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Studies on Evaluation for Long-Term Structural Performance of *Pinus densiflora* Sieb. et Zucc. (I)[*1]

-Shear Creep and Mechano-Sorptive Behavior of Drift Pin Jointed Lumber-

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ABSTRACT

This study was carried out to evaluate the mechano-sorptive deflection of shear creep of drift pin jointed solid wood. Specimens were the solid wood of *Pinus densiflora*. The joint was composed with steel plate and drift pin, 85mm in length and 10mm in diameter. The creep tests were conducted under the constant loads in an variable environment. Five different shearing loads were applied parallel to the grain of specimens. The shearing loads applied were 170, 340, 510, 680 and 850 kgf. The stress levels were 10, 20, and 30, 40 and 50% of the bearing strength obtained from the tension-type lateral strength test. The creep tests for specimens were carried out for 10300 hours. A few general conclusions could be drawn from this study: The mechano-sorptive deflection (δms) is defined as δms = δt - (δc + δsh) - δo, where δt is the total deflection, δc is the pure creep, δsh is shrinkage-swelling behavior, and δo is the initial deflection. Changes of relative humidity may cause more severe creep deflection than those of constant humidity, especially during the drying process. The mechano-sorptive behaviors of specimens, except the effects of shrinkage and swelling, gradually increased with increasing time. The deflection is increased in desorption process and recovered in adsorption process. The deflections of drift pin jointed solid wood under different loads showed almost same tendency in all specimens. Although the creep deflection tendencies of each series are very similar, the specimens subjected to a large shearing load exhibit large creep deflections in the desorption process than do those to the small shearing load specimens.

Keywords : creep, mechano-sorptive deflection

1. INTRODUCTION

The structural performances of wooden buildings are related closely to the behaviors of the joints or connections between the members. The effect of moisture cycling can be significant and should be taken into account in wooden design when the wood structural members are exposed to the cyclic moisture conditions. The viscoelastic behaviors of joints are very important in the

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designs of wood structures. The analytical models that predict the joint behaviors are extremely complex due to the large number of influencing variables such as fastener characteristics, joint geometry, and material variability. Also, because of the large number of proprietary fasteners in the market place, the unified design methods for connections have not been developed, even for short- term loadings. Consequently, because of the complexity of the problem, few model have been developed to predict the long-term performance of timber connections.

Most joint models are based on the phenomenological studies of the lateral slip stiffness. For example, the reduction of lateral slip stiffness over time has been studied and the models were developed for the dowel-type joints, including nails and bolts, split ring connectors, and toothed plate connectors. There are few studies on the mechano-sorptive effects of the drift pin joints of wood and wood based materials. Drift pin, bolt and spilt ring connector are commonly used in the timber engineering designs. Drift pins are usually stressed in single or double shear, but more shear plane can be involved. Most studies of creep have been limited to a steady state, because it is difficult to apply the long-term variable environment to the test specimens. The purpose of this study is to present the experimental data of shear the creep deflection of the drift pin jointed solid wood under changing relative humidity (RH).

2. EXPERIMENT

The creep test specimens (40×60×300 mm) were cut from the solid wood of *Pinus densiflora*. The average modulus of elasticity (MOE), measured by the flatwise static bending test, was 100,000 kgf/cm^2. The average moisture content (MC) was approximately 11% and the specific gravity ranged from 0.54 to 0.56. The creep test specimens were made of the three-member joints with the inserted steel gusset.

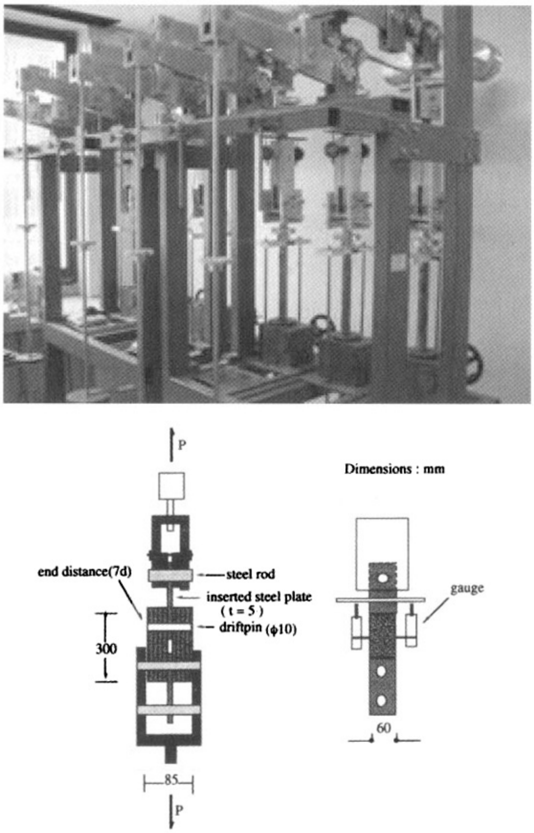


Fig. 1. Representation of the experiment.

Figure 1 shows the dimensions of the test specimen and steel gusset. The gussets were made of steel plates with 5 mm of thickness. The drift pins were 85 mm in length and 10 mm in diameter.

Shearing loads applied were 170, 340, 510, 680 and 850 kgf, and the load levels were 10, 20, 30, 40 and 50% of the bearing strength obtained from the static testing. The surface of specimen was not coated. The specimens were tested under the constant load in the changing environmental conditions (relative humidity, temperature). The test was carried out in the room that was well ventilated through a window. The creep test specimens were loaded for 10,300 hours.

In each load condition, one specimen was used for determining MC, which was monitored by a load cell recording the weight change and measuring the deflection of the loaded specimens at the same time.

During the test period one specimen was unloaded and the deflection caused by pure swelling and shrinkage under changing RH was measured. The same measurement was done on the loaded specimen.

The following abbreviations are used for the test variables in the presentation of results.

G10 (20, 30, 40, 50): corrected creep deflection loaded parallel to the grain with the constant loads of 170, 340, 510, 680, 850 kgf. The corrected creep obtained by subtracting the deflection of the unloaded specimens from the total creep deflections of the loaded specimens.

Deflection was measured to an accuracy of 0.01 mm. The RH and temperature were measured simultaneously every hour after the instantaneous elastic deflection was measured. The deflections were measured at 17:00 everyday. A gauge was mounted on either side of the connection as shown in Fig. 1, and deflection was determined with the average value of the two measurements.

Average values of RH and temperature were obtained at the interval of 18:00 of the previous day to 17:00 of the day of the deflection measurement.

3. RESULT and DISCUSSION

3.1. Creep Deflections Under Changing Relative Humidity

The mechanical properties of the wood joints or connections depend on the RH, and the dimensional changes caused by the moisture variations often lead to substantially greater deflections than those caused by the mechanical loading. Moreover, the interactions of moisture changes and mechanical loading may lead to the excessive creep deflections in the wooden structures.

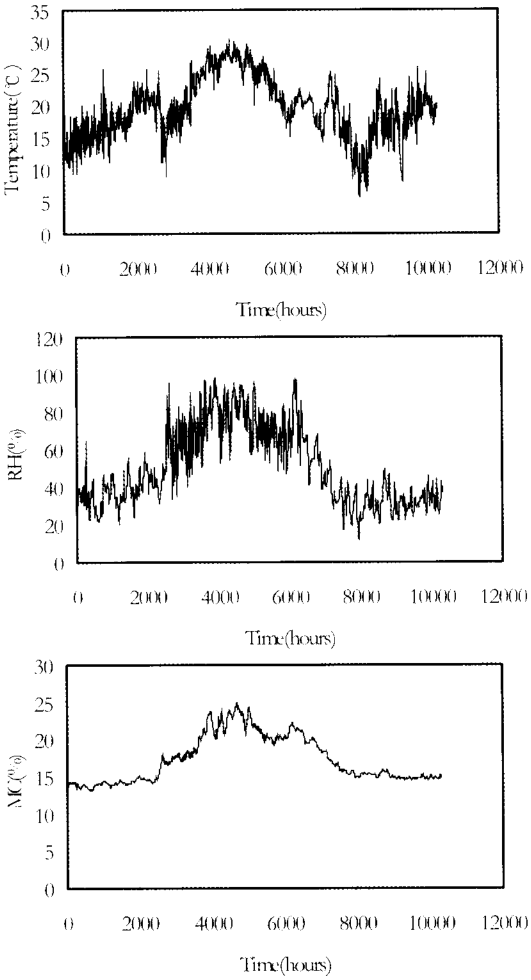


Fig. 2. Temperature, relative humidity (RH) and moisture content (MC).

The total creep under changing RH is assumed to consist of four main parts: one elastic part, one part describing pure creep under constant-humidity conditions, one part describing the shrinkage-swelling behavior, and finally one

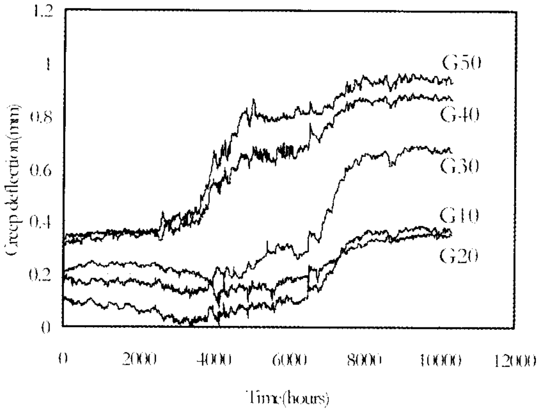


Fig. 3. Corrected (δ_t - δ_{sh}) creep deflection under varying environment.

Table 1. Relative creep of the test specimens

	r (2,000 hours)	r (6,000 hours)	r (10,300 hours)
G10	0.95	1.61	5.71
G20	1.33	1.42	2.76
G30	1.25	1.65	3.60
G40	1.35	2.66	3.41
G50	1.34	2.94	3.43

$$r = \frac{\delta_t}{\delta_0}$$

δ_0 : instantaneous deflection at initial environment
δ_t : actual creep deflection

mechanosorptive part. The constitutive relation is then $\delta_t = \delta_0 + \delta_c + \delta_{sh} + \delta_{ms}$, where δ_t = total creep; δ_0 = instantaneous deflection; δ_c = pure creep; δ_{sh} = deflection due to the shrinkage-swelling behavior; δ_{ms} = mechano-sorptive deflection. Fig. 3 shows the results for the corrected creep of specimens under changing RH. Fig. 4 shows the relation between the corrected creep and RH. The creep deflections were affected by loading until 2000 hours, and then by the changing RH. From the 2500 hours, the deflections of G40 and G50 increased with time. Deflections for G10, G20 and G30 gradually decreased until 6000 hours after the instantaneous elastic deflection and then deflection increases. This tendency may be related to the changing RH. In the high stress level, the tendencies of the deflections for G40 and G50 were similar, and the mechanism of the deflection is simple in the exposed environment. The deflections of the low stress levels are more complex than those of the high stress levels. It has been well demonstrated that the specimens loaded parallel to the grain are affected by the applied stress levels. The irregular changes of the deflection were caused by the different MCs of specimens due to the changes in RH and temperature. The desorption process increases the deflection, and the adsorption process acts in the opposite way (recovery). Until 2000 hours of load the deflection is caused by the mechanical forces and than by the sorption stress. The creep deflection, beyond stress level 0.3, increased approximately 3.6 times after 10,300 hours compared with the instantaneous elastic deflection (Table 1).

3.2. Estimation of Mechano-Sorptive Deflections

The creep displacement, excluding the effects of shrinkage and swelling of drift pin joined lumber under changing relative humidity (RH), was measured until 10,300 hours after loading. After 2,000 hours, it was observed that the creep deflection was affected severely by the change in RH (Fig. 4).

The curve of total creep is the sum of the creep of the affected load in the steady state and the quantity of deflection in the varying environmental conditions (unsteady state). Arima *et al.* reported that the creep deflection of the nailed joint was affected by the applied maximum load and time, and stabilized by adding plastic strain to the nailed joint. In this study the three-parameter model was applied to determine pure creep in the steady state of the

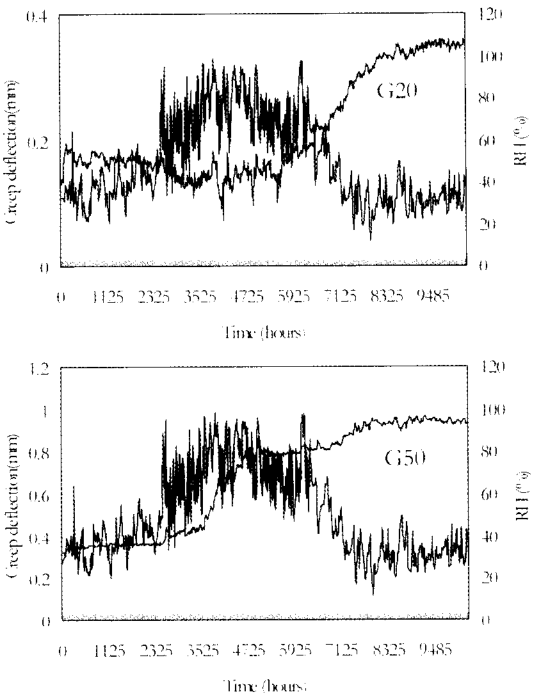


Fig. 4. Relationship between creep deflection under varying environment and RH.

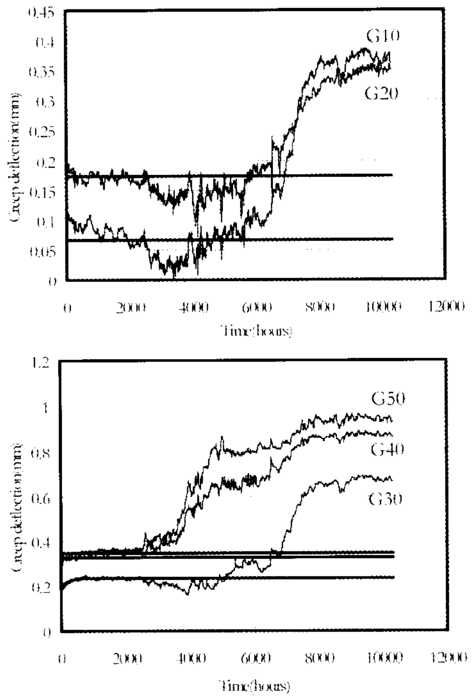


Fig. 5. Plots of projected 3-parameter model equation (MPG) and experiment data.

drift pin jointed lumber. The assummption of the steady state was based on initial conditions of the experiment.

The corrected total deflection can be predicted as the sum of the creep in the steady state (three-parameter model) and the mechano-sorptive deflection caused by varying environmental conditions. This equation (three-paramenter model) can be expressed as follows:

$$MPG = r_0 + r_1[1\text{-}\exp(1\text{-}\beta t)] \qquad (1)$$

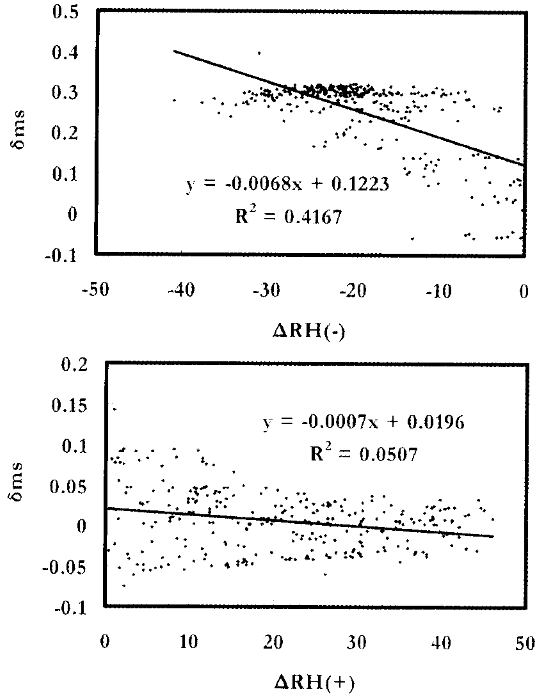
$$\delta_{ms} = G5(10,\ 20,\ 30,\ 40,\ 50) \qquad MPG \ (2)$$

where r_0= instantaneous deflection; r_1, β = coefficients; G5(10, 20, 30, 40, 50) = corrected creep deflection (δ_t - δ_{sh}); MPG = three-parameter model (δ_c + δ_0); and δ_{ms}= difference of experimental data and three-parameter model (mechano-sorptive deflection).

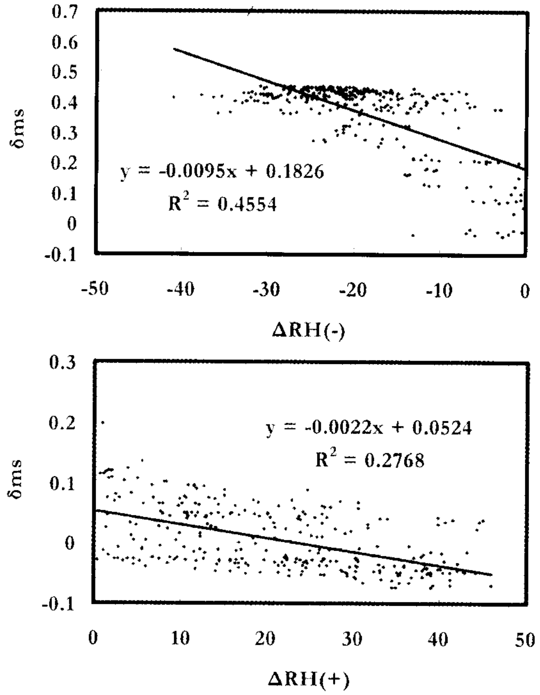
A three-parameter model for curve fitting was applied up to 2000 hours for each specimem (Fig. 5). The mechano-sorptive deflection was estimated from Eqs. (1) and (2).

$$MPG10 = 0.064 + 0.02829 \cdot \{1\text{-}\exp(-0.30414t)\}$$
$$R = 0.49$$
$$MPG20 = 0.129 + 0.04465 \cdot \{1\text{-}\exp(-0.11115t)\}$$
$$R = 0.75$$
$$MPG30 = 0.185 + 0.05252 \cdot \{1\text{-}\exp(-0.005058t)\}$$
$$R = 0.90$$
$$MPG40 = 0.254 + 0.076192 \cdot \{1\text{-}\exp(-0.04468t)\}$$
$$R = 0.89$$
$$MPG50 = 0.27 + 0.0802 \cdot \{1\text{-}\exp(-0.10798t)\}$$
$$R = 0.90$$

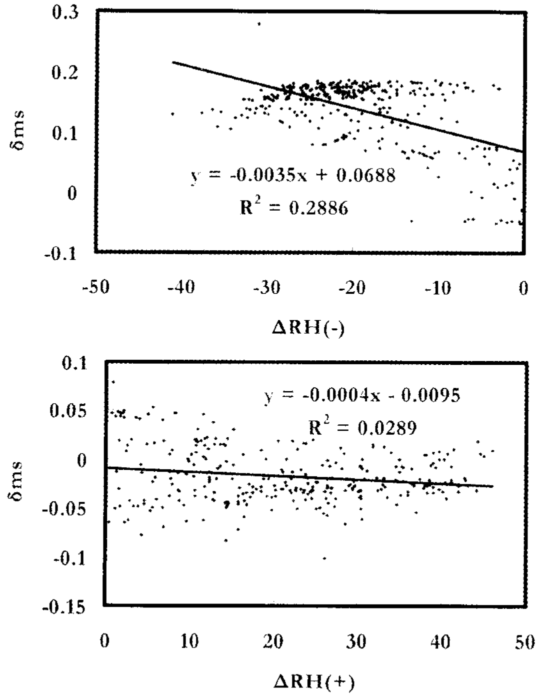
The Fig. 6 shows the relationship between the mechano-sorptive (δ_{ms}) defection and ΔRH. The mechano-sorptive deflections calculated with the equations (1) and (2) are divided into the desorption (-ΔRH) process and the adsorption (+ΔRH)


0.5
0.4
0.3
0.2
0.1
0
-0.1
δms
y = -0.0068x + 0.1223
R^2 = 0.4167
-50
-40
-30
-20
-10
0
ΔRH(-)
0.2
0.15
0.1
0.05
0
-0.05
-0.1
δms
y = -0.0007x + 0.0196
R^2 = 0.0507
0
10
20
30
40
50
ΔRH(+)

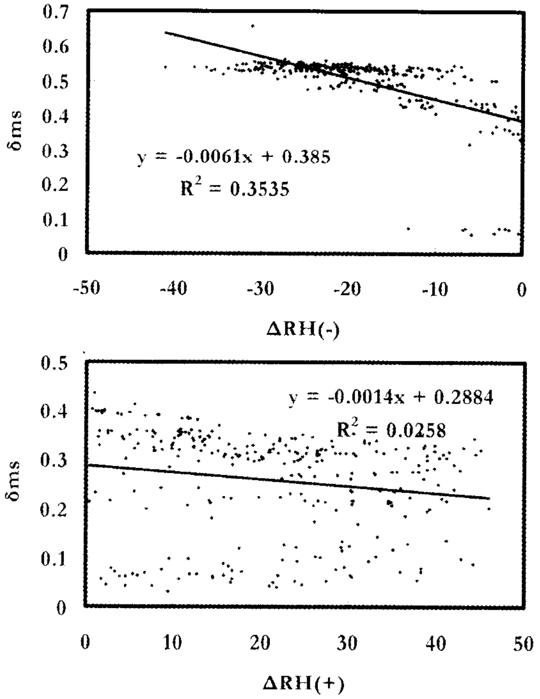
<G10>


0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
δms
y = -0.0095x + 0.1826
R^2 = 0.4554
-50
-40
-30
-20
-10
0
ΔRH(-)
0.3
0.2
0.1
0
-0.1
δms
y = -0.0022x + 0.0524
R^2 = 0.2768
0
10
20
30
40
50
ΔRH(+)

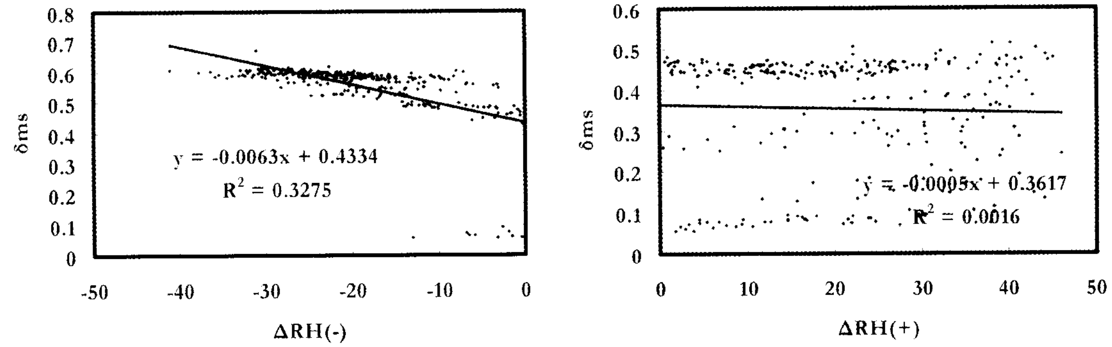
<G30>


0.3
0.2
0.1
0
-0.1
δms
y = -0.0035x + 0.0688
R^2 = 0.2886
-50
-40
-30
-20
-10
0
ΔRH(-)
0.1
0.05
0
-0.05
-0.1
-0.15
δms
y = -0.0004x - 0.0095
R^2 = 0.0289
0
10
20
30
40
50
ΔRH(+)

<G20>


0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
δms
y = -0.0061x + 0.385
R^2 = 0.3535
-50
-40
-30
-20
-10
0
ΔRH(-)
0.5
0.4
0.3
0.2
0.1
0
δms
y = -0.0014x + 0.2884
R^2 = 0.0258
0
10
20
30
40
50
ΔRH(+)

<G40>



<G50>

Fig. 6. Regression fits of mechano-sorptive deflection of desorption and adsorption process.

process, ΔRH is defined as $\Delta RH = RH_t - RH_0$. Where RH_t is current RH and RH_0 is a reference RH (initial condition of creep test RH). In all stress levels the mechano-sorptive deflections increase in the desorptions process, and are changed in the adsorption process but almost not correlated with ΔRH_s. This tendency is clearer as the stress level increases.

Even though the changes of ΔRHs are same, the mechano-sorptive deflections are changed with the loading time. Therefore, the mechano-sorptive deflections are sorted into +ΔRH and -ΔRH with the loading time, and then the multiple regression analysis is done using the mechano- sorptive deflection as the dependent variable and the ΔRH as the independent. The results are as follows.

$\delta_{ms}10(-) = 0.000047t - 0.003340\ \Delta RH \quad R=0.93$
$\delta_{ms}20(-) = 0.000034t - 0.001064\ \Delta RH \quad R=0.94$
$\delta_{ms}30(-) = 0.000062t - 0.004962\ \Delta RH \quad R=0.94$
$\delta_{ms}40(-) = 0.000046t - 0.002793\ \Delta RH \quad R=0.89$
$\delta_{ms}50(-) = 0.000047t - 0.002790\ \Delta RH \quad R=0.86$

$\delta_{ms}10(+) = 0.000031t + 0.000069\ \Delta RH \quad R=0.91$
$\delta_{ms}20(+) = 0.000020t + 0.000082\ \Delta RH \quad R=0.75$
$\delta_{ms}30(+) = 0.000037t - 0.001337\ \Delta RH \quad R=0.92$
$\delta_{ms}40(+) = 0.000091t + 0.000811\ \Delta RH \quad R=0.92$
$\delta_{ms}50(+) = 0.000120t - 0.002436\ \Delta RH \quad R=0.89$

The mechano-sorptive deflections increase with the loading time in the desorption (-ΔRH), and are changed in the adsorption (+ΔRH) but much less than those in the desorption. The fluctuations of deflections by the loading time and the changes of ΔRHs are higher in the desorption than in the adsorption, and the creep deflections under the temperature and humidity changing increase in the desorption but are recovered in the adsorption.

4. CONCLUSION

The creep deflections were affected by loading until 2,000 hours, and then by the changing RH. Deflections for G10, G20 and G30 gradually decreased until 6,000 hours after the instantaneous elastic deflection and then deflection increases. From the 2,500 hours, the deflections of G40 and G50 increased with time. This tendency may be related to the changing RH. In the high stress level, the tendencies of the deflections for G40 and G50 were similar. The mechanism of the deflection is simple in the exposed environment. The mechano-sorptive deflections increased with the loading time in the desorption (-ΔRH), and were changed in the absorption (+ΔRH) but much less than those in the desorption. The fluctuations of deflections by the loading time and the changes of ΔRHs were higher in the desorption than in the absorption. The creep deflections under the temperature and humidity changing increased in the desorption were recovered in the absorption.

The result of our study indicates that the mechano-sorptive deflection decreases with increasing load level and increasing RH changes. There was less mechano-sorptive deflection increase in a highly stressed joint than in a low-stressed joint. The mechano-sorptive behaviors are caused by the interaction of sorption and mechanical stress. The desorption process causes increases deflection, and the adsorption process acts in the opposite way (recovery).

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