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Effect of Adhesives and Finger Pitches on Bending Creep Performances of Finger-Jointed Woods*1

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ABSTRACT

Following our previous reports for finger-jointed woods with various finger profiles studied for the efficient use of small diameter logs and woods containing various defects, twelve types of finger-jointed woods glued with three kinds of adhesives and with two sizes of finger pitches were made with sitka spruce and red pine. The effects of the adhesives and finger pitches on bending creep performances of finger-jointed woods were investigated. The shape of creep curves differed among the used adhesives and finger pitches of finger-jointed woods for both tested species. Their creep curves showed a linear behavior beyond about one hour, and the N values fitted to power law increased with increasing finger pitches. The initial deformation increased with increasing finger pitches, regardless of the tested species and kinds of adhesives, whereas the effect of finger pitches on the creep deformation was not clear. For finger-jointed woods glued with polyvinyl acetate (PVAc) resin, creep failure occurred in 106 hours after the load was applied. And the difference of the creep compliance between finger-jointed woods glued with resorcinol-phenol formaldehyde (RPF) resin and aqueous vinyl urethane (AVU) resin was small. The ratios for creep performances of finger-jointed woods glued with RPF resin and AVU resin versus solid wood were higher in creep deformation than initial deformation for both species, and the difference between both adhesives was not found. The relative creep decreased with increasing finger pitches, and the marked differences was not found between RPF resin and AVU resin.

Keywords : finger-jointed wood, pitch, initial deformation, creep deformation, relative creep

1. INTRODUCTION

Woods and wood-based materials show creep phenomenon which the deformation increases with increasing time under constantly applied load due to breaking and recombining of secondary bonds such as hydrogen bond, and this property must be grasped to obtain the safety of the materials under the applied load for a long time. However, it is difficult to analyze exactly the creep behavior owing to various variation facts such as humidity, temperature, adhesives for gluing and configurations of joining parts. Recently, the use of wood-based materials to

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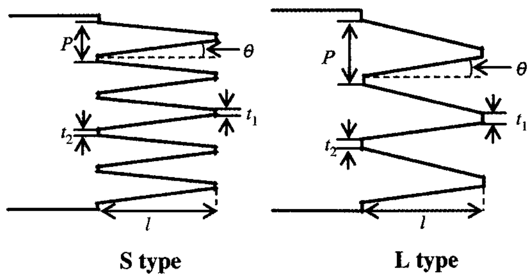


(unit: mm)

	S	L
P	4.4	6.8
l	15.3	15.3
$\tan^{-1}\theta$	13.48	7.57
t_1	0.95	1.05
t_2	0.80	0.90
$t_1 - t_2$	0.15	0.15

Fig. 1. Dimension and finger profile.
Notes : P : pitch, l : Length of finger, t_1 : Tip width, t_2 : Root width, θ: Slope angle of finger. S : 4.4 mm finger pitch, L : 6.8 mm finger pitch.

reconstitute efficiently small lumbers and waste woods such as glulam, cross-laminated wood, oriented strand board, particle board and fiber board are gradually increasing due to problems of logs import caused by exhaustion of the superior logs and the resource conservation policy of the country of logs production. Hence, many researches to investigate their properties have been performed, and various researches on their creep performances have been reported (Moslemi, 1964, Bryan *et al.*, 1965, Schniewind, 1968, Fushitani *et al.*, 1975, Nakai, 1978, Arima, *et al.*, 1981, Hong *et al.*, 1993, Hoyle *et al.*, 1994, Park, *et al.*, 2002), however there are little researches on creep performances of finger-jointed woods with finger joint which is widely used for end-jointing of structural materials such as glulam.

In our previous reports (Byeon *et al.*, 1997, Ryu *et al.*, 2003, Park *et al.*, 2004), we investigated static bending strength performances of finger-jointed woods which had different finger profiles, kinds of adhesives and densities of species to study the efficient use of the wood containing various defects such as knots and domestic small diameter logs. As a result, it was found that the efficiency of static bending strength performances of finger-jointed woods increased with increasing the glued area and with decreasing the density of species, and indicated a marked difference as kinds of adhesive. In this study, twelve types of finger-jointed woods which had two sizes of finger pitches and three kinds of adhesives for gluing were prepared from red pine and sitka spruce, the effects of finger pitches and kinds of adhesives on bending creep performances of finger-jointed woods were investigated.

2. MATERIALS and METHODS

2.1. Specimen Preparation

Domestic red pine (*Pinus densiflora* Sieb. et Zucc.) and imported sitka spruce (*Picea sitchensis* Carr.) were selected for this study. Longitudinal elements without visible defects measuring 22 (T)×22(R)×400(L) mm were cut from each of two species. Density and static MOE of the species were measured, and their ranges were in 0.443～0.666 Mg/m^3 and 8.74～15.6 GPa for red pine and 0.404～0.555 Mg/m^3 and 8.98～16.5 GPa for sitka spruce, respectively. The elements were classified without density and static modulus of elasticity (MOE) bias among the conditions for adhesives and finger pitches. The center of the longitudinal elements was cut to make fingers with 4.4 mm(S) and 6.8 mm(L) pitches as shown in Fig. 1. A polyvinyl acetate (PVAc) resin, resorcinol-phenol formaldehyde (RPF) resin and aqueous vinyl urethane (AVU) resin formulated for room temperature curewere used. The finger-jointing parts were pressed under a pressure of 3.92 MPa for 20 seconds, andcured for more than a week in a room maintained at 20°C and 65% RH. And then the

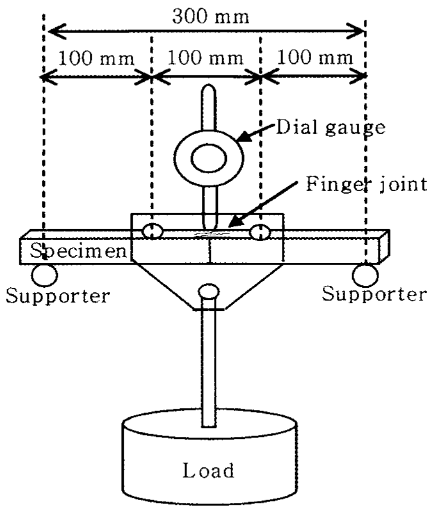


Fig. 2. Schematic diagram of bending creep test.

finger-jointed specimens of 20(T)×20(R)× 370(L) mm were completed. The number of specimen for each type of both species was 4, respectively.

2.2. Bending Creep Test

Bending creep test for finger-jointed wood specimens was conducted by four-point loading. The span was 300 mm, and the distance between a loading point and a supporting point was 100 mm. The stress corresponding to 25% of breaking stress obtained from static bending test was applied to each specimen. The creep test was conducted for 240 hrs (10 days) in a constant atmosphere maintained at 20°C and 65% RH. The deflection of the mid-span was measured with a dial gauge. The creep deflection was measured at interval of 0.5, 1, 3, 5, 10 minutes until 30 minute after initial deformation, and then was measured for 2 hours at interval of 30 minute. After 2 hours, it was measured at interval of 1, 2 and 3 hours until 10 hours, and then was masured at interval of 12 hours for 2 days and at interval of 24 hours for 7 days. The schematic diagram of bending creep test is shown in Fig. 2. Total creep compliance $D(t)$ and creep compliance $D_c(t)$ (total creep compliance except for initial compliance) were obtained using Eqs.(1) and (2) as follows:

$$D(t) = \frac{4bh^3y(t)}{Pl_1(3l^2 - 4l_1^2)} \qquad (1)$$

where P is the applied load; l is the span; b, h are the width and depth of the specimen; l_l is the distance between a loading point and a supporting point; and $y(t)$ is the creep deflection at time(t).

$$D_c(t) = D(t) - D(0.008) \qquad (2)$$

where $D(0.008)$ is the initial compliance at t = 0.008 hr (30s).

3. RESULTS and DISCUSSION

3.1. Bending Creep Curves of Finger-Jointed Woods

Bending creep curves of each type of finger-jointed woods are shown in Figs. 3 and 4. Fig. 3 shows the logarithm plots of time for typical examples of each type of finger-jointed wood specimens and the difference among the used adhesives was compared. The shape of creep curves of finger-jointed woods showed the parabolas which the upper right-side increased for all adhesives, and the inclination of their creep curves was markedly higher in finger-jointed woods glued with PVAc resin than in those glued with RPF resin and with AVU resin. But it was not clear that the difference of the creep curves between finger-jointed woods glued with RPF resin and AVU resin. For the finger-jointed woods glued with PVAc resin, the creep failure occurred in 106 hours after the load was applied. It was found that it was not able to use

Table 1. Values of constants N and A in the exponential regression equation between creep compliance and time ($D_c(t) = At^N$) for finger-jointed woods

Type	N		$A(10^{-11}Pa^{-1})$		r	
	AV	CV (%)	AV	CV (%)	AV	CV (%)
PS	0.270	2.8	0.408	34.5	0.993	0.5
PSR	0.273	7.0	0.392	37.3	0.996	0.2
PSA	0.322	16.0	0.364	47.7	0.985	0.8
PLR	0.291	9.2	0.369	42.8	0.982	1.8
PLA	0.266	9.0	0.393	22.2	0.992	0.5
SS	0.336	6.7	0.196	44.3	0.978	1.6
SSR	0.328	27.9	0.243	19.3	0.991	0.4
SSA	0.326	19.5	0.256	50.8	0.989	0.3
SLR	0.341	20.8	0.221	51.9	0.984	1.6
SLA	0.338	14.6	0.270	54.7	0.977	1.4

Notes : AV : Average value of four measurements, CV : Coefficient of variation, r : Correlation coefficient. PS : Red pine solid wood, SS : Sitka spruce solid wood, PSR : Red pine finger-jointed wood-4.4 mm pitch-RPF resin, PSA : Red pine finger-jointed wood-4.4 mm pitch-AVU resin, PLR : Red pine finger-jointed wood-6.8 mm pitch-RPF resin, PLA : Red pine finger-jointed wood-6.8 mm pitch-AVU resin, SSR : Sitka spruce finger-jointed wood-4.4 mm pitch-RPF resin, SSA : Sitka spruce finger-jointed wood-4.4 mm pitch-AVU resin, SLR : Sitka spruce finger-jointed wood-6.8 mm pitch-RPF resin, SLA : Sitka spruce finger-jointed wood-6.8 mm pitch-AVU resin.

as an adhesive for structural materials. Fig. 4 shows the double logarithm plots of creep compliance and time for typical example of each type of finger-jointed woods, and the comparison for the types glued with RPF resin and AVU resin was performed. There were differences in creep curves among each type of finger-jointed woods, and their creep curves showed a linear behavior beyond about one hour. The creep curve ($D_c(t)$) was expressed by the following equation (power law):

$$D_c(t) = At^N \quad (3)$$

where A and N are constants, and t is time.

It has been reported in many papers (Kitahara *et al.*, 1965; Schniewind, 1968; Nakai, 1978; Saito *et al.*, 1980; Arima *et al.*, 1981; Morizumi, 1981; Hoyle *et al.*, 1994; Aratake *et al.*, 2002) that the creep curves of wood and wood-based materials were fitted to power law.

In the logarithmic regression of the Eq. (3), the correlation coefficients were in the range of 0.982～0.996 for red pine finger-jointed woods and of 0.978～0.991 for sitka spruce finger-jointed woods. The fitted values of N and A were shown in Table 1. For all types, sitka spruce finger-jointed woods showed the higher N values and the lower A values than those of red pine finger-jointed woods. The N values increased with increasing finger pitches and finger-jointed woods glued with RPF resin had the lower N values than those glued with AVU resin except for red pine finger-jointed woods with the finger pitch of 6.8 mm, and it was found that there was little difference between solid woods and finger-jointed woods. However, the A values hardly depended on the finger pitches and kinds of adhesives. The N values of both solid woods and finger-jointed woods were about 2 times higher than that of Japanese cypress solid wood under constant humidity, and the values for red pine finger-jointed woods were similar to those of Japanese cedar and kastura solid woods reported by Arima (1981) and spruce finger-jointed woods were slightly

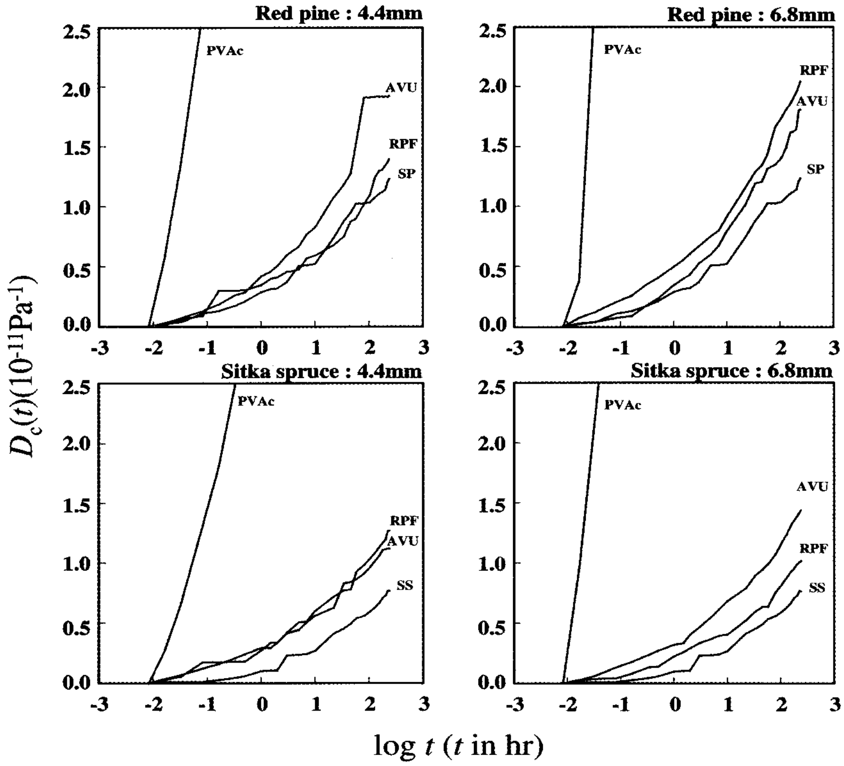


Fig. 3. Typical examples of creep curves for each type of finger-jointed woods.

Notes : SP : Solid red pine, SS : Solid sitka spruce, RPF : Finger-jointed woods glued with resorcinol-phenol formaldehyde resin, AVU : Finger-jointed wood glued with aqueous vinyl urethane resin, PVAc : Finger-jointed woods glued with polyvinyl acetate resin.

higher than the values of their species reported by Arima (1981). However, the N values of red pine finger-jointed woods were considerably smaller than those of solid woods and glulams of Japanese cedar and Douglas-fir under humidity change (Hoyle *et al.*, 1994; Aratake *et al.*, 2002), and the values for sitka spruce finger-jointed woods were smaller than those of Japanese cedar and Douglas-fir solid woods, and were nearly equal to those of Japanese cedar and Douglas-fir glulam beams (Aratake *et al.*, 2002). Also, their values were higher than those of Japanese cedar cross-laminated woods with 45 annual ring angle in the core (Park *et al.*, 2002) and lauan plywood (Nakai, 1978) under constant humidity.

3.2. Initial Deformation and Creep Deformation of Finger-jointed Woods

The results of bending creep test are shown in Table 2. The relations between the initial compliance (total creep compliance at 0.008 hr), creep compliance (total creep compliance except for initial compliance at 240 hr) and finger pitches are shown in Fig. 5. Finger-jointed woods glued with PVAc resin were compared for only initial deformation because creep failure occurred in 106 hours after the load was applied.

For red pine finger-jointed woods, the initial

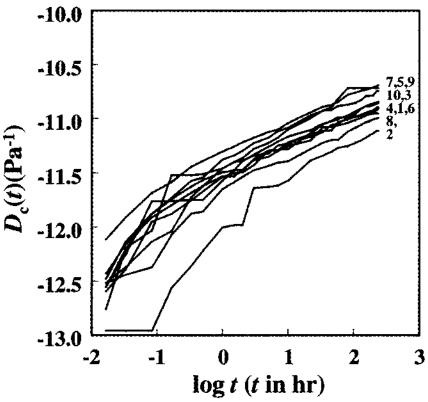


Fig. 4. Double logarithm plot of creep deformation and time for typical examples of each type of finger-jointed woods.

Notes : 1: Red pine solid wood, 2 : Sitka spruce solid wood, 3 : Red pine finger jointed wood-4.4 mm(S) pitch-RPF resin, 4 : Sitka spruce finger jointed wood-4.4 mm(S) pitch-RPF resin, 5 : Red pine finger jointed wood-4.4 mm(S) pitch-AVU resin, 6 : Sitka spruce finger jointed wood-4.4 mm(S) pitch-AVU resin, 7 : Red pine finger jointed wood-6.8 mm(L) pitch-RPF resin, 8 : Sitka spruce finger jointed wood-6.8 mm(L) pitch-RPF resin, 9 : Red pine finger jointed wood-6.8 mm(L) pitch-AVU resin, 10 : Sitka spruce finger jointed wood-6.8 mm(L) pitch-AVU resin.

compliance showed the highest value in those glued with PVAc resin for both 4.4 mm and 6.8 mm pitches, and showed the lowest values in those glued with AVU resin for 4.4 mm pitch and in those glued with RPF resin for 6.8 mm pitch. They increased with increasing finger pitches in all adhesives. This is considered because the glued area decreased with increasing finger pitches as mentioned in the previous report (Park *et al.*, 2004). The extent of the increase was greatest in those glued with PVAc resin and was smallest in those glued with RPF resin. However, the creep compliance hardly varied with increasing finger pitches and the difference of creep compliance between those glued with RPF resin and AVU resin was small. The initial compliances of red pine finger-jointed woods glued with PVAc, AVU and RPF resin showed 1.23~1.56, 0.97~1.27 and 1.07 ~1.20 times values of red pine solid wood at 240 hr, respectively. And the creep compliance of red pine finger-jointed woods glued with RPF resin were 1.22~1.23 times of red pine solid wood at 240 hr and those glued with AVU resin were 1.13~1.30 times of red pine solid wood. It was found that the extent of the increase was greater in the creep deformation than in the initial deformation.

For sitka spruce finger-jointed woods, the initial compliance showed the highest value in those glued with PVAc resin for both finger pitches, and showed the lowest values in those glued with RPF resin for 4.4 mm pitch and in those glued with AVU resin for 6.8 mm pitch. The initial compliance increased with increasing finger pitches, and the extent of the increase was greatest in those glued with PVAc resin and was smallest in those glued with RPF resin like red pine finger-jointed woods. The creep compliance for both finger-jointed woods glued with RPF resin and with AVU resin had the same tendency with their initial compliance, whereas the effect of finger pitches between finger-jointed woods glued with both adhesives was not found. The initial compliances of sitka spruce finger-jointed woods glued with PVAc, AVU and RPF resin showed 1.23~1.30, 1.02~1.05 and 0.99~1.12 times values of sitka spruce solid wood, respectively. And the creep compliances of sitka spruce finger-jointed woods glued with RPF resin showed 1.08~1.43 times values of sitka spruce solid wood and those glued with AVU resin showed 1.29~1.37 times values. The extent of the increase was found to be greater in the creep deformation than in the initial deformation like red pine finger-jointed woods. These results indicated that the effect of finger joint was greater in creep deformation than in initial deformation, and it is considered because the creep deformation by various facts such as stress concentration in finger joint part and slippage of glued line increased with increasing time.

Table 2. Results of bending creep tests for each type of finger-jointed woods

Type	Density (Mg/m^3)	$D(0.008)$ ($10^{-11}Pa^{-1}$)	CV (%)	$D_c(240)$ ($10^{-11}Pa^{-1}$)	CV (%)	Relative creep (%)	CV (%)
PS	0.518	8.10	15.6	1.51	32.3	18.3	17.3
PSR	0.558	8.65	15.2	1.84	47.6	20.3	29.6
PSA	0.541	7.81	16.2	1.96	34.0	24.6	25.6
PLR	0.537	9.73	16.5	1.85	45.9	18.2	30.0
PLA	0.552	10.3	12.9	1.71	31.9	16.3	19.0
PSCH	0.520	9.98	12.8	-	-	-	-
PLCH	0.574	12.6	16.1	-	-	-	-
SS	0.477	7.56	15.9	1.18	52.0	14.9	34.9
SSR	0.478	7.68	22.0	1.69	64.8	20.3	39.5
SSA	0.490	7.49	10.6	1.52	50.3	19.6	39.1
SLR	0.491	7.91	11.8	1.28	51.1	15.5	39.3
SLA	0.511	8.49	18.8	1.62	57.7	17.8	38.8
SSCH	0.499	9.30	6.7	-	-	-	-
SLCH	0.478	9.82	7.2	-	-	-	-

Notes : Each value is the average of four measurements, Bars(-) : Creep failure types in 106 hours. $D(0.008)$: Initial compliance at 0.008 hr, $D_c(240)$: Creep compliance except for initial creep compliance at 240 hr ($D(240)$-$D(0.008)$). SSCH : Sitka spruce finger-jointed wood-4.4 mm pitch-PVAc resin, SLCH : Sitka spruce finger-jointed wood-6.8 mm pitch-PVAc resin. CV, PS, SS, PSR, PSA, PLR, PLA, SSR, SSA, SLR, SLA, SSCH and SLCH are the same as in Table 1.

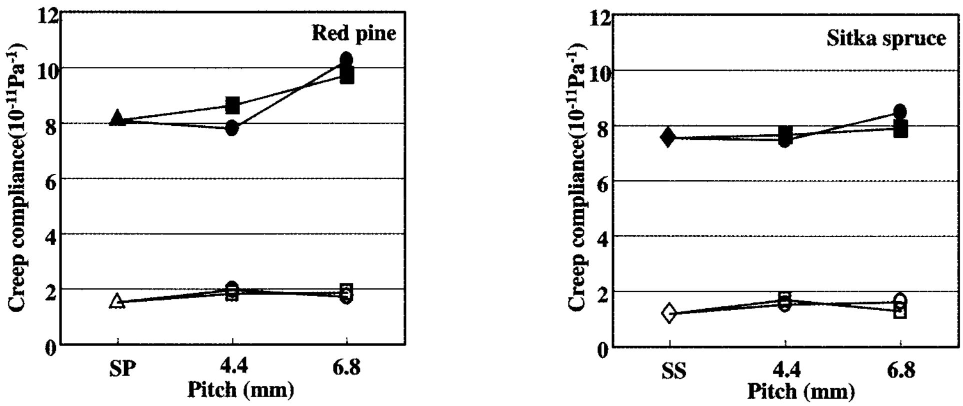
3.3. Relative Creep of Finger-jointed Woods

Fig. 6 shows relative creep of finger-jointed woods represented as the percentage of creep compliance to initial compliance. For red pine finger-jointed woods, the relative creep for 4.4 mm pitch showed the higher values in those glued with AVU resin than in those glued with RPF resin, whereas that for 6.8 mm pitch was higher than in those glued with RPF resin. Their values decreased with increasing finger pitches in both adhesives, and the extent of the decrease was found to be greater in AVU resin than in RPF resin. The values for red pine finger-jointed woods glued with RPF resin were 0.99~1.11 times of red pine solid wood and those for red pine finger-jointed woods glued with AVU resin showed 0.89~1.34 times of red pine solid wood.

For sitka spruce finger-jointed woods, the relative creep for 4.4 mm pitch showed a similar values between both adhesives, whereas that for 6.8 mm pitch was greater in those glued with AVU resin than in those glued with RPF resin. Their values decreased with increasing finger pitches for both adhesives like red pine finger-jointed woods, and the extent of the decrease was greater in RPF resin than in AVU resin. The values for sitka spruce finger-jointed woods glued with RPF resin were 1.04~1.36 times of sitka spruce solid wood and those for sitka spruce finger-jointed woods glued with AVU resin were 1.19~1.32 times of sitka spruce solid wood. The extent of the increase was found to be higher in sitka spruce finger-jointed woods than those of red pine finger-jointed woods.

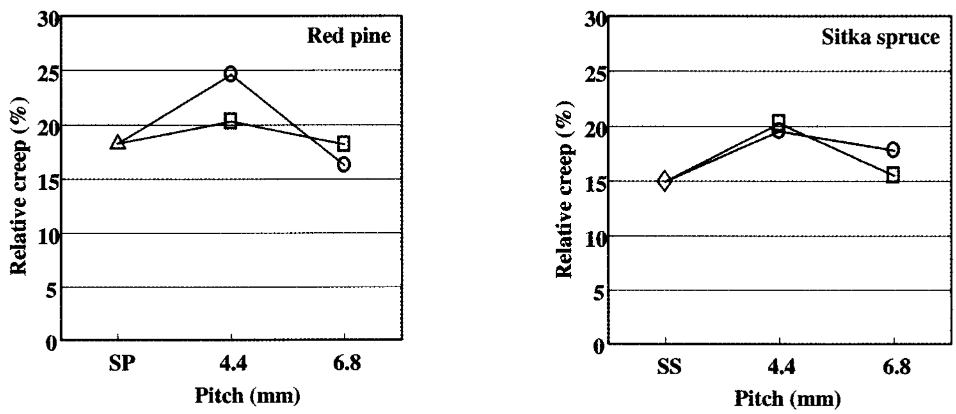
4. CONCLUSIONS

Twelve types of finger-jointed woods glued with three kinds of adhesives and with two sizes of finger pitches were made with sitka spruce and red pine in order to study the efficient use of small diameter logs and woods containing various defects, the effects of the



Legend : ▲: Initial compliance at 0.008 hr of red pine solid wood, ◆: Initial compliance at 0.008 hr of sitka spruce solid wood, ■: Initial compliance at 0.008 hr of finger jointed wood glued with RPF resin, ●: Initial compliance at 0.008 hr of finger jointed wood glued with AVU resin, △: Creep compliance at 240 hr of red pine solid wood, ◇: Creep compliance at 240 hr of sitka spruce solid wood, □: Creep compliance at 240 hr of finger-jointed woods glued with RPF resin, ○: Creep compliance at 240 hr of finger-jointed woods glued with AVU resin.

Fig. 5. Effect of finger pitches on initial deformation and creep deformation of finger-jointed woods.



Legend : △: Red pine solid wood, ◇: Sitka spruce solid wood, □: Finger-jointed woods glued with RPF resin, ○: Finger-jointed woods glued with AVU resin.

Fig. 6. Effect of finger pitches on relative creep at 240 hr of finger-jointed woods.

adhesives and finger pitches on bending creep performances of finger-jointed woods were investigated.

The shape of creep curves differed among the used adhesives and finger pitches of finger-jointed woods for both tested species. It was found that their creep curves showed a linear behavior beyond about one hour, and the N values of the creep curves fitted to power law increased with increasing finger pitches. Moreover, the N values were smaller in red pine finger-jointed woods than in sitka spruce finger-jointed woods, and there was little difference between soild woods and finger-jointed woods. The initial deformation increased with increasing finger pitches regardless of the tested species and kinds of adhesives, whereas the effect of finger pitches on the creep deformation was not clear. For finger-jointed woods glued with PVAc resin, creep failure occurred in 106 hours after the load was applied. The difference of initial and creep compliance between finger-jointed woods glued with RPF resin and AVU resin was small. Moreover, the ratios of creep performances of finger-jointed woods to solid woods were similar between both adhesives. Therefore, it was concluded that AVU resin without release of formalin after gluing was able to use as an adhesive for structural materials, whereas PVAc resin was not desirable.

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