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Creep of Sugi (*Cryptomeria japonica* D.Don) Structural Members Processed by Various Drying Methods

Shiro Aratake, Takanori Arima and Hiroshi Tanaka*
Miyazaki Prefectural Wood Utilization Research Center,
21-2 Hanaguri Miyakonojo-shi, Miyazaki, 885-0037, Japan,
Fax: +81-986-46-6047, e-mail: aratake-shiro@pref.miyazaki.lg.jp
*Miyazaki Prefectural Government, Nishiusuki Branch Office
22 Oazamitai Takachiho-cho, Miyazaki, 882-1101, Japan,
Fax: +81-0982-72-3760, e-mail: tanaka-hiroshi@ pref.miyazaki.lg.jp

In order to gather information about the influence of drying methods on long term performance, a bending creep test (B-test) and a compression creep test perpendicular to the grain (C-test) were conducted in practical conditions for the conventional construction in Japan. The specimens used were sugi (*Cryptomeria japonica* D.Don) structural members in green conditions for B-test and air-dried conditions made by various drying methods for both B-test and C-test. For the B-test, the creep test was applied at 4 points with the stress levels of standard allowable unit stress by 1.1. And for the C-test, column-and-sill joints for the conventional construction in Japan with two different tenon lengths of 90mm (S-type) and 105mm (L-type) were manufactured, then the compression creep test perpendicular to the grain was examined with the loading condition of 891kgf, which is the maximum column axial designed load for a model house. As a result, the difference of creep behavior was hardly recognized among the drying methods for both B-test and C-test, whereas the creep deflection of green specimens was much higher than that of air-dried specimens for the B-test. For the C-test, the creep displacement of S-type was much higher than that of L-type.
Key words: creep, sugi, column-and-sill joint, mechano-sorptive deflection, drying

1. INTRODUCTION

Japanese cedar, sugi (*Cryptomeria japonica* D.Don), is the most common softwood in Japan, and therefore has been used in various situations for a long time. However, because it usually contains a lot of moisture and has anatomic traits, which make drying process difficult, much research on effective drying methods has been conducted mainly targeting wooden construction [1, 2]. On the other hand, there have been few research examples on the relationship between creep performance and drying methods [3] . With this point as background, we conducted a bending creep test (B-test) and a compression creep test perpendicular to the grain (C-test) with structural members in green conditions and air-dried conditions made by various drying methods.

2. MATERIALS AND METHODS

2.1 Bending creep test (B-test)

The specimens used were 8 pieces of sugi sawn lumber with pith, whose dimensions are 10.5cm in width and depth, 230cm in length. We divided them into two groups with the same number (4 specimens), then dried the one group until the moisture content became about air-dried state and did not dry the other group. For the former group, we used kiln-drying with a temperature of 125℃ (HD) and 80-85℃ (MD), smoke seasoning with a temperature of 115℃ (SS), and natural drying under ambient conditions of 2.6-33.5℃ (ND). For the latter group, specimens (GR1, GR2, GR3 and GR4) were wrapped up in vinyl until the B-test started; so that the moisture content, which was higher than fiber saturation point, would not change. The stress of the creep test, which was standard allowable unit stress by 1.1 [4] , was applied at 4 points with the span lengths of 200cm and the load span lengths of 70cm. This creep test started on June 12, 2002 and ended on December 20, 2004. Table 1 shows the properties of specimens and drying conditions for both B-test and C-test.

2.2 Compression creep test perpendicular to the grain of column-and-sill joints (C-test)

After the B-test, which had been conducted for about two and a half years, we manufactured Japanese typical column-and-sill joints (CAS-joint) using the exact same specimens. Needless to say, GR1, GR2, GR3, and GR4, which had been green states when the B-test started, became air-dried states when those were used as the members of the CAS-joints (See Table 1). The joints applied to manufacture the CAS-joints were two types of pinned full mortise-and-tenon joints, whose tenon depths were 90mm (S-type) and 105mm (L-type), respectively (see Fig.1). Here, in the former type, it seems that stresses perpendicular to the grain at shoulder mainly support the load. In the latter type, however, because the tip of the tenons directly contacts foundations, it seems that

Table 1 Properties of specimens and drying conditions.

Specimen	Density (g/cm³)		Moisture content (%)		Modului of elasticity (GPa)		Drying conditions	
	B-test	C-test	B-test	C-test	B-test	C-test	B-test	C-test
HD	0.355	0.356	9.75	12.1	6.34	6.52	Highest dty-bulb temperature = 125℃, 7 days	
SS	0.405	0.405	11.7	12.4	6.30	6.49	Highest temperature = 115℃, 6 days	
MD	0.360	0.364	11.3	12.3	6.25	6.49	Dty-bulb temperature = 80~85℃, 10 days	
ND	0.347	0.354	12.8	14.0	6.19	6.51	Natural drying in a room	
GR1	0.641	0.355	79.5	15.3	5.85	6.40	Green condition	Natural drying during the B-test for 2.5 years
GR2	0.678	0.394	66.1	15.5	6.63	6.24		
GR3	0.501	0.379	49.4	15.3	6.05	6.76		
GR4	0.428	0.367	25.8	15.5	6.66	7.11		

Notes: B-test: Bending creep test, C-test: Compression creep test perpendicular to the grain, HD: High-temperature kiln-drying, SS: Smoke seasoning, MD: Middle-temperature kiln-drying, ND: Natural drying , GR1-GR4: Green lumber when the B-test started, and air-dried lumber when the C test started.

compression stresses parallel to the grain of columns mainly support the load. Therefore, we can not consider the latter case compression creep perpendicular to the grain; even so, we deal with both cases as compression creep perpendicular to the grain, considering the actual conditions at construction sites in Japan. The number of CAS-joints was 4 for each joint type (8 in total).

The creep test was conducted by apparatus specialized for compression and tension creep test under the ambient conditions with the loading condition of maximum column axial designed load for a model house in Japan (891kgf) [5] . For the creep test, displacement transducers (censor) were set on the CAS-joints as shown in Fig.1, and the displacement was automatically measured through a data logger with temperature and humidity during the test. Here, the censors of No1, No2, No3, and No4 were set to measure the compression creep perpendicular to the grain, while those of No5 and No6 were set to measure the contraction or swelling of sills and beams. The creep test was started on April 26, 2005 and still going on now. Incidentally, when the creep curves went into secondary creep, we started an accidental drenching test using particular equipment at regular intervals (see Fig.1). This purpose was mainly to examine an influence of drenching by a leak in roofs.

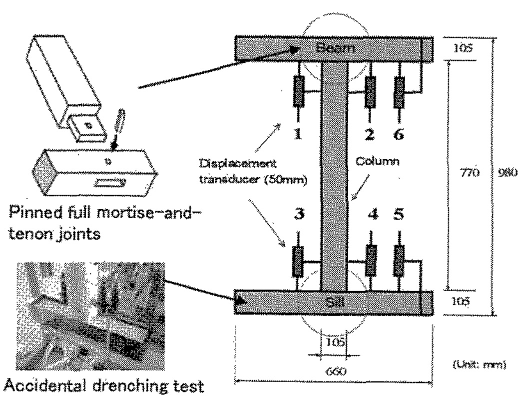

Fig.1. The shape and size of column-and-sill joints (CAS-joints) and the setting positions of displacement transducers.

3. RESULTS AND DISCUSSIONS

3.1 Bending creep test (B-test)

Fig.2 shows the changes of relative creep, which is the ratio of creep deflection including the mechano-sorptive deflection to initial deflection, and moisture content for all specimens. As a whole, difference of creep behavior among the 4 green specimens (GR1, GR2, GR3, GR4) and among the 4 air-dried specimens (HD, SS, MD, ND) was not pronounced, while that of creep behavior between green specimens and air-dried ones was remarkable. This shows that the mechano-sorptive deflection in the process of desorption, namely, in the process of drying is far more significant than the process of repetitive humidity changes, and also shows that the proper drying treatment considering the practical use for the structural lumber is extremely important [6,7] . Incidentally, SS shows the lowest relative creep in 4 air-dried specimens. In this case, soot which covered the specimen's surface might have prevented the vapor sorption and desorption, and therefore the influence of mechano-sorptive effect could have decreased.

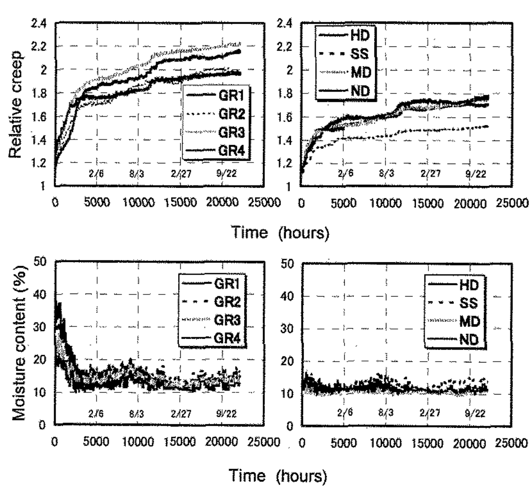

Fig. 2. Changes of relative creep and moisture content.

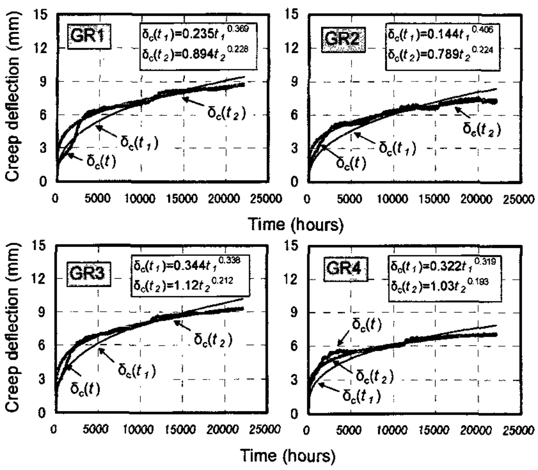

Fig. 3. Comparisons between measured creep deflections [$\delta_c(t)$] and creep deflections calculated by power law[$\delta_c(t_1)$, $\delta_c(t_2)$] for GR1,GR2, GR3 and GR4.
Legends: $\delta c(t_1)$: The creep deflections obtained from the primary and secondary creep (1-922days).
$\delta c(t_2)$: The creep deflections obtained only from the secondary creep (208-922days).

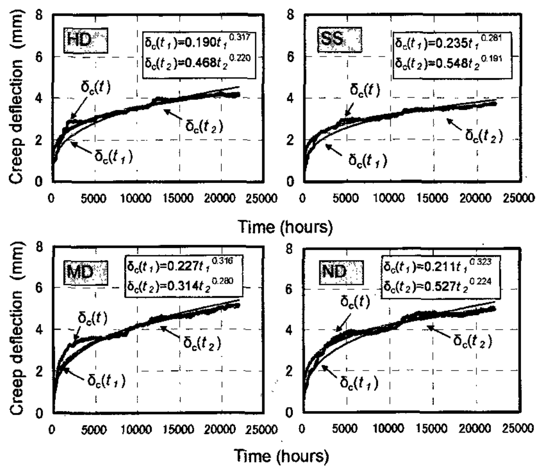

Fig. 4. Comparisons between $\delta_c(t)$ and $\delta_c(t_1)$ or $\delta_c(t_2)$ for HD, SS, MD and ND.

Fig.3 and Fig.4 shows the comparisons between measured creep deflections [$\delta c(t)$] and creep deflections calculated by following power law [$\delta c(t_1)$, $\delta c(t_2)$] for green specimens (GR1, GR2, GR3, GR4) and air-dried specimens (HD, SS, MD, ND), respectively.

$$\delta c(t_1) = At_1^N \quad [1]$$
$$\delta c(t_2) = At_2^N \quad [2]$$

Here, the constants (A and N) of $\delta c(t_1)$ were obtained from the whole curve including the primary creep (t_1=0 - 992 days), while those of $\delta c(t_2)$ were obtained only from the secondary creep (t_2 = 208 - 992 days).

As shown in Fig.3 and Fig.4, $\delta c(t_2)$ is in good agreement with $\delta c(t)$, while $\delta c(t_1)$ is gradually separated from $\delta c(t)$ in the direction of the safety side in the latter half for both green specimens and air-dried specimens. From these results, the creep deflection seems to be expressed as the sum of the power law regardless of the initial moisture content or the drying methods on condition that the constants (A and N) are obtained from the time when the creep curve becomes stable after loading (in secondary creep).

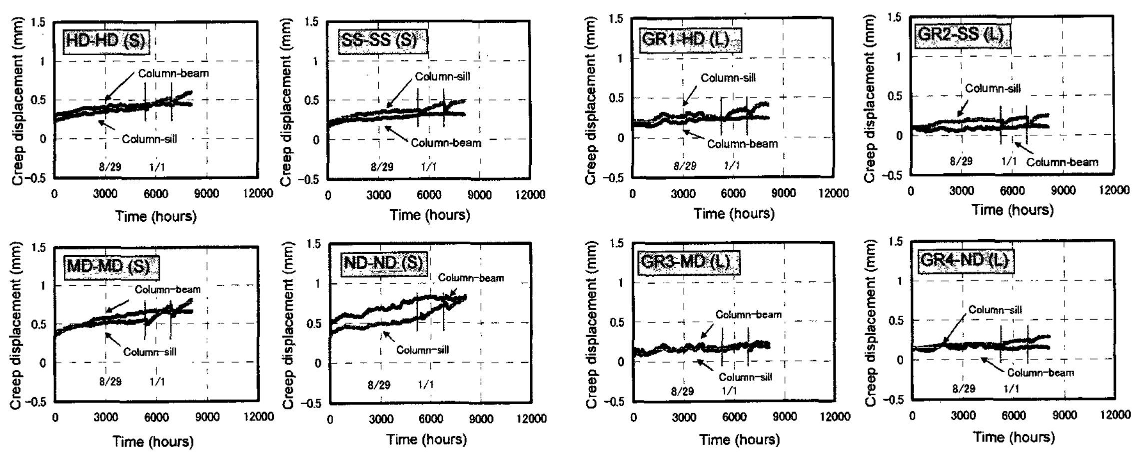

Fig.5. Changes of compression creep displacement perpendicular to the grain of column-and-sill joints (CAS-joints).
Legends: HD-HD, SS-SS, MD-MD, ND-ND, GR1-HD, GR2-SS, GR3-MD and GR4-ND: Member of beam — Member of sill, (S) : Tenon depth = 90mm, (L) : Tenon depth = 105mm, | | : The point of time when the sills were drenched for 1 hour and 3 hours from the left.

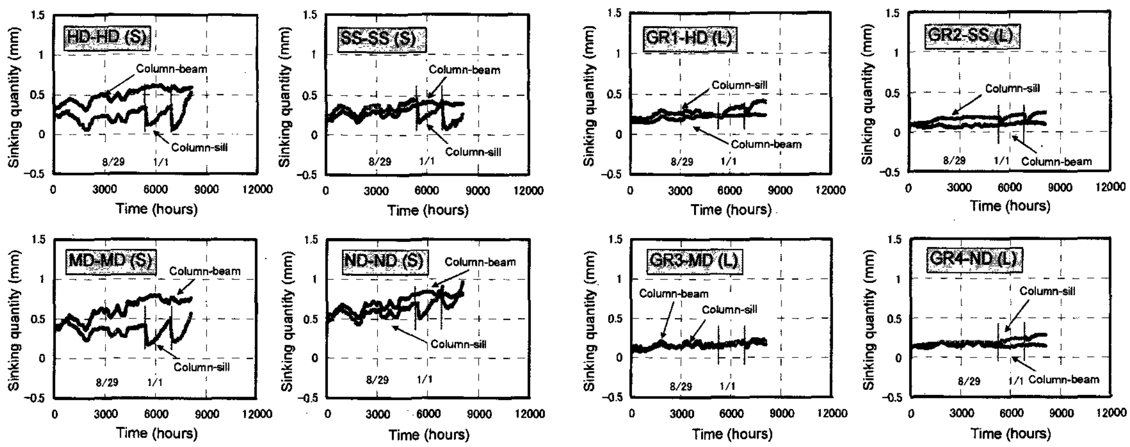

Fig.6. Changes of sinking quantity, which means sum of the creep displacement and the contraction or swelling of sills, of CAS joints.

3.2 Compression creep test perpendicular to the grain of column-and-sill joints (C-test)

Fig.5 shows the changes of compression creep displacement perpendicular to the grain of CAS joints. As a whole, the behavior of creep displacement is stable, while differences between S-type and L-type are clearly recognized. That is to say, for the L-type, the increase of creep displacement is only slightly recognized, and the difference of behavior among the 4 drying methods is not clear. On the other hand, for the S-type, the primary creep and the secondary creep are clearly recognized, and the difference of creep behavior among the 4 drying methods is also recognized, showing behavior that the lower drying temperature becomes, the more remarkable creep displacement becomes. The factors which affected this behavior could be the difference of vapor sorption or desorption performance caused by the drying temperature. Furthermore, an influence of drenching by a leak is clearly recognized only for the S-type. This behavior becomes more remarkable in the case of sinking quantity, which means sum of the creep displacement and the contraction or swelling of sills (See Fig.6). Here, in the S-type, it seems that there is a great influence of contraction or swelling of sills because the sills directly support a load at the part of shoulders. However in the L-type, there is almost no influence of contraction or swelling of sills because the tip of tenons directly contacts the foundation as was stated previously. Therefore, it can be considered that the large difference between S-type and L-type has been coming out in this experiment.

4. CONCLUSION

We conducted a bending creep test (B-test) and a compression creep test perpendicular to the grain (C-test) with structural members in green conditions and air-dried conditions made by various drying methods. As a result, the difference of creep behavior was hardly recognized among the drying methods for both B-test and C-test, whereas the creep deflection of green specimens was much higher than that of air-dried specimens for the B-test. For the C-test, the creep displacement of S-type was much higher than that of L-type.

5. ACKNOWLEDGEMENT

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