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Relationship between bending performance and chip size of strand board made from reed

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Abstract

In this article, we report the development of Reed Strand Board (RSB), which is a strand board made from reed. Recently, reed is little utilized with the decline of reed industries in Japan. The aim of this study is to develop a new effective use of reed. However, the reed in raw state has large variations in strength and dimensions. Therefore it is very difficult to use as a structural material despite having similar tensile strength to wood and bamboo. For the purpose of eliminating the variations of strength and dimensions of the material, a strand board is developed in which reeds are finely cut and chipped and hot pressed with an adhesive. In this paper, we investigate the relationship between the size of reed chip and the bending properties of the board.

Keywords: composite materials, strand board, reed, bending strength, bending modulus

1. Introduction

"Nishi-no-ko Lake" (Western Lake) located in Omihachiman-City, Shiga Prefecture, has the largest area among the endorheic lakes of "Lake Biwa", and has vast reedbeds that are dispersed over the lakefront. In the past, reed has been a valuable resource which supported daily necessities and local industries, marsh-reed screen, reed roofing, etc. However, as such lifestyle and industry has recently declined, the use of reed has greatly diminished. In the case of the Nishi-no-ko Lake, unmanaged reed has grown to the point to whereby the landscape of the lake is significantly impacted, and there are concerns that unattended field expansion could deteriorate and pollute water quality through eutrophication.

A solution of structural applying to this problem can be a sustainable utilization of reed. For this purpose, we have tried to design temporary pavilions [1], [2] using large quantities of reed and held an exhibition to demonstrate construction possibilities as shown in Figure 1.

Figure 1: Reed pavilions [1] (from left to right: Reed Dome 2016, Reed Field 2017, Reed Cocoon 2018)

In these constructions, the reeds were not processed at all and used in raw condition. Although, the reed in raw state has high average tensile strength as shown in the next section, the variation is large.

Moreover, the dimensions also vary widely among individuals, and it is not easy to use as a structural material in raw state.

For the purpose of eliminating variations in strength and dimensions of reeds, we develop "Reed Strand Board" (RSB) in which reeds are finely cut and chipped and formed together with an adhesive by hot pressing. The mechanical properties, appearance, touch, etc. of the strand board are greatly affected by the manufacturing method. There have been reported some trials. Hermawan *et al.* [3] reported a research to make strand board utilizing construction waste. In recent years, researches to evaluate mechanical properties of Oriented Strand Board (OSB) more accurately (Jin *et al.* [4], Wang *et al.* [5]) are also being conducted.

Since wood waste and scraps can be used as chips for strand boards, it is effective to develop methods for stabilizing strand board performance from the viewpoint of ecology and resource conservation as well. In this paper, with the aim of using reed as a structural material, a basic research on RSB is conducted focusing on the relationship between reed chip size and bending performance.

2. Mechanical properties of reed

In this section, basic characteristics such as dimensions and tensile strength of reed (scientific name: *Phragmites Australis*) are shown. Management of reedbed is generally conducted in a one-year cycle. The reed that grows from spring to autumn is harvested in winter and dried for several months before using later in that year. The reeds used in this research were all harvested one year after germination and stored for about half a year in an indoor warehouse.

Using 217 standing trees of reed, the diameter, thickness, and weight per meter of length were measured by the method shown in Figure 2. In addition, 10 individuals were extracted from each of Sections 1 and 2 within 2 m from the root on the root side, and tensile tests were performed.

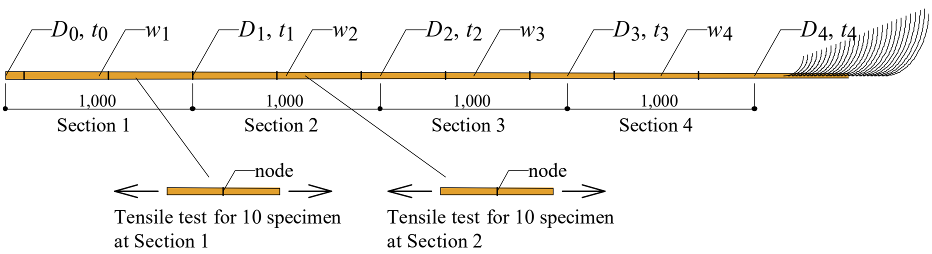


Figure 2: Sampling method of test specimen and measurement items

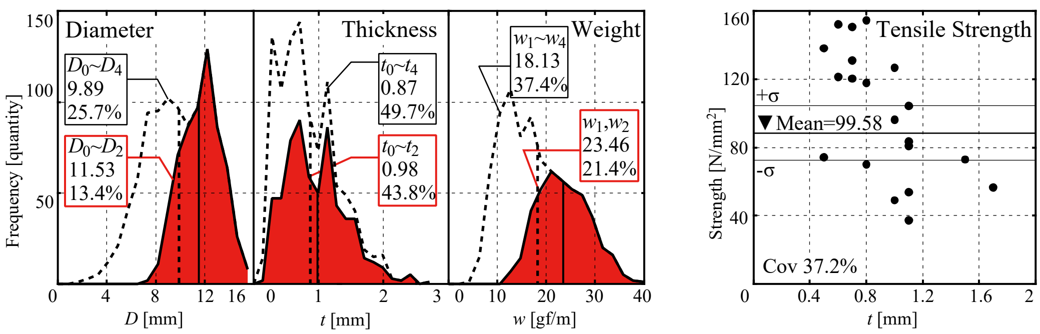


Figure 3: Distribution of measured values (left), scatter plot of tensile strength (right) [2]

The distributions of each value are shown on the left side of Figure 3. The solid line represents the distribution of measured values within 2 m from the root (sections 1 to 2, shaded portions in red), and the dotted line represents the measured values within 4 m from the root (sections 1 to 4). The average (vertical line) and the coefficient of variation (%) are shown in the figure. The diameter and weight decrease in average value from the root of the reed to the tip, but the stem thickness changes little with the location and the distribution is similar. The average tensile strength shown on the right side of the figure is about 100 N/mm^2, which is equivalent to wood (cedar, cypress) or bamboo generally used in Japan. Tensile failure occurs at the node on the stem. Also, a negative correlation is observed between tensile strength and stem thickness.

3. Manufacturing RSB for test trial

3.1. Manufacturing procedure

The basic preparation procedure of RSB is the same as that of commercially available OSB. Figure 4 shows a procedure of RSB for this test trial. First, the well-naturally-dried reeds are finely crushed using a chipper. Next, the chips are stirred while spraying an adhesive with a spray gun. The adhesive is an aqueous polymer-isocyanate adhesive. This is a kind of thermosetting resin adhesive and is widely used in Japan for the production of laminated wood and CLT. It is certified that the emission of formaldehyde after curing is extremely low, and there is no restriction on the place of use by JIS standard. After thoroughly stirring the reed chips and the adhesive, they are spread in a rectangular mold, and the pressing plates of the hot press are brought into a state of 150 to 200 degrees Celsius, and pressure is applied so as to achieve a target thickness. The RSB in this article is produced with the aim of achieving a specific gravity of about 0.7 after reference to a commercially available OSB. The thickness of the RSB is 10 mm, and the pressure required for that purpose is about 40 to 50 Mpa. The thickness is controlled by a steel plate spacer. The period of pressure application is 6 minutes.

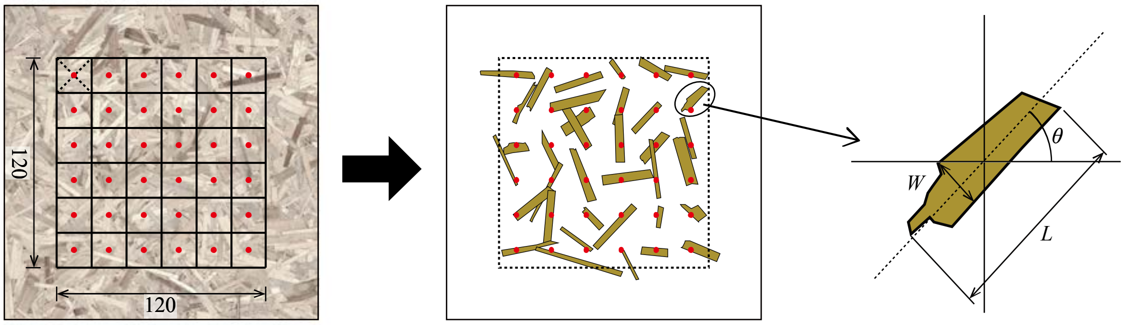
Figure 4: Manufacturing procedure of RSB

Table 1: Parameters of RSB specimen

Name	Target chip Length (mm)	Thickness (mm)	Board size (mm)	Weight (g)	Specific gravity	Adhesive weight ratio (%)
S1	30	10	286 × 289	603.0	0.730	5.571
S2	30	10	275 × 290	556.9	0.698	5.571
S3	30	10	276 × 282	596.6	0.767	5.521
S4	30	10	273 × 282	542.8	0.705	5.521
S5	30	10	279 × 288	646.1	0.804	5.252
S6	30	10	273 × 273	530.4	0.712	5.252
S7	30	10	275 × 285	543.5	0.693	5.169
S8	30	10	275 × 277	542.6	0.712	5.169
L1	70	10	280 × 282	557.9	0.707	5.571
L2	70	10	287 × 287	582.1	0.707	5.571
L3	70	10	265 × 269	526.1	0.738	5.123
L4	70	10	274 × 276	556.4	0.736	5.123
L5	70	10	273 × 273	580.7	0.779	5.368
L6	70	10	278 × 292	590.4	0.727	5.368
L7	70	10	254 × 274	496.7	0.714	5.532
L8	70	10	278 × 278	564.9	0.731	5.532

3.2. Configuration of reed chip in RSB

For each RSB specimen, we investigate the configuration of reed chips. The items are the size (length, width) and angle of reed chips on both surfaces of the board. In the measurement, the average value and the coefficient of variation of each item are calculated over the reed chips randomly extracted from each surface of the specimen. The method of sampling is shown in Figure 5. A grid of 6 squares x 6 squares (one square is 20 mm square) is placed on the center of the board surface, and a reed chip at the center of each square (red dot) is selected. In this way, 36 extracted chips were measured.



Place a grid to center of board | Extract 36 reed chips | Measureed values

Figure 5: Extraction method of reed chip on board

Table 2 shows the measured values of the chip size and angle of each specimen. The angle was measured in the range of ± 90 degrees, with the span direction of the bending test shown in the next section being zero degree. The mean and variance of the angles are calculated for absolute values. The "Upper surface" and the "Lower surface" of the board are respectively corresponding to each surface at the time of hot pressing.

Table 2: Size and angle of reed chip on board surface (Cov: %)

Name	Upper surface						Lower surface					
	Length (mm)		Width (mm)		Angle (deg.)		Length (mm)		Width (mm)		Angle (deg.)	
	Mean	Cov	Mean	Cov	Mean	Cov	Mean	Cov	Mean	Cov	Mean	Cov
S1	26.8	20.7	4.22	33.5	49.3	55.1	23.6	27.2	4.31	45.7	57.8	39.9
S2	27.5	25.5	5.00	36.8	45.6	53.2	21.4	31.0	3.58	38.6	43.8	57.1
S3	29.6	32.0	5.03	41.5	45.3	55.8	25.4	32.5	3.50	32.6	40.9	58.0
S4	26.2	17.9	4.00	41.7	36.3	64.9	17.1	41.0	3.06	36.9	56.4	35.8
S5	30.1	25.7	4.11	41.3	46.9	49.9	25.3	27.4	4.22	46.4	53.8	43.8
S6	30.1	34.8	4.36	52.7	49.8	42.5	23.1	34.7	4.00	39.1	35.2	61.1
S7	34.0	47.2	4.33	34.8	54.2	49.1	19.6	43.8	4.28	55.5	51.0	51.0
S8	27.0	19.6	4.56	37.1	45.8	51.2	20.7	36.9	3.97	37.3	48.3	52.9
L1	61.5	48.6	5.72	34.6	53.3	42.1	36.1	42.6	4.94	52.4	50.6	43.6
L2	62.5	33.3	5.78	31.9	43.0	57.8	40.0	32.8	4.47	32.3	39.6	63.9
L3	62.9	40.9	5.42	41.4	55.8	40.4	36.0	45.7	3.81	28.9	41.2	68.4
L4	43.2	40.2	4.31	36.2	46.7	53.2	39.5	39.0	4.28	41.1	40.8	56.0
L5	69.1	28.0	4.94	34.7	57.7	35.2	53.1	34.3	5.53	32.6	41.3	64.2
L6	56.4	33.4	5.92	61.4	43.4	53.3	52.3	49.5	5.17	43.9	53.3	44.7
L7	72.2	34.6	5.00	39.4	46.1	53.2	59.2	31.3	5.53	43.4	49.2	39.2
L8	70.1	42.8	5.89	42.7	51.1	49.9	45.5	49.0	4.56	44.6	51.5	48.4

The average chip size on the top surface of "S-series" (S1, S2, …) and "L-series" (L1, L2, …) is sufficiently close to the target value (30, 70 mm) respectively. However, the average chip length is generally smaller on the lower surface than on the upper surface. This is because small pieces are easily accumulated at the bottom when chips are laid in the formwork. The average value of the angles is around 45 degrees for any specimens because the orientation of the chip cannot be controlled in this trial production.

4. Bending test

4.1. Testing method

In order to calculate the bending strength and bending Young's modulus of the RSB specimen, a bending test was conducted by the method shown in Figure 6. The test is a 3-point bending with both ends simple supported, and the span between fulcrums is 210 mm. As described in the previous section, the average chip length is different on the upper and lower surface of the board. Therefore, in order to observe the influence from such condition, the upper surface of each series 1 to 4 is set to loaded surface (the lower surface is in a tensile state), and the lower surface of 5 to 8 is set to loaded surface (the upper surface is in a tensile state).

Figure 6: Bending test condition (left and middle) and failure situation after test of S1 (right)

4.2. Test results and analysis

Figure 7 shows the bending stress-deformation relationship of each test body. The left side of the figure shows the results of "S series", the right shows "L series". The bending stress and deformation are both calculated at the center of the board (loading point).

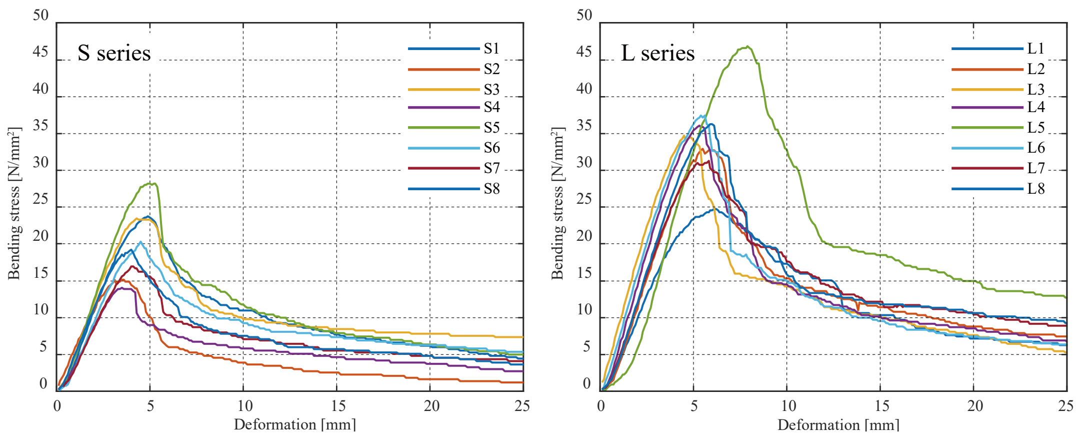


Figure 7: Bending stress-deformation relationship of RSB (left: S series, right: L series)

The main cause of breakage is separation of reed chips on the opposite side of the loading point (center of the span), and almost no tensile breakage of the chip itself occurs. In addition, no particular damage was observed at both end fulcrums. All the specimens show linear behavior up to the maximum load, and the load drops sharply after the maximum load.

Table 3 shows the bending strength and the bending Young's modulus of each specimen. The bending Young's modulus is calculated as secant stiffness connecting a load of 0.4 times the maximum load and the origin. The "L series" is overall superior than the "S series" in both bending strength and bending Young's modulus.

Figure 8 shows the relationship between chip length and bending performance. The bending strength have an evident positive correlation with the chip length. Table 4 shows the correlation coefficients between the chip length on each surface and the bending performance. The values of the bending stress are all 0.7 or more. Therefore, accurate control of the chip length and minimizing the variation is important for stabilizing the bending strength of RSB. However, the bending Young's modulus is not so strongly correlated as the bending strength.

Table 3: Bending strength and bending Young's modulus of RSB

Name	Loaded surface	Bending strength (N/mm^2)	Bending Young's Modulus(N/mm^2)
S1	Upper	23.79	3780.71
S2	Upper	15.12	4233.60
S3	Upper	23.51	4189.21
S4	Upper	14.08	2854.22
S5	Lower	28.23	4485.61
S6	Lower	20.31	3227.28
S7	Lower	16.95	3020.67
S8	Lower	19.24	3901.81
L1	Upper	24.75	3549.51
L2	Upper	32.93	4302.44
L3	Upper	34.71	6583.60
L4	Upper	36.10	5177.06
L5	Lower	46.85	3992.11
L6	Lower	37.39	5942.31
L7	Lower	31.25	4481.99
L8	Lower	36.26	4536.23

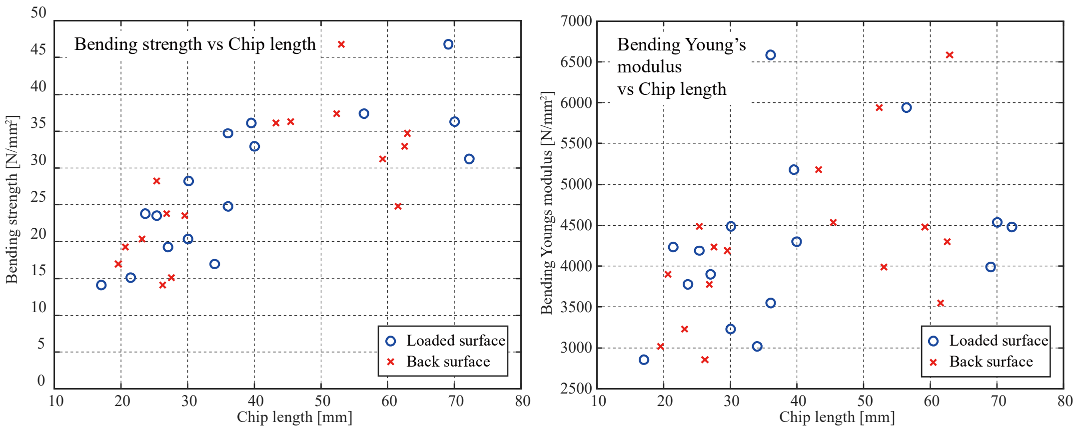


Figure 8: Relationship between bending performance and chip length

Table 4: Correlation coefficient between chip length and bending performance

Surface	Bending strength	Bending Young's modulus
Upper	0.784	0.338
Lower	0.712	0.558

Figure 9 shows the relationship between the bending performance and the angle of the reed chip. In this trial production, the orientation of the chip could not be controlled, so the average angles (absolute values) are concentrated around 45 degrees. In this range, it is difficult to specify the relationship between the chip angle and the bending performance.

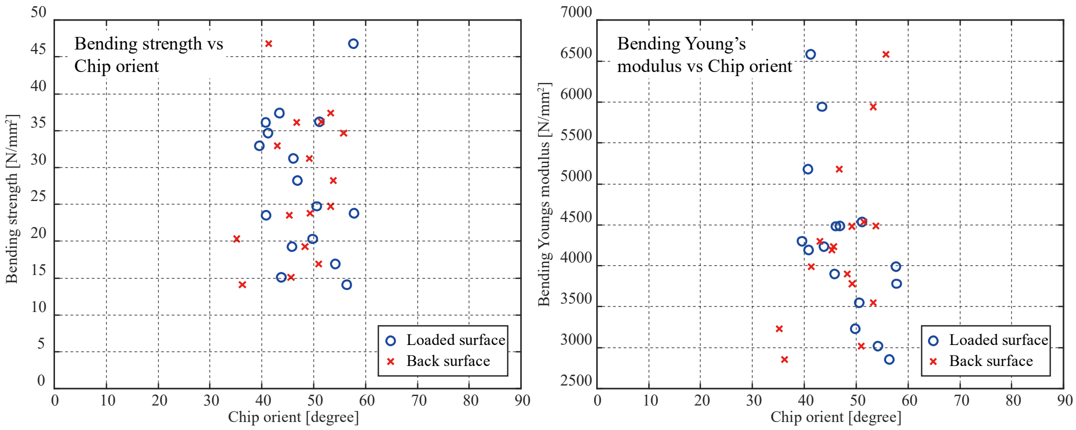


Figure 9: Relationship between bending performance and chip angle

5. Conclusion

In this article, the manufacturing procedure of the strand board using reed and the bending test results were shown. The bending strength of the board have a strong correlation with the chip length, and it was confirmed that a specimen with mean length of 60 mm or more had a sufficient bending strength for structural utilization. Therefore, the development of a method to accurately manage the chip length and minimize the variation is an important challenge to be addressed.

On the other hand, with regard to the bending Young's modulus, the chip length was not so correlated with that. The stiffness might be presumed to have a significant effect on the chip angle. The relation between bending stiffness and chip angle also should be studied in the future.

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