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Long-term Behaviour of Steel-strip Reinforced Wood Shaving–cement Board Roof Panel

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Abstract

In order to provide a better understanding of the behaviour of a steel-strip reinforced high-density wood shaving–cement board flexural member, a 3-year long-term loading test was carried out on midsize beams and full-scale ribbed roof panels. The long-term behaviour of the members is presented and explained. The test results indicate that a steel strip has a significant influence on long-term stiffness. It is also shown that the long-term load-carrying capacity of the flexural members is about 0.5 × the short-term load-carrying capacity and the long-term deflection is about 1.6–2.5 × the short-term deflection. © 1998 Elsevier Science Ltd. All rights reserved.

Keywords: steel-strip, wood shaving-cement board.

INTRODUCTION

High-density wood shaving–cement board is a low cost and energy-efficient material.[1–4] In order to use this material more rationally I carried out a study on a steel-strip reinforced wood shaving–cement board flexural member.[5] The reinforced specimens showed a good short-term performance in an earlier study.

However, it should be noted that the properties of wood shaving–cement board are time dependent. Creep is an inherent feature of wood and hydrated cement. In addition, during manufacturing, if any water in excess of the amount required for the chemical reaction with the cement is present in the mix, part of that water remains in a free state at the interface of the wood shaving and the cement paste, forming pores and voids in the board. These pores and voids may induce microcracking due to the variations in temperature or humidity prior to application of the load. Under long-term loading conditions, the length, width and number of the very fine cracks existing at the interface, and also the creep of the wood shaving and the cement paste, increase with increasing time, resulting in a decrease in the load-carrying capacity and stiffness of the member.

In order to obtain a better understanding of the long-term behaviour of flexural members an experimental study of the long-term behaviour was carried out simultaneous with an investigation of the short-term performance of the flexural members.[5]

MATERIALS

In order to obtain a more reliable comparison the same batches of materials as used previously in a short-term study[5] were chosen. The main short-term mechanical properties of the wood shaving–cement board are listed in Table 1. The strength and elastic modulus of the steel strips are given in Table 2. A mixture of unsaturated polyester and silicon powder was chosen as an adhesive for gluing the wood shaving–cement board and the steel strip.

Table 1. Short-term mechanical properties of wood shaving–cement board

Mechanical properties	*Number of specimens*	*Average*	*Cov (%)*
Bending tension strength R_{ft}	9	6.9 MPa	9.9
Bending elastic modulus E_f	9	5571 MPa	17.0
Compression strength R_c	21	11.5 MPa	13.8
Compression elastic modulus E_c	21	6846 MPa	7.6
Poisson's ratio μ	14	0.223	19.2

SPECIMEN PREPARATION AND LOADING METHOD

Two series of specimens (Fig. 1 and Fig. 2, Table 3) were prepared for the long-term loading test. They were made at the same time as the short-term loading specimens.[5]

First series — midsize specimens

The first series included three plain wood shaving–cement board rectangular beams with a

Table 2. Testing data of mechanical properties of steel strips

Thickness (mm)	*Number of specimens*	*Mechanical properties*	*Average (MPa)*	*Cov. (%)*	*Remarks*
1	10	Yield strength Rs	241	10.3	Hot rolling
		Ultimate strength Rsu	392	13.2	
		Elastic modulus Es	200180	4.1	
2	8	Yield strength Rs	223	10.0	Cold rolling
		Ultimate strength Rsu	345	12.7	
		Elastic modulus Es	214394	8.1	

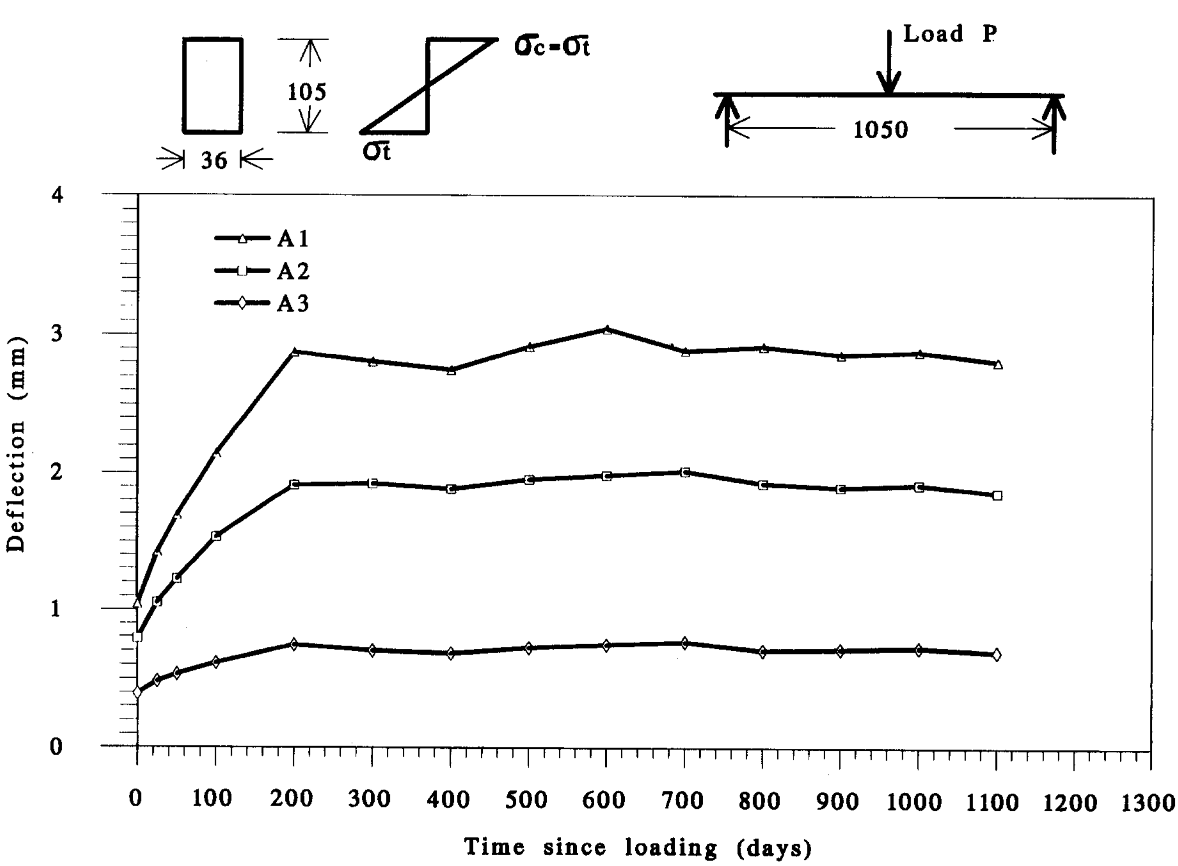

Fig. 1. Cross-sectionand time–deflection curves for plain beams.

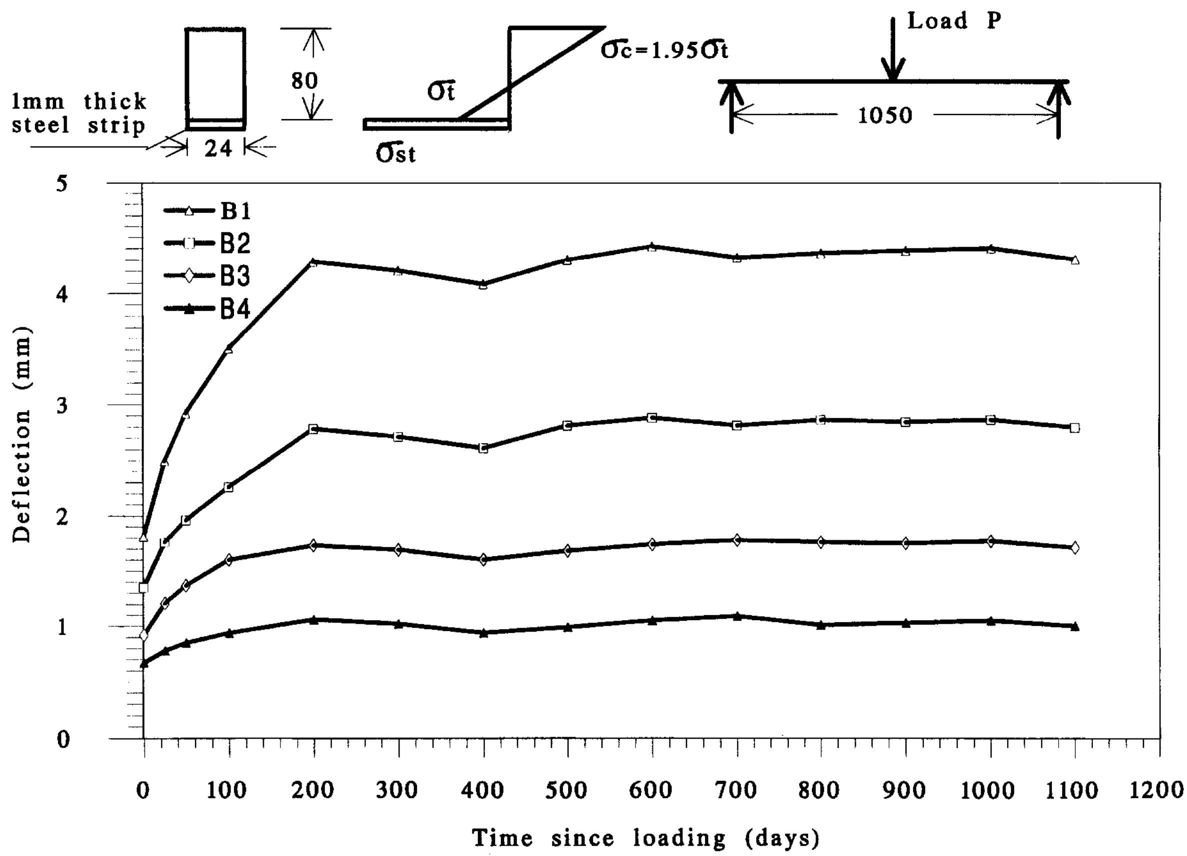

Fig. 2. Cross-section and time–deflection curves for reinforced beams.

cross-section of 36 × 105 mm and four 1-mm thick steel-strip reinforced wood shaving–cement board rectangular beams with a cross-section of 24 × 81 mm (Fig. 1, Fig. 2 and Table 3). The short-term stiffness ratio between the plain and reinforced beams was 1.73. The span of the beams was 1050 mm and a concentrated load was applied at the midspan of each beam by means of hanging iron pieces. The three plain specimens were each tested for stress levels of 48, 36 and 19% of the short-term bending tension strength. For the four reinforced specimens, the tensile stress levels at the bottom of the wood shaving–cement board were taken to be 50, 38, 25 and 19% that of the short-term bending tension strength. The deflections of the beams were measured twice a week. The test was carried out in an indoor environment. The temperature varied between 12 and 21°C and the relative humidity ranged between 65 and 85% annually.

Table 3. Long-term loading test results of middle size specimens

No. of specimen	σ_t/R_{ft}	f_s (mm)	f_{200} *(mm)*	f_L *(mm)*	f_L/f_s
Plain A_1	0.48	1.04	2.87	3.04	2.92
Plain A_2	0.36	0.79	1.91	2.01	2.54
Plain A_3	0.19	0.39	0.74	0.76	1.96
Reinforced B_1	0.50	1.81	4.28	4.42	2.44
Reinforced B_2	0.38	1.35	2.78	2.88	2.13
Reinforced B_3	0.25	0.92	1.73	1.78	1.93
Reinforced B_4	0.19	0.67	1.06	1.09	1.62

f_s, f_{200} and f_L: Short-term deflection, the 200th day deflection and maximum long-term deflection within 3 years, respectively.

Second series — full-scale ribbed roof panels

The second series consisted of five 2-mm thick steel-strip reinforced wood shaving–cement board ribbed roof panels (Fig. 3 and Table 4). The span was 2.7 m and the panels were uniformly loaded with bricks. The five roof panels were tested for each load level at 90, 75, 60, 40 and 20% of the tested short-term ultimate load carrying capacity. (These load levels correspond to 6.57, 5.48, 4.38, 2.92 and 1.46 × the factored load of 1 kPa in Beijing.) The deflections of the panels were measured twice each week. The test at 60% of the ultimate load level specimen

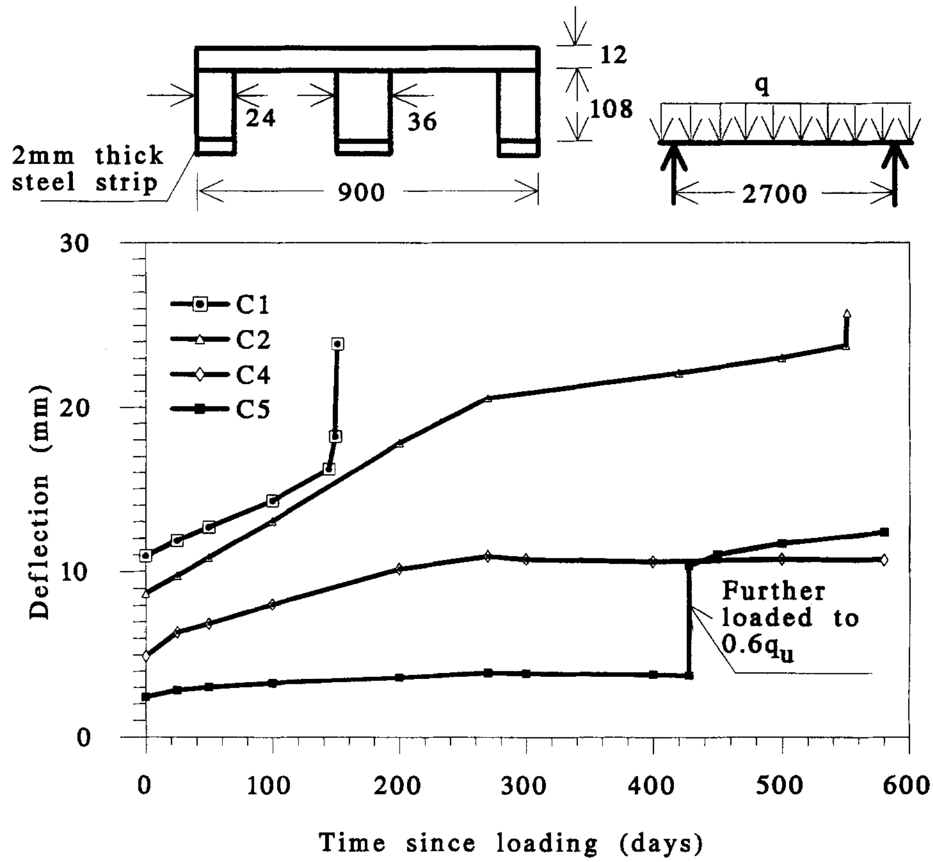

Fig. 3. Cross-section and time–deflection curves for roof panels.

was not completed. As a result, the panel subjected to 20% of the ultimate load level was loaded further to the 60% level after 428 days.

TEST RESULTS AND DISCUSSION

Midsize specimens

Figures 1 and 2 show the time-deflection curves for plain and reinforced beams respectively. The short-term deflection, the 200th day deflection and maximum deflection within 3 years are listed in Table 3.

It can be seen that most of the creep was accomplished within 200 days and the deflection increased or decreased within a small range after 200 days. Less creep can be seen from day 200 to 400 (with temperature between 13 and 21°C and relative humidity between 65 and 85%), and more creep can be seen from day 400 to 600 (temperature between 12 and 21°C,

Table 4. Long-term loading test results of reinforced roof panels

No. of specimen	C_1	C_2	C_4	C_5
q/q_u	0.90	0.75	0.40	0.20
q/q_e	1.026	0.855	0.456	0.228
f_s	10.93	8.71	4.92	2.42
$f_{l/\text{measured time (days)}}$	23.58/151	20.58/270	10.92/270	3.99/270
f_s/f_l	2.18	2.36	2.22	1.65
Remark	failed on 152th day	failed on 553rd day	worked, normal	worked, normal

qq_u and q_e: long-term load, tested short-term ultimate load-carrying capacity (7.3 kPa) and calculated short-term elastic ultimate load-carrying capacity (6.3 kPa) respectively.
f_s and f_l: short- and long-term deflection, respectively (in mm).

relative humidity between 66 and 80%). Evidence shows that lower relative humidity leads to greater creep. Based on the 3-year test, the deformation can be thought of as being relatively stable if the short-term maximum tensile stress of the wood shaving–cement board is $\leq 50\%$ of the bending tension strength.

From Table 3 it can be seen that the higher the stress, the greater the ratio between the long- and short-term deflection. This is because higher stress leads to greater creep. For reinforced beams the long-term deformation is less than 2.5 × the short-term deformation when the short-term maximum tensile stress in the lower edge of the board is $\leq 0.5 \times$ bending tension strength.

Although the short-term maximum tensile stresses of the reinforced beam B_1, B_2 and B_4 were close to those of the plain beam A_1, A_2 and A_3 respectively, the maximum compressive stresses of the reinforced beams were about 1.95 × the maximum compressive stresses of the plain beams as shown in Figs 1 and 2 and Table 3. As a result the short-term deflections of the reinforced beams were larger than those of plain beams. However, the ratios of long- to short-term deflections (Table 3) of the reinforced beams were lower than those of plain beams. One of the main reasons is that a part of the stress of the wood shaving–cement board was transferred to the steel strip because of creep. The evidence indicates that the use of a steel strip leads to an effective confinement of creep and a full utilization of the compression strength of wood shaving–cement board.

Full-scale ribbed roof panels

The test lasted 31 months. However, due to a change of test site on the 580th day, the test data lacked continuity. Only Fig. 3 shows the deflection–time curves of the roof panels up to 580 days. The short term-deflection, the 270th day deflection and maximum deflection within 580 days are listed in Table 4.

The loading of panel C_1 was equal to 1.027 × the short-term elastic ultimate load,[5] inducing a short-term deflection of 9.73 mm. The stress in a short length of steel strip reached the yield strength immediately after loading. Because the short-term maximum tensile stress of the rib was lower than the bending tension strength cracking did not happen straight away.[5] The deflection–time curve of C_1 shows three distinct stages. In the first stage the deflection increased to 5.28 mm, the stress and the length of the elastic–plastic zone of the steel strip also increased moderately over 144 days due to the creep of wood shaving–cement board. In the second stage the deflection had a fast increase of 2 mm from 144 to 149 days, indicating that the stress and the length of the plastic zone of the steel strip had increased significantly due to the further creep of the wood shaving–cement board. The beginning of the third stage was indicated by a cracking of the ribs on the 150th, day because the maximum stress in the lower edge of ribs exceeded the long-term strength. It should be noted that the rib stress decreased throughout the test period due to creep. However, because the decrease rate of the stress was lower than the decrease rate of the long-term strength, cracking took place in the ribs. As in the short-term test[5] only one crack was observed in each rib of the roof panel. While the stress in the steel strip remaine high, that in the lower edge of the rib had to be zero at cracked section. This caused a shear stress concentration in the glue line between the steel and the rib, resulting in a gradual progression in debonding from the cracked section towards the two supports. The deflection had increased abruptly by 5.65 mm in the following 2 days, the debonding length stretched further, and finally an excessive debonding length led to the loss of load-carrying capacity of the member.

The short-term maximum tensile stress of the wood shaving–cement board ribs of panel C_2 was equal to 0.855 × short-term bending tension strength. The creep increased moderately in 270 days. The deflection rate decreased from 270 to 550 days. However, the deflection of the panel increased sharply from the 550th day and failure similar to that of the panel C_1 was seen.

The ribs of panel C_4 subjected to a short-term maximum tensile stress of 0.456 flexure tension strength. The deflection reached the maximum value of 10.92 mm on the 270th day. This value is much lower than the allowable value of 2700/150 = 18 mm. The deflection increased or decreased within a small range during the following 10 months, indicating that most of the creep was completed. The test site was changed on the 580th day. The deformation of the panel decreased or increased within a small range in the new test site and the test stopped at 31 months.

The short-term maximum tensile stress of ribs of panel C_5 was equal to $0.228 \times$ flexure tension strength. The deflection attained the maximum value of 3.99 mm at the 270th day and tended to stabilization in the following days. In order to complement the test dada of panel C_3, panel C_5 was further loaded to 4.38 kPa on the 428th day, inducing a maximum rib tensile stress of approximately $0.684 \times$ the bending tension strength. The test site was changed on the 580th day. Although the test data obtained after the changing of the test site could not be linked with the previous test data, observation showed that the deformation at the new site retained a tendency to increase throughout. The reliability of the panel is suspect.

For a conservative and simple design it is suggested that the short-term maximum tensile stress of the wood shaving–cement board rib should be controlled to be less than $0.5 \times$ the bending tension strength based on the test results of midsize and full-scale specimens. The ratio between the long- and short-term deflection depends mainly on the stress value. However, the long-term deformation is generally less than $2.5 \times$ the short-term deformation if the short-term maximum tensile stress of the rib is $\leq 0.5 \times$ the bending tension strength.

CONCLUSIONS

1. A steel strip is very effective at confining the creep of wood shaving–cement board.
2. The long-term bending tension strength of wood shaving–cement board can be assumed to be approximatley equal to $0.5 \times$ that of the short-term bending tension strength.
3. Long-term deformation increased with increasing stress. However, it is generally less than $2.5 \times$ the short-term deformation in the case of steel-strip reinforcements. In the case of non-reinforced boards the corresponding ratio is less than 3.0. Long-term deformation tends to stabilize within 3 years.

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