

Theoretical research on aluminium members under cyclic axial loading

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Abstract. This paper studies the influence of various parameters, such as alloy types and slenderness ratios, on the hysteretic behavior of compression aluminium members under cyclic axial loading. In this research, a method by finite element analysis was proposed. The method was based on FEA software, ANSYS. The effects of material nonlinearity, geometrical nonlinearity and initial imperfection were considered in this analysis model. By comparing the hysteretic curves, reversal skeleton curves and stiffness degradation curves of aluminium columns obtained by the model, it concludes that, for the same slenderness ratio, the hysteretic behavior of 6061-T6 aluminium columns were better than 6061-T4. For the same alloy type, the specimen which has smaller slenderness ratio has the superior performance under cyclic loading.

Introduction

Aluminium alloy structures are gradually used in the field of modern architecture, such as aluminium alloy frames, aluminium alloy bridges, aluminium alloy factories and aluminium alloy reticulated shell structures. The structures have the characteristics of light weight, good formability, beautiful appearance, corrosion resistance, good durability, convenient construction, good low temperature resistance, easy recovery, and so on. According to these characteristics, aluminium alloy structures are more suitable for the buildings which have large-span buildings or in corrosive environment than reinforced concrete structures. In China, with the rapidly development of aluminium alloy structure, there are many applications of them. Aluminium alloy structures play a more and more important role in the field of building structure with their superior performances.

With the wide application of aluminium structures, research on the aluminium alloy materials and the aluminium columns are increasing. Previous studies [1-3] mainly concentrated on static performances. Studies on the hysteretic behavior of aluminium alloy structure and the mechanism of action are still in the blank stage. The lack of appropriate norms and standards also limits the widely use of aluminium alloy structures. Therefore, it is very necessary to study the dynamic performance of the aluminium alloy structures.

With the goal of developing improved understanding of the hysteretic behavior of aluminium alloy structures, this paper presents a method to build up finite element models to simulate the aluminium members under cyclic axial loading. Depending on finite element methods, this paper analyzes the influence of various parameters, such as alloy types and slenderness ratios, on hysteretic performance of aluminium alloy structures. The result of this paper provides a new idea for seismic design and engineering application of aluminium alloy structure.

Finite element model

Aluminium alloys possess mechanical properties considerably different from each other, and their constitutive relationship cannot be simplified to perfectly elastic-plastic behavior which is commonly used for steel. The Ramberg-Osgood law, i.e., $\varepsilon = \sigma/E + 0.002(\sigma/f_{0.2})^n$, is now widely used because its predicted behavior is very close for aluminium alloys. The exponent n is the characteristic of the

strain-hardening rate of the inelastic portion of the σ - ϵ curve. The Ramberg-Osgood law and the Steinhardt proposal [2], i.e., $10n = f_{0.2}$, were used as the constitutive relationship of aluminium alloys.

General FEA software ANSYS was adopted to calculate the hysteretic curves of aluminium columns. BEAM189 element was used, the model of section size was shown by Fig. 1, and the finite element model was shown by Fig. 2. The specimens analyzed were axial compression members. One end of the specimen is a fixed hinge support, and another end is a sliding hinge support. The study uses 6061-T6 and 6061-T4 aluminium alloy, their constitutive relationships were shown by Fig. 3. The elastic modulus of aluminium alloy was set to 70 GPa, and Poisson's ratio was set to 0.3. The nominal yield strengths of 6061-T6 and 6061-T4 aluminium alloy were 240 MPa and 110 MPa, respectively.

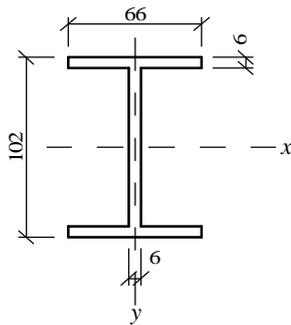


Fig. 1 Section

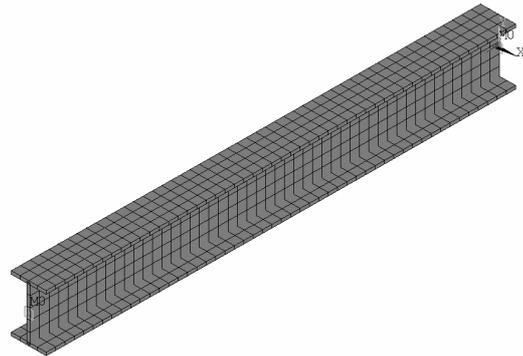


Fig. 2 Finite element model

The analysis model considered the effects of material nonlinearity, geometrical nonlinearity, and initial imperfection. The effect of various parameters, including alloy types and slenderness ratios, i.e., 60, 80, 100, 120, was studied. In order to identify the specimen, coding the specimens as T4/T6-SXX, T4 for 6061-T4 while T6 for 6061-T6, S for slenderness ratios. For example, T6-S60 means the 6061-T6 aluminium members and its slenderness ratio is 60.

The specimen cyclic loading system used the entire displacement controlled loading method. The basic displacement value δ_0 of 6061-T6 and 6061-T4 aluminium alloy were set to 1.0 mm and 1.5mm, respectively, and then each loading stage was multiples of the basic displacement value. Each level displacement load repeated the cycle three times, until the loading stage 7, as shown by Fig. 4.

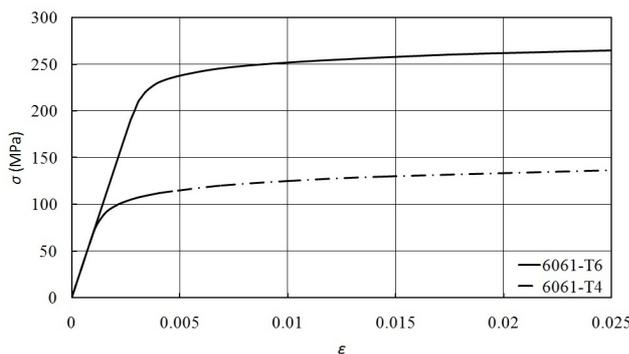


Fig. 3 Constitutive relationships

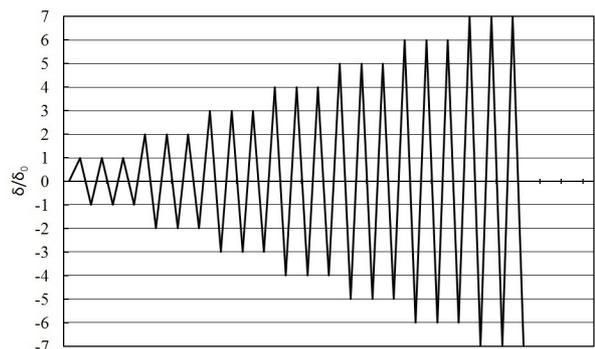
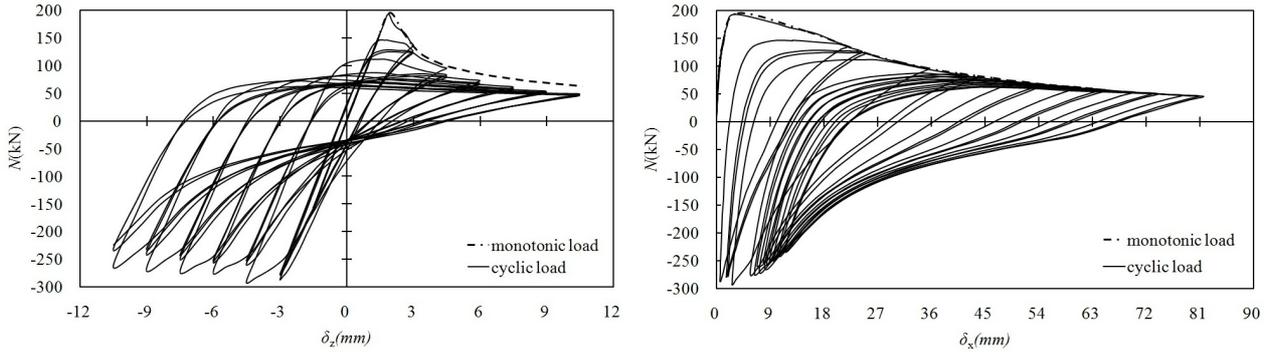


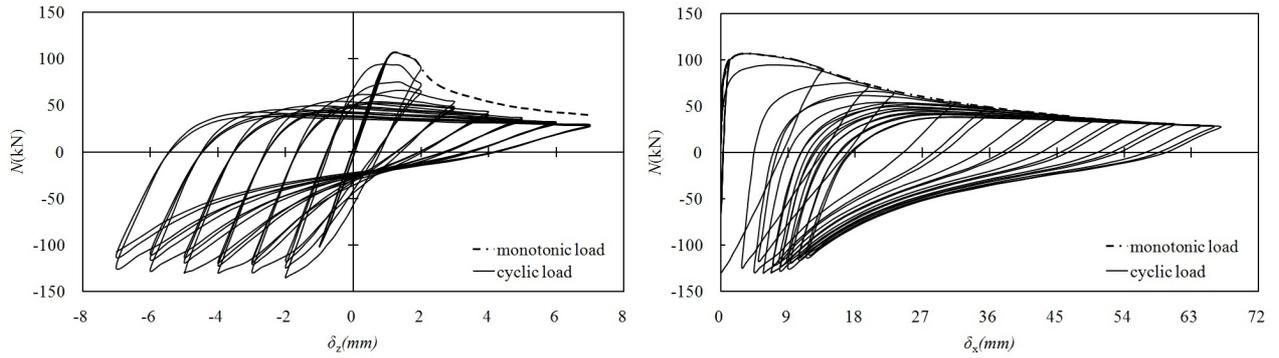
Fig. 4 Cyclic loading system

Hysteretic analysis

Through the finite element calculation by ANSYS, the hysteretic curves of these specimens, only for slenderness ratio 60, were shown by Fig. 5. The y-axis was the axial load N (positive value is compression), and the x-axis was the axial deflection δ_z or the mid-span deflection δ_x .



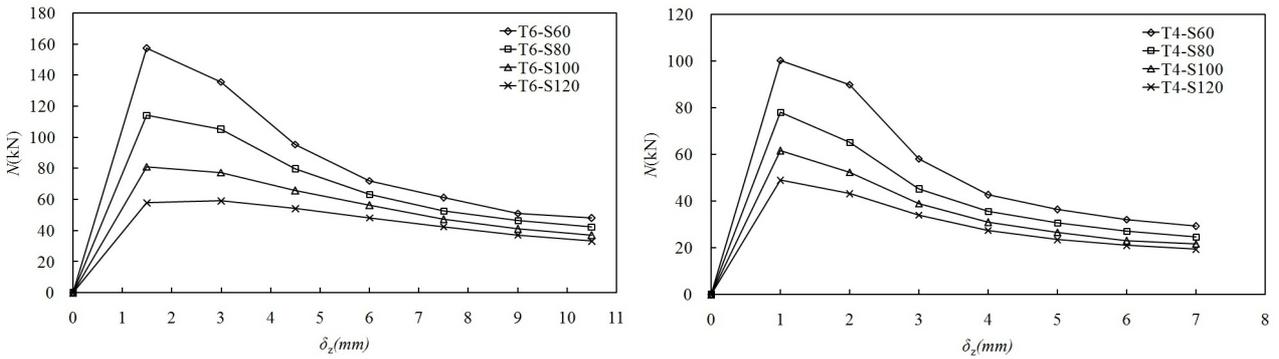
(a) T6-S60



(b) T4-S60

Fig. 5 Hysteretic curves

The reversal skeleton curves of these specimens were shown by Fig. 6, in which the axial load N was set to positive peak point of the first circle of each loading stage. The stiffness of the specimens could be represented by the secant stiffness $K_i = (|+N_i| + |-N_i|) / (|\delta_{zi}| + |\delta_{zi}|)$ in which $\pm N_i$ and $\pm \delta_{zi}$ were the axial load and the axial deflection at positive or negative peak points of the first circle of loading stage i [4].

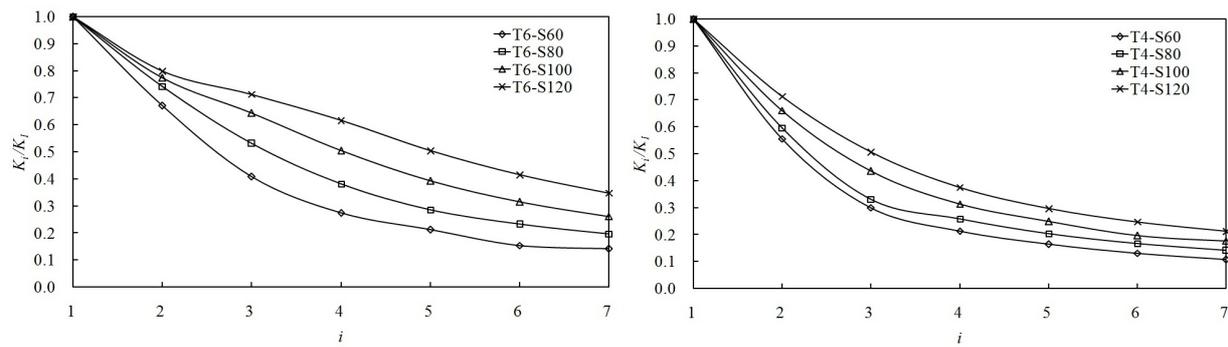


(a) 6061-T6 aluminium alloy

(b) 6061-T4 aluminium alloy

Fig. 6 Reversal skeleton curves

According to the calculation results, the specimens' stiffness degradation values with displacement load increase were obtained, as shown by Fig. 7.



(a) 6061-T6 aluminium alloy

(b) 6061-T4 aluminium alloy

Fig. 7 Stiffness degradation curves

From Fig. 6, it is found that, with slenderness ratio increase, the reversal skeleton curves of two kinds of specimens exhibit similar characteristics. Fig. 7 shows that the stiffness degradation of 6061-T4 aluminium alloy happened earlier than 6061-T6 aluminium alloy.

Discussion

This paper uses a FEA model to study the influence of various parameters on the mechanical property of compression aluminium members under cyclic axial loading. Conclusions and the discussions are as follows:

- (1) The alloy types of aluminium have an important influence on their hysteretic behavior.
- (2) For the same alloy type, with the increase of slenderness ratio, the change trend of hysteretic curves and reversal skeleton curves are similar, but the max bearing capacity of the specimen decreases. The specimen which has smaller slenderness ratio has a fuller hysteretic curve.
- (3) With regard to the stiffness of both loading and unloading in the same cyclic stage, for the same alloy type, the bigger slenderness ratio the slower stiffness degradation. For the same slenderness ratio, 6061-T4 aluminium alloy has faster stiffness degradation than 6061-T6 in the early. Stiffness degradation both slow down in the later.

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