

EXPERIMENTS ON MOMENT RESISTING FINGER JOINTS OF GLUED LAMINATED TIMBERS

Hiroyasu SAKATA¹, Hisayuki OKADA², Hiroshi ABE³, Toshihiro KUSUNOKI⁴ And Hiromichi ITO⁵

SUMMARY

This paper describes the performance of moment resisting finger joints applied to glued laminated timbers jointed together at angles. A tension test on laminas and an L-shape bending test on finger joint of glued laminated timbers were done. The following conclusions were derived.

No fracture occurs in the finger-joint regions when members are finger-jointed with their fibre lines angled at 30 degrees or greater angles.

Moment-resisting finger joints have a lower displacement capacity than moment resisting joints by drift pins but a higher yield strength and a greater stiffness than those by metal joints. All things considered, moment resisting finger joints provide a greater degree of integral solid.

More efficient joining will be obtainable if materials having less acute anisotropy and greater strength are finger-jointed at more appropriate points.

INTRODUCTION

Glued laminated timbers are being increasingly used as structural members. They retain the good properties of wood and distribute the weaknesses through the member. A number of experimental data have been accumulated and the performance has been clarified where drift pins are used as well as other metal parts in moment resisting joints [1]. Finger joints are also used as a jointing method. This results in a small partial loss of area, but there is no need for metal parts. Studies have advanced in this area [2], [3]. The finger joint has also been used in large span frames in Japan. However, if the members to be jointed are at a large angle, the member fibres cannot be kept parallel. Thus, an effective and practical jointing method using finger joint has not been clarified for this situation. The objective of this study is to clarify joint performance where glued laminated timbers at a certain angle to each other are jointed by finger joints, and moment resistance is maintained. This paper describes a tension test carried out on a lamina jointed with a finger joint and a bending test on finger joint of glued laminated timbers and discusses its mechanical properties.

TENSION TEST ON LAMINA

Test Pieces:

Lamina test pieces were prepared and tension tests were conducted to investigate the basic mechanical properties of the finger joint. Table 1 lists the test pieces, and Figure 1 shows their configuration. The lamina was 30 mm thick, and it increased to 50 mm thick at the finger joint part. The laminated materials used were Douglas fir (D), Akita cedar (A) and plywood (P). Fifty-five pieces comprising nine materials were prepared with parameters of fibre angle and presence or absence of a Finger joint (F). The finger joint was given a pressure of about 0.9 MPa using resorcinol resin.

¹ Structural Engineering Research Center, Tokyo Institute of Technology, Japan, E-mail:hsakata@serc.titech.ac.jp

² Dept. of Architectural Engineering, Faculty of Engineering, Aichi Institute of Technology, Toyota 470-0392 Japan

³ Office of New Frontier Engineering, Takenaka Corporation, Tokyo 104-8182 Japan

⁴ Research & Development Institute, Takenaka Corporation, Chiba 270-1395 Japan

⁵ Development Institute, NCN Corporation, Minokamo 505-0016 Japan

Table 1: Lists of Tension Test Pieces and Their Strength

Specimen	Lamina	Angle of Fibre Line	Number of Test Pieces	Finger Joint	Mean Value of σ_{max} (Mpa)
D0	Douglas Fir	0	5	no	45
D0-F-D0	Douglas Fir + Douglas Fir	0 + 0	7	yes	42
D30	Douglas Fir	30	6	no	8
D0-F-D30	Douglas Fir + Douglas Fir	0 + 30	7	yes	6
P	Plywood	0,90	4	no	19
D0-F-P	Douglas Fir + Plywood	0 + 0,90	7	yes	17
AO	Akita Ceder	0	5	no	27
AO-F-D0	Akita Ceder + Douglas Fir	0+0	7	yes	26
AO-F-D30	Akita Ceder + Douglas Fir	0+30	7	yes	8

Angle of Fibre Line is One to Longitudinal Direction

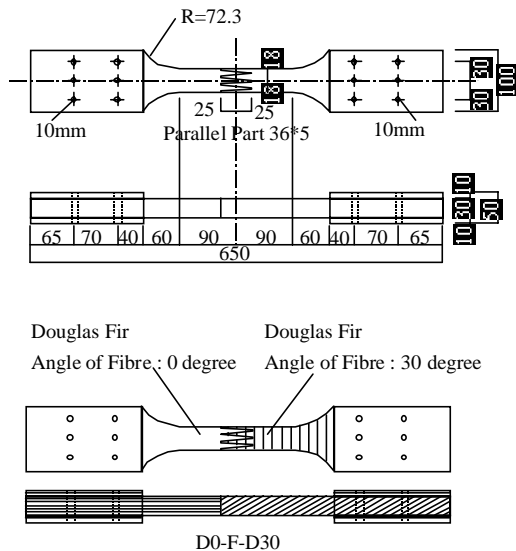


Figure 1: Tension Specimen

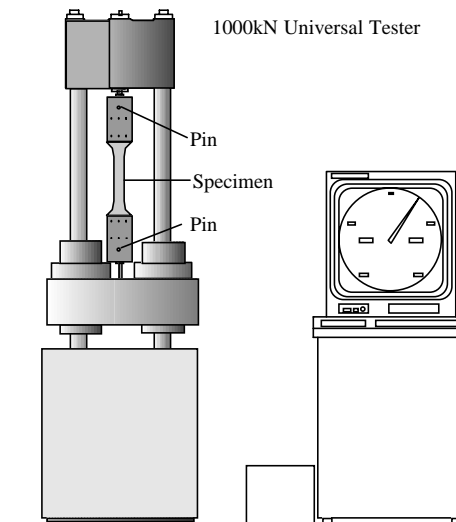


Figure 2: Universal Tester

Loading:

The tension loading was conducted with a 1000 kN universal tester as shown in Figure 2. The ends of the pieces were bolted together with two steel plates. A tensile force was applied via pins so that no bending acted on the test part.

Results:

Table 1 shows the mean values of the maximum tensile strength of each test piece obtained from the tension test. The Douglas fir at a fibre angle of zero degrees without a finger joint (D0) showed the highest strength. The same material with a finger joint (D0-F-D0) showed a strength a little higher than 90 percent that of D0. This corresponds to the partial loss of area due to the finger joint. The piece using Akita cedar as a lamina had a strength a little less than 60 percent that of D0. The strength of the piece using plywood had a strength about 40 percent that of D0. The piece using Douglas fir at a lamina fibre angle of 30 degrees had a strength about 20 percent that of D0, which was much lower than the others. These above strengths were found to have no relationship to the presence or absence of a finger joint. Most of the test pieces, except for the following, did not reach their breaking point at the finger joint, but in the lamina. The exceptions were those consisting of Douglas fir jointed at a lamina fibre angle of zero degrees with the finger joint, and those consisting of Japanese larch plywood with a finger joint.

BENDING TEST ON MOMENT RESISTING JOINTS

Specimens:

Moment resistance joint bending tests were carried out on the six test pieces as shown in Table 2. In these specimens, the members were jointed at 90 degrees, and included the conventional type using a drift pin (DP-90), the metal joint using a plate (SE1-90) and the metal joint using two plates (SE2-90). These specimens are shown in Figure 3. A test was also carried out on a specimen with a finger joint (FD-90) using Douglas fir as the joint

Table 2: Lists of Bending Specimens

Specimen	Members	Joint	Joint Method	Angle of Members
DP-90	Douglas Fir	Douglas Fir	Drift Pin	90 degrees
FD-90	Douglas Fir	Douglas Fir	Finger	90 degrees
SE1-90	Douglas Fir	Douglas Fir	Metal Single Plate	90 degrees
SE2-90	Douglas Fir	Douglas Fir	Metal Double Plate	90 degrees
FD-120	Douglas Fir	Douglas Fir	Finger	120 degrees
FP-120	Douglas Fir	Plywood	Finger	120 degrees

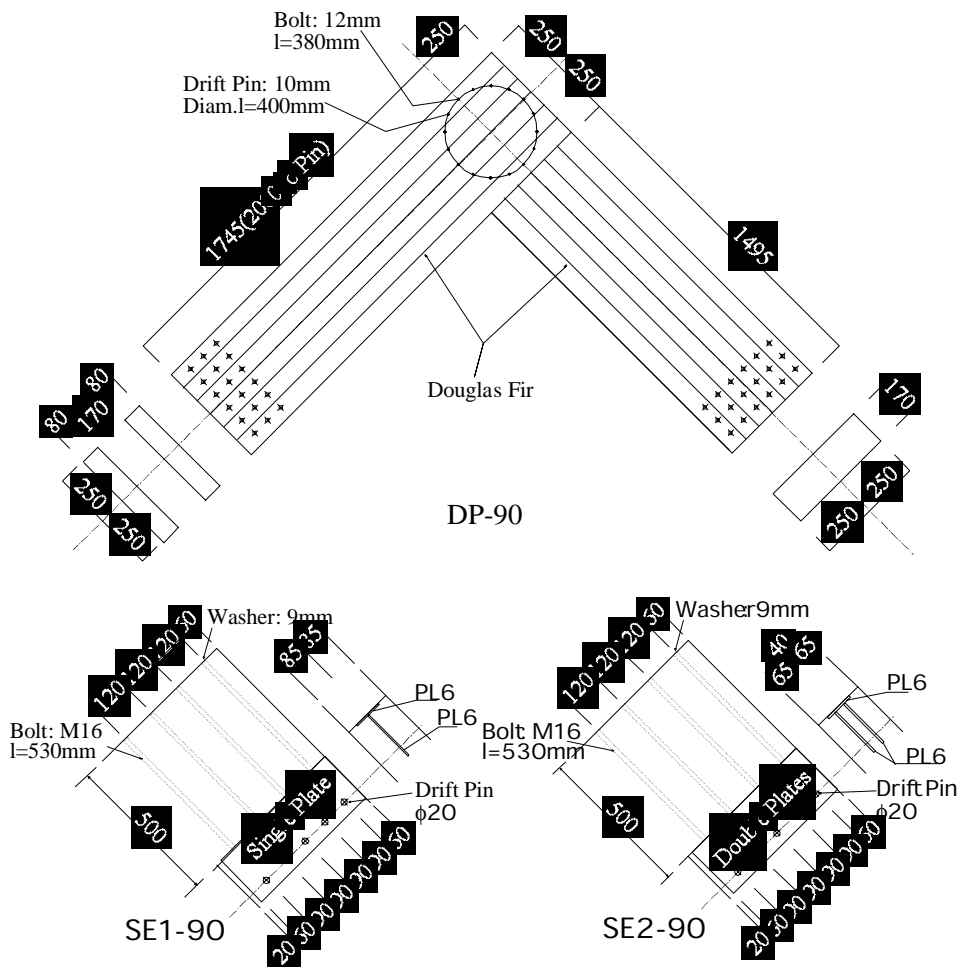


Figure 3: 90 Degrees Specimen (DP-90, SE1-90,SE2-90)

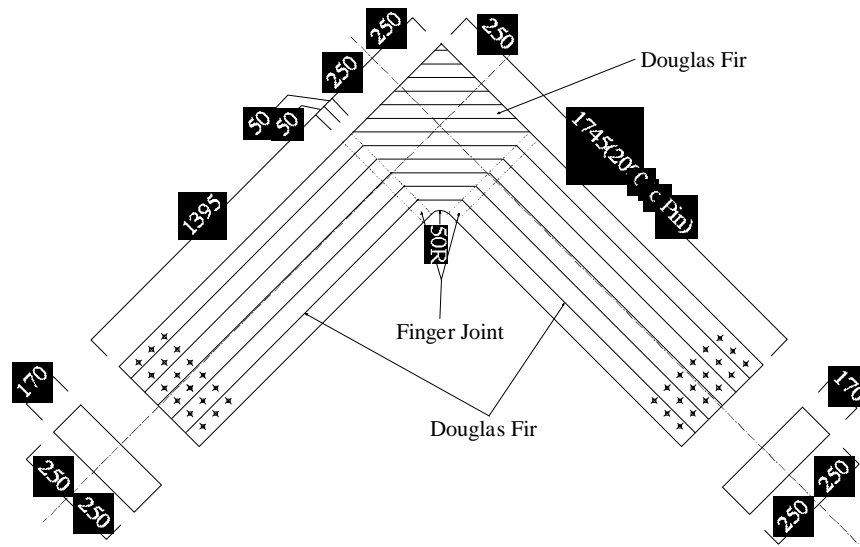


Figure 4: 90 Degrees Finger Joint Specimen (FD-90)

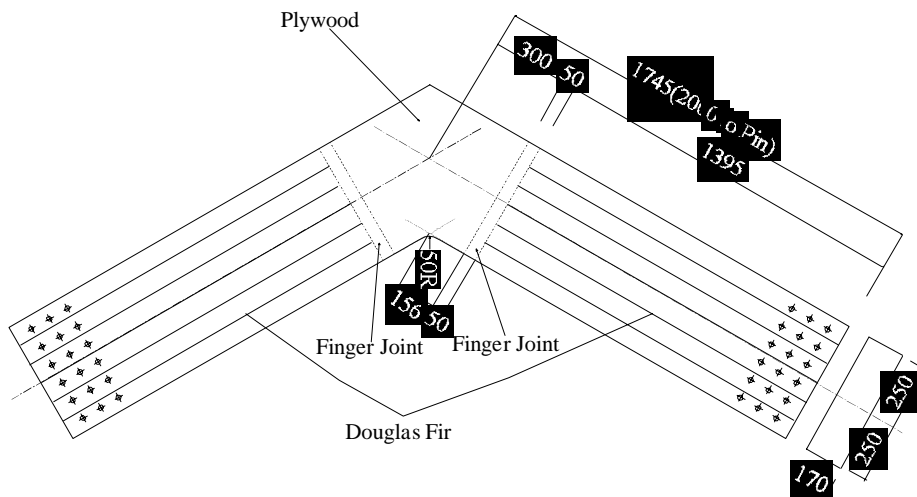


Figure 5: 120 Degrees Finger Joint Specimen; Joint: Plywood (FP-120)

part. Tests were also carried out on finger jointed specimens with the member jointed at 120 degrees. These specimens included one using Douglas fir as the joint part (FD-120) and another using Japanese larch plywood (FP-120). Figure 4 shows the 90-degree finger jointed specimen using Douglas fir as the joint part (FD-90). Figure 5 shows the 120-degree finger-jointed specimen using Japanese larch plywood as the joint part (FP-120). In FD-90, the fibre angle at the joint part becomes 45 degrees against the fibres of the column and the beam members. In FD-120, it becomes 30 degrees. In FP-120, angles of 30 degrees and the orthogonal direction to this coexist. The drift pin joint employed twelve drift pins of 10φ and four M12 bolts on the circumference of diameter 400-mm as a standard type. In the metal joint, the joint was formed by four M15 bolts and five drift pins of 20φ on 6 mm steel plate.

Loading:

The loading apparatus is shown in Figure 6. Increasing cyclic loading was carried out with reference to the hysteresis rule for the story deformation angle shown in Figure 7, which was determined in the Nihon Jutaku Mokuzai Gijutu Centre in Japan.

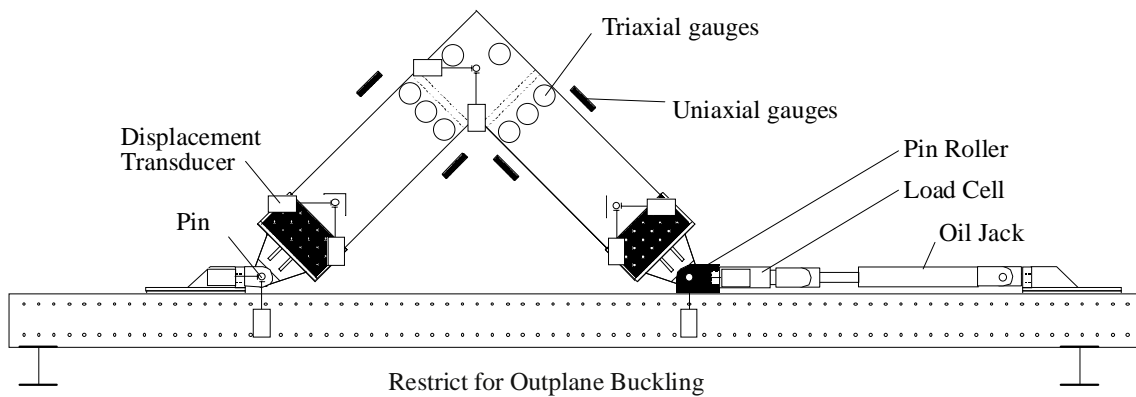


Figure 6: Loading Arrangement and Position of Measurement

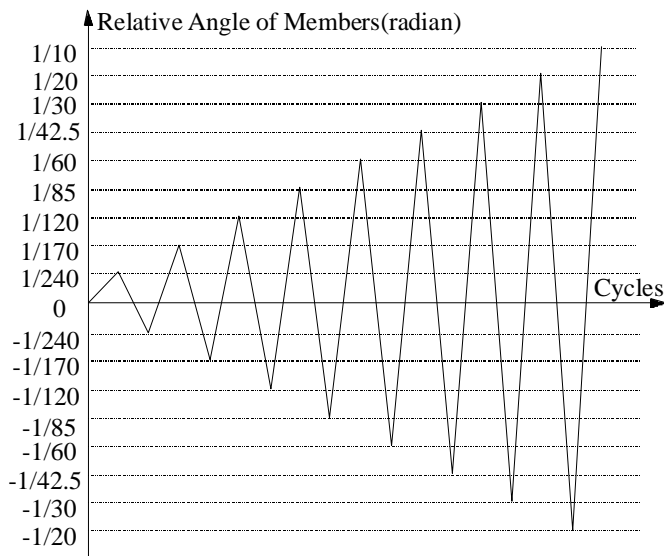


Figure 7: Loading Schedule

Measurement of Displacement and Strain:

Settings were made for 16 triaxial gauges, four (six for the drift pin DP-90) uniaxial gauges and 20 displacement transducers, as shown in Figure 6, and the strain and deformation were measured.

Moment and Relative Angle of Members Relationships:

Figure 8 shows the relationship between the bending moment and the relative member angle at the central position of the joint. The positive loading (positive moment) denotes when the pin position of the test piece expands in a relative manner. The negative loading (negative moment) denotes the opposite. The 120-degree finger-jointed Japanese larch plywood (FP-120) showed the maximum moment, which was a negative moment of 148 kN*m. The highest rigidity was found in the 120-degree finger-jointed Douglas fir (FD-120). This specimen also had the lowest deformation capacity. Both of the specimens with metal plates (SE1-90 and SE2-90) showed the same behaviour, because the washers became stuck in the members, resulting in joint breakdown. The drift pin and the metal joint showed slip properties. It was found that the deformation became excessive when they reached their maximum strength. The finger joint showed high strength and high rigidity and high monolithic capability. When comparing the 90-degree and 120-degree finger-jointed Douglas fir, the 120-degree joint showed higher strength as the fibre angle decreased.

Stress at Critical Section and Relative Angle of Members Relationships:

Figure 9 shows the relationship between the fibre stress and the relative member angle at the critical section. Here, the critical section was positioned at the finger joint section or 300 mm from the joint centre. The largest fibre stress was found in the 120-degree finger-jointed Japanese larch plywood (FP-120), as shown in Figure 2. The stress was a maximum of 17MPa at the upper side, which eventually broke down. This is the same as that shown for the tension test on the finger joint given in Table 1. This finding corresponds to the fact that FP-120 is the only specimen which had a fracture at the upper side of the finger joint. The other specimens broke down at the joint.

Principal Strain Distribution:

Figure 10 shows the principal strains at relative member angles of $1/120$ and $-1/120$. However, it is noted that the principal strains at $1/170$ and $-1/170$ are shown for the 120-degree finger-jointed Douglas fir (FD-120). This is because the test pieces for FD-120 had no deformation capacity up to $1/120$. In the drift pin joint (DF-90) and the metal joints (SE1-90 and SE2-90), the principal strain was as small as about $1/5$ through $1/10$ of that of the finger joint. The maximum principal strain occurred vertically at the finger joint for $1/120$. However, for $-1/120$, the minimum principal strain occurred vertically in the joint. It was indicated that the finger joint generally showed larger strain and higher jointing capability than the drift pin and the metal joint

Results of Bending Test; Ultimate State:

Figure 11 shows the ultimate breakdown state of the finger jointed specimens. The pin was greatly deformed and a large member angle was generated in the drift pin joint (DP-90). Damage was found around the circumference of the hole where the drift pin was inserted, but no large damage was found in the members. The 90-degree finger-jointed Douglas fir developed a tensile shear fracture at the joint along the direction of the lamina fibre during positive loading, and the strength decreased. This corresponds to the distribution of principal strains as mentioned above. The strength of the metal joint was established by the fact that the steel plates became stuck in the cases of both single and double plates. In the 120-degree finger-jointed Douglas fir, a tensile shear fracture developed along the lamina fibre direction in the joint during positive loading and the load decreased as for FD-90. In the 120-degree finger-jointed Japanese larch plywood, a fracture occurred at the joint as the moment increased. Thereafter, no increase was observed in the load. However, this behaviour was not observed as the strength instantaneously decreased and reached breakdown with a fracture, as when Douglas fir was used in the joint. Even after the fracture, it showed a little ductility. Eventually, however, breakdown occurred during the negative loading at the finger joint and the strength greatly decreased. The 120-degree finger-jointed Japanese larch plywood developed a fracture due to shear at the central part of the member in the final stage.

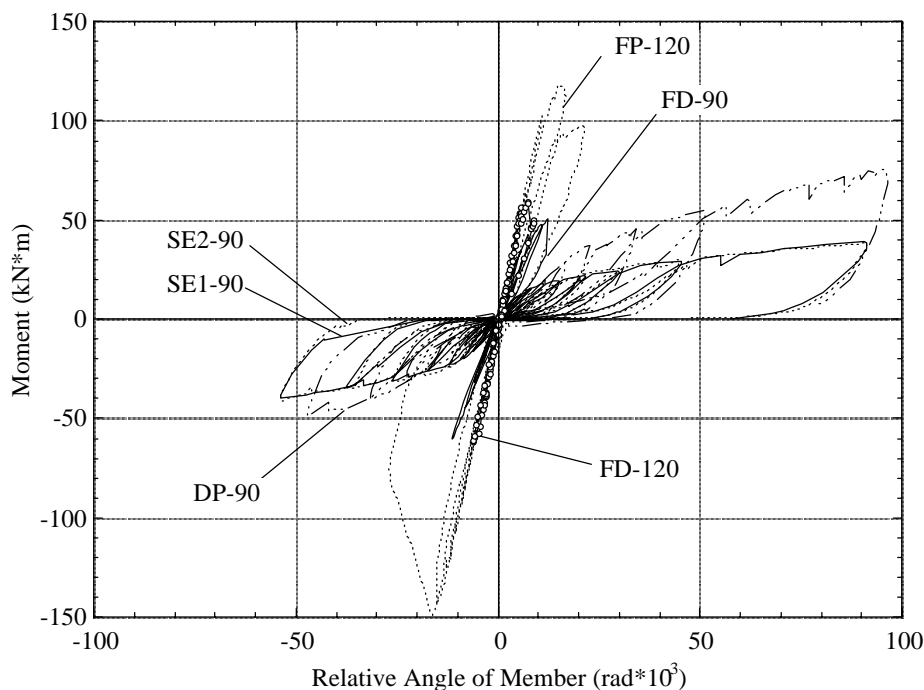


Figure 8: Moment and Relative Angle of Members Relationships

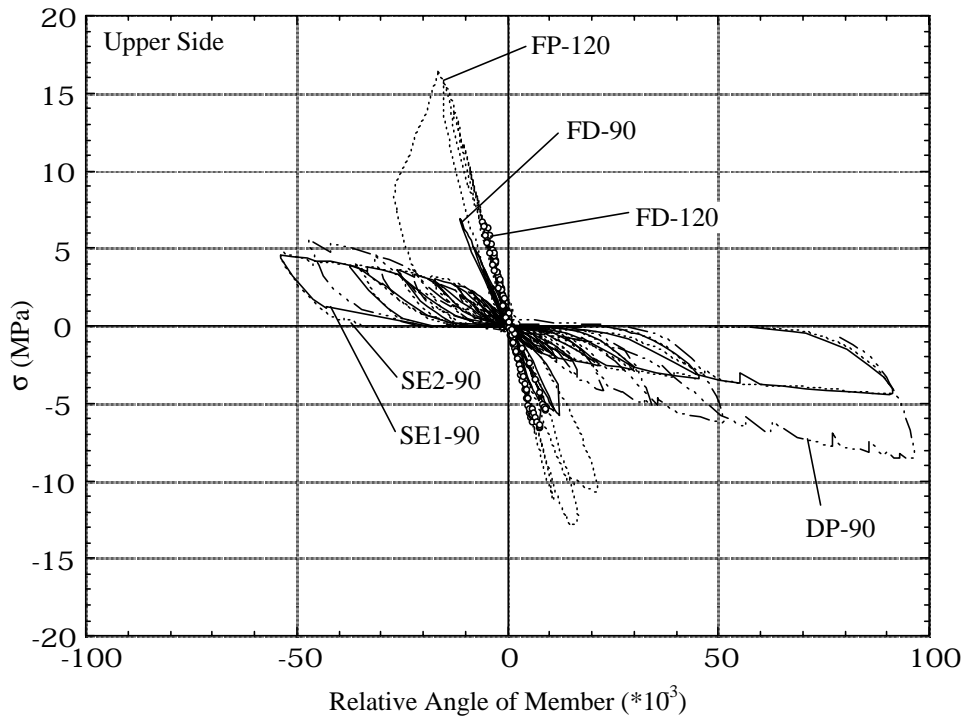


Figure 9: Stress and Relative Angle of Members Relationships

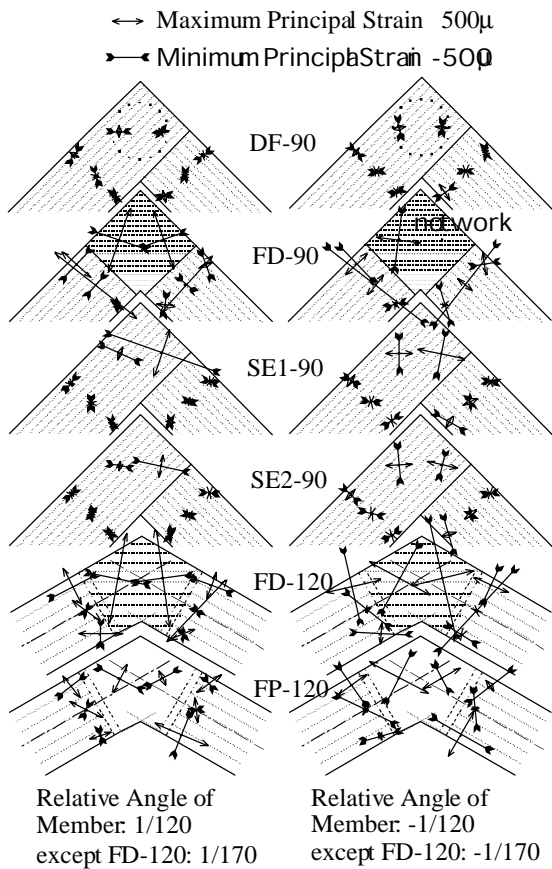


Figure 10: Principal Strain Distribution

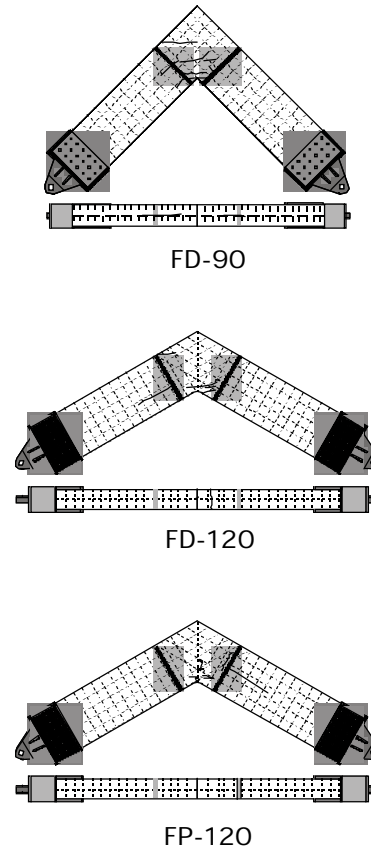


Figure 11: Ultimate State

CONCLUSIONS

According to the results of the lamina tension test, the strength reduction due to partial loss of area of the joint part due to the finger joint was as small as about 10 percent where the fibres were parallel. This showed high jointing efficiency. Most of the finger jointed test pieces with a lamina fibre angle of 30 degrees did not break out at the finger joint part, but at the lamina. The above results indicate that break out at the finger joint will not occur when the finger joint is accomplished while maintaining the fibre angle between the members at 30 degrees or more.

Of the moment resisting joints, those using the drift pin had the highest deformation capacity. However, the 120-degree finger-jointed Japanese larch plywood showed the highest strength. In comparison, the moment resisting finger joints with members at an angle had lower strength than those with a drift pin. However, this type was found to have high monolithic capability owing to their high rigidity. In the 90-degree finger-jointed Douglas, tensile shear breakdown occurred at its end. However, tensile shear breakdown did not occur in the 120-degree finger-jointed Japanese larch plywood, because the anisotropy due to fibre angle was relaxed. It eventually fractured at the finger joint and reached breakdown. The above results suggest the following. More efficient jointing may be achieved by using high strength materials of relaxed anisotropy for the joint and taking into account the position, press method, etc. for the finger joint.

REFERENCES

- 1 KUSUNOKI, T., KIMURA, M. and KOMATSU, K. et al. (1991) "Bending Test on Glulam Big Finger Joint" , AIJ Annual Meeting, September, pp65-66 (In Japanese)
 - 2 KUSUNOKI, T., KIMURA, M. and KOMATSU, K. et al. (1992) "Bending Test and Evaluation of Strength on Douglas Fir Glulam Big Finger Joint" , AIJ Annual Meeting, September, pp67-68 (In Japanese)
- ONO, T. et al. (1994), "Study on Bending Strength of Drift-pin joints in Glued Laminated Timber" , AIJ Annual Meeting, September, pp35-36 (In Japanese)