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*Full Length Research paper*

# Enhancement of T-joints of Spruce wood reinforced by using glass-fiber composite laminate

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**In this study, T-joints constructed from Spruce wood and reinforced with glass-fiber fabric have been investigated under bending moment experimentally. Five types of T-joint were investigated. One of them is unreinforced and the others are reinforced with glass epoxy composite laminate. The specimens were subjected to bending moment until the failure of the joint. Five specimens were tested for each configuration. The statistical analyses of those failures load were also performed. Weibull distribution was used for the statistical analysis. Results show that the failure loads of the joints were greatly influenced by the reinforcement. The failure load of the reinforced specimens, the four edges of which were surrounded by glass epoxy composite laminate is twelve times higher than the unreinforced ones.**

**Key words:** Dowel, failure load, glass-fiber fabric, reinforced, Spruce wood, T-type joint.

## INTRODUCTION

The rational design of joints in a furniture frame implies that the joints are designed to have sufficient strength to carry the loads that will be imposed upon them in service (Eckelman and Erdil, 2000). Two factors are important in designing a joint. First, the average ultimate strength of this type joints, and secondly, the variation in strength from joint to joint. The smaller the variation in strength, the more reliable the joint and the greater the allowable strength design value which can be assigned to it (Eckelman, 1971). The strength and stiffness of joints used in furniture construction will normally determine the furniture’s strength and rigidity. Unfortunately, the seeming propensity of furniture frames toward failure has led to the belief that stronger joints are needed. However, it must be noted that within certain limits, joints are inherently neither weak nor strong. Their strength, in fact, has meaning only in relation to the loads that they must carry (Eckelman, 1968). Dowel joints are the most popular method of joining members together in wood furniture frame construction (Eckelman, 1979a). Dowel joints are widely used in furniture frame construction, both as structural load bearing connections and also as simple locations for pars (Eckelman and Erdil, 2000). The strength of these joints is somewhat limited relative to the strength of the joined members, so unless they are properly designed, they may be the weakest part of a furniture frame (Eckelman, 1979b). In a typical furniture frame, dowel joints may be subjected to axial, shear, torsional, and bending forces (Eckelman, 1979a). The individual dowel pins used in the joints, however, are subjected to withdrawal and shear forces only (Eckelman and Erdil, 2000). Bending forces are usually of most concern, however, because their magnitude may easily exceed the maximum theoretical resistance of a particular joint configuration (Eckelman 1979a).

Two-pin moment-resisting dowel joints are among the most important structural joints in upholstered furniture frame construction. They are commonly used, for

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example, to connect the front rail to the front post and the side rail to the back and front posts (Eckelman and Erdil, 2000). Dowel joints are adhesive-based joints, that is, they rely on the adhesive for their strength. For maximum strength and durability, it is absolutely essential that the walls of the dowel hole be thoroughly coated with adhesive (Eckelman and Erdil, 2000). Many researchers have investigated strengths of T-type end-to-side-grain joints with two pin dowel joints, mortise-and-tenon joints, metal-plate-connected joints, minifix plus dowel joints and screw joints constructed of furniture. For example, Zhang et al. (2003) concluded that fatigue life comparisons among joint groups with different static bending strength indicated that a significant increase in static bending strength might not yield a significant fatigue life increase when a joint was subjected to cyclic stepped loads. They concluded that joints failures always occurred first at the dowel in the tension side. Eckelman (1971) concluded that the bending strength of the joints was found to regularly increase as rail width and/or dowel spacing were increased. Zhang et al. (2001) investigated the bending moment capacity and moment-rotation characteristics of T-type two-pin dowel joints constructed of solid woods and wood composites. Zhang et al. (2003) concluded that joint bending strength increased significantly rail widths increased from four to seven inches with an increment of one inch.

Eckelman (1971) concluded that staple-glued product gussets can be used to fabricate joints of high strength. In particular, as the width of a member framing into a joint increases to three inches and greater, the strength of a joint constructed with staple-glued gussets located on each side of the joint and whose width is equal to the member becomes greater than what could normally be achieved with either doweled or mortise-and-tenon construction. Zhang et al. (2005) concluded that metal-plate and rail widths affected the moment capacity of MPC plywood joints significantly; moment capacity increased significantly as metal-plate lengths increased from 3 to 4.5 in, but no significant moment capacity of tested joints ranged from 2.863 to 13.721 lb.-in; the minimum metal-plate length to prevent having joints with tooth withdrawal failure and to have joints fail with plate yield mode is 6 in. They determined that three types of failure modes occurred in the tests: metal plate tooth withdrawal from plywood, metal-plate yield on the tension side, and post member compression and rolling shear between the plies in rail members on the compression side.

Efe et al. (2004) concluded that increases in the screw diameter from 6 to 7 mm. however, had no significant effect on either withdrawal strength or bending moment resistance. Efe et al. (2005) concluded that while mortise-and-tenon joints yielded the highest bending moment capacity, minifix plus dowel joints had the lowest bending moment capacity. They concluded that screw joints could produce higher bending moment capacities than traditional glued dowel joints. They concluded that two-pin dowel joints failed with modes of glueline fracture, dowel surface shear (parallel to grain), and dowel fracture.

These type studies were investigated. But no researcher has examined glass-fiber fabric reinforcement in T-shaped joints constructed of furniture or upholstered furniture frame construction. Many researchers have studied glass fiber fabric reinforcement. For example, Windorski et al. (1997) investigated the use of fiberglass reinforcement to enhance the load-carrying capacity of bolted wood connections. A series of specimens were prepared from standard 38- by 89-mm (nominal 2- by 4-in.) lumber from the Spruce–Pine–Fir lumber grouping. Matched specimens were reinforced with one, two, or three layers of bi-directional fiberglass cloth. Results indicate that connection strength increases as the layers of fiberglass reinforcement increase. The largest increase occurred when adding the first layer to the non reinforced connection. The average strength increased as the number of fiberglass layers increased. The ultimate strength of a three-layer reinforced connection was 33% greater than the non reinforced connection for parallel-to grain loading and more than 100% for perpendicular-to-grain loading. All non reinforced specimens failed by a split beneath the bolt. Approximately half the specimens reinforced with one layer failed by a combination of splitting of the wood and tearing of the fiberglass along the split. The remainder of the specimens reinforced with one layer and all the specimens with two or three layers failed by crushing of the wood beneath the bolt.

Several studies have examined how various reinforcing systems contribute to the performance of a wood member, exclusive of the connection. The earliest studies used metal reinforcement. More recently, fiberglass-reinforced polymer (FRP) has been investigated. For example, Triantafillou et al. (1992) investigated non prestressed and prestressed FRP sheets as external reinforcement of wood members. They bonded FRP sheets with epoxy to the tension zone of a wood beam. Rowlands et al. (1986) investigated tension and flexure of fiber-reinforced wood composites. They concluded an increase up to 45% in tensile strength over that of non reinforced Douglas-fir beams by using 18% by volume glass reinforcement. Spaun (1981) studied reinforcement of wood with fiberglass. He investigated composite members with Douglas-fir veneers and FRP layers between the core and veneers. Poplis and Mitzner (1973) investigated strength of plywood overlaid with FRP. They tested three bolt diameters and three plywood thicknesses. They concluded that the overlaid reinforcement increased the ultimate strength of the connections 54 to 117%. They conducted bolt-bearing tests which revealed that the use of FRP typically increased strength and stiffness. Miyatake and Fujii (1995) investigated strength of epoxy bonded joints for timber members with internal fiber reinforced-plastic

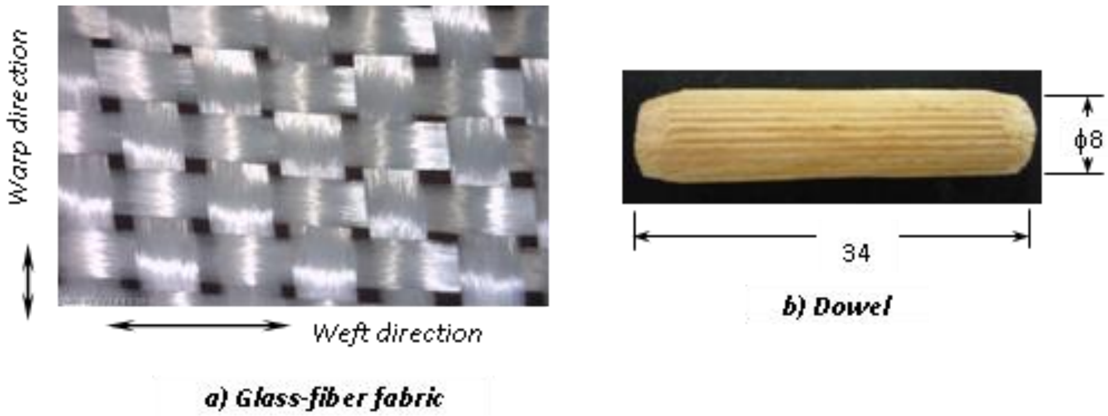


**Figure 1.** Fastener materials (Dimensions in mm).

gusset plates. They concluded that strength increased with length of gusset plate. Haller et al. (1996) investigated glass fiber reinforced and densified timber joints. They found an approximately twofold increase in ultimate strength and deformability. Larsen et al. (1996) investigated glass fiber reinforcement of dowel-type joints with polyester glue. They concluded more ductile connection behavior, with some increase in ultimate strength, compared to non reinforced connections. In addition, they concluded that spacings and end distances can be reduced. Chen (1998) investigated the mechanical performance of dowel-type timber joints by applying composite materials as reinforcements. He explained that the reinforcement of wood with fiberglass material leads to a higher performance and provides a good security factor to the reinforced structures and joints.

All studies are almost based on average strength values. The reliability of these values is not known. Presumably, the highest reliability of these values is 50%. Average strength values obtained with this reliability lead to errors in point of failure load for T-type joints. Therefore, failure load 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 failure load at the 95 to 99% reliability level, Weibull distribution can be used.

The aim of this study is to obtain the failure load of T-type joints (unreinforced (UR)) constructed with spruce wood, and to determine the effects of the T-type joints reinforced by a composite laminate (2 layer edge-reinforced (2LER), 4 layer edge-reinforced (4LER), 2 layer edge-surface-reinforced (2LESR), and 4 layer edge-surface-reinforced (4LESR)). Also, to determine the effect of reinforced with glass-fiber fabric. Five compression tests have been performed for each specimen configuration. Using the test data, Weibull distribution has been determined to find the 95% reliability of each compressive failure load value.

## SPECIMEN PREPARATION AND TESTING PROCEDURES

### Materials

**Spruce timber (*Picea orientalis* (L.) Link.):** Approximately 35-mm-thick, 55-mm-width and 2000-mm-long spruce timbers were selected for this study. The oven-dry density of these timber samples was 0.41 g/cm³. The moisture content of samples was about 11%.

**Adhesives:** Glass-fiber fabrics were fastened with epoxy adhesive and hardener. The type of epoxy resin used in the matrix material is Bisphenol ACY-225 and hardener is Anhydride HY-225. A post and rail members, and dowels were assembled with the polyvinyl acetate (PVAc) adhesive.

**Glass-fiber woven fabrics:** Glass-fiber woven fabrics having 400 $g/m^2$ were used (Figure 1a). Glass-fiber fabrics were prepared by cutting to 100 mm in long and 44 mm in width.

**Dowel:** Multi-groove beech dowels 8 mm in diameter and 34 mm in length were used (Figure 1b). Multi-groove beech dowels with no loose or torn surface fibers were selected to assemble the post and the rail member.

### Specimen preparation

All specimens were constructed of Spruce wood. The joints of all specimens were the two-pin dowel joint (Figure 2). In order to determine failure loads of T-type joints, two-pin, end-to-side dowel joint constructions were used in this study. These constructions are unreinforced (UR), 2 layer edge-reinforced (2LER), 4 layer edge-reinforced (4LER), 2 layer edge-surface-reinforced (2LESR), and 4 layer edge-surface-reinforced (4LESR) as shown in Figure 3. Five specimens were prepared and tested for every configuration. Each specimen consisted of two principal structural members, a post and a rail, joined together by two dowels symmetrically spaced in the rail with reference to the rail width centerline. The rail members of each joint were measured 150 mm long by 44 mm wide by 22 mm thick. The post members of each joint were measured 300 × 50 × 22 mm (long × wide × thick).

Timbers were machined in a planing machine and their one edge and one surface were found to be the cleanest. Then using the thickness machine, these were machined to 22 mm in thickness, and 50 and 44 mm in width. The timbers were machined to 300 and

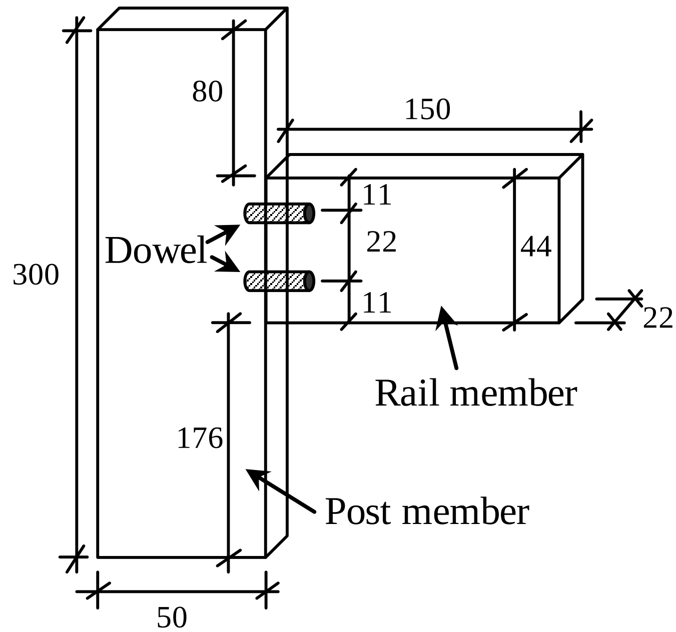


**Figure 2.** Typical configuration of the specimens used in the test (Dimensions in mm).

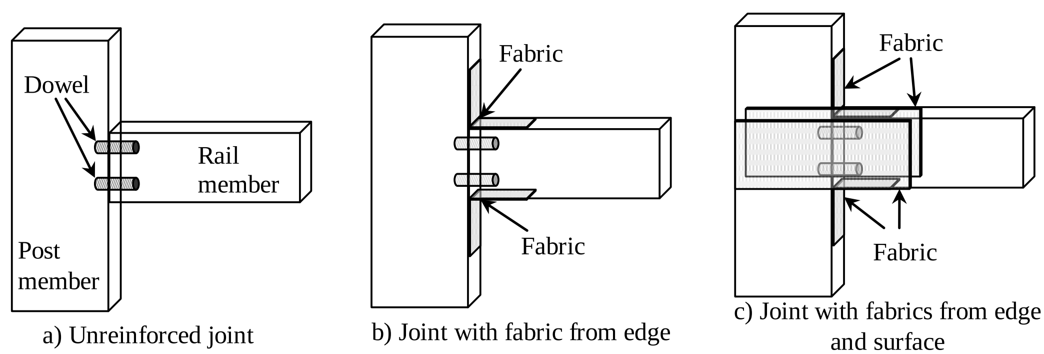


**Figure 3.** The configuration of T-type joints.

150 mm in length using a diamond saw in the circular saw machine. Specimens were drilled with a drilling machine (Three Lines Multi-Boring Machine BJK65) at the speed of 500 rpm. Depths of embedment of the dowel in both the post and the rail were 18 mm. The distance between the centerlines of the two dowels was 22 mm. The specimens were cleaned. Dowel hole and joining surface were glued with polyvinyl acetate (PVAc) adhesive prior to assembly. Then, dowels were driven into this glued hole by a mould (the way into 17 mm). The post and the rail members were placed in conjunction. All dowels fitted snugly in the holes. These specimens were left to dry for two days. Then, areas where the glass-fiber composite laminates were to be placed were glued with a mixture of epoxy adhesive and hardener. Two or four layers of composite were placed on these areas and epoxy applied. These specimens were left to dry two days.

**Testing procedures**

The T joint of Spruce wood was subjected to compression load (Figure 4). That load results in a moment in the connection area. This moment cause tensile stress at point A and a compression stress at point B (Figure 4c). 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. A total of 25 joint specimens were used for the tests. Specimens were placed on the test machine then load was applied to each specimen until a failure or full separation occurred between post and rail members in the specimens. In the tests, only the ultimate loads carried by the joints were recorded with ±0.0001 N sensitivity by a computer for all tests in Newton (N).

**Analysis**

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 variation of the failure load of corner joints has been modeled using the two-parameter Weibull distribution. Five test specimens have

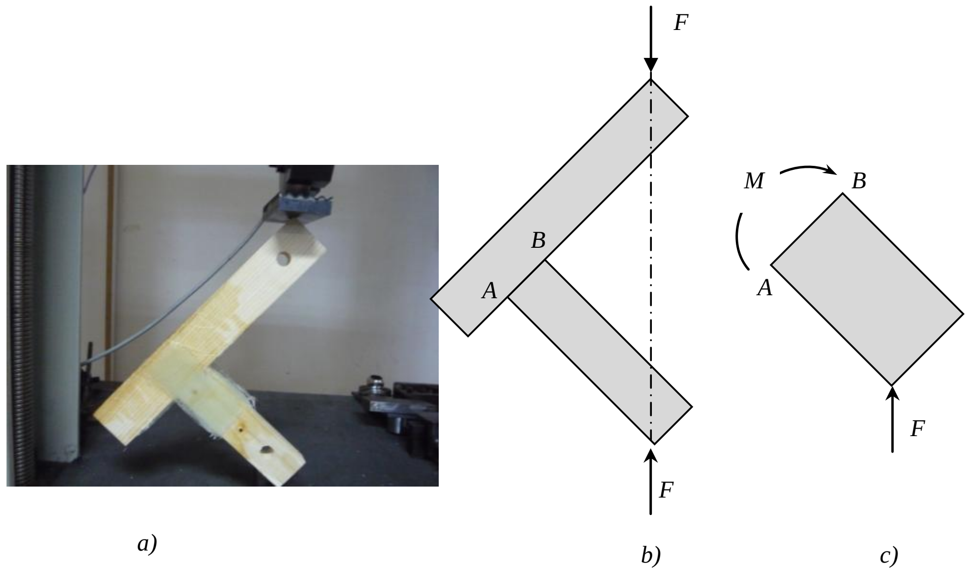


**Figure 4.** Load specimen and loading type.

**Table 1.** Failure load values obtained from the experiments.

| Joint types | Failure load [N] | |
|---|---|---|
| | Average | Standard deviation |
| Unreinforced (UR) | 287.158 | 10.85851 |
| 2 layer edge-reinforced (2LER) | 509.2554 | 16.67562 |
| 4 layer edge-reinforced (4LER) | 871.5945 | 108.0338 |
| 2 layer edge-surface-reinforced (2LESR) | 2302.024 | 121.9933 |
| 4 layer edge-surface-reinforced (4LESR) | 2933.348 | 141.646 |

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.

## RESULTS

### Failure load

The results obtained from the experiments in the present work are given in Table 1. As seen in the Table 1, the failure load takes its highest values at 4LESR. This maximum result is obtained when the fabric from both edge and surface in the T-type joint is used. The lowest values were obtained at unreinforced. These minimum results are obtained when the fabric is not used. Respectively, 2LER, 2LESR, and 4LER followed for both experimental and statistical analysis.

### Weibull distribution

In order to compute *b* and *c*, the results obtained from the experiments as given in Table 1 are first ordered from the smallest to largest. And, ($X_i$, Y) values are computed. Then, linear regression was applied to these (X, Y) values. The linear regression model with the regression line in 4LESR joint is obtained (Figure 5). The first point in Figure 5 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 21.29, 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 values is computed as b = 2999 using the point the line intersects the Y axis (= -170.48) in b = e(-Y/c). Therefore, c= 21.294 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(2999; 2999, 21.294) = exp (-(x/b)c) = 0.368, that is, 36.8% of the tested specimens have a failure load of at least 2999 N.

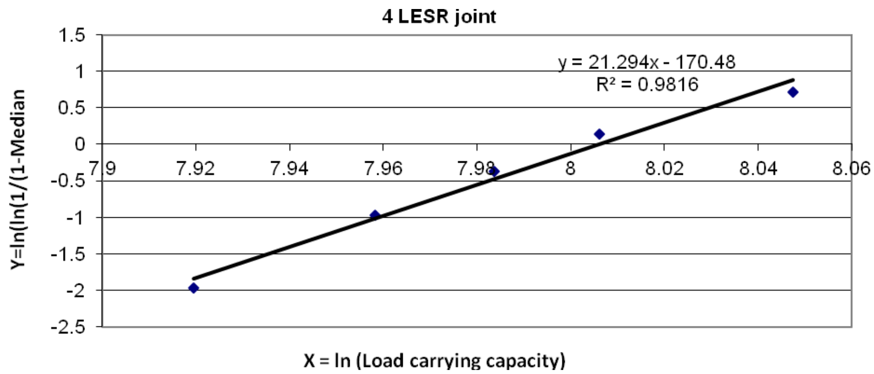


**Figure 5.** Regression line for 4LESR joint.

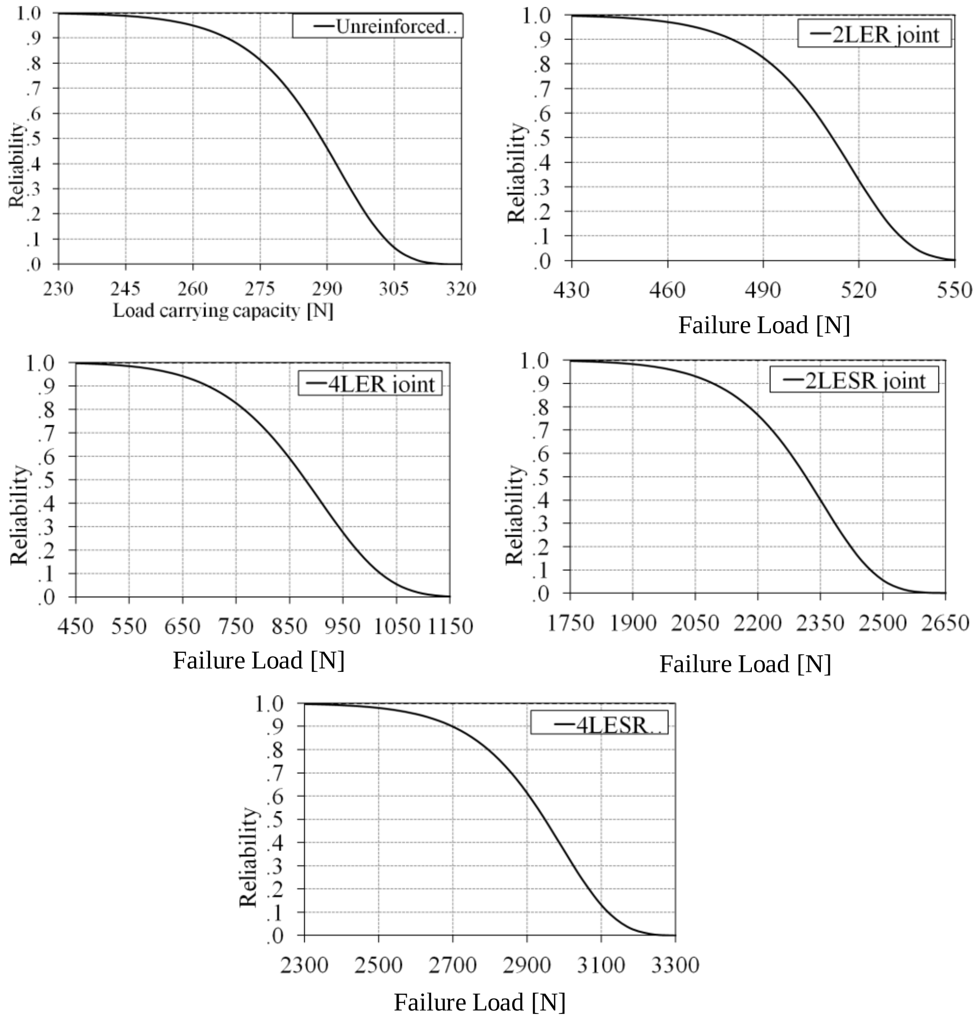


**Figure 6.** Weibull reliability distribution for failure load.

The plot of R(x; b, c) is shown in Figure 6. The reliability curve in Figure 6 shows that failure load values roughly less than or equal to 230, 430, 450, 1750, and 2300 N (for UR, 2LER, 4LER, 2LESR, and 4LESR, respectively) will provide high reliability. For a more certain assessment, consider 0.95 a reliability level.

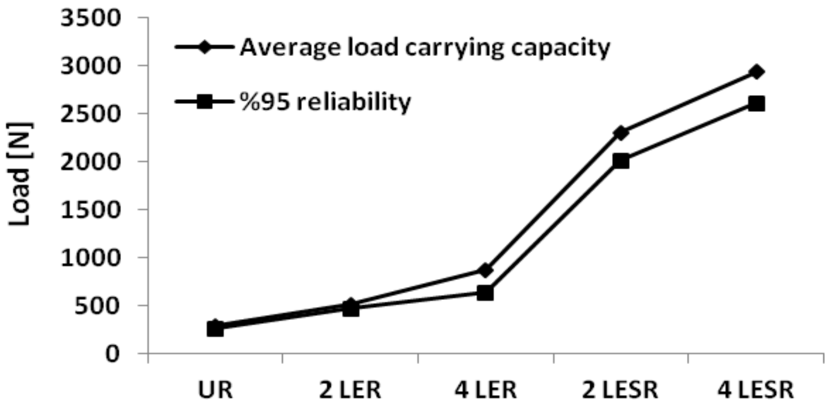


**Figure 7.** Failure load.

When these values are put as R(x; b, c) in Equation (3) and the equation is solved for x, the failure load values 260, 469, 637, 2013 and 2608 N (for UR, 2LER, 4LER, 2LESR, and 4LESR, respectively) are obtained. In other words, this material will fail with 0.95 probability for 260, 469, 637, 2013 and 2608 N (for UR, 2LER, 4LER, 2LESR, and 4LESR, respectively) or more.

### 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 Figure 7. For both experimental and for statistical analysis, it can be seen from the figure that the failure load takes its highest values at 4LESR. The lowest values were obtained at unreinforced. Respectively, 2LER, 2LESR, and 4LER followed for both experimental and statistical analysis. The failure loads obtained from the Weibull analysis are approximately 15% lower than those obtained from the experimental data.

The failure load of reinforced joints (for 2LER, 4LER, 2LESR, and 4LESR joints, respectively) increased by factors of 1.78, 3.04, 8.02 and 10.22 of the failure load of unreinforced joints. In other words, the average failure load of reinforced joints with 2LER, 4LER, 2LESR, and 4LESR are 77, 204, 702 and 922% more strength than unreinforced joint.

The average failure load values were obtained at 45, 45, 47, 47 and 46% of reliability (for UR, 2LER, 4LER, 2LESR, and 4LESR, respectively). On the other hand, the 95% reliability values of reinforced joints (for 2LER, 4LER, 2LESR, and 4LESR joints, respectively) increased by factors of 1.8, 2.45, 7.74 and 10 of the 95% reliability values of unreinforced joints. In other words, the average failure load values of reinforced joints (for 2LER, 4LER, 2LESR, and 4LESR joints, respectively) increased 80, 145, 674 and 903% more than the average failure load values of unreinforced joints.

### Failure mechanism

For unreinforced joints (Figure 8a), opening formed in the region of tensile stresses due to glue the cracks of local. For 2LER joints (Figure 8b), according to the UR joints, composite plate prevents cracking. However, crack is formed wood because of the flexibility in this region because laminate is less. For 2LESR joints (Figure 8c), cracks occurred in wood as with 2LER joints. This situation has impacted the laminate, and thus cracks occurred on the side surface composite. For 4LER joints (Figure 8d), the cracks are almost identical with 2LER joints. But, composite material behaves more rigid because there is more than the number of layer. Therefore, the cracks are made slightly more inside. For 4LESR joints (Figure 8e), cracks were similar to cracks in 2LER joints. However, cracks formed in the remote parts of the connection because composite laminates were resistant to T-junction region.

## DISCUSSION

The average failure load of reinforced joints with 2LER, 4LER, 2LESR, and 4LESR are 77, 204, 702 and 922% more strength than unreinforced joint. Windorski et al. (1997) concluded that the average strength increased as the number of fiberglass layers increased. In addition, they concluded that the ultimate strength of a three-layer reinforced connection was 33% greater than the non reinforced connection for parallel-to grain loading and more than 100% for perpendicular-to-grain loading. Rowlands et al. (1986) reported an increase up to 45% in tensile strength over that of non reinforced Douglas-fir beams by using 18% by volume glass reinforcement. Poplis and Mitzner (1973) concluded that the overlaid reinforcement increased the ultimate strength of the

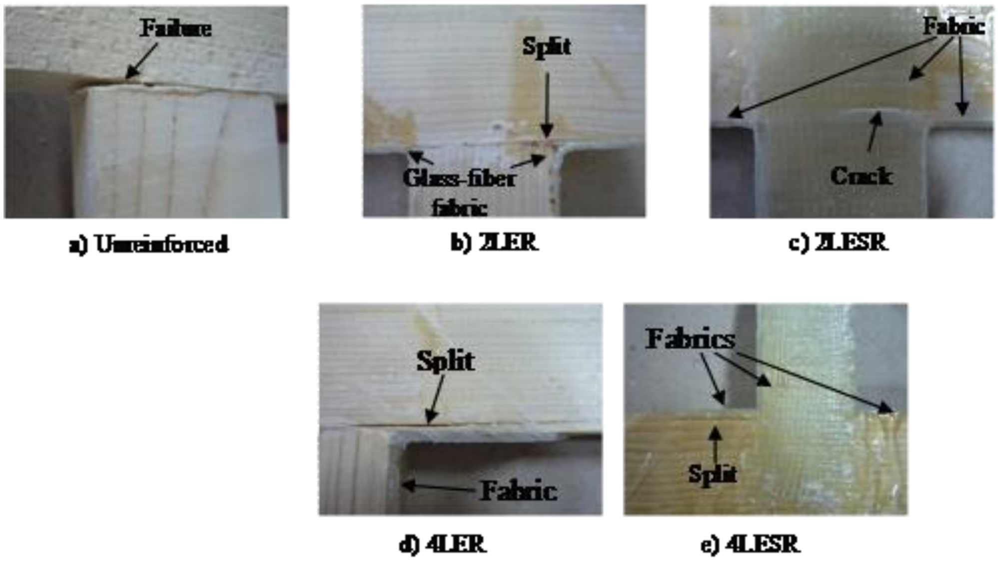


**Figure 8.** Photography of failed specimens.

connections 54 to 117%.

## CONCLUSION AND RECOMMENDATION

T-type joints with two-pin constructed from Spruce wood and reinforced with glass-fiber fabric have been investigated under compression load experimentally and statistically. According to experimental and statistical analysis results, the highest values were obtained at 4LESR while the lowest values were obtained at unreinforced. Respectively, 2LER, 2LESR, and 4LER followed.

The average failure loads of reinforced joints (for 2LER, 4LER, 2LESR, and 4LESR joints, respectively) are 78, 204, 702 and 924% more strength than unreinforced joint.

The average failure load values were obtained at 53, 53, 52, 53 and 52% of reliability (for UR, 2LER, 4LER, 2LESR, and 4LESR, respectively).

Failures occurred by opening from the joining surface for unreinforced joints, as a split of wood in the post member for 2LER, 4LER, and 4LESR joints, and as a crack of glass-fiber fabric for 2LESR joints.

To enhance the strength in T-shaped joints constructed of furniture or upholstered furniture frame construction, glass-fiber fabric reinforcement can be recommended because these joints with glass-fiber fabric significantly increase the strength, particularly, the 4LESR joints.

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