Thin-Walled Structures 131 (2018) 566–576

Contents lists available at ScienceDirect

Thin-Walled Structures

journal homepage: www.elsevier.com/locate/tws

Full length article

Experimental, numerical and analytical studies on the aluminum foam filled energy absorption connectors under impact loading

Yonghui Wang[a,b,*], Ximei Zhai[a,b], Jiachuan Yan[a,b], Wenjian Ying[a,b], Wei Wang[a,b]

[a] Key Lab of Structures Dynamic Behavior and Control of the Ministry of Education, Harbin Institute of Technology, Harbin 150090, China
[b] Key Lab of Smart Prevention and Mitigation of Civil Engineering Disasters of the Ministry of Industry and Information Technology, Harbin Institute of Technology, Harbin 150090, China

ARTICLE INFO

Keywords:
Aluminum foam
Analytical model
Energy absorption connector
Impact loading
Numerical model

ABSTRACT

In this paper, the energy absorption performances of the aluminum foam filled connectors under drop-weight impact loading were first evaluated via using experimental method. The dynamic crushing behaviors of the connectors were examined and three deformation processes were identified from the experiments. The effects of loading rate, filled aluminum foam, pleated plate thickness and angle θ_o (the angle between flat plate and pleated plate) on the energy absorption performances of the connectors were experimentally investigated, which showed that the energy absorption capacity was improved by filling the connector with aluminum foam as well as increasing loading rate, pleated plate thickness and angle θ_o. Moreover, the numerical and analytical models were also developed to predict the force–displacement responses of the connectors, which showed good agreement with the test results. The developed analytical model could be used as a convenient tool to quickly evaluate the energy absorption performances of such connectors under impact loading.

1. Introduction

Recently, due to the increasing extreme events and threats related to blast attack on buildings, many blast resistant facades/panels were developed to reduce the blast-induced damage on the buildings [1–9]. Besides this, the 'soft' connection (like energy absorption connector) was usually employed to attach the blast resistant façades to buildings [10–18], which could further reduce the damage on buildings by means of dissipating part of blast energy and reducing peak blast load transferred to buildings [10,13]. In the past, Steel material was usually employed to fabricate the energy absorption connectors which were designed to absorb energy via plastic deformation or friction [14,15]. Besides, Amadio and Bedon [10–12] also developed a novel dissipative device for the blast mitigation of glazing façade supported by pre-stressed cables. In order to improve the energy absorption capacity of the current connector, a novel aluminum foam filled energy absorption connector shown in Fig. 1 was developed by the authors and its behaviors under quasi-static loading were also experimentally, numerically and analytically studied [16,17]. In this paper, the experimental, numerical and analytical studies are extended to the dynamic crushing behaviors of the connectors, since they usually experience dynamic loading under blast attack.

In the past, the metallic material was usually employed for the energy absorbers [19–27] which were designed to dissipate energy by plastic deformation [19–25], splitting of steel plate, friction [26] and free inversion of circular tubes [27]. The dynamic crushing behaviors of the metallic energy absorbers were also widely investigated [28–32] and the inertia and strain rate effect could lead to different energy absorption performance as compared to the quasi-static loading case [28,29]. It was noted by Baroutaji et al. [30] that the response of the nested system under low-velocity impact loading was similar to that under quasi-static loading due to the insignificant strain rate and inertia effect. However, the numerical results demonstrated that increasing impact velocity could lead to higher energy absorption capacity of the nested system due to the inertia effect which could increase plastic deformation around the plastic hinges [30].

Recently, the utilization of metal foams as energy absorption material has attracted a considerable amount of interest [33–48] and the improvement in energy absorption capacity was observed when filling the tubes with metal foams [37–39]. Hence, extensive studies have been conducted to reveal the energy absorption performances of the energy absorbers filled with metal foam under quasi-static loading [36–41]. As compared to the crushing behaviors of the metal foam-filled columns/tubes under axial and oblique loading [36,37], their

* Corresponding author at: Key Lab of Structures Dynamic Behavior and Control of the Ministry of Education, Harbin Institute of Technology, Harbin 150090, China.

E-mail address: wangyonghui@hit.edu.cn (Y. Wang).

https://doi.org/10.1016/j.tws.2018.07.056
Received 9 May 2018; Received in revised form 27 June 2018; Accepted 30 July 2018

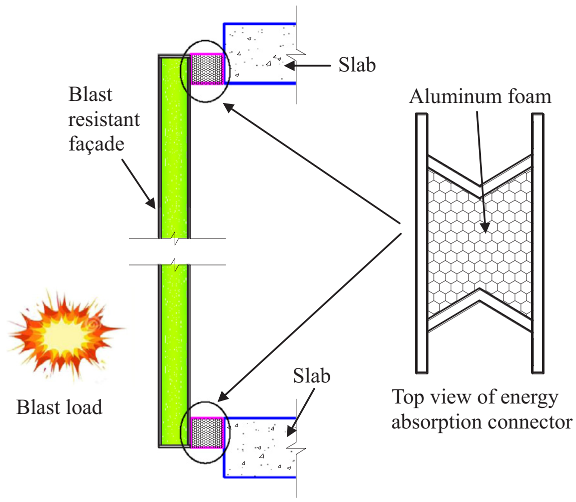

Fig. 1. Application example of the energy absorption connector.

behaviors under lateral compression loading [38–40] were more desirable in terms of fewer fluctuations of load and low amplitude of peak load [39]. The dynamic crushing behaviors of the metal foam-filled energy absorbers were also extensively studied [42–47]. Fan et al. [44] investigated the dynamic lateral crushing behaviors of sandwich circular tubes which consisted of two concentric aluminum tubes of different diameters filled with aluminum foam and significant increase was observed for the dynamic crushing load. Moreover, the energy absorption over its quasi-static counterpart and the deformation profile also showed some differences, which could be attributed to the inertia effect under dynamic loading. The energy absorption performances of foam-filled conical tubes under axial impact loading were numerically studied by Ahmad and Thambiratnam [46] and the effects of geometrical, material and loading parameters on the impact responses were also evaluated. It was found that the foam filler could stabilize the crushing process and improve the energy absorption capacity. The dynamic crushing responses of aluminum foam-filled corrugated single- and double-tubes with different corrugation lengths were comparatively studied and the specific energy absorption of foam-filled corrugated double-tube was found to be superior to foam-filled straight tubes. It was also noted that the tubes with corrugations experienced progressive and concertina type of deformation and tubes with smaller corrugation length showed smooth force–displacement curve with low initial peak load [47].

In the present study, the drop-weight impact loading tests were conducted to study the dynamic crushing behaviors of the aluminum foam filled energy absorption connectors. The effects of filled aluminum foam, pleated plate thickness and angle θ_o (the angle between flat plate and pleated plate) on the energy absorption performances of the connectors were also experimentally investigated. Then, the numerical studies on the tested connectors were conducted by utilizing the explicit code in LS-DYNA which has been widely used to simulate the crushing behaviors of aluminum foam [49–54]. Finally, an analytical model considering strain rate effect of mild steel was developed to predict the force–displacement responses of the connectors under impact loading.

2. Experimental study

The drop-weight impact loading tests on the energy absorption connectors were conducted to acquire their deformation process, force–displacement responses and energy absorption performances. In addition, two of the connectors were tested under quasi-static loading to investigate the loading rate effect. The test specimens, setup and results are presented in this section.

2.1. Specimens

The energy absorption connectors shown in Fig. 2 were fabricated from mild steel as face plates and closed cell aluminum foam as core material. Two pleated plates were firstly bolted to the top and bottom flat plates to form a four-side confined space where the aluminum foam was inserted thereafter. There were totally eight connectors being fabricated for this experimental study with six of them for impact loading test and two of them for quasi-static loading test. The geometries of the connectors are given in Fig. 3 and summarized in Table 1. The parameters including aluminum foam, pleated plate thickness and angle θ_o were experimentally studied under impact loading. There were two same connectors being fabricated for T5.70A45 and T5.70A45N with one for impact loading test and another for quasi-static loading test to investigate the loading rate effect on the crushing behaviors of the connectors. The material properties of mild steel and aluminum foam were obtained from the tensile coupon test and uniaxial compression loading test, respectively, and are given in Table 2.

2.2. Test setup and instrumentation

The impact loading test was conducted using an instrumented drop-weight impact test machine as shown in Fig. 4. A hydraulic controlled mechanical hoisting system is used to raise the hammer to the target drop height. The drop height of each specimen given in Table 1 was determined from trial numerical analyses by ensuring the maximum impact force slightly below the measurement range of piezoelectric force transducer (600 kN). Once the electromagnet release mechanism is manually triggered, the hammer, which has weight of 400 kg in this test, can slide freely along the vertical guide rails towards the specimen below it. The connector was placed between the hammer and a

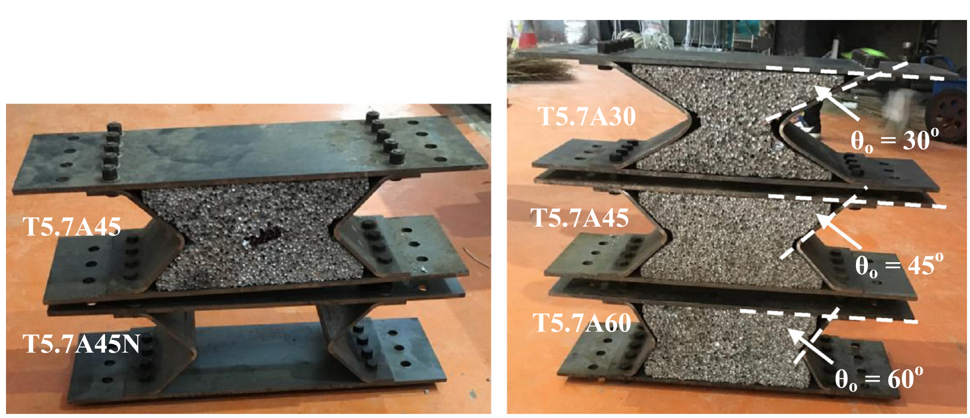

Fig. 2. Photos of energy absorption connectors.