Advanced Materials Research Vols. 919-921 (2014) pp 1805-1811
Online available since 2014/Apr/17 at www.scientific.net

doi:10.4028/www.scientific.net/AMR.919-921.1805

Experimental Study on Performance of Steel and Composite Plate Combined Column

Fan Wu[1, a], Xiaoyan Zheng[1,a], Jianwei Ding[1,a]

[1] Department of Building Engineering, Nanjing Forestry University, Nanjing, China, 210037

[a]565006198@qq.com

Keywords: cold-formed C steel; bamboo and wood composite plate; combined column; cooperative work

ABSTRACT: Four I-section specimens have been produced, and epoxy resin structural adhesive and bolts have been used to combine the cold-formed thin-walled C steel with bamboo- wood composite plate, through which the cooperative work performance of the combined column was detected, and the failure mode and mechanism were explored. The feature of load vs. deflection and load vs. strain was also analyzed. Then stiffness and calculation formula of bearing capacity were proposed. The results show that the unitary mechanical behavior and plastic properties are very good, and the combined column is divided into three stages from loading to failure, including adhesive cracking, local area degumming and failure. And the stiffness accords with double slash model in serviceability

Introduction

Cold bending thin formed steel is in favor due to flexibility of the cross section shape, good mechanical properties, high utilization rate of steel. But it has the problems of local buckling because of its thin wall. At the same time, performance degradation caused by steel corrosion is more serious than ordinary steel structure [1]. Bamboo and wood composite plate is a kind of artificial plate which made of bits and pieces of bamboo and wood and epoxy glue by specific processing technology. It's widely used in building templates, furniture carpentry board etc. It is of a smooth and evens surface, a sense of wood. It has high toughness, deformation ability, moisture and high temperature resistant. Bamboo and wood composite plate after high temperature treatment is a good substitute for wood because of it's free of disease. And it is easy to machine because of wide format [2-3]. The combination of the cold-formed thin-walled C steel and bamboo- wood composite plate, could solve the problem of local buckling of the cold-formed thin-walled steel very well, at the same time, composite plate give a protective effect to the cold-formed thin-walled steel, could prevent corrosion of it. Then this combined structure can unify the structure and decoration with bamboo wood's outer surface.

Some research about combined structure of steel and wood (bamboo) has been achieved. Most of the results are separate combined structure (respectively forming the member of structure) [4-5]. There is little research on integral combined structures (together forming a member of the structure) at present home and abroad. So, this paper studies integral combined structures mechanical behavior [6-8] ,which is made of cold bending thin formed steel and bamboo plywood, including plates, beams, walls, columns .But the study on the performance of combined structure made of the steel-bamboo and wood composite plate have not been carried out. In this paper, four I-section combined column specimens have been produced, and epoxy resin structural adhesive and bolts has been used to combine the cold-formed thin-walled C steel and bamboo- wood composite plate. By experimental studying, the mechanical performance, combination effect, failure characteristics were observed, and calculation theory of the composite column was suggested.

Experimental

2.1Material testing

The modulus and bending strength of composite plate were measured according to GB-T17657-1999, the results are as follows: the modulus E_{cw} is equal to3883 in MPa, and bending strength σ_{cwy} equal to 39.6 in MPa. The modulus and strength of cold bending thin formed steel were measured according to the GB/T 228.1-2010. E_s is equal to 198000 in MPa, yield strength σ_{sy} equal to192.3 in MPa and ultimate strength σ_{su} equal to 309.7 in MPa.

2.2Specimens

Four I-section combined specimens were made of cold-formed C steel and composite plate. shows the combined column cross section, used 2 C steels and 3 composite plates, the dimension in cross section of thin-wall C steel being 120×60×20×2.4 in mm, composite plate average thickness is 16.5 in mm, and column length is 1200 in mm. M4.5 bolts were used to intensify the connection, a group bolts (five) were fixed up every 220mm axially, the position is in the ribs and flange of C steel. Combined column geometric parameter was listed in table 1.

The test was carried on the servo loading system, and the arrangement of measuring points is shown in fig.1, strain gauge are layout in the three section (1-1, 2-2, 3-3), these being upper, middle and lower of the combined column . In order to avoid the influence of the device at ends, the distance from strain gauge in upper and lower to end is equal to150 in mm respectively. Displacement meter is fixed in the bottom of the column to measure compression deformation of the combined column.

Tab. 1 Combined column geometric parameter

Sequence number	Web thickness /mm	Flange thickness/mm	Area of composite plateA_c/mm^2	Area of columnA_{sc}/mm^2	$n_c=A_c/A_{cs}$ (%)
Z-1	16.4	16.7	6644	7868	84.4
Z-2	16.7	16.5	6624	7859	84.3
Z-3	16.5	16.5	6600	7829	84.3
Z-4	16.4	16.4	6560	7786	84.3
Average	16.5	16.5	6607	7836	84.3

RESULTS AND DISCUSSION

3.1Stages of the Specimens from the Beginning of Loading to Failure

Loading process was controlled by force earlier, then by displacement. Taking Z-2 as an example which has the greatest capacity in Four I-section combined column, experimental phenomenon is described. With load increasing, the first adhesive crack arose when load reached 130kN.Since then Glue cracked as one falls, open more and more. When the load reached 235kN, the sound of cracking became intense suddenly, and the crack developed from spots, to lines and sheets, in other words, bond was failure between composite plate and steel in

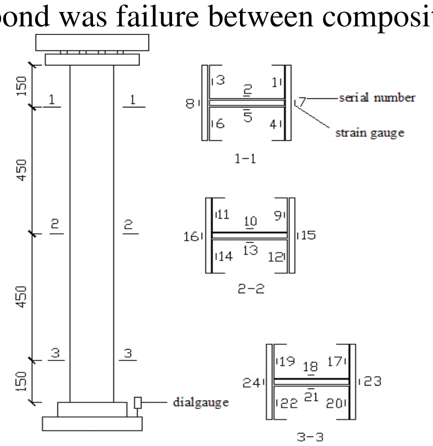


Fig. 1 Arrangement of measuring points

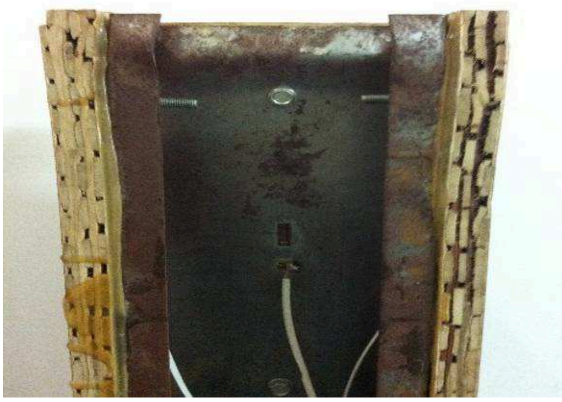


Fig.2 Z-2 Failure mode

local interface. However, owe to the presence of the bolt, the crack doesn't develop through the whole interface. When the load approached 408kN, the separation was obvious in flange between composite plate and C steel in local interface, the local buckling outward, into the S-type, in upper of the specimen. Finally, combined column was lost capacity, then failure immediately.

As show in fig. 2, it is specimen of Z-2 after the destruction forms. The other failure mode was similar to Z-2, there were different in the loading of cracking, local degumming and failure, as well as demolition sites. For comparison, these were listed in Table 2.

Throughout the four test specimens from the beginning of Loading to failure, the combined columns showed 3 stages:

a) Adhesive splitting (as stage I)

In the early of loading, cold-formed steel and bamboo and wood composite plate showed a good cooperative work under the action of bolts and structural adhesive. With the load increasing, although material property, such as elastic modulus and Poisson's ratio, are different

Tab. 2 The bearing capacity in each stage and demolition site of combined column

Test specimen	Splitting load P_{cr}/kN	Degumming load P_{de}/kN	Failure load P_u/kN	P_{cr}/P_u /%	P_{de}/P_u /%	Demolition sites
Z-1	95	250	375	25	67	middle part
Z-2	130	235	408	32	58	upper part
Z-3	110	240	383	29	63	upper part
Z-4	60	220	381	16	58	lower part
average	99	236	386	26	61	

between them, but they were coordinated deformation to resist compression because of the adhesive and bolts. The elastic modulus of steel is much larger than composite plate, so most of the load was born by the cold-formed steel, and the stress of steel increases rapidly, then composite panels stress is small, but the composite panels is important for the whole column stability. Continue to increase load, adhesive splitting was appeared in the weakest parts of the bond of the combined column, because of the variability of bond strength in four specimens , the positions of adhesive splitting were different .The load of adhesive splitting is about 30% of the failure load, as the load in stage I is (0 ~ 30%) P_u.

b)Local degumming (as stage II)

Cooperative work performance of the combined column was good until the steel yield, the bond stress increased sharply between steel and composite panels because of plastic deformation of type steel now. When the stress exceeds the bind strength in many parts of the column, adhesive splitting was appeared by points into face gradually because of bond failure. With the degumming area increasing continuously, cold-formed thin-walled steel and composite plate compression of the combined column was stripped, and column independent has been formed. The load of this stage was about (30%~60%)P_u.

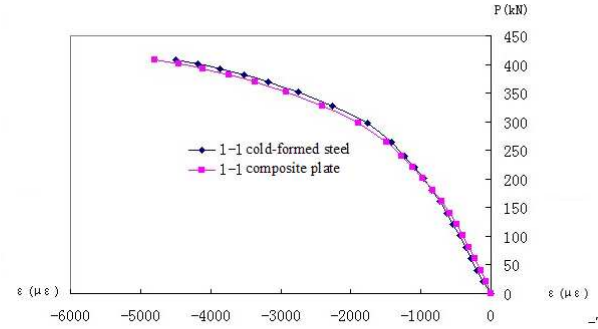
c) Failure (as stage III)

With the load increasing, the degumming area expanded. In addition, many new degumming areas appeared. However the degumming areas have been not through the whole column along the axial direction due to the restrain of the bolts. Finally, bamboo and wood composite plate was damaged or the thin-walled steel was buckling (outward or inward) in one or more degumming areas, then the specimen was broken. The load at this stage was about (60%～100%)P_u.

The results show that the failure positions of the four combined column are different, and they occurred in the more serious regional degumming. Although the combined column could still bore load after steel yield, it is not satisfied with the normal application requirement from the exterior view.

3.2The testing curve of load vs. strain

Strain was recorded, including three sections, a total of 24 measuring points per specimen, as section 1-1, 2-2, 3-3 shown in the fig. 1. The fig 3 to fig 5 shows only partial result of Z-2 lacking of space forbids. Where strain of steel in the fig was taken from the average of 6 strain gages in a same section, the strain of composite plate was taken from the average of 2 strain gages in a same section.



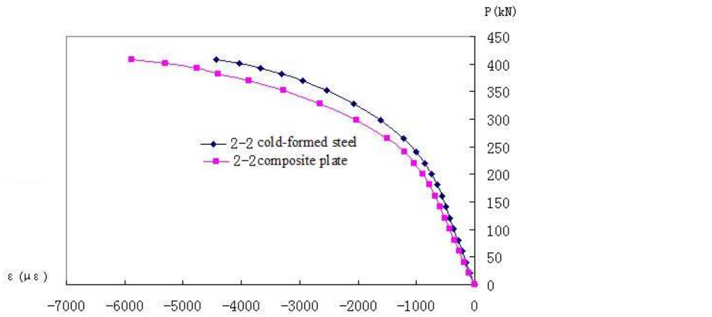
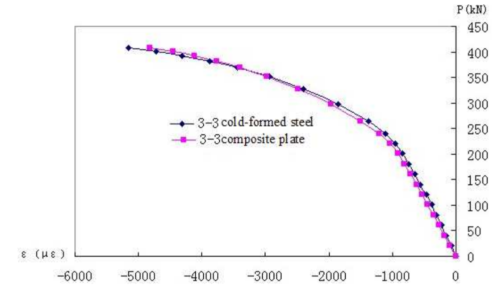


Fig.3 Relation between load and strain for section 1-1of Z-2

Fig.4 Relation between load and strain for section 2-2of Z-2



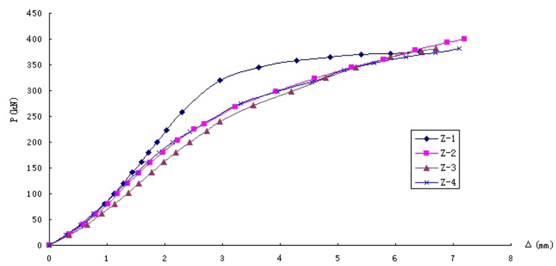


Fig.5 Relation between load and strain for section 3-3of Z-2

Fig.6 Relation between load and displacement

Obviously, the testing curves of load vs. strain under axial compression are different from these of the single material, material testing shows that steel has obvious yield stage and composite plate has been elastic from loading to failure, Good elastic-plastic performance of the specimen was showed by the P-strain curves.

Before adhesive splitting, the specimen was elastic (corresponding to stage Ⅰ).From adhesive splitting to local degumming, the specimen showed a plastic properties more and more,

As steel yielded, the strain of steel increased sharply. At the same time the bond between steel and composite plate was increased until combined column degummed (one or more places), then its stiffness reduction and deformation increased more rapidly, and the curves of load-strain began to bend (corresponding to stage II). At this stage, the nonlinear deformation of combined column come from plastic deformation of steel, on the other hand, from composite plate local buckling by degumming. With the increase of the load, the degumming region is enlarged. Finally the specimen is separated into 2 independent compression body in some degumming area, and deformation of combined column increased rapidly because of bending of independent compression bodies , and the stiffness of specimen was decreased.

3.3The testing curve of load vs. displacement

Fig 6 shows the load-displacement curve of 4 combined columns. It is evident from fig. 6 that integral stiffness of the 4 combined columns is nearly equal to each other. In addition, the displacement of specimens is large at the beginning of loading due to the gap between the column end and test machine. With the increasing of the load, after the displacement is over 1 mm, the integral stiffness of combined column rises up and then the slope of curves remains unchanged, until adhesive splitting. From the splitting to degumming of local area, the slope of curve becomes slow, and the stiffness of the combined column begins to decline. As specimen is divided into independent compression bodies of cold bending thin-wall steel and composite panel, stiffness decreases sharply. Finally the load reached its ultimate, and specimen was failure.

Because of the difference in specimen process, especially the bond strength of steel and plate, as well as variations of material properties of 4 combined columns, the curves weren't exactly identical. However the combined columns were of the good plasticity and the ultimate strain was more than 5000 $\mu\varepsilon$. The limiting strain(as ε_{scu}), the strain at the end of the stage II (as ε_{scy})and its corresponding nominal stress(as σ_{scy}), the stiffness in stage I(as B_{sc}) and its in stage II(as B'_{sc})are also listed in. The column 7 in table 3 is ratio of them, the mean value is 0.49.

To sum up, the combined column have not been damaged or buckled in any regions during stage I and II in general appearance, steel and composed plate worked together, the deformation of them was coordinated. After into the stage III, thin-walled steel or composite plate was buckling because of degumming, then combination effect of the combined columns was decreased. In the whole loading, the yield segments of combined column did not exist, and hardening stage of it was not as obvious as steel either.

Based on the results and analysis, the assumptions were made as the following for design of the combined column:

(1) The combined column can keep coordinate and work together in serviceability. In addition, the compressive stiffness is in accordance with the bilinear model. That is, the combined column stiffness in stage I being two times of its in stage II.

(2) The bearing capacity of combined column at the end of the phase II can be used as design capacity, the bearing capacity in the stage III can be used as a safety reserve.

Tab.3 Strain and stiffness of the combined column

Specimen	$\varepsilon_{scu}/10^{-6}$	$\varepsilon_{scy}/10^{-6}$	σ_{scy} /MPa	B_{sc} /10^6N	$B'_{sc}/10^6$N	B'_{sc}/B_{sc}	E_{sc} /MP
Z-1	5458	1938	32.4	265.6	147.7	0.56	33756
Z-2	5932	1813	28.0	254.5	120.7	0.47	32385
Z-3	5688	2450	30.7	280.9	110.2	0.39	35879
Z-4	5784	1568	28.3	263.0	139.9	0.53	33779
average	5716	1942	29.9	266.0	129.6	0.49	33949

The compressive stiffness and bearing capacity

4.1Axial compressive stiffness

When the cross section is known, combined column stiffness depends on the nominal elastic modulus.

（1）the nominal elastic modulus in stage I

Formula.(1) shows nominal elastic modulus E_{sc}. This is obtained ignoring the transverse constraint between bamboo wood composite plate and the cold-formed steel and adding them stiffness simple:

$$B_{sc} = E_c A_c + E_s A_s$$
$$E_{sc} = E_c A_c / A_{sc} + E_s A_s / A_{sc} = n_c E_c + n_s E_s \quad (1)$$

Where n_c and n_s is composed plate and steel area ratio of the combined column cross-sectional area respectively. Table 1 shows detailed data. It is clear that, $n_s = 1 - n_c$. When all data of geometric parameter and elastic modulus of specimen are set into formula.(1), E_{sc} is equal to 34343 in MPa.

The testing data of the stiffness in first stage is filled in the fifth column in table 3, divided by the cross-sectional area of the combined column, is experimental data of nominal elastic modulus, filled in the last column of table 3. The average nominal elastic modulus of 4 specimens is gained, that is equal to 33949 in MPa, is equivalent to it approximately. Therefore formula.(1) is feasible.

(2) The nominal elastic modulus in stage II

According to the test results, tab.3 shows the stiffness in stage II ,listed seventh column, it is equal to the half of its in stage I approximately. That is to say the nominal elastic modulus in stage II is equal to the half of it's in stage I approximately:

$$B'_{scw} = 0.5B_{scw}$$
$$E'_{scw} = 0.5E_{scw} \quad (2)$$

The compression deformation of the combined column calculated based on the stiffness in two stages basically identical with the experimental results.

4.2 Bearing Capacity of combined Column

Formula (3) and formula (4) shows the bearing capacity of combined column:

$$N_{scu} = E'_{sc}A_{sc}\varepsilon'_{scy} \quad (3)$$

$$N_{sc,u} = \sigma'_{scy}A_{sc} \quad (4)$$

When all experimental data based on the average of 4 specimens are set into formula (3) or formula (4), N_{scu} is equal to 234.3 in kN. The results is remarkably close to the experimental load at local degumming, as shown in Table 2, the average equal to 236 in kN.

Conclusion

a) In serviceability (corresponds to stage I1and stage II), cold-formed thin-walled steel and composite plate can keep the same deformation and work coordinately. Bamboo-wood composite plate takes significant effects in preventing local bucking of cold-formed thin-walled C steel as well as ensuring integral stability of composite column.

b) The combined column has three stages from the beginning of loading to failure, including adhesive splitting, local degumming and failure, with a linear good elasticity before adhesive splitting, then good plasticity.

c) The compression stiffness is accord to double slash model. The nominal modulus of elasticity in stage I is obtained by superposition principle and its in stage II is the half of that in stage I.

d) Although combined column can keep on bearing into stage III, the appearance of the damage is very serious because of cold-formed thin-walled steel and bamboo-wood composite plate local buckling respectively. Therefore bearing capacity at the end of stage II is considered as designed value.

e) The integral work performance and bearing capacity of the combined column depend on strengthen of the connection between formed steel and composite plate, It is very important to reinforce the bond between them, especially making good use of bolt.

Acknowledgement

The project was supported by PAPD of Jiangsu Higher Education Institutions and National Undergraduate Training Programs for Innovation and Entrepreneurship (No.201310298030Z)

Reference

[1] Wang Xiaoqing. Study on laminated veneer lumber composite strengthening bamboo [D]. Beijing: Beijing Forest university, 2004.

[2] Gao Yimin. Research of Composite Steel-Timber Bridge Deck System Based on CLT[D].Xian :Chang An university,2010

[3] Qu qin, Zheng xiaoyan. Study on Steel wood composite structure of staggered truss system performance[J]. Journal of Shenyang Construction University 2010,26(5)，P892-295.

[4] LI Yushun，SHAN Wei，HUANG Zubo. Experimental study on mechanical behavior of profiled steel sheet-bamboo plywood composite slabs[J] Journal of Building Structures,2008,29(1):96-102.

[5] Shan Wei,Li Yushun,Jiang Tianyuan,et al. Design method of steel-bamboo composite structure system[J].Journal of Architecture and Civil Engineering,2012,29(1):32—38.(in Chinese)

[6] LI Yushun，SHEN Huangying，ZHANG Wangli. Experimental Study on Seismic Behavior of Bamboo-Steel Composite Walls[J]Engineering Mechanics, 2010,27(Sup.I):108-112.

[7] XIE Qi-tie,ZHANG Wang-li,JIANG Tian-yuan et al. Experimental study on performance of steel-bambo composite column under axial compression [J]Engineering Mechanics,2012,12:221-225

[8] Ding Jianwei. Study on performance of cold bending thin formed steel –bamboo and wood Composite Board Combination Column under Axial Compression [D].Nanjing: Nanjing forest university,2013.

Advanced Construction Technologies
10.4028/www.scientific.net/AMR.919-921

Experimental Study on Performance of Steel and Composite Plate Combined Column
10.4028/www.scientific.net/AMR.919-921.1805