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Research on the Mechanical Properties of Some New Aluminum Alloy Composite Structures in Construction Engineering

Mengting Fan[1] and Xuan Wang[2†]

[1]School of Architectural Engineering, Chongqing City Vocational College, Chongqing 402160, China
[2]School of Architecture and Construction, Chongqing University of Arts and Sciences, Chongqing 402160, China

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Abstract The lightweight and high strength characteristics of aluminum alloy materials make them have promising prospects in the field of construction engineering. This paper primarily focuses on aluminum alloy materials. Aluminum alloy was combined with concrete, wood and carbon fiber reinforced plastic (CFRP) cloth to create a composite column. The axial compression test was then conducted to understand the mechanical properties of different composite structures. It was found that the pure aluminum tube exhibited poor performance in the axial compression test, with an ultimate load of only 302.56 kN. However, the performance of the various composite columns showed varying degrees of improvement. With the increase of the load, the displacement and strain of each specimen rapidly increased, and after reaching the ultimate load, both load and strain gradually decreased. In comparison, the aluminum alloy-concrete composite column performed better than the aluminum alloy-wood composite column, while the aluminum alloy-wood-CFRP cloth composite column demonstrated superior performance. These results highlight excellent performance potential for aluminum alloy-wood-CFRP composite columns in practical applications.

Key words aluminum alloy, composite structure, construction engineering, mechanical property, extreme load.

1. Introduction

Under the influence of social development and economic progress, the construction of architectural engineering has also progressed, and wood structures, steel structures, and various composite structures have been widely used.[1)] However, wood structures are prone to flammability and moisture damage,[2)] while steel structures are susceptible to corrosion,[3)] both of which have some shortcomings in terms of usage and maintenance. Therefore, finding new and reliable materials has become an important issue in construction engineering.[4)] Aluminum alloy material is suitable for applications in aerospace industries,[5)] machinery manufacturing sectors,[6)] etc. The advantages of aluminum are listed below: (1) light weight: aluminum is much lighter than steel due to its lower density,[7)] making it more convenient for transportation and construction in the same structure; (2) strong plasticity: aluminum can be extruded, hot rolled, and welded to produce complex structures that are conducive to applications in complex projects;[8)] (3) strong ornamental: the silver-white surface of aluminum makes it look brighter and more comfortable, so it is more suitable for construction projects with aesthetic needs; (4) low-temperature resistance: unlike materials such as steel and concrete which are prone to cold brittleness at low temperatures, aluminum has good low-temperature resistance and can work well in low-temperature areas; (5) corrosion resistance: due to its excellent corrosion resistance, aluminum can be used in harsh environments where other materials may not be available. With the continuous improvement of aluminum production capacity, researchers have also paid extensive attention to analyzing its properties. Abioye et al.[9)] investigated the effect of equal

†Corresponding author
E-Mail : vx41702@163.com (X. Wang, CQWU)

channel angular extrusion (ECAE) on the tensile properties of aluminum alloys and found that it was a method for strengthening them. Krymskiy et al.[10] identified composition, volume fraction, and distribution as factors related to the corrosion behavior of aluminum alloys. Mason et al.[11] analyzed the impact of process parameters on both microstructure and mechanical response of aluminum alloys, discovering that the overgrowth of reinforcing precipitates could cause sample fracture. Wan et al.[12] studied the anti-icing properties of aluminum alloy materials. Through experimental observations of water droplet cooling time and icing specimens, they found that the anti-icing effect was influenced by the wettability of the material and the specimens exhibited good stability. Although aluminum has advantages such as lightweight and corrosion resistance, it also suffers from issues like large deflection and local instability. Various composite structures have been developed in order to maximize their effect in construction projects.[13] The reasonable combination of different materials can effectively leverage the strengths and complement weaknesses, enhancing structural performance. As a result, research and application of composite structures in construction engineering is increasing. While aluminum is widely used in glass curtain walls, bridges, and other structures,[14] its use in load-bearing structures is still limited. In order to address the limitations of aluminum, this paper designed new composite structures using aluminum alloy and tested their axial compression properties. The aim is to assess the reliability of different structures in construction engineering applications and provide theoretical support for the enhanced utilization of aluminum in the field of construction.

2. Design of New Aluminum Alloy Composite Structure and Axial Compression Performance Test

2.1. Materials and properties

From the perspective of aluminum's characteristics, it has a significant advantage as a load-bearing structure. Compared to commonly used steel-concrete structures, aluminum materials possess characteristics such as lightweight, high strength, and non-magnetic properties.[15] Although they may have slightly higher material and construction costs, their longer lifespan results in lower maintenance expenses. However, it is important to consider the impact of thermal expansion and contraction on the structure during design and construction due to aluminum's relatively high coefficient of thermal expansion. To further improve the understanding of the effect of aluminum composite structures on load-bearing structure, this paper investigates the axial compression performance of new aluminum alloy composite structures through the design of various short-column specimens. The following composite structures are mainly studied.

(1) Aluminum-concrete composite columns: steel-concrete structures are commonly used nowadays, but there is an obvious deficiency of steel in terms of corrosion resistance.[16] Aluminum can not only provide a restraining effect on concrete but also offer better corrosion resistance.[17]

(2) Aluminum-wood composite columns: both aluminum and wood have the advantage of light self-weight. Wood has excellent load-bearing capacity,[18] but there are problems with insect infestation and corrosion,[19] which can be improved by using aluminum.

(3) Aluminum alloy-wood-carbon fiber reinforced composite (CFRP) composite column: CFRP has excellent specific strength and specific stiffness,[20] and adding CFRP to the aluminum alloy-wood composite column can further increase the binding force on the composite column.

Based on the previous literature survey, it was found that the test results of short column specimens can be affected if their slenderness ratio is either too large or too small. In axial compression tests, the slenderness ratio is usually set to 3; therefore, in the subsequent study of this paper, the slenderness ratio of various composite columns is also set to 3.

6061-T6 is a commonly used aluminum alloy with extensive applications in practical construction projects, exhibiting excellent strength, toughness, durability, corrosion resistance, and machinability. Therefore, all the composite columns studied in this article are made of 6061-T6 aluminum tubes. Tests were conducted to evaluate the material properties of the aluminum alloy according to 'Metallic Materials - Tensile Testing - Part 1: Method of Test at Room Temperature' (GB/T 228.1-20120). Its properties are shown in Table 1.

The materials used in the aluminium alloy-concrete composite columns are shown in Table 2.

The materials used in the aluminum alloy-wood composite columns are shown in Table 3.

The materials used in the aluminum alloy-wood-CFRP composite columns are shown in Table 4.

Wooden test specimens was produced in accordance with the 'Standard for Test Methods of Timber Structures' (GNB/T50329-2012). The details are as follows.

(1) Aluminum alloy-concrete composite columns: the method of pouring layer by layer was used. Concrete was poured into an aluminum tube, and after the concrete became dense, the concrete at the cross section was leveled, followed by maintenance.

(2) Aluminum alloy-wood composite columns: after sanding the cedarwood smooth, an even waterproof coating was applied. The production of the composite columns started after the waterproof treatment. Wood columns were fixed on the level ground, and aluminum tubes were fixed with sealing mud. The gaps between the wood columns and aluminum tubes were filled with cement mortar, and sufficient vibration was performed to ensure dense combination of the two materials. The mortar was supplemented after 24 h. After initial setting, the surface was cleaned up, followed by maintenance.

Table 1. Properties of 6061-T6 aluminum alloy.

6061-T6 aluminum alloy	
Yield strength/MPa	78
Ultimate strength/MPa	162
Modulus of elasticity/MPa	65,445
Poisson's ratio	0.35

Table 2. Concrete properties.

C40 concrete	
Age/day	90
Cubic compressive strength/MPa	45.5
Modulus of elasticity/MPa	34,000
C50 concrete	
Age/day	90
Cubic compressive strength/MPa	52.5
Modulus of elasticity/MPa	35,000

Table 3. Properties of wood and cement paste.

Cedarwood	
Compressive strength/MPa	42.36
Modulus of elasticity/MPa	11,012
Cement paste	
Water-cement ratio	0.4
Cubic compressive strength/MPa	55
Modulus of elasticity/MPa	14,200

Table 4. Properties of CFRP cloth and binding agent.

CFRP cloth	
Tensile strength/MPa	≥3,500
Modulus of elasticity/MPa	≥250,000
Flexural strength/MPa	≥730
Shear strength/MPa	≥45
Binding agent	
Tensile strength/MPa	≥60
Modulus of elasticity/MPa	≥2,500
Flexural strength/MPa	≥80
Shear strength/MPa	≥80

Table 5. Composite column specimens for axial compression test.

Specimen number	Diameter/ mm	Length/ mm	Wall thickness/ mm	Padding	Quantity
A0	120	360	3	Blank tube	3
AC40	120	360	3	C40 concrete	3
AC50	120	360	3	C50 concrete	3
AW60	120	360	3	60 mm diameter wooden column	3
AW80	120	360	3	80 mm diameter wooden column	3
AW100	120	360	3	100 mm diameter wooden column	3
AWC1	120	360	3	60 mm diameter wooden column + one layer of CFRP cloth	3
AWC2	120	360	3	60 mm diameter wooden column + two layers of CFRP cloth	3
AWC3	120	360	3	60 mm diameter wooden column + three layers of CFRP cloth	3

(3) Aluminum alloy-wood-CFRP composite columns: based on the aluminum alloy-wood composite column, the test specimen was sanded. The surface of the test specimen was wiped with alcohol and then coated with CFRP cloth using a binding agent. Air bubbles and excess binding agent were removed with a squeegee. After hardening, the excess CFRP cloth was cut off, and finally, the surface was sanded.

The final specimens obtained are presented in Table 5.

2.2. Measurement point arrangement and axial pressure performance test

After the specimen was placed on the test bench, a vertical displacement gauge with a measuring range of 50 mm was placed at each of the four corner points to measure the axial deformation of the specimen; a strain gauge was placed in the midspan of each composite column specimen at 90° intervals to measure the strain of the specimen. The location of the measurement points is shown in Fig. 1.

Axial compression tests were carried out on a 5,000 kN hydraulic testing machine. A spirit level was used for centering. The load was applied through a flat plate hinge. Data was collected using a UCAM 70A data collector. A graded loading scheme was used:

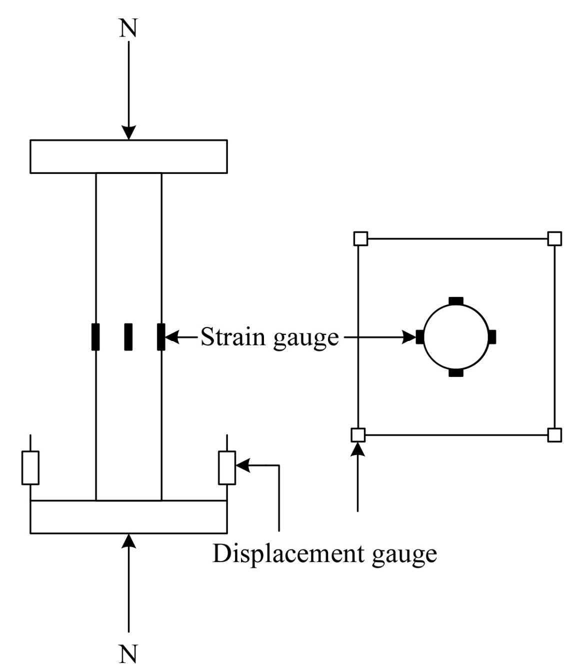

Fig. 1. Schematic layout of measurement points of a composite column specimen.

① Elastic phase: each grade of load is 1/10 of the expected ultimate load, for 2 min;

② Yield stage: each grade of load is 1/15 of the expected ultimate load, for 2 min.

After the specimen reached the ultimate load, slow, uniform loading was performed until the specimen was destroyed.

3. Results and Analysis

First, the load-displacement curves of each specimen were analyzed, as shown in Fig. 2.

From Fig. 2, it can be seen that during the elastic stage, the displacement of the specimens increased gradually with the increasing load in a nearly linear manner. In the elastic-plastic stage, the load increased slowly until reaching the ultimate load, after which it decreased until the specimen failure. Comparing different composite columns revealed poor load-carrying capacity for the pure aluminum tube (A0), while filling with concrete significantly improved the load-carrying capacity for both AC40 and AC50. This indicated that con-

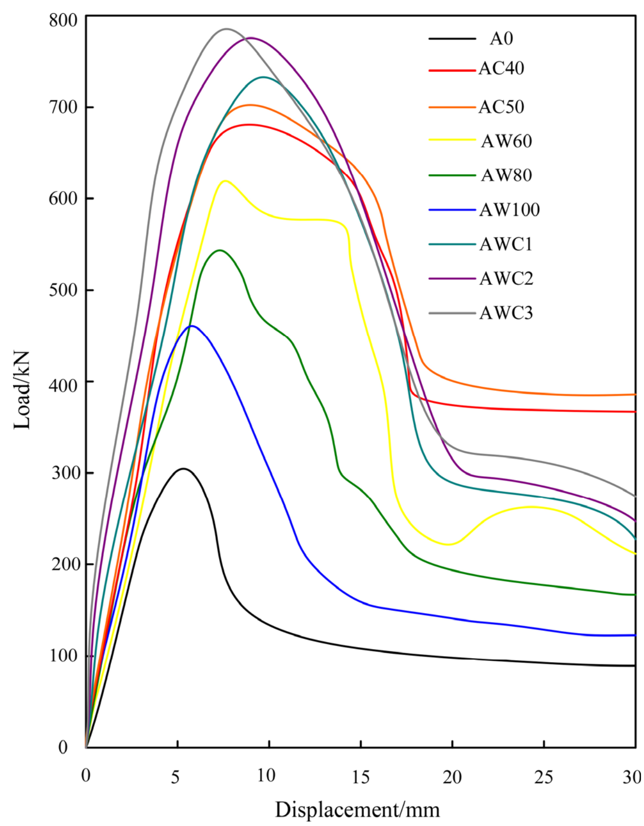

Fig. 2. Load-displacement curve.

crete played a crucial role and the mechanical properties of the aluminum alloy-concrete composite column were closely related to the properties of filled concrete. In the aluminum alloy-wood composite columns (AW60, AW80, and AW100), the smaller size of the filled wood columns resulted in better performance of the composite columns. This may be due to the fact that larger wood reduces the amount of filled cement mortar, which then fails to provide enough restraining effect after wood damage. Finally, in the aluminum alloy-wood-CFRP cloth composite columns (AWC1, AWC2, and AWC3), more layers of CFRP cloth outside the aluminum alloy tubes led to stronger restraining effects and therefore better specimen performance. Comparison among the different specimens suggested that AWC3 exhibited the best performance.

The load-strain curves for the specimens are shown in Fig. 3.

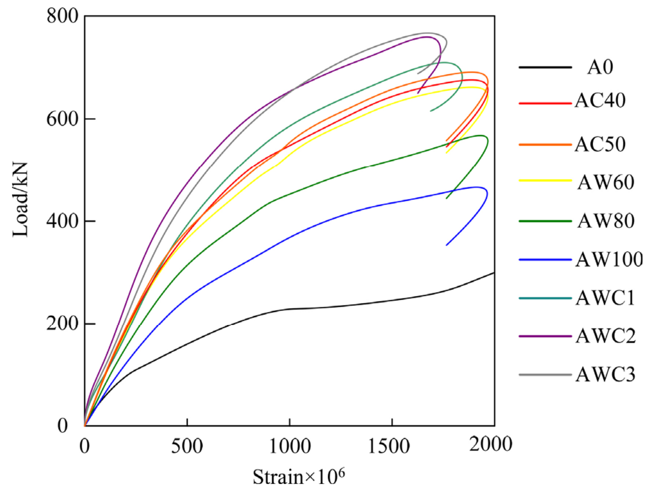

Fig. 3. Load-strain curve of each specimen.

From Fig. 3, it can be observed that the load-strain curves exhibited a rapid increase followed by a decrease towards the end at different time intervals. This suggested that the structure might undergo localized damage such as cracking and deformation, resulting in an overall reduction in strain. Firstly, the strain of the pure aluminum tube (A0) showed a rapid growth trend. After being filling with concrete, the strains of AC40 and AC50 gradually decreased after reaching ultimate load. The remaining composite columns exhibited similar changes. In the elastic stage, the strain of the composite columns grew linearly; in the elasto-plastic stage, the specimens started to yield and their strains increased rapidly. When the aluminum tubes flexed to a certain degree, their strain appeared to decrease rapidly. This result was consistent with load-displacement changes, which indicated that the mechanical properties of the pure aluminum tubes were poor while those of the combined composite significantly improved after adding fillers. Among them, the aluminum alloy-wood-CFRP composite columns demonstrated superior performance.

The ultimate load of each specimen is shown in Fig. 4.

From Fig. 4, it can be seen that the pure aluminum tube

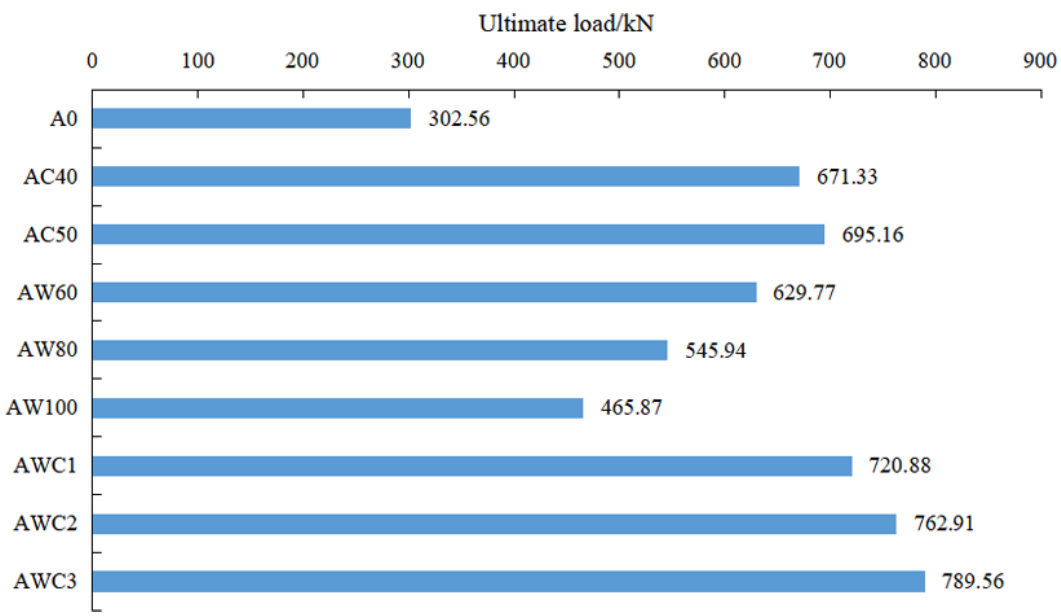

Fig. 4. Comparison of specimen ultimate loads.

(A0) exhibited the lowest ultimate load of 302.56 kN. However, when filled with concrete, the ultimate loads of AC40 and AC50 increased by 120.89 % and 129.76 %, respectively, compared to A0, which indicated a significant improvement in specimen performance due to the interaction between the aluminum tubes and the concrete. When filled with wood columns, AW60, AW80, and AW100 exhibited increased ultimate loads of 108.15 %, 80.44 %, and 53.98 %, respectively, compared to A0. Since the paste has superior compressive strength than wood, the greater the content of the paste, the stronger the restraining effect on wood, and the greater the ultimate load. Finally, when the CFRP cloth was added outside the aluminum alloy-wood composite columns, AWC 1, AWC2, and AWC3 exhibited increased ultimate loads of 138.26 %, 152.15 %, and 160.96 %, respectively, compared to A0; furthermore, they showed increases of 14.47 %, 21.14 %, and 25.37 %, respectively over AW60. This indicated that the CFRP cloth pasted outside the aluminum tube can further improve the load carrying capacity of the composite column and limit the buckling of the specimen by restraining the composite column.

4. Conclusion

This article focuses on the load-bearing structures in construction engineering and designs several new types of aluminum alloy composite structures. The mechanical properties of these structures are analyzed through axial compression tests. It was found that compared to pure aluminum tubes, all kinds of aluminum alloy composite columns showed better mechanical performance. Among them, the aluminum-wood-CFRP composite column had the highest ultimate load capacity, reaching 789.56 kN when three layers of CFRP fabric were bonded, which increased by 160.96 % compared to pure aluminum tubes and can be applied in practical construction engineering projects.

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Author Information

Mengting Fan

Lecturer, School of Architectural Engineering, Chongqing City Vocational College

Xuan Wang

Lecturer, School of Architecture and Construction, Chongqing University of Arts and Sciences