J Wood Sci (2002) 48:484–490

ORIGINAL ARTICLE

Tomoyuki Hayashi · Masahiko Karube · Kouji Harada
Toshihiro Mori · Tomonori Ohno · Kohei Komatsu
Yasuo Iijima

Shear tests of timber joints composed of sugi composite glulam beams using newly developed steel connectors

Received: July 4, 2001 / Accepted: January 11, 2002

Abstract
A research project supported by the Japan Wood Working Machinery Association has been conducted since 1999 to examine the feasibility of sugi (*Cryptomeria japonica* D. Don) composite glulam beams reinforced with Douglas fir (*Pseudotsuga menziesii* Franco) lamination. This study, part of the project, was concerned with the strength properties of timber joints composed of composite glulams using newly developed structural steel connectors. Two types of beam were prepared: 10 plies (inner 6 plies sugi, outer 4 plies Douglas fir) and 8 plies (inner 4 plies sugi, outer 4 plies Douglas fir). Two types of structural steel connector, "Haratec" and "Standard," were used for joining the beam with a post or a girder. The relation between load and deformation of the joints was represented as a typical nonlinear curve. Initial stiffness and maximum load of the joint composed of the composite glulam were in the range between those of sugi and Douglas fir. Strength properties of the joints varied with three variables: type of connector, depth of the glulams, and the type of joint. Thus, the allowable loads for the connectors should be determined for each combination of these variables.

Key words Composite glulam · Timber joint · Structural connector · Sugi

Introduction

Sugi composite glulams[1] of which the compression and tension laminations are composed of Douglas fir (D-fir) with higher strength properties have been proposed to increase the demand of sugi timber. Although the Japanese Agricultural Standard (JAS) for structural glued laminated timber[2] permits the production of such glulams, they have not yet been produced, mainly because of the lack of strength data.

A research project supported by the Japan Wood Working Machinery Association has been conducted since 1999 to investigate sugi composite glulams. A production system has been developed, and a quality control and evaluation system for the products has been established for this project.

This study, part of the project, was concerned with the strength properties of timber joints composed of the composite glulams fastened with newly developed structural steel connectors.[3] These connectors have been developed and used for timber joints in Japanese conventional post and beam structures because of their advantages of easy processing and rapid assembly of the members. Shear tests were conducted on the specimens using: (1) two types of composite glulam beam; (2) two types of timber joint; and (3) two types of structural connector. Their strength properties were compared with those of control specimens using ordinary sugi and D-fir glulams specified in JAS.[2]

Specimen

Two types of composite glulam beam were prepared for the test. Figure 1 shows the schematics for the cross section of composite glulams. The number written in each lamination (e.g., L50) is the strength grade specified in JAS. "Type 8"

T. Hayashi (✉) · M. Karube
Engineered Timber and Joints Laboratory, Forestry and Forest Products Research Institute, Kukizaki, Ibaraki 305-8687, Japan
Tel. +81-298-73-3211 (ext. 585); Fax +81-298-74-3720
e-mail: tomoyuki@ffpri.affrc.go.jp

K. Harada · T. Mori
Yamasa Mokuzai Co., Kimotuki-gun, Kagoshima 893-1206, Japan

T. Ohno
Kuma Koiki Forest Association, Kamiukiana-gun, Ehime 791-1223, Japan

K. Komatsu
Wood Research Institute, Kyoto University, Uji, Kyoto 611-0011, Japan

Y. Iijima
Institute of Wood Technology, Akita Prefectural University, Noshiro, Akita 016-0876, Japan

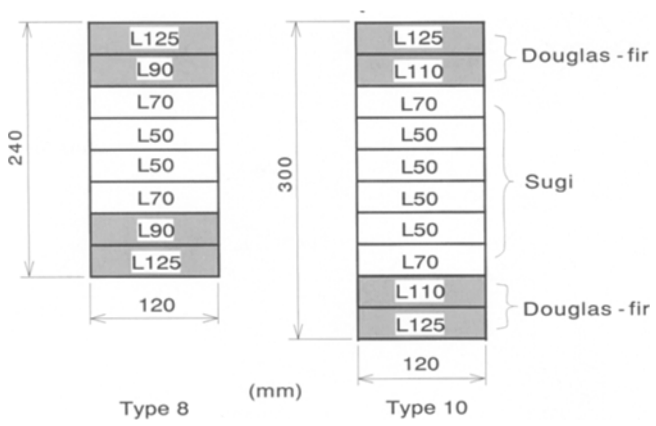

Fig. 1. Cross section of composite glulam. *L*, strength grade of a lamination specified in JAS

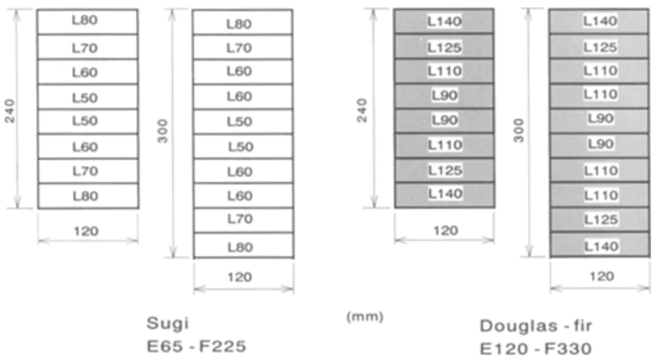

Fig. 2. Cross section of sugi and Douglas fir glulam used as control specimens

had eight plies of laminations in which the inner 4 plies were sugi and the outer 4 plies (2 plies for each compression and tension side) were D-fir. "Type 10" had 6 inner plies of sugi and 4 outer plies of D-fir. The beam depths of types 8 and 10 were 240 and 300mm, respectively. Their widths were the same (120mm).

Ordinary sugi and D-fir glulams specified in JAS as E65-F225 and E120-F330, respectively, were prepared for control tests (Fig. 2).

Two types of structural steel connectors were used: the "Haratec connector" and the "Standard connector," developed by Hara Komuten Co. and Shelter Co., respectively (Figs. 3, 4). Two types of joint were tested: a beam connected to a post, and a beam connected to a girder (Fig. 5). For the post member, D-fir glulam (E120) or sugi (E50) glulam composed of homogeneous grade lamination were used. The former was connected to a composite or D-fir glulam beam, and the latter was connected to a sugi glulam beam. For the girder member, the same glulam as the beam was used.

Figures 6 and 7 show the location of drift pins in the beam. The height of the Haratec connector could be adjusted with an adjustable bolt (Fig. 3) of appropriate length so only one kind of connector was needed for the test. In contrast, the Standard connector had a fixed height so two

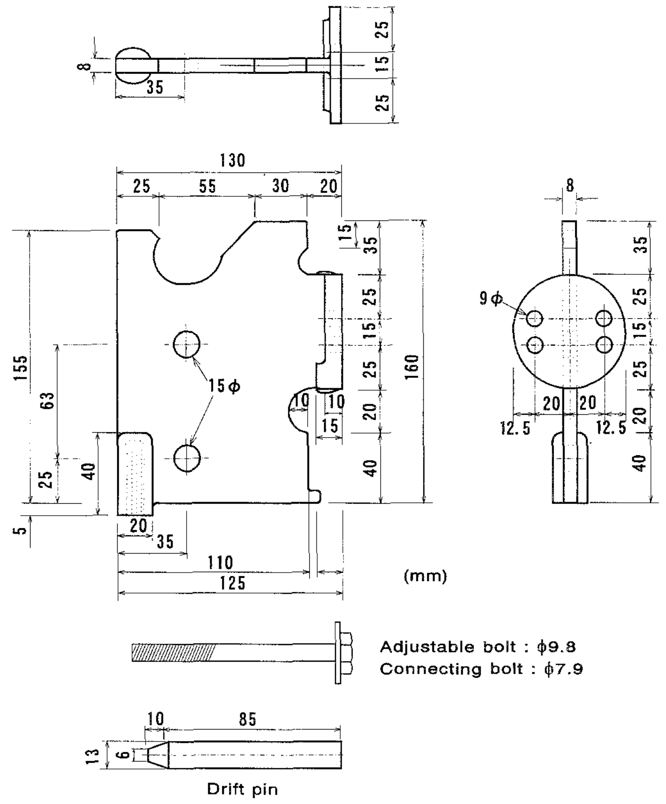

Fig. 3. Haratec connector

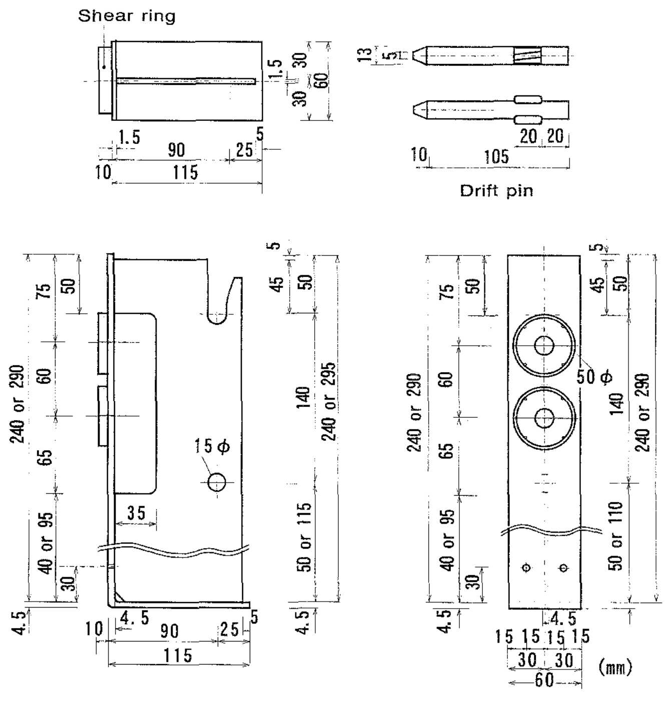

Fig. 4. Standard connector

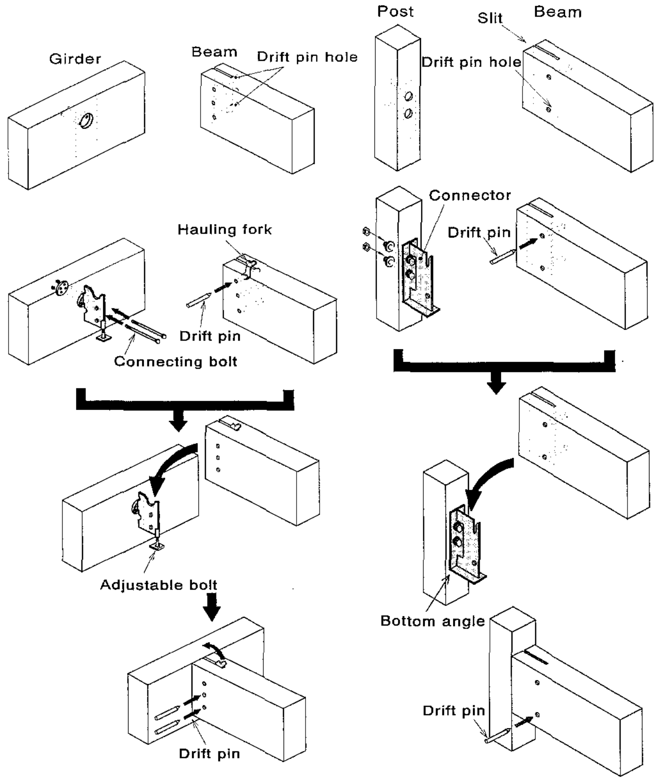

Fig. 5. Joint assembly. Post–beam joint with Haratec connector (*left*) and girder–beam joint with Standard connector (*right*)

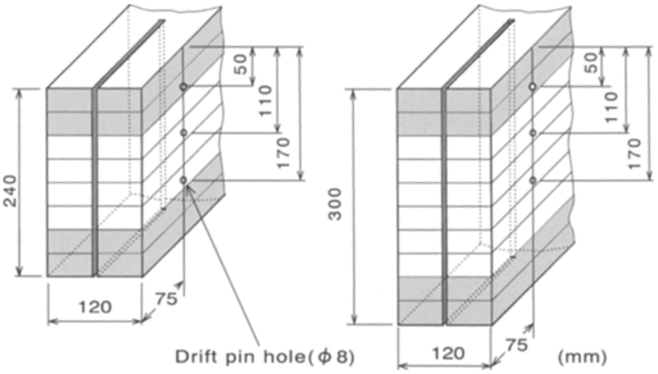

Fig. 6. Location of drift pins in the beam using the Haratec connector

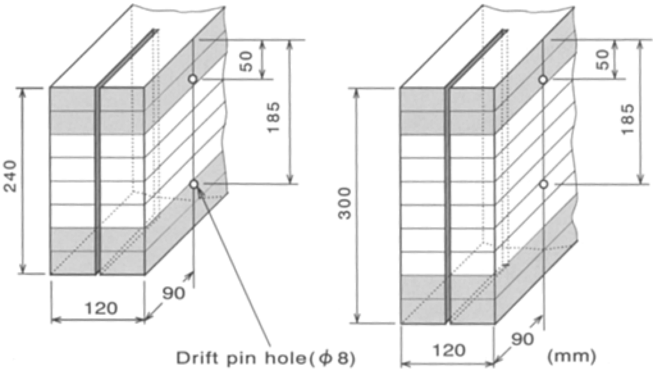

Fig. 7. Location of drift pins in the beam using the Standard connector

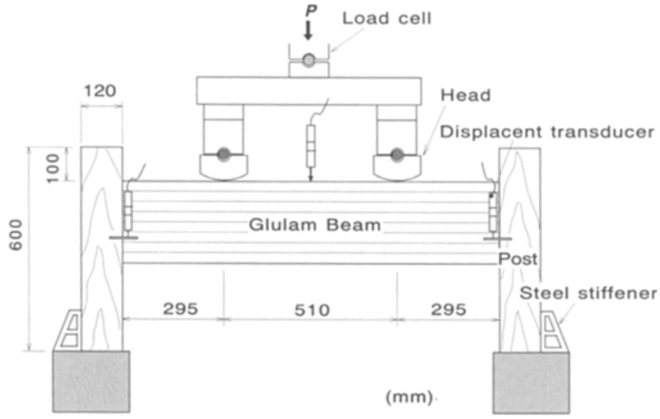

Fig. 8. Loading apparatus and specimen (beam–post joint)

types of the connector (240 and 300 mm) were needed for the test.

There were three specimens for each testing condition. Consequently, a total of 72 specimens (2 types of beam depth × 3 types of glulam × 2 types of connector × 2 types of joint × 3 specimens) was used for the test (Table 1).

Test method

A hydraulic loading machine with a capacity of 1000 kN was used for the test. Figure 8 shows the schematics for a loading apparatus and a specimen composed of a beam and two posts. To mount the connector on the post–beam joint, the standard connector was attached to the narrow face of the lamination in a post, whereas the Haratec connector was attached to the wide face of the lamination.

Load was applied monotonously to the specimen with two loading heads. Loading was stopped after the load attained a maximum value ($P_{\max}$) and then dropped to less than 80% of the maximum. During the loading, digital output signals for load and relative displacement were automatically recorded on a personal computer through a general purpose interface bus (GPIB) device. The interval from the beginning of loading to the end was about 7–14 min for each specimen.

After the loading test a small wood block was cut from the specimen, and its moisture content was measured by the oven-drying method. The average for all the specimens was 13.0%.

Results and discussion

Failure characteristics

Failure modes of the joints were classified into four types: (1) S type, several shear failures occurred in a beam horizontally; (2) C type, large cleavage occurred in a post vertically; (3) B type, a bending failure of the connector occurred at the bottom angle; (4) T type, connecting bolts failed under tension. The failure modes for all the specimens are listed in Table 2.

With the Haratec connector, most of the specimens had S-type failure, with several exceptions of T-type failure. With the Standard connector, the girder–beam specimens had S-type failure, as did those with the Haratec connector; most of the post–beam specimens had B- or C-type failure. B-type failure (bending failure of the bottom angle) with the Standard connector is one of the common failures of that connector. On the other hand, C-type failure (large cleavage in the post) is specific to these specimens. It is a practical problem as it decreases the performance of the joint. Because the connecting bolt is parallel to the glue line of the post in Standard specimens, there is more possibility of cleavage. The short length of the post was another cause of the cleavage. In conclusion, it should be noted that attaching a steel connector to the narrow face of the lamination in a glulam post can lead to reduced strength properties.

Load and displacement

Figure 9 shows some load-displacement curves for a post–beam specimen of 300mm depth using the Haratec connector. As is clear from Fig. 9, the relation between load and relative displacement of the joints is represented as a typical nonlinear curve usually observed in a test of dowel-type timber joints. Another characteristic of these relations is that the curves of composite glulam specimens are somewhere between those of sugi and D-fir.

Figure 10 shows definitions and a method for calculating the strength properties of mechanical timber joints. The Japan Housing and Wood Technology Center[4] proposed this method, and the calculation is performed as follows.

1. Line I, joining 0.1 P_{max} and 0.4 P_{max} in the load-deformation curve, is drawn.
2. Line II, joining 0.4 P_{max} and 0.9 P_{max} in the curve, is drawn.

Table 1. Combination of test variables

Joint	Depth (mm)	Glulam		
		Sugi	D-fir	Composite
Haratec connector				
Girder–beam	240	Nos. 1, 2, 3	Nos. 1, 2, 3	Nos. 1, 2, 3
	300	Nos. 1, 2, 3	Nos. 1, 2, 3	Nos. 1, 2, 3
Post–beam	240	Nos. 1, 2, 3	Nos. 1, 2, 3	Nos. 1, 2, 3
	300	Nos. 1, 2, 3	Nos. 1, 2, 3	Nos. 1, 2, 3
Standard connector				
Girder–beam	240	Nos. 1, 2, 3	Nos. 1, 2, 3	Nos. 1, 2, 3
	300	Nos. 1, 2, 3	Nos. 1, 2, 3	Nos. 1, 2, 3
Post–beam	240	Nos. 1, 2, 3	Nos. 1, 2, 3	Nos. 1, 2, 3
	300	Nos. 1, 2, 3	Nos. 1, 2, 3	Nos. 1, 2, 3

D-fir, Douglas fir
Nos. 1, 2, 3 are the three specimens tested

Table 2. Failure mode of the joints

Joint	Depth (mm)	Edge	Sugi			D-fir			Composite		
			No. 1	No. 2	No. 3	No. 1	No. 2	No. 3	No. 1	No. 2	No. 3
Haratec connector											
Girder–beam	240	Right	S	S	S	S	S	T	S	–	S
		Left	S	S	S	S	S	–	S	–	S
	300	Right	S	S	S	S	S	–	S	–	S
		Left	S	S	S	S	S	T	S	–	S
Post–beam	240	Right	S	S	–	–	–	S	–	S	–
		Left	–	S	S	S	S	–	S	–	S
	300	Right	S	S	S	S	S	S	S	S	–
		Left	S	S	S	S	S	S	S	S	S
Standard connector											
Girder–beam	240	Right	S	S	S	S	S	S	S	S	S
		Left	S	S	S	S	S	S	S	S	S
	300	Right	S	S	S	S	S	S	S	S	S
		Left	S	S	S	S	–	S	S	S	S
Post–beam	240	Right	C	–	B	B	B	C	C	B	B
		Left	C	S	S	B	B	B	B	B	B
	300	Right	–	S	C	C	C	C	C	S	–
		Left	C	S	–	C	C	C	S	S	C

S, shear failure in the beam; C, cleavage in the post; B, bending failure at the bottom angle; T, tearing off of the bolt; –, no failure

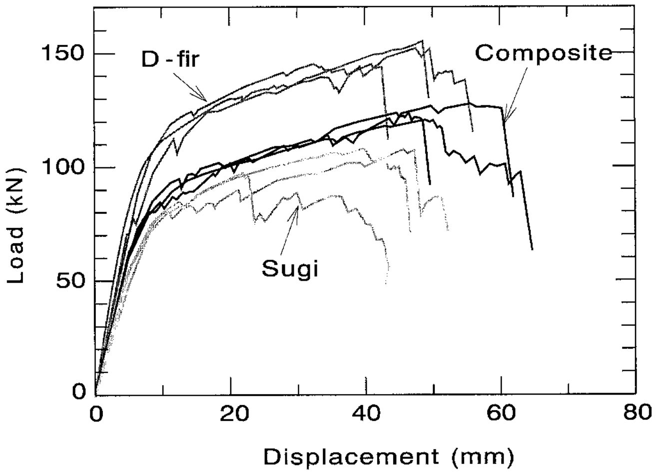

Fig. 9. Examples of load-displacement curves (post–beam specimens with 300 mm depth using a Haratec connector). Displacement: Average of four readings obtained from four displacement transducers

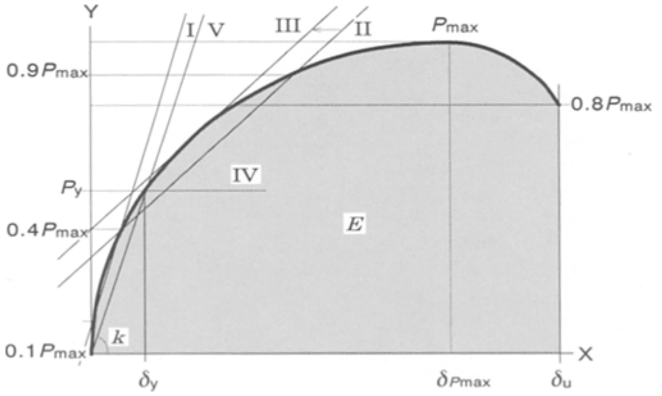

Fig. 10. Definition of the strength properties of the joints. K, initial stiffness; δ_y, yield displacement; $\delta_{P_{max}}$, displacement at P_{max}; δ_u, maximum displacement; E, dissipated energy

3. Line II is translated along with the x-axis to be a tangent to the curve. This new line is defined as line III.
4. The load corresponding to the intersection of lines I and III is defined as the yield strength (P_y). Line IV is drawn parallel to the x-axis through this point.
5. Displacement corresponding to the intersection of line IV and the curve is defined as the yield displacement (δ_y).
6. Line V is drawn joining the origin and the coordinates P_y and δ_y. A gradient of this line is defined as the initial stiffness (k).
7. Displacement at 0.8 P_{max} in the curve after the peak is defined as the maximum displacement (δ_u).
8. An area enclosed by the curve, the x-axis, and a perpendicular from δu is defined as the dissipated energy (E).

Effects of variables

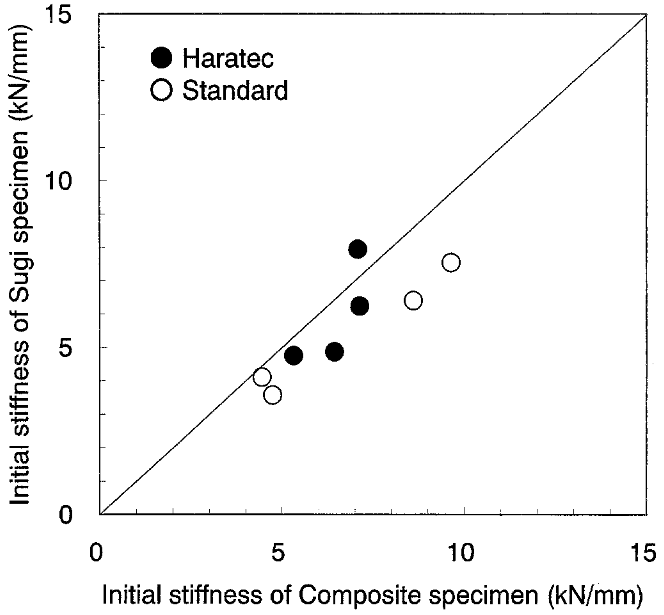

Fig. 11. Initial stiffness of the composite specimen compared to that of the sugi specimen

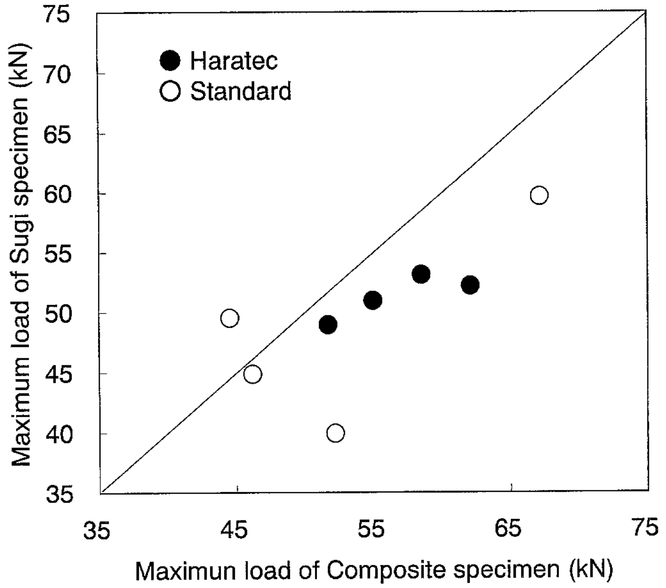

Fig. 12. Maximum load of the composite specimen compared to that of the sugi specimen

Tables 3 and 4 summarize the initial stiffness and maximum load of the joints, respectively. Each value is for one connector and an average of three sets of data obtained from three specimens. The percentages represent the ratio of each value to that of the corresponding sugi specimen. Though there are several exceptions, it is found that the initial stiffness and maximum load of the joint composed of the composite glulam were generally somewhere between those of sugi and D-fir.

The coordinates for the initial stiffness of the composite specimens and corresponding sugi specimens are plotted in Fig. 11, ignoring the type of beam depth and joint. The same relation as for maximum load is shown in Fig. 12.

Table 3. Initial stiffness of the joints

Joint	Depth (mm)	Sugi	D-fir	Composite
Haratec connector				
Girder–beam	240	4.75 (100%)	5.80 (122%)	5.32 (112%)
	300	7.93 (100%)	8.52 (107%)	7.08 (89%)
Post–beam	240	6.23 (100%)	10.00 (161%)	7.13 (114%)
	300	4.86 (100%)	6.28 (129%)	6.44 (132%)
Average		100%	130%	112%
Standard connector				
Girder–beam	240	4.11 (100%)	4.23 (103%)	4.45 (108%)
	300	3.57 (100%)	4.78 (134%)	4.75 (133%)
Post–beam	240	6.40 (100%)	7.91 (124%)	8.61 (135%)
	300	7.54 (100%)	12.03 (160%)	9.65 (128%)
Average		100%	130%	126%

Results are in kN/mm. Percentages represent the ratio of each value to that of the corresponding sugi specimen

Table 4. Maximum load of the joints

Joint	Depth (mm)	Sugi	D-fir	Composite
Haratec connector				
Girder–beam	240	51.0 (100%)	64.8 (127%)	55.0 (108%)
	300	49.0 (100%)	62.6 (128%)	51.7 (106%)
Post–beam	240	53.1 (100%)	76.7 (144%)	58.5 (110%)
	300	52.2 (100%)	75.3 (144%)	62.1 (119%)
Average		100%	136%	111%
Standard connector				
Girder–beam	240	39.9 (100%)	52.1 (131%)	52.2 (131%)
	300	59.7 (100%)	67.8 (114%)	67.2 (113%)
Post–beam	240	44.9 (100%)	57.0 (127%)	46.2 (103%)
	300	49.5 (100%)	65.5 (132%)	44.5 (90%)
Average		100%	126%	109%

Results are in kN. Percentages are explained in Table 3

Table 5. Dissipated energy of the joints

Joint	Depth (mm)	Sugi	D-fir	Composite
Haratec connector				
Girder–beam	240	1828 (100%)	1711 (94%)	1974 (108%)
	300	2174 (100%)	1781 (82%)	1518 (70%)
Post–beam	240	1505 (100%)	2511 (167%)	1938 (129%)
	300	1882 (100%)	2964 (157%)	2848 (151%)
Average		100%	125%	114%
Standard connector				
Girder–beam	240	1895 (100%)	1925 (102%)	2089 (110%)
	300	2941 (100%)	2633 (90%)	3058 (104%)
Post–beam	240	1323 (100%)	1955 (148%)	1402 (106%)
	300	1629 (100%)	2652 (163%)	1244 (76%)
Average		100%	125%	99%

Results are in kN·mm. Percentages are explained in Table 3

As is clear from Figs. 11 and 12, most of the plots are located in the right side of a line, indicating that strength properties are influenced by the D-fir lamination. It is obvious that reinforcement with D-fir laminations improves the strength properties of the joint.

Figure 13 shows the coordinates of initial stiffness of the 300mm depth specimen and the corresponding 240mm depth specimen, disregarding the type of beam and joint. The effects of beam depth on the initial stiffness of the joints are obvious in specimens with the Standard connector

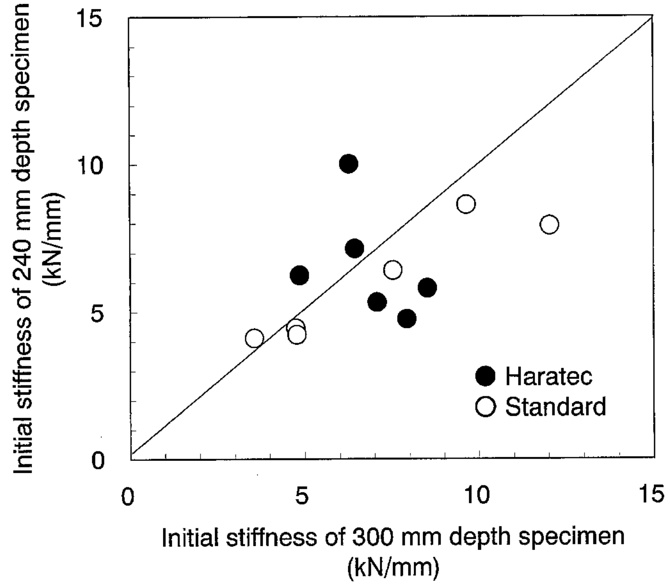

Fig. 13. Initial stiffness of 300 mm depth specimen compared to that of the 240 mm depth specimen

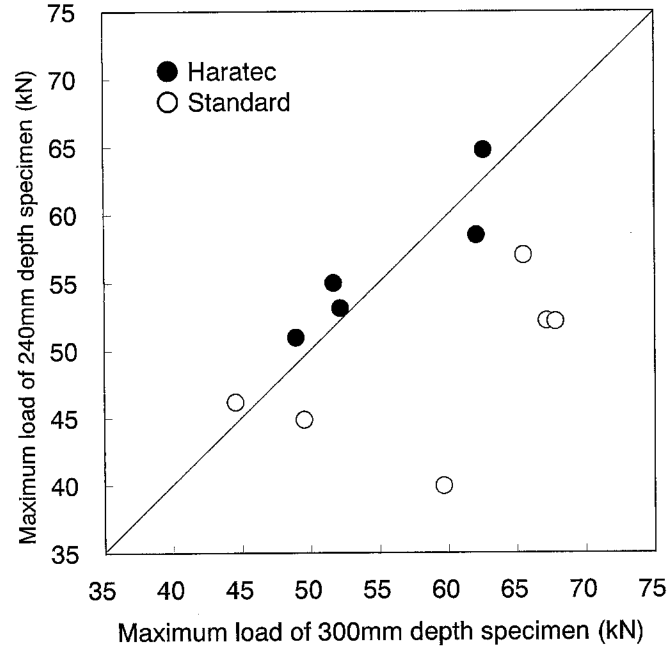

Fig. 14. Maximum load of 300 mm depth specimen compared to that of the 240 mm depth specimen

but not in those with the Haratec connector. A similar relation is observed in Fig. 14, which shows the coordinates of maximum load for 300 mm depth specimens and corresponding 240 mm depth specimens. Here, five-sixths of the plots for specimens with the Standard connector are located below the line. This is because connectors of different sizes were used for the Standard connector, whereas only one kind of Haratec connector was used.

A method for evaluating the allowable load for this type of connector has not been established in Japan. In addition, the load-carrying mechanism is so complicated that an estimation of strength properties is difficult when analyzing the strength data for each element. Thus, we cannot determine or discuss the allowable load in this study. Judging from the test results, however, we can at least propose that the allowable load for this type of connector should be determined by tests on full-size specimens of each type of connector and joint.

Table 5 summarizes the dissipated energy (Fig. 10) of the joints. Each value in Table 5 is for one connector and an average of three data sets obtained for three specimens. Compared with the average values in Tables 3 and 4, the disparity of the average values in Table 5 is somewhat higher, as they ranged widely from 1244 to 2964 kN·mm. There are five types of specimen in which the ratio of each value to that of the corresponding sugi specimen is less than 100%. The dispersion of the data is so great that we cannot discuss the effects of variables precisely, but the same tendencies for initial stiffness and maximum load are observed in general.

Conclusions

Timber joints composed of sugi composite glulams have better strength properties than those of sugi glulams. Reinforcement with D-fir laminations was apparently effective for improving the strength properties of the joint. The relation between load and deformation of the joints is represented as a typical nonlinear curve. The initial stiffness and maximum load of the joint composed of the composite glulam were somewhere between those of sugi and D-fir.

The strength properties of the joints varied with three factors: the depth of the glulams, the type of connector, and the type of joint. Allowable load for the connectors should be determined by tests on full-size specimens of each combination of these variables.

References

1. Hayashi T, Miyatake A (1991) Strength properties of sugi composite-glulam beams I (in Japanese). Mokuzai Gakkaishi 37: 200–205
2. Ministry of Agriculture, Forestry and Fisheries (1996) Japanese agricultural standard for structural glued laminated timber
3. Hayashi T, Itagaki N (2000) Light frame wood constructions with specially designed metal fasteners (in Japanese). Mokuzai Kogyo 55:103–108
4. Oshiumi S (2000) Testing and evaluation method for the elements in post and beam structures (in Japanese). Kentiku Gijyutu 608:174–179