DEVELOPMENT OF CONNECTING METHOD FOR TIMBER STRUCTURE USING EXPANDING DENSIFIED WOOD - APPLICATION TO KEYED MORTISE AND TENON CONNECTION WITH DENSIFIED WOOD

Masaya Kato¹, Akinori Iwasaki², Kei Tanaka¹ and Masafumi Inoue¹

ABSTRACT: In recent year, for rubbish disposal and waste problem, the segregation of wood and the metal are difficult problem to be solved. The problem will be solved to use the wood based connector such as densified wood connector instead of metal connector at joints in timber structures. In this study, the densified technique is adopted for sugi. The usage of densified sugi lead to improve recycling rate because the segregation is not necessary. The strength characteristics of keyed mortise and tenon connection with key made from densified sugi was unveiled by the tension test of joint. From the test results, the key made of 70% densified ratio without steam treatment is suitable for keyed mortise and tenon connection.

KEYWORDS: Densified wood, Sugi, Expanding, Keyed mortise and tenon connection, Tension test

1 INTRODUCTION

In recent year, the rubbish disposal and waste problem should be solved in all industry. The technology to promote the recycling of construction waste is not yet established. Especially, for the construction waste, the recycling ratio is lower than that of other industry. One of the reason for this problem is that the segregation of wood and the metal are difficult. It is preferable to substitute the metal connector to wooden connector in timber structures. The hardwoods are generally used for the connector in timber structures such as dowel. However, the percentage of hardwood in the wood resource is few. Sugi is typical artificial softwood in Japan. On the other hand, the resource of sugi is huge in Japan. The densified technique is adopted for sugi. The usage of densified sugi leads to improve recycling rate because the segregation is not necessary. The strength characteristics of keyed mortise and tenon connection with key made from densified sugi was unveiled by the tension test of joint.

2 OVERVIEW OF KEYED MORTISE AND TENON CONNECTION

Figure 1 shows the detail of a keyed mortise and tenon connection. The keyed mortise and tenon connection is composed of beam with long tenon, column with mortise and key. This is a traditional detail of connection in Japan.

3 DENSIFIED METHOD

The outline of method of densification was shown as below. The densified woods are compressed to the direction perpendicular to fiber. Only sugi materials are compressed. The sugi materials are pressed by cold-press.
after microwave treatment by high frequency oven for one minute. The sugi materials were fixed about 3 days after compressed. Steam treatment is used to expand densified sugi in artificial expanding method. The definition of densification ratio is shown Eq.(1).

\[
\text{Densification ratio} = \frac{A - B}{A} \times 100 \quad (\%) \quad (1)
\]

where A=thickness before densification, B=thickness after densification.

4 TENSION TEST OF JOINT

4.1 TESTING METHOD

The list of specimens is shown in table 1. The parameters of this test are species of the key, difference of densified ratio of the key, and difference of steam treatment time at the densified sugi. The parameters of the species of the key are sugi, hinoki and oak. Difference of densified ratio at the keys are 0%, 30%, 50% and 70%. And difference of steam treatment times at densified sugi are 0min, 1min, 3min and 5min.

All specimens are loaded by monotonous tension loading.

**Table 1: List of specimens in tension test**

<table>
<thead>
<tr>
<th>Name</th>
<th>Species</th>
<th>Density ($10^3$kg/m$^3$) Before densification</th>
<th>Density ($10^3$kg/m$^3$) After densification</th>
<th>Densified ratio (%)</th>
<th>Steam treatment time</th>
<th>Number of sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>NPJ-S</td>
<td>Sugi</td>
<td>0.34~0.36</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NPJ-H</td>
<td>Hinoki</td>
<td>0.44~0.48</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NPJ-K</td>
<td>Oak</td>
<td>0.76~0.83</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NPJ-Cw 5-S-30-S3</td>
<td>Sugi</td>
<td>0.36~0.43</td>
<td>0.38~0.56</td>
<td>30</td>
<td>3min</td>
<td>2 samples</td>
</tr>
<tr>
<td>NPJ-Cw 5-S-50-S3</td>
<td>Sugi</td>
<td>0.35~0.41</td>
<td>0.52~0.60</td>
<td>50</td>
<td>3min</td>
<td>2 samples</td>
</tr>
<tr>
<td>NPJ-Cw 5-S-70-N</td>
<td>Sugi</td>
<td>0.39~0.41</td>
<td>1.02~1.05</td>
<td>70</td>
<td>3min</td>
<td>2 samples</td>
</tr>
<tr>
<td>NPJ-Cw 5-S-70-S1</td>
<td>Sugi</td>
<td>0.30~0.41</td>
<td>0.90~1.05</td>
<td>70</td>
<td>3min</td>
<td>2 samples</td>
</tr>
<tr>
<td>NPJ-Cw 5-S-70-S3</td>
<td>Sugi</td>
<td>0.30~0.41</td>
<td>0.90~1.04</td>
<td>70</td>
<td>3min</td>
<td>2 samples</td>
</tr>
</tbody>
</table>

4.2 TEST RESULT

4.2.1 Failure mode

Photo 1 and 2 shows typical failure mode. Final failure modes are fracture of key in all specimens.

**Photo 1 and 2: Failure mode**

4.2.2 Initial stiffness

Initial stiffness of all specimens are shown in figure 2. In specimens used non-densified key, initial stiffness are almost the same values. Compared to the difference of densified ratio, specimens for 50% of densified ratios are the highest values. At the difference of steam treatment time, specimens without steam treatment are the highest stiffness. Initial stiffness decreases gradually to steam treatment time becomes longer.

4.2.3 Maximum load

Maximum loads of all specimens are shown in figure 3. In specimens used non-densified key, maximum load is increased to density becomes higher. Compared to the difference of densified ratio, specimens used key for 70% of densified ratios are the highest values. At the difference of steam treatment time, specimens without steam treatment are the highest values. Maximum load decreases gradually to steam treatment time becomes longer.

**Figure 2: Initial stiffness**

**Figure 3: Maximum load**

5 CONCLUSIONS

The following conclusions obtained from the results of tension test. Key made of 70% densified sugi without steam treatment have higher initial stiffness and maximum load than oak. Initial stiffness and maximum load decreases gradually to the time of steam treatment becomes longer.

Therefore, the key made of 70% densified sugi without steam treatment is suitable for keyed mortise and tenon connection.