specimens were drilled

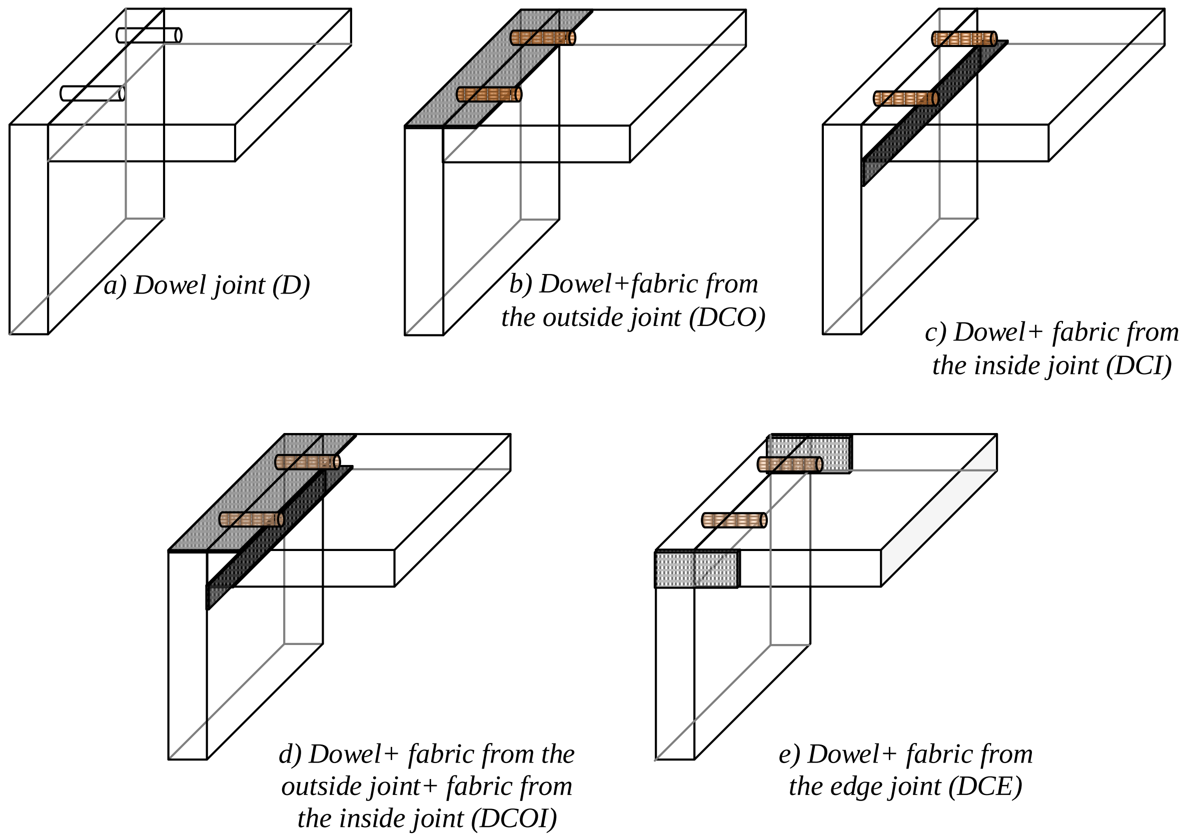

Figure 2. The configuration of L-type corner joints.

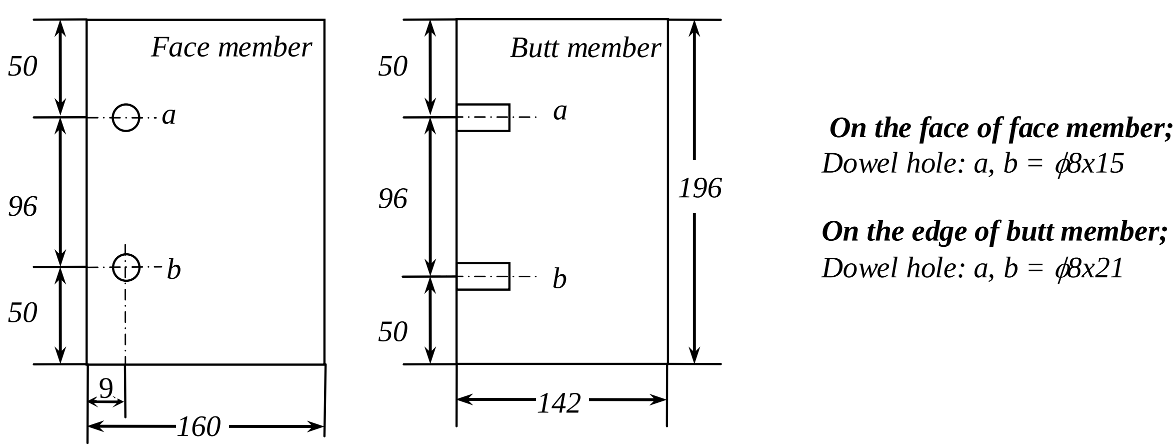

Figure 3. Drilling plans of specimen (dimensions in mm).

according to drilling plans with a drilling machine (Three Lines Multi-Boring Machine BJK65) at the speed of 500 rpm as shown in Figure 3.

Typical configuration of the specimens used in the tests is given in Figure 4. In all the specimens, after only the dowel holes on both the butt and face member were glued with PVAc adhesive, dowels were driven into this glued hole for the butt member by a mold (Figure 4(a)). Then, face and butt members were placed in conjunction. For the specimen using fabric joints, areas where the fabrics were to be placed were glued with a mixture of epoxy resin and hardener. Two layers of fabric were placed on these areas and epoxy applied (Figure 4(b), (c), (d), and (e)). These specimens were left to dry for two days.

A horizontal force is applied to a typical case-type construction. When a horizontal force is applied, one corner of the construction is subjected to a moment trying to open the joint (Figure 5 point a), and the other corner is subjected to a moment trying to close the joint (Figure 5 point b). In order to simulate these forces, two tests

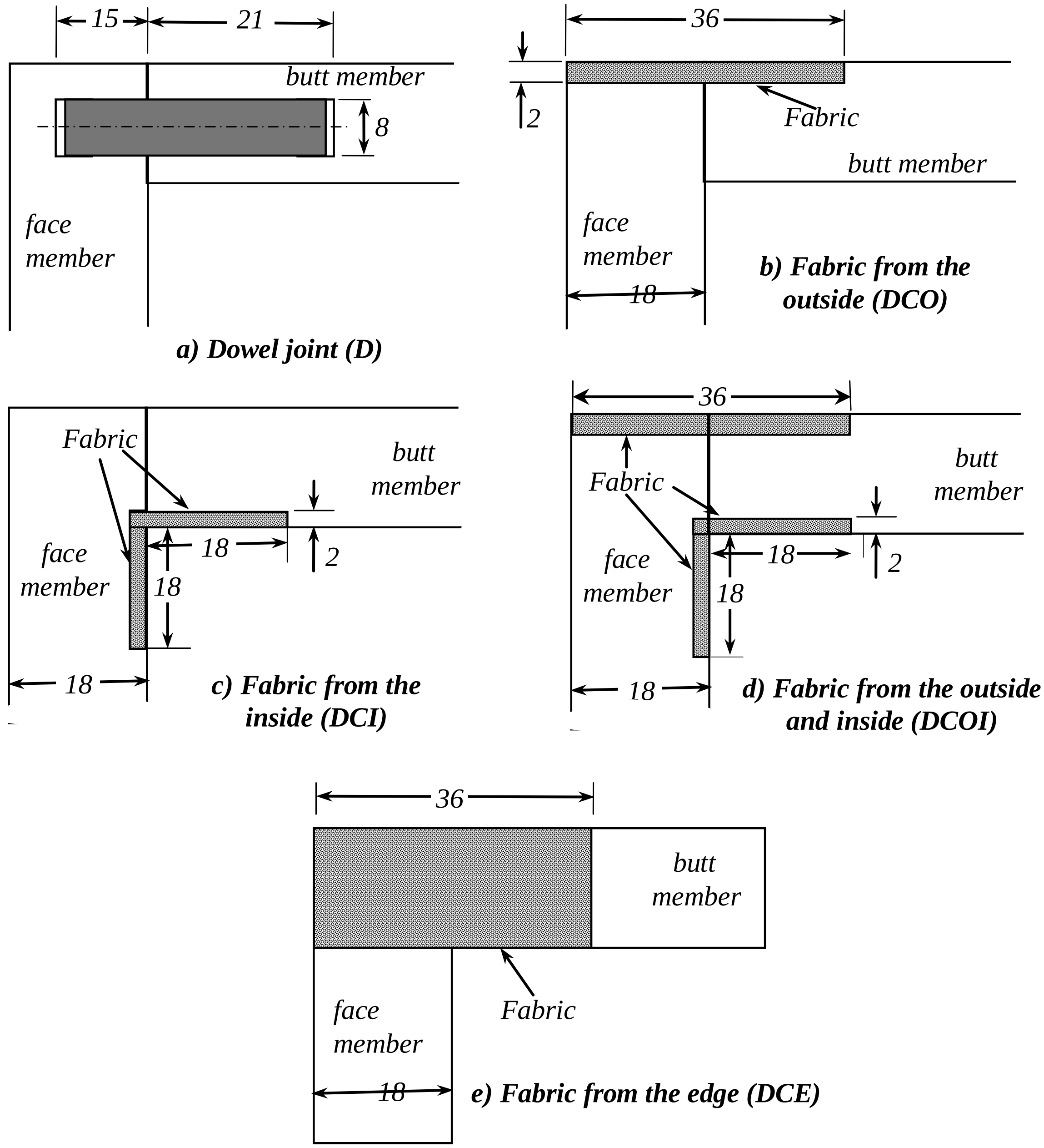

Figure 4. Typical configuration of the specimens used in the test (dimensions in mm).

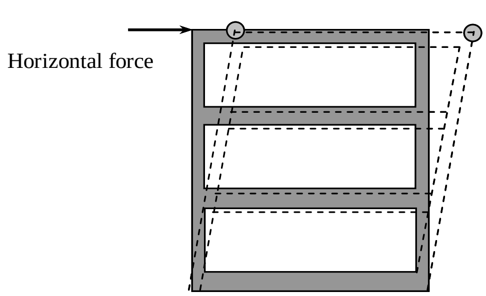

Figure 5. A typical case-type construction applied by a horizontal force.

were developed. One is a corner joint subjected to compression force causing a moment tending to open the joint (Figure 6(a)), and the other is a corner joint subjected to tension force causing a moment tending to close the joint (Figure 6(b)). In the tension test setup, each of the supports was placed on metal plates with four bearings so that the two joint members were free to move sideways. Load was applied to each specimen until some separation occurred between face and butt members. The load and displacement graphs were plotted by a computer for all tests. The tests were carried out at room temperature of ~20°C with a 10 kN loading capacity Universal testing machine at a speed of 1.5 mm/min.

In this study, the variation of the bending moment of corner joints has been modeled using Weibull distribution. Five test specimens

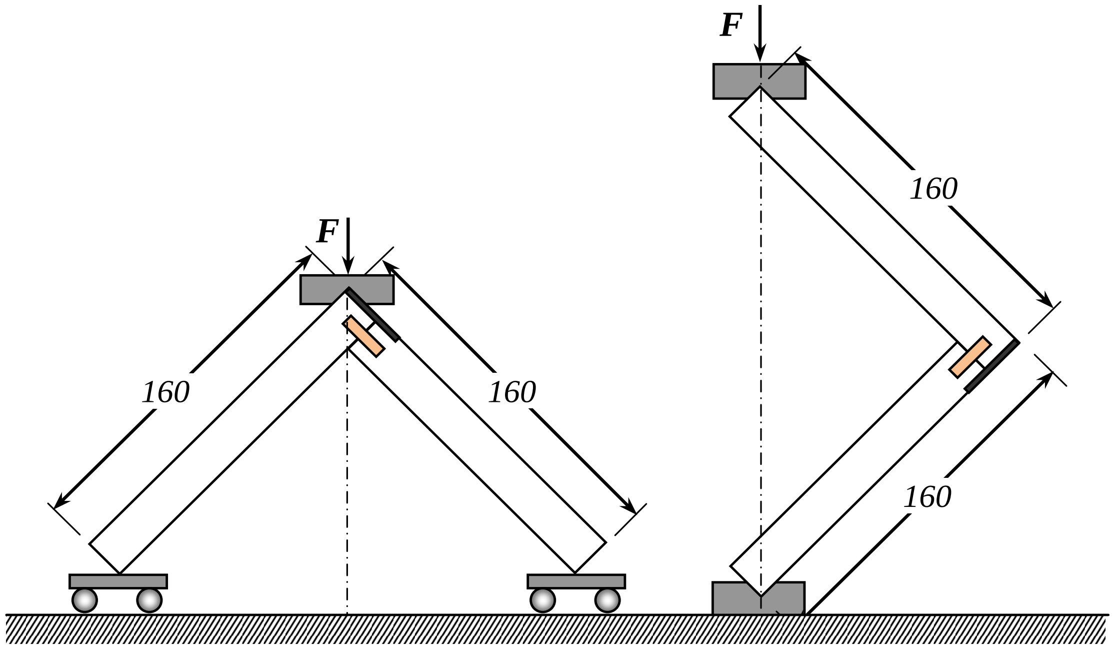

Figure 6. Loading forms of specimen subjected to tension and compression loads (measurements in mm).

have been performed for each specimen configuration. Using the test data, the corresponding Weibull distribution has been determined. Finally, the 95% reliability values of each failure load configuration were compared with respect to failure load values of the same set.

This and the next five parts of this work are taken from the study by Aktas (2007). Weibull distribution was used to model extreme values such as failure times and failure load. Two popular forms of this distribution are two- and three-parameter Weibull distributions. In this study, the two-parameter Weibull distribution is considered. The distribution function in this case can then be written as follows:

$$F(x;b,c)=1-exp\left(-(\frac{x}{b})^c\right), \quad b\geq 0, c\geq 0 \qquad (1)$$

In the context of this study, *F(x; b, c)*, represents the probability that the failure load is equal to or less than *x*. Using the equality *F(x; b, c)* + *R(x; b, c)* = 1, the reliability *R(x; b, c)*, that is, the probability that the failure load is at least *x*, is defined as

$$R(x;b,c)=exp\left(-(\frac{x}{b})^c\right), \quad b\geq 0, c\geq 0 \qquad (2)$$

The parameters *b* and *c* of the distribution function *F(x; b, c)* are estimated from observations. The methods usually employed in estimation of these parameters are the method of linear regression, the method of maximum likelihood and the method of moments. In this paper, linear regression is still common among practitioners, and is used for parameter estimation. However, software programs with statistical abilities MS Excel™ have replaced the use of Weibull graph papers.

Method of Linear Regression is based on transforming Equation (1) into $1-F(x;b,c)=exp\left(-(\frac{x}{b})^c\right)$ and taking double logarithms of both sides. Hence, a linear regression model in the form *Y* = *m X* + *r* is obtained:

$$ln\left[ln\left(\frac{1}{1-F(x;b,c)}\right)\right]=c\,ln(x)-c\,ln(b) \qquad (3)$$

F(x; b, c) is an unknown in (3) and so it is estimated from observed values: order *n* observations from smallest to largest, and let $x_{(i)}$ denote the *i*th smallest observation (*i*=1 corresponds to the smallest and *i* = *n* corresponds to the largest). Then a good estimator of $F(x_{(i)}; b, c)$ is the median rank of $x_{(i)}$:

$$\hat{F}(x_{(i)};b,c)=\frac{i-0.3}{(n+0.4)} \qquad (4)$$

When linear regression, based on least squares minimization, is applied to the paired values *(X*, *Y)* = $\left(ln(x_{(i)}), ln\left[ln\left(\frac{1}{1-\hat{F}(x_{(i)};b,c)}\right)\right]\right)$ for the model in Equation (3), the parameter estimates for *b* and *c* are obtained.

RESULTS

SG, MC, and MOE values of the LMDF panels used in the tests is given in Table 1.

Failure load

The results obtained from the experiments in the present

Table 1. Average MC and mechanical properties of the LMDF used in the test.

MC (%)	SG	MOE (N/mm^2)
7.56 (3)	0.75	3522

MC: Moisture content, SG: Specific gravity, MOE: Modulus of elasticity.

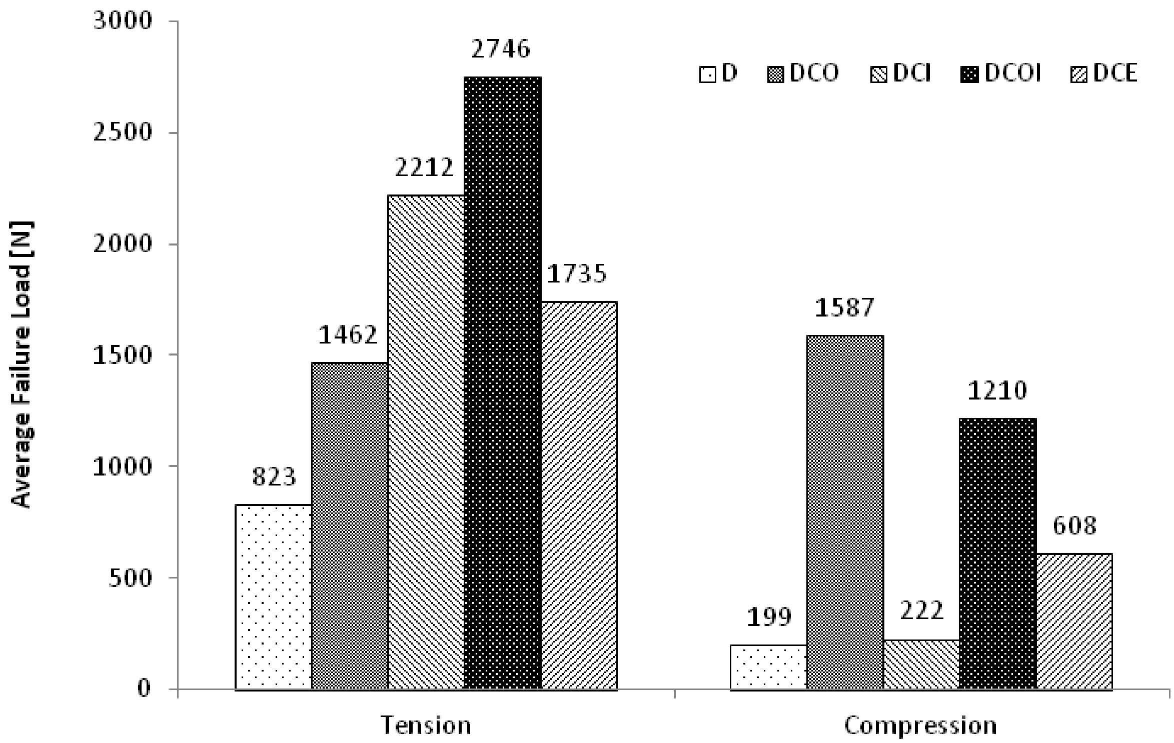

Figure 7. Experimental results.

Table 2. Failure load values from tension and compression tests.

Test No.	Tension [N]						Compression [N]					
Joint type	**1**	**2**	**3**	**4**	**5**	**Average**	**1**	**2**	**3**	**4**	**5**	**Average**
D	892	754	904	746	821	823	223	190	156	178	248	199
DCO	1618	1335	1336	1342	1677	1462	1459	1531	1573	1717	1655	1587
DCI	1735	2396	2490	2532	1909	2212	200	241	192	274	201	222
DCOI	2955	3095	3041	2202	2436	2746	1102	1079	1272	1132	1467	1210
DCE	1826	1697	1699	1701	1750	1735	578	660	566	655	580	608

work are given in Figure 7. For tension tests, which tend to open the corners of test specimens, the average values of failure loads are obtained as 823, 1462, 2212, 2746 and 1735 N for D, DCO, DCI, DCOI, and DCE, respectively. For compression tests, which tend to open the joints of specimens, the average values of failure loads are obtained as 199, 1587, 222, 1210 and 608 N for D, DCO, DCI, DCOI, and DCE respectively.

Weibull distribution

In order to compute *b* and *c*, the results obtained from the experiments as given in Table 2 are first ordered from the smallest to largest and (X_i, Y) values are computed. Then applying linear regression to these (X, Y) values, the linear regression model with the regression line in Figure 8 (for example, D joint type at compression) is obtained.

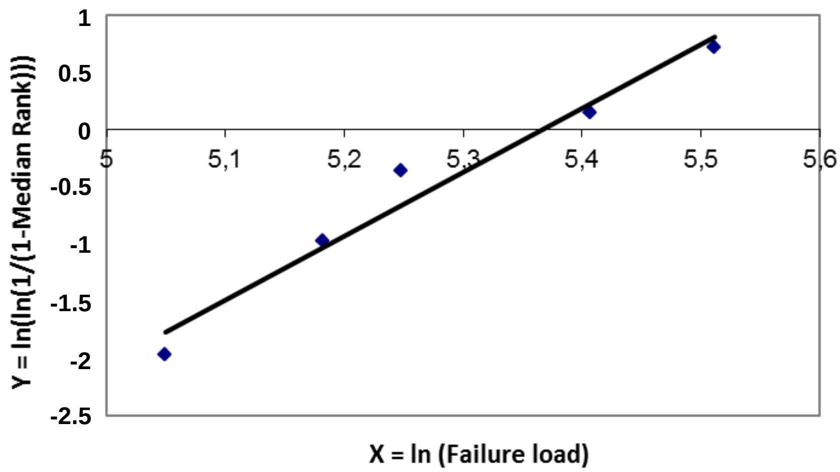

Figure 8. Regression line for D joint type at compression.

The first point in Figure 8 does not appear to fit the line well. However, this is an expected situation in the method of linear regression; among consecutive $(Y_{(i)}, Y_{(i+1)})$ pairs, $(Y_{(1)}, Y_{(2)})$ has the largest absolute difference. The slope of the line is 5.58, which is the value of the shape parameter *c*.

A finding that $c < 1.0$ indicates that the material has a decreasing failure rate. Similarly, a finding that $c = 0$ indicates constant failure, and that $c > 1.0$ indicates an increasing failure rate. The *b* value is computed as $b = 214$ using the point the line intersects the *Y* axis (= -29.938) in $b = e^{(-Y/c)}$. Therefore, *c*=5.58 indicates that there is a higher probability that the material will fracture with every unit of increase in applied compression. The scale parameter *b* measures the spread in the distribution of data. As a theoretical property, $R(b;\ b,\ c) = 0.368$. Therefore, $R(214;\ 214,\ 5.58) = exp\ (-(x/b)^c) = 0.368$, that is, 36.8 % of the tested specimens have a fracture strength of at least 199 N.

Figures 9 (tension) and 10 (compression), the configuration of the specimens are D, DCO, DCI, DCOI, and DCE), shows a Weibull distribution plot of the data obtained from the failure load tests. For tension, the reliability curve in Figure 9 shows that failure load values roughly less than or equal to 500, 700, 900, 1000 and 1400 N (for D, DCO, DCI, DCOI, and DCE, respectively) will provide high reliability. For a more certain assessment, consider 0.95 a reliability level. When these values are put as $R(x;\ b,\ c)$ in Equation (2) and the equation is solved for *x*, the failure load values 652, 1046, 1418, 1859 and 1580 N (for D, DCO, DCI, DCOI, and DCE, respectively) are obtained. For compression, the reliability curve in Figure 10 shows that failure load values roughly less than or equal to 50, 1100, 80, 550 and 400 N (for D, DCO, DCI, DCOI, and DCE, respectively) will provide high reliability. For a more certain assessment, consider 0.95 a reliability level. When these values are put as $R(x;\ b,\ c)$ in Equation (2) and the equation is solved for *x*, the failure load values to 126, 1358, 146, 850 and 500 N (for D, DCO, DCI, DCOI, and DCE, respectively) are obtained.

Comparison of the failure load and 95% reliability values

The failure load obtained from the average values of the experiments and 95% reliability obtained by Weibull distribution are given in Figures 11 (tension) and 12 (compression). For tension, as a result of both average values of the test and 95% reliability of Weibull distribution, the failure load takes its highest value for DCOI joints and lowest value for D joints. These maximum results are obtained when the fabric from outside and inside in the corner joint is used. Since the fabric is at the outer and inner surface of the corner, the fabric on the outer surface is subjected to compression and the fabric on the inner surface subjected to tension. These minimum results are obtained when the fabric is not used. The failure load values for DCI joints are higher than DCO joints. The reason for this is the effect of fabric from outside on failure load is also low. For compression, it can be seen from the figure that the failure loads take their highest values for DCOI joints and lowest values for D and DCI joints for both experimental and statistical analysis. These maximum results are obtained when the fabric from outside and inside is used in the corner joint. Because of this the fabric on the outer surface is subjected to compression and the fabric on the inner surface is subjected to tension. These minimum results are obtained when the fabric is not used and the fabric from inside is used.

While the average failure load values of reinforced corner joints (for DCO, DCI, DCOI, and DCE joints, respectively) in tension situations increased by factors of 1.78, 2.69, 3.34 and 2.11 of the average failure load

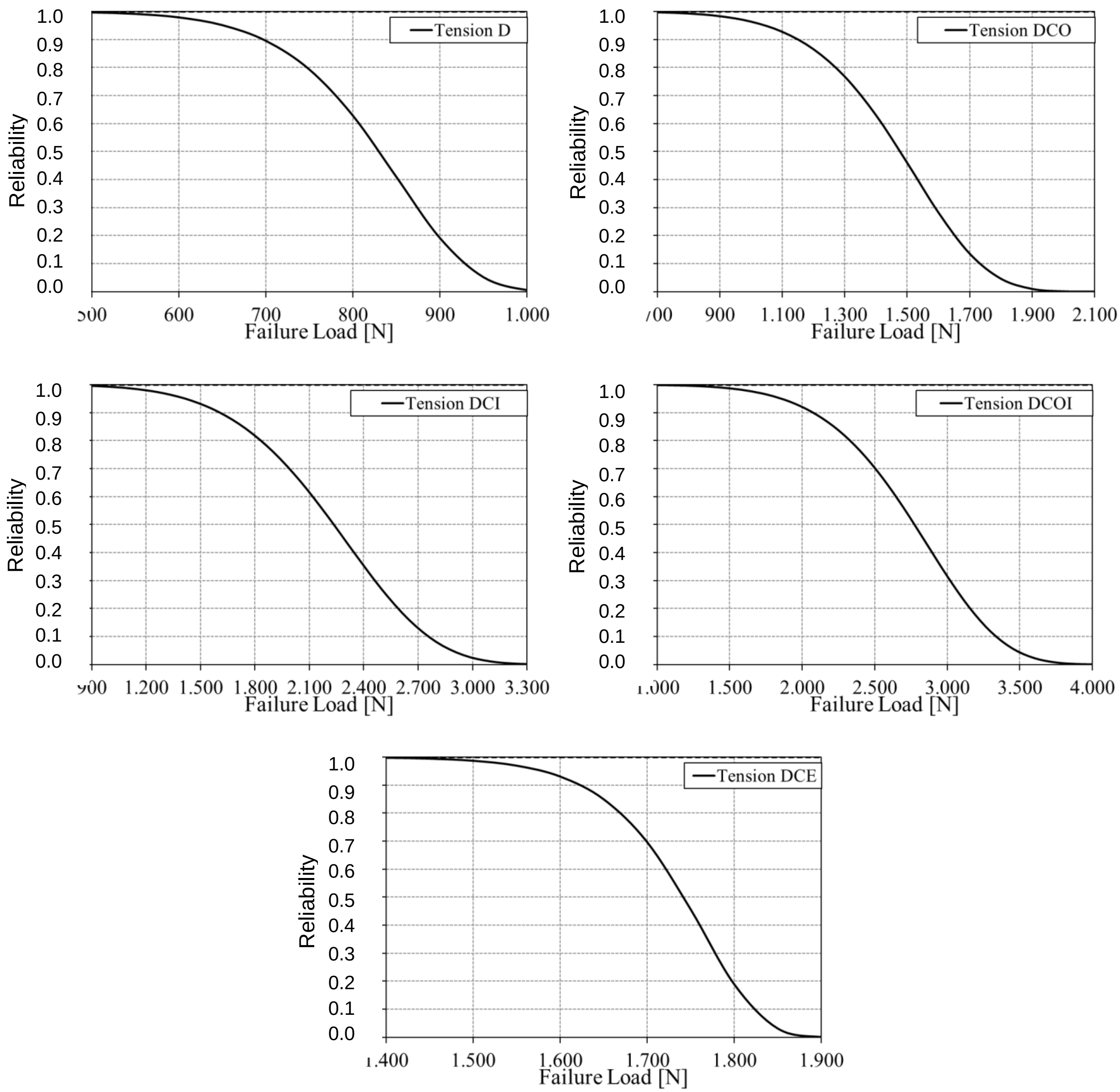

Figure 9. Weibull reliability distribution (for tension test).

values of unreinforced corner joints (D joints), the average failure load values of reinforced joints in compression situation are 7.98, 1.12, 6.08 and 3.06 times as much as the average failure load values of unreinforced joints.

On the other hand, while the 95% reliability values of reinforced corner joints (for DCO, DCI, DCOI, and DCE joints, respectively) in tension situations increased by factors of 1.6, 2.18, 2.85 and 2.42 of the 95% reliability values of unreinforced corner joints, the 95% reliability values of reinforced joints in compression situation are 10.78, 1.16, 6.75 and 3.97 times as much as the 95% reliability values of unreinforced joints.

In other words, while the average failure load values of reinforced corner joints in tension situations increased 78, 169, 234 and 111% more than the average failure load

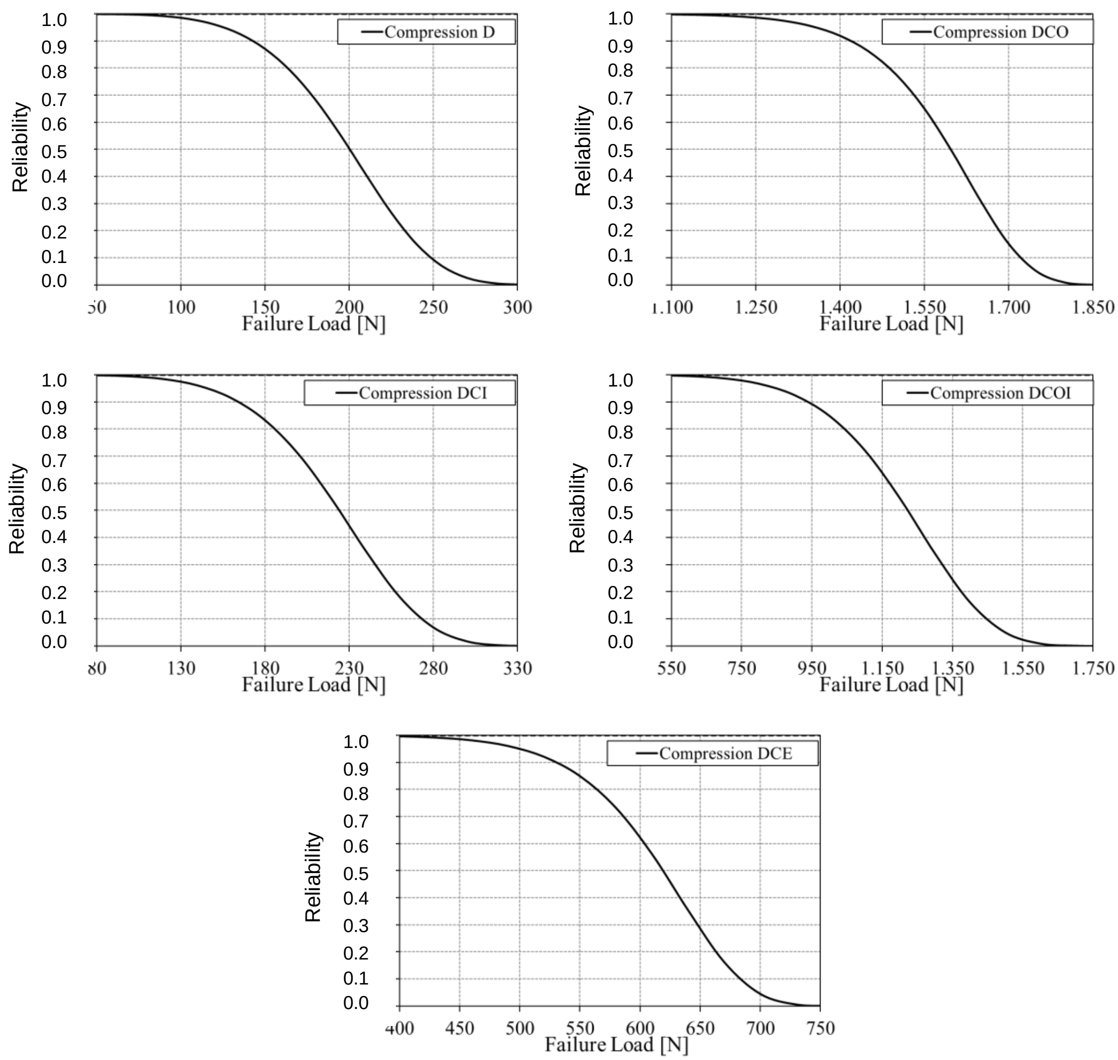

Figure 10. Weibull reliability distribution (for compression test).

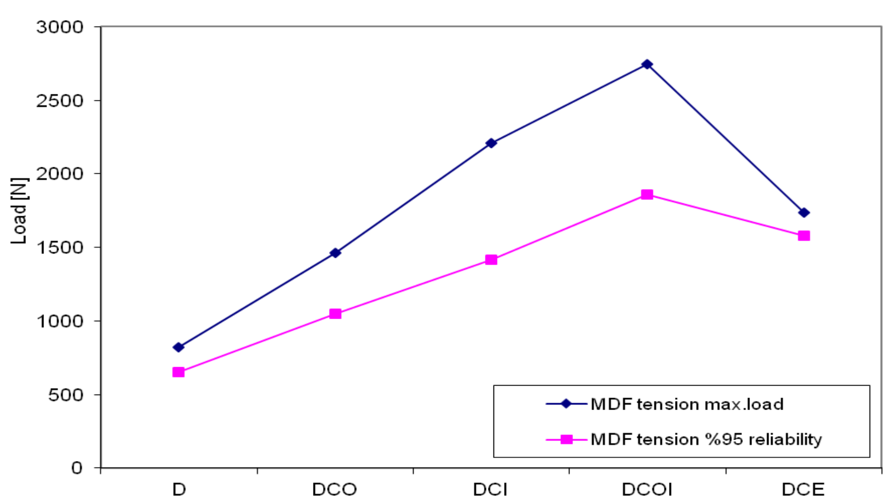

Figure 11. Failure load for tension test.

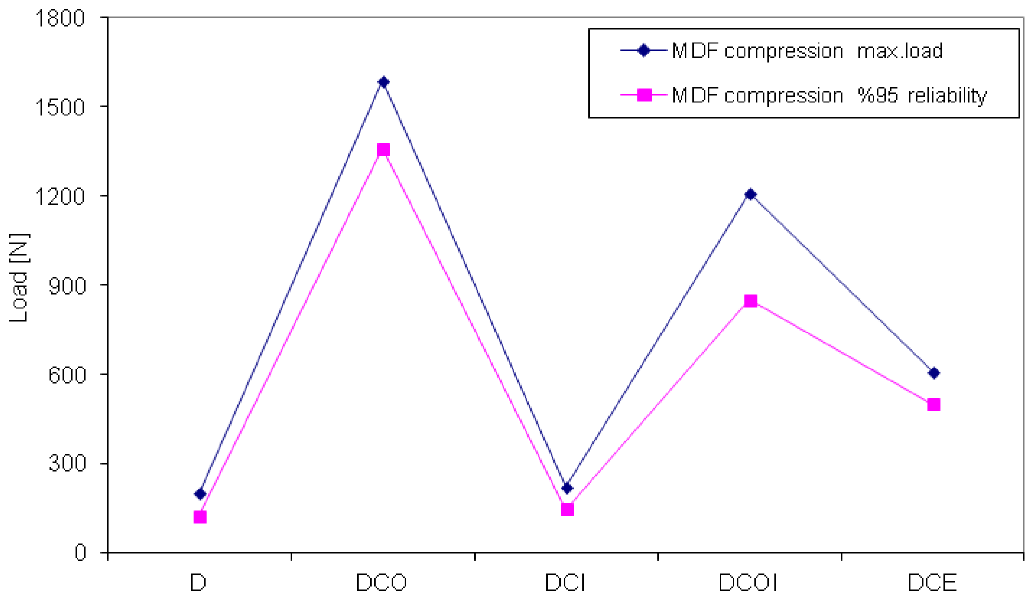

Figure 12. Failure load for compression test.

values of unreinforced corner joints, the average failure load values of reinforced joints in compression situations increased 698, 12, 508 and 206% more than the average failure load values of unreinforced joints (for DCO, DCI, DCOI, and DCE joints, respectively).

On the other hand, while the 95% reliability values of reinforced corner joints in tension situations increased 60, 118, 185 and 142% more than the 95% reliability values of unreinforced corner joints, the 95% reliability values of reinforced joints in compression situations increased 978, 16, 577 and 297% more than the 95% reliability values of unreinforced joints (for DCO, DCI, DCOI, and DCE joints, respectively).

The tension average failure load values were greater than the compression failure load of L-type reinforced corner joints except for DCO joints. However, compression and tension failure loads for DCO joints are nearly the same (Figure 12).

While the average failure load values in tension situations were obtained at 53, 53, 52, 52 and 54% of reliability, the values in compression situation were obtained at 52, 54, 52, 53 and 57% of reliability for D, DCO, DCI, DCOI and DCE, respectively.

Failure mode

Figure 13 shows photographs of failed specimens in the tension tests. For D and DCO joint types, failures initially occurred as opening at the inner face of joints when those joints were subjected to tension moment [Figure 13(a), (b)]. For DCI joints, failures occurred as a split of particleboard in the face member [Figure 13(c)]. As is clear from this result, the bonding strength of board with glass fiber fabric is higher than the internal bond strength of the board can be specified. For DCOI joints, failures occurred in three types as shown Figure 13(d): (1) failures occurred as a split of particleboard in the butt member, (2) failures occurred as a split of particleboard in the face member, (3) failures occurred as a split of particleboard in both the face and butt members. For DCE joints, cracks occurred on the inner face of the face members [Figure 13(e)].

Figure 14 shows photographs of failed specimens for joint configurations subjected to compression moment. For D and DCI joints, failures occurred as splitting of the boards at the point of entry of the dowel in the face members [Figure 14(a), (c)]. Resistance to failure, presumably, was related to the internal bond strength of the board. At the same time, the border of the dowel hole of the face member also cracked, because the rigidity of the dowel is higher than that of the board. Tankut and Tankut (2010) concluded that the face member was the weakest part of the joint connection in compression tests. For DCO joints as shown Figure 14(b), the cracks occurred just at the junction of the outer corner of the face member and fabrics or at the junction of the end of the fabrics and butt member. That is because applied compression load didn't open the joint places and fabrics, the members cracked from the outer face. For DCOI joints, failures occurred as a result of cracking at the junction of the end of the fabrics and butt member, and at the same time as a split of particleboard in the butt member (Figure 14(d)). This is because the joint rigidity of joints with the fabric from the outer is higher than the board. As for DCE joints, failures occurred as a result of

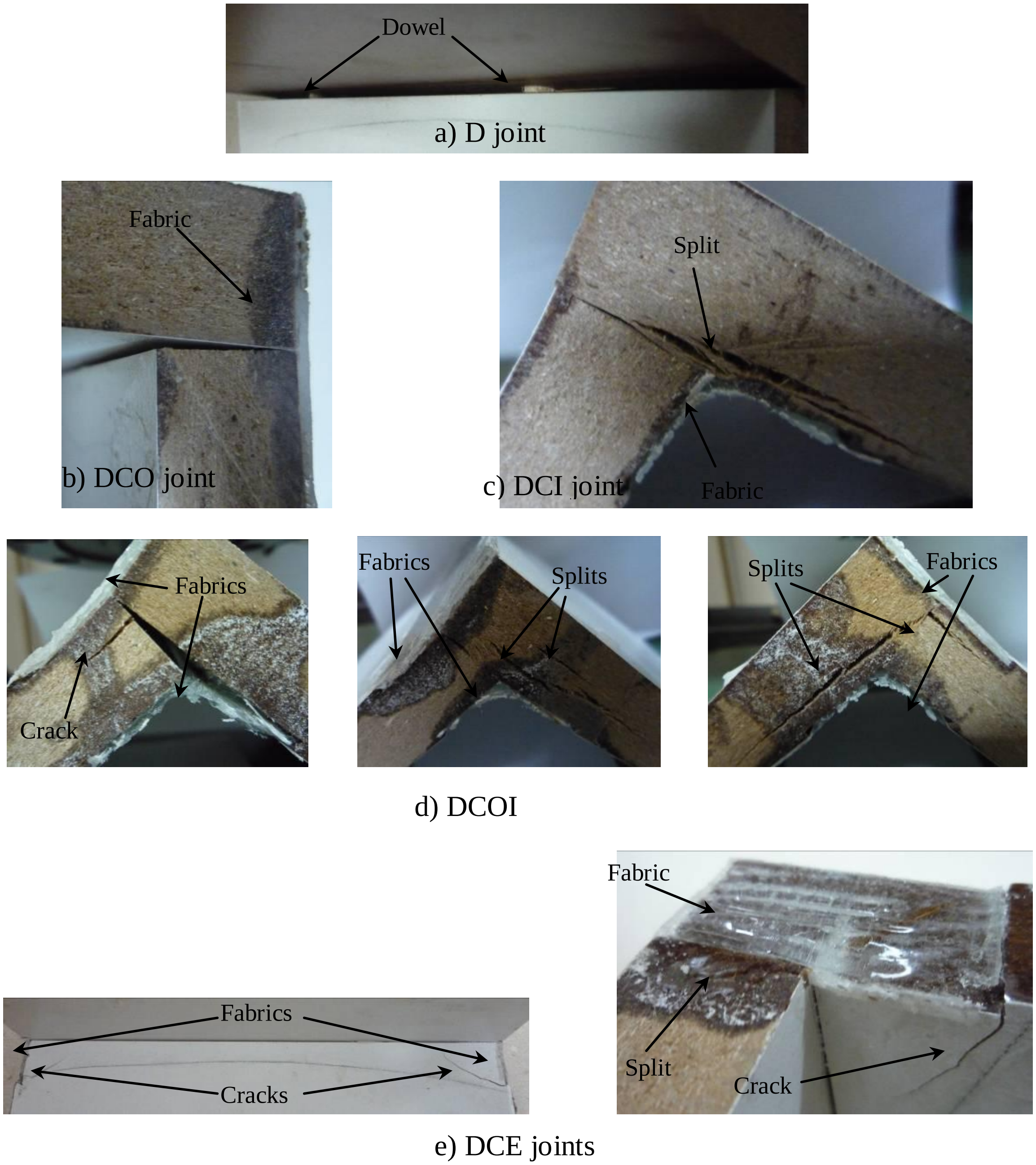

Figure 13. Photography of failed specimen for tension moment.

cracking from near the fabrics in the face or butt members [Figure 14(e)]. This can be explained because the strength of the fabric is greater than the strength of the particleboard.

DISCUSSION

While the average failure load values of reinforced corner joints (for DCO, DCI, DCOI, and DCE joints, respectively) in tension situations increased by factors of 1.78, 2.69, 3.34 and 2.11 of the average failure load values of unreinforced corner joints (D joints), the average failure load values of reinforced joints in compression situation are 7.98, 1.12, 6.08 and 3.06 times as much as the average failure load values of unreinforced joints. Yerlikaya and Aktas (2012) concluded that the average failure load values of dowel joint which are reinforced with glass-fiber fabric increased by factors of 2.66 (in compression), 0.13 (in tension) of the dowel joint. In addition to, they concluded that the dowel + minifix joint which are reinforced with glass-fiber fabric increased by

Figure 14. Photography of failed specimen for compression moment.

factors of 1.58 (in compression), 0.19 (in tension) of the dowel + minifix joint. Heiduschke et al. (2008) concluded that when compared to the unreinforced columns, the load-carrying capacity of the reinforced columns increased by factors of 1.46 and 1.22. Stevens and Criner (2000) determined that the FRP-reinforced beams are stronger than non-reinforced glulam beams because the reinforcement absorbs some of the most damaging tension stresses endured by conventional wooden glulam beams.

In other words, while the average failure load values of reinforced corner joints in tension situations increased 78, 169, 234 and 111% more than the average failure load values of unreinforced corner joints, the average failure load values of reinforced joints in compression situations increased 698, 12, 508 and 206% more than the average failure load values of unreinforced joints (for DCO, DCI, DCOI, and DCE joints, respectively). Ghassan (2011) also concluded that testing results of addition of FRP revealed a 14% increase in compression, and 10% increase in tension. Heiduschke and Haller (2010) concluded that when compared to unreinforced tubes, the ultimate load of FRP reinforced tubes is an increase of about 60%. Rowlands et al. (1986) concluded that glass-fiber reinforced Douglas fir (18% glass by volume) produced a 40% stiffness enhancement and doubled the strength over similar unreinforced wood. Cabrero et al. (2010) explained that the strength of the unreinforced material was about 2/3 of the reinforced. Windorski et al. (1997) concluded that the ultimate strength of a three-layer reinforced connection was 33% greater than the unreinforced connection for parallel-to-grain loading and more than 100% for perpendicular-to-grain loading.

On the other hand, while the 95% reliability values of reinforced corner joints in tension situations increased 60, 118, 185 and 142% more than the 95% reliability values of unreinforced corner joints, the 95% reliability values of reinforced joints in compression situations increased 978, 16, 577 and 297% more than the 95% reliability values of unreinforced joints (for DCO, DCI, DCOI, and DCE joints, respectively). Yerlikaya and Aktas (2012) concluded that the 95% reliability values of dowel joint which are reinforced with glass-fiber fabric increased by factors of 4.3 (in compression), 0.07 (in tension) of the dowel joint. In addition to, they concluded that the dowel + minifix joint which are reinforced with glass-fiber fabric increased by factors of 2.21 (in compression), 0.33 (in tension) of the dowel + minifix joint.

The tension average failure load values were greater than the compression failure load of L-type reinforced corner joints except for DCO joints. However, compression and tension failure loads for DCO joints are nearly the same. The tension average failure load values increased 314, 896, 127 and 185% more than the compression average failure load values for D, DCI, DCOI, and DCE joints, respectively. For DCO joints, the tension average failure load values decreased 8% more than the compression average failure load values. On the other hand, the 95% reliability values increased 418, 871, 119 and 216% more than the compression average failure load values for D, DCI, DCOI, and DCE joints, respectively. For DCO joints, the tension average failure load values decreased 30% more than the compression average failure load values. In other words, while the tension average failure load values are 4.14, 9.96, 2.27 and 2.85 times as much as the compression average failure load values for D, DCI, DCOI, and DCE joints, the tension average failure load values are 1.08, times less than the compression average failure load values for DCO joints. On the other hand, while the 95% reliability values are 5.18, 9.71, 2.19 and 3.16 times as much as the compression at the 95% reliability values for D, DCI, DCOI, and DCE joints, the tension at the 95% reliability values are 1.3, times less than the compression at the 95% reliability values for DCO joints. According to several researches (Tankut, 2005; Liu and Eckelman, 1998; Tankut and Tankut, 2010; Yerlikaya and Aktas, 2012), the reason for the phenomena in which the tension strength was greater than the compression strength is that the bending strength of joints loaded in compression is presumably related to the internal bond strength of the board, whereas the bending strength of joints loaded in tension is presumably related to the surface tensile strength parallel to the plane of the board.

Conclusion

The failure loads obtained from the Weibull analysis are approximately 52% lower than those obtained from the experimental data. This means that if designers take the average values into consideration, then they will have little confidence. If they want assurance they should take the failure load obtained from the statistical analysis.

As a result of both average values of the test and 95% a reliability of Weibull distribution, while the failure load takes its highest value for DCOI joints and lowest value for D joints in the tension tests, the failure loads take their highest values for DCOI joints and lowest values for D and DCI joints in the compression tests.

Both tension and compression situation, the average failure load values of reinforced corner joints (DCO, DCI, DCOI, and DCE joints) were greater than the average failure load values of unreinforced corner joints (D joints).

Both tension and compression situation, the average failure load values were approximately obtained at 53% of reliability.

As for failure mode, in tension tests, D and DCO joint failures initially occurred as opening at the inner face of joints. DCI and DCE joint failures occurred in the face member. DCOI joint failures occurred in the face and butt members. In compression tests, D and DCI joint failures occurred in the face members. DCO and DCE joint failures occurred in the face and butt member. DCOI joint failures occurred in the butt member.

Additional work is needed in order to establish the failure sensitivity of the reinforced corner joints for all wood composite materials and wood panels, e.g. particleboard, MDF massive panels, and for different thickness of panels, for example, 16 mm, 22 mm, and different thickness or layers of glass-fiber fabric, for example, one and three layers.

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